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Isabel L. Nunes *Editor*

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7th International Conference on Applied Human Factors and Ergonomics

Proceedings of the AHFE 2016 International Conference on Human Factors and System Interactions, July 27–31, 2016, Walt Disney World®, Florida, USA

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Preface

Human Factors and Systems Interaction aims to address the main issues of concern within systems interface with a particular emphasis on the system lifecycle development and implementation of interfaces and the general implications of virtual, augmented and mixed reality with respect to human and technology interaction. Human Factors and Systems Interaction is, in the first instance, affected by the forces shaping the nature of future computing and systems development. The objective of Human Factors and Systems Interaction is to provide equal consideration to the human along with the hardware and software in the technical and technical management processes for developing systems that will optimize total system performance and minimize total ownership costs. This book aims to explore and discuss innovative studies of technology and its application in system interfaces and welcomes research in progress, case studies and poster demonstrations.

A total of five sections are presented in this book. Each section contains research papers that have been reviewed by members of the international editorial board. Our sincere thanks and appreciation to the following board members:

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July 2016

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Part I
Human Systems Integration Applications

Blind Waypoint Navigation Using a Computer Controlled Vibrotactile Belt

Ricardo Jimenez and Ana M. Jimenez

Abstract Tactons are computer-generated tactile cues that work in conjunction with a vibrotactile device placed on the skin surface. A belt prototype was designed and controlled wirelessly from a laptop. Each tacton was encoded as four pulses at 250 Hz. The vibrotactile belt was secured along the waistline of 22 participants (20–26 years old); who were blindfolded and asked to alternatively navigate to a waypoint through one of two courses of equivalent complexity, guided one only by audio cues and the other only by vibrotactile cues. Half of the participants first navigated using audio cues and then tacton cues, while the other half navigated in the alternate order. Although the analysis showed average completion time through the tacton-guided course was slower and with more errors, than the audio-guided course, those who navigated first using audio cues completed the tacton maze faster and with less errors.

Keywords Human factors · Human-computer interaction · Vibrotactile belt · Blind navigation · Tacton · EAI C2 tactors · Vibrotactile cues · Audio cues · Navigation to waypoint

1 Introduction

In almost any situation environmental visibility is paramount when navigating to any destination; unfortunately, this is not possible for the blind population and in low-visibility situations. Whether the aim is to improve quality of life or to escape in a life-threatening situation, non-visual cues can aid in successfully and quickly traveling through an unknown course to a non-visible destination. To that end the purpose of this paper is to show effective navigation to waypoint by blindfolded

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subjects when using a wearable vibrotactile device that delivers simple directional commands; as well as improvements made when training with non-visual cues.

1.1 Tactons, Vibrotactile Devices, and Ideal Body Location

A tacton is a vibrational cue which an individual can perceived as data. Tactons are delivered through vibrotactile devices, also known as tactors, placed on the skin and are generated by a computer interface as real-time commands or as encoded protocols.

There are few commercially available vibrotactile devices, which have been specifically designed for use on the skin. These devices are capable of faithfully reproducing more complex waveforms and can be more precisely controlled using linear actuators with moving contacts directly placed on the skin to provide more localized and precise transfer of vibrations. The best example of such a device is the EAI C2 Tactor. The C2 Tactor is currently the more commonly used device found in the academic literature and is extensively being explored for use in military applications [1].

Research has been conducted to determine how the placement of the vibrotactile device on different parts of the body affects tacton perception [2] and continues to be an area of interest. The literature shows that the fingertip appears to be the most sensitive area with the lowest threshold [3–5]; but unfortunately, it is also a very cumbersome location. A more practical and less intrusive placement location is the volar forearm; which Morioka et al., showed to have higher detection thresholds as compared to other sites tested [6]. In addition, the trunk of the body is also a good practical placement location which has been shown by various studies that have developed vibrotactile vests to be effective [7].

1.2 Vibrotactile Belts and Blind Waypoint Navigation

Ertan et al. [8] developed a haptic aide system using a wearable vest composed of an array of vibrotactile actuators that worked in conjunction with an infrared guiding system that successfully guided participants to navigate test paths. Similar research has been conducted by Tsukada and Yasumura [9], who developed the "ActiveBelt", a device very similar to the one used by McDaniel et al. [10] that provides navigational information through a GPS. Jones et al. [11] developed a vibrotactile vest prototype with a 3X3 tactor array for directional awareness that expanded on the one developed by Ertan et al. [12]. Tactons and vibrotactile devices can have wide-ranging potential of use. They can supplement and even replace visual displays, and thus be useful when display size is limited or unavailable [13]. This naturally lends itself to enhancing Human Computer Interaction (HCI) for the blind and visually impaired computer users.

Several studies have looked at tacton design to enhance blind-users' computer interaction and to provide navigational aid [14–17]. Specifically, McDaniel et al. [18] found that tactile rhythm-cues can be used to aid in gauging interpersonal distance by blind users. Moreover, Ghiani et al. [19] used tactons as a navigational aid for blind users, and demonstrated how they can be incorporated into mobile museum guides. Other example worth noting includes, Dobbins and Samways [20] who developed the Navigation Tactile Interface System (NTIS) that provides tacton navigation cues. This system was used by a blind pilot of a high-speed boat to break the blind world water speed record. Ahmaniemi and Lantz [21] concluded that with similar results to visual or audio feedback, using tactile cues is a viable modality for indicating direction finding. In their experiment, dynamic tacton cues were given to indicate the proximity to a target to enhance target acquisition with very promising results.

Tacton cues can also facilitate navigational and situational awareness for a general population; therefore, tacton use should not be viewed as exclusively for a blind or low vision population. Bosman et al. [22] developed a pedestrian guidance system, "GentleGuide", which showed promising results, since this application could be used as both an aide to blind or deaf users; as well as, a general guiding system in large facilities. Visual and auditory navigational cues from mobile devices are often difficult to use in a pedestrian situation due to distractions, including problems associated with focusing on visual feedback while still being aware of surroundings, or audio feedback that may be masked by external noises. Lin et al. proposed a tacton-based system that uses rhythm as a parameter to indicate direction of travel and proximity to desired destination [23] in order to aid pedestrian navigation in visual or auditory rich environments. Van Veen and Van Erp [24] and Naja et al. [25] proposed tactile feedback for waypoint navigation. Waypoints can be coordinates, beacons, or physical landmarks that aid in navigation. Van Veen et al. [26] showed successful navigation using a vibrotactile belt and two dimensional tactons consisting of rhythm and spatial location similar to those used by McDaniel et al. [27]. Naja et al. [28] used a single dimension, spatial location vibrotactile vest with multiple simple vibrators that indicated direction and showed performance improvements in navigation when used in conjunction with certain types of navigation displays.

2 Materials and Methods

2.1 Participants

This study was a within-subject design that compared the performance of 22 blindfolded subjects (average age = 23, StaDev ± 1.8 years old, males, n = 18, females n = 4) when navigating to a waypoint through one of two "mazes" guided by either audio- or vibrotactile-cues. The IRB approved protocol (BU 131011) included participant screening through a written questionnaire to determine age, gender, dominant hand, recent use of vibrating equipment, medications, and any relevant medical history. There were several exclusion criteria based on factors which affect vibrotactile sensation, none of the participants exhibited any of the exclusion criteria. Exclusion criteria included factors shown to affect tactile sensations; to name a few, diseases such as diabetes mellitus [29], neurological conditions such as stroke or Parkinson's disease [30], or prolonged use of vibrating equipment such as drills, jack hammers, and vibrating videogame controllers [31]. The blindfolded subject was accompanied at all times by another researcher to ensure safety when navigating to the waypoint.

2.2 Equipment

Twelve of the blindfolded subjects navigated first through the "tacton maze" guided by real-time commands given by the researcher exclusively from the vibrotactile belt, while the other ten subjects first navigated through the "audio maze" guided only by voice commands. The vibrotactile cues were delivered by the tactor SDK-interface through an in-house designed belt equipped with four C2-Tactor vibrotactile devices, which are commercially produced by EAI systems, with a maximum applied voltage of $\sim$1.6 Vpp. The four C2-Tactors were wired to an Eval 3.0 Controller worn by the subject and subsequently connected wirelessly through Bluetooth to a Windows XP operated laptop. Each tacton was encoded as four 250-ms pulses with an on-time of 125-ms at a frequency of 250 Hz.

Tactor placement was guided by individual subject's midline (umbilicus) and designated by its corresponding command, specifically, superior midline "stop", inferior midline "forward", inferior right of midline "right turn of 90°", inferior left of midline "left turn of 90°", with the "right", "forward" and "left" tactors in a horizontal line across the abdomen. A Go-pro camera (HERO4) was used to video record navigation through both mazes. The subjects were individually filmed in one take. Video recordings were used to analyze time spent in maze, number of errors, and number of angular corrections. The experimental interface and data collection was done on a Windows based personal computer, and the statistical analysis was performed using Excel.

2.3 Experimental Protocol and Procedures

The experiments took place in a laboratory (14′ wide by 19′ long) with only the participant and two researchers present to ensure no distractions or interruptions. An initial orientation and training period was conducted, where the subject became familiar with the belt, vibration stimuli, and corresponding commands, until self-reported as comfortable. About half of the blindfolded subjects (n = 10) were guided to a waypoint "end" through a course guided only by audio-cues from one of the researchers, i.e., "audio-maze". The audio cues were simply, "forward", "stop", "right", or "left". When the end-point was reached, another researcher guided the subject to the "start" point of another course to a different waypoint guided only by vibrotactile cues, i.e., "tactor-maze". The remaining subjects (n = 12) were guided through the tacton-maze first and then the audio-maze.

The researcher giving the commands was guided by marks on the floor not visible to the subject. After the test began, the experimenter provided audio cues only during the audio-maze; while the another experimenter interacted with the subject only to prevent the blindfolded subject from walking into a barrier; as well as for physical guidance to the start of the corresponding maze, in order to prevent visualization of either maze before the test began. In addition, blindfolded subjects were physically guided by one of the researchers to the start. In cases where the subject asked for additional training, the participant was allowed to redo the blindfolded test (n = 1), but not to visualize the maze while training. Subjects were required to complete the experiment in one uninterrupted session, specifically both mazes sequentially.

Both mazes were equidistant and of equivalent complexity, with "start" and "end" points on opposite sides of the room, both mazes included a "stop" command before a turn command to either the left or the right. During navigation and subsequent analyses, a navigational error was defined as responding incorrectly to the sent cue, i.e., turning left when cued to turn right. A navigational correction was defined as an angle correction due to angular error by test subject, i.e., not turning 90° or drifting off course.

3 Results

Overall, the results showed that the completion time through the tacton maze was statistically slower (Table 1) and with more errors (Table 3) as compared to when guided by audio cues (audio maze). In addition, there was a statistically significant difference in the completion time depending on which maze was tested first; on average, subjects completed the tacton maze faster if guided through the audio maze first (Table 2).

These results show that even without visual cues, subjects can be trained by audio cues to improve navigation-time when subsequently guided through a different maze with only tacton cues. All twenty two blindfolded subjects followed tacton cues and audio cues successfully and completed both the mazes. Specifically, Table 1 shows an average completion time through the tacton-guided maze of 154 s as compared to the audio-guided maze of 94 s (1 min faster), with a larger variance when navigating through the tacton maze.

As shown on Fig. 1, when analyzing individual subject response, 21 of the subjects completed the tacton-guided maze (solid bar) slower than the audio-guided maze (striped bar), except for subject 'L' who was in the group guided through the

Table 1 Comparison of average travel time to waypoint with vibrotactile or audio cues by blindfolded subjects

	Tacton maze (s)	Audio maze (s)
Mean	154	94
Standard dev (±)	47	22
Variance	2185	504

Participants spent a statistically significant longer amount of time navigating to the waypoint when guided by vibrotactile cues (tacton maze) than when guided by audio cues (audio maze), with a much greater variability of response time when in the tacton-maze ($n = 22$, $df = 30$, tStat = 5.44, $P(T \leq t)$ one-tail = 3.28E-06, tCritical one-tail = 1.69, $P(T \leq t)$ two-tail = 6.57E-06, tCritical two-tail 2.04)

Table 2 Comparison of average travel time to waypoint given the order in which cues were first experienced by the subject

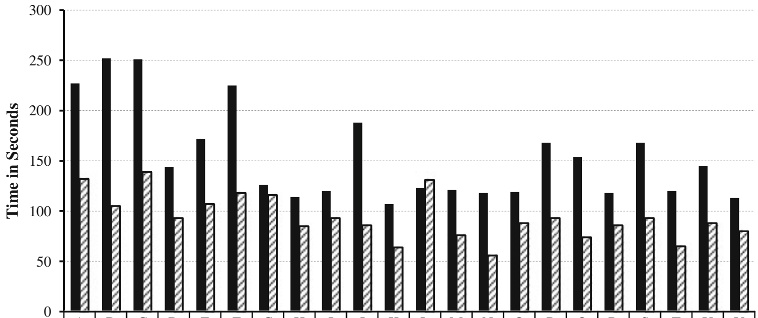
	Tacton first (s)	Tacton second (s)	Audio first (s)	Audio second (s)
Mean	171	133	95	94
Standard dev (±)	53	26	16	27
Variance	2894	655	259	749
Subjects (n)	12	10	10	12

($df = 16$, tStat = 2.16, $P(T \leq t)$ one-tail = 0.023, tCritical one-tail = 1.75, $P(T \leq t)$ two-tail = 0.047, tCritical two-tail 2.12). ($df = 18$, tStat = 0.12, $P(T \leq t)$ one-tail = 0.45, tCritical one-tail = 1.73, $P(T \leq t)$ two-tail = 0.09, tCritical two-tail 2.1)

audio-guided maze before the tacton-guided maze. Each subject navigated each maze only once to prevent the effects of learning the maze on navigational completion time.

Interestingly as shown on Table 2, subjects initially guided through the audio maze completed, on average, the tacton maze faster at 133 s as compared to the subjects traveling through the tacton maze first at 171 s; suggesting a significant travel-time improvement by blindfolded subjects guided through an unknown course and to an unknown waypoint, if first given audio-guided cues, even when navigating through a different course. The same effect is not seen in the order in which the audio-guided maze is traveled, indicating that the audio-maze was traveled as fast as possible by the blindfolded subjects or that the tacton-guided cues do not aid in improving travel time when guided only by audio-cues.

As seen on Table 2 participants spent a statistically significant longer amount of time navigating to the waypoint when initially guided by vibrotactile cues (tacton maze) as compared to those who were initially guided by audio cues (audio maze), with a much greater variability of response time when first guided through



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
■Tacton	227	252	251	144	172	225	126	114	120	188	107	123	121	118	119	168	154	118	168	120	145	113
▨Audio	132	105	139	93	107	118	116	85	93	86	64	131	76	56	88	93	74	86	93	65	88	80

Fig. 1 Comparison of time spent to waypoint when navigating blindfolded through either the tacton-maze (*solid bar*) or the audio-maze (*striped bar*) by each of the twenty-two subjects tested. Subjects that first navigated the tacton-guided maze are represented by the letters, A, B, C, D, E, F, K, M, N, Q, S, T, while subjects that first navigated the audio-guided maze are represented by letter G, H, I, J, L, O, P, R, U, V

tacton-maze. In comparison, the average time spend traveling to the waypoint when initially guided by auditory cues was not affected by the order in which the subject experienced the delivery of commands.

Expectedly, as seen on Table 3 participants made statistically significant more navigational errors on average, i.e., 1.6 errors to the waypoint when guided by vibrotactile cues (tacton maze) as compared to when guided by audio cues (audio maze) with only 0.4 navigational errors on average, with a much greater variability of number of errors made in the tacton maze. Navigational errors where defined as an incorrect response to the cue, i.e., turning right when cued to turn left.

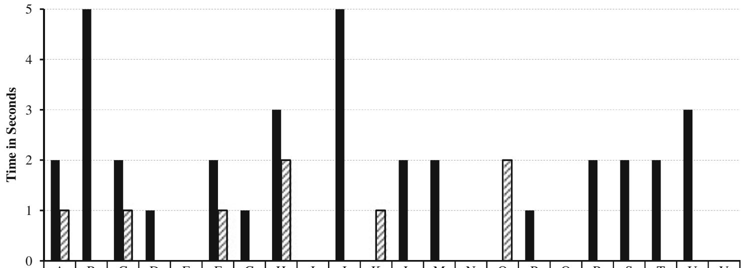
The researcher corrected navigational errors, by sending additional cues (appropriate for the maze that was being navigated vibrotactile or audio maze) to reroute the subject back to the correct course to waypoint. It is expected that the increased number of navigational corrections increased the time spent traveling to the waypoint. Interestingly, as shown on Fig. 2, for the subjects who made the most navigational errors (B and J), 5 errors in the tacton maze, and for the ones who did not make any errors in either the tacton maze or the audio maze (E, I, N, Q, and V), the order in which they were guided to the waypoint was not significant. Although the order in which subjects were guided through the mazes did not have an effect on the number of errors, on average more navigational errors where made when navigating guided by the vibrotactile cues.

As shown on Table 4, type of cue, i.e., vibrotactile or auditory did not have a statistically significant effect on navigational angular corrections. Angular corrections were defined as a correct response to the given cue, but a course that if not eventually corrected by the researcher the waypoint would not be reached; specifically, ‘turn right’ resulted in turning right but not at 90 degrees. Additional cues may have been necessary by the researcher for the subject to reach the

Table 3 Comparison of navigational errors made to the waypoint with vibrotactile or audio cues

	Tacton-maze (errors)	Audio-maze (errors)
Mean	1.6	0.4
Standard dev (±)	1.5	0.7
Variance	2.3	0.4

n = 22, df = 29, tStat = 3.51, P(T ≤ t) one-tail = 7.38E-04, tCritical one-tail = 1.7, P(T ≤ t) two-tail = 1.47E-03, tCritical two-tail 2.05



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
■Tacton	2	5	2	1	0	2	1	3	0	5	0	2	2	0	0	1	0	2	2	2	3	0
◻Audio	1	0	1	0	0	1	0	2	0	0	1	0	0	0	2	0	0	0	0	0	0	0

Fig. 2 Comparison of navigational errors made to waypoint when navigating blindfolded through either the tacton maze (*solid bar*) or the audio maze (*striped bar*) by each of the twenty-two subjects tested. Subjects that first navigated the tacton-guided maze are represented by the letters, A, B, C, D, E, F, K, M, N, Q, S, T, while subjects that first navigated the audio-guided maze are represented by letter G, H, I, J, L, O, P, R, U, V

Table 4 Comparison of navigational angular corrections to the waypoint with vibrotactile or audio cues

	Tacton-maze (corrections)	Audio-maze (corrections)
Mean	1.6	1.3
Standard dev (±)	1.6	1.3
Variance	2.5	1.8

When navigating to the waypoint guided by vibrotactile cues or audio cues participants (n = 22, df = 41, tStat = 0.73, P(T ≤ t) one-tail = 0.23, tCritical one-tail = 1.7, P(T ≤ t) two-tail = 0.47, tCritical two-tail 2.02)

waypoint, but it does not seem to have been a significant contributor to the effects seen in travel time through each of the mazes.

Overall results show that when navigating blind to an unknown waypoint through an unfamiliar course, vibrotactile cues can be effective; as well as, that time of completion can be improved by training with audio cues even when navigating through a different course to a different waypoint.

4 Discussion

Results show that with additional training, the time differences can be reduced along with the number of errors. In particular, it appears that training first with audio cues can significantly improve tacton-cue blind navigation, independent of navigational course. One possible explanation is that apprehension decreases while navigating blindfolded; further emphasizing that additional training will result in tacton guided navigation being equally as effective as audio cue navigation. There were no significant differences in the number of angular corrections regardless of cue. We attribute this to the disorientation that occurs normally in blind navigation and not a factor of the type of cue. Additionally, we expect that with blind navigation training, the number of angular corrections will be reduced for both groups.

Although using tacton based navigation has obvious implications for a blind population; we feel that this study shows that with proper training, one possible important application of tacton-driven belts is that they can be effectively used in low visibility and in sensory disruptive situations as a possible redundant mechanism to locate exits. Future work will emphasize proper training methods for locating exists in commercial and industrial settings where such disruptive environments may occur and where using a vibrotactile belt can serve as an additional sensory modality.

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Horizontal and Vertical Handheld Pointing Devices Comparison for Increasing Human Systems Integration at the Design Stage

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Abstract In addition to postural and biomechanical aspects related to usage of handheld pointing devices it is also important to perform usability assessment. The paper reports on an experimental study comparing two computer pointing devices, a standard horizontal PC mouse and a vertical device (for neutral pronation of the forearm), both commercially available. The standardized tasks implemented by software and performed by 20 experienced computer mouse users included pointing, dragging and steering. The usability parameters of effectiveness and efficiency were calculated and the participants subjectively assessed their discomfort, effort and ease of use in relation to each device in each task. Efficiency and effectiveness were higher for the horizontal device. Assessments of discomfort, effort and ease of use across the different tasks also supported the consideration of preference for the horizontal device in detriment of the vertical model. The results suggest that designing hybrid configurations may configure a better compromise.

Keywords Ergonomics · Human-systems integration · Usability · Handheld pointing devices

1 Introduction

Computer usage can be associated with the development of neck and upper extremity pain, especially hand and forearm musculoskeletal pain induced by intensive mouse use [1]. About ten years ago, approximately 30–80 % of computer

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work involved the mouse [2], depending on the type of work. The PC mouse has become an essential part of computer work, even today; actually, the more recent use of tablet PCs does not substitute all the types of work usually performed using a conventional PC, CAD (computer aided design) operations are part of this group. Furthermore, recent research has concluded that tablet PC users are exposed to extreme wrist postures that are less neutral than those assumed with other computing technologies [3] and may be at greater risk of developing musculoskeletal injuries, especially when these devices are intensively used for long periods of time. One important issue is that screen positioning and pointing area positioning get in conflict for best posturing. Hence, methods have been developed in an attempt to relieve these problems, such as palm rejection technology, although the results of research on the use of this technology show that it generally reduces discomfort but with increased wrist extension and with no benefit to shoulder unloading [4]. Extended use of computer pointing devices is bound to endure in present and future days, because in computer tasks such as pointing, dragging and steering, continuously needed, touch screens have so far not been able to replace the PC mouse, e.g. in 3D computer aided design [5]. The complexity of certain CAD operations and the time involved to produce this kind of computer work led some companies to invest in expensive pointing devices. In this field there are some types of pointing devices that can lead to occupy both hands, one standard device for use by one of the hands and one device for use by the other hand, called knob, intended for use with certain operational functions [6]. Computer usage and particularly computer pointing devices, such as PC mice, have been widely studied. The biggest concern reported in previous studies is related with musculoskeletal disorders. Therefore, research is conducted by collecting data from muscle activity and motion analysis [7, 8], often the same emphasis is not given to usability, even when it comes to developing a new pointing device. Evaluation of pointing devices from an ergonomics and usability perspective involves the assessment of postural and biomechanical aspects as well as the efficiency, effectiveness and satisfaction of the person in the activity of task completion. Hence, human systems integration is typically assessed in this application domain from both an objective and subjective standpoint.

The paper reports on an experimental study comparing two commercially available PC pointing devices, having a major difference between them in what concerns the orientation of the device and its shape, although with additional differences in size and weight. The mouse weight is thought to influence wrist motion and muscle activity of the forearm when using the device in high-speed operation, while such effect is reduced in low speed operation; moreover, a mouse with proper weight would promote improved movement efficiency and decreased muscular activity during fast operation [7]. A proper mouse weight could hence benefit the users in terms of increasing movement efficiency. Its dimensions and geometry should be based on anthropometry, hand gestures and comfortable hand postures [9]. Hand size of the subjects seems to make a difference during computer mouse usage, affecting grasp position and the level of muscle activity, suggesting that a computer mouse must be chosen according to the size of the hand of the subject

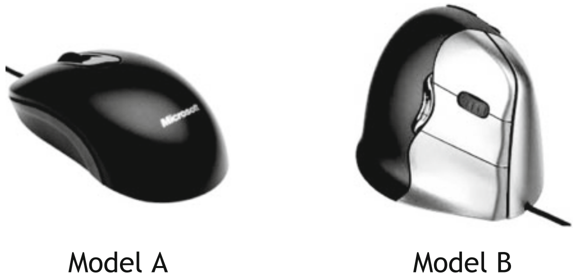

Fig. 1 Handheld pointing devices studied (model A and model B)

[10]. Moreover, previous tests performed on a standard PC mouse (model A in the present study) revealed statistically significant association between hand width and effectiveness of dragging with the middle button of the mouse [11].

Figure 1 shows de devices under study, model A is a Microsoft® standard horizontal PC mouse, while model B is an Evoluent® vertical PC mouse (supporting the adoption of a neutral forearm pronation posture by the person in the pointing activity). Standard PC mouse model A (Fig. 1) has a mass of 57 g (taken from weighing the device on a precision scale with the cable horizontally supported; the total weight including cable and USB plug is 78 g). Analogously, vertical PC mouse (model B) has a mass of 137 g and the total weight including cable and USB plug is 170 g.

The overall aim of this paper is to contribute to the body of knowledge supporting the design of handheld computer pointing devices for increased human systems compatibility at the design stage.

2 Methods

A set of tasks representative of a CAD operator's activity were standardized and recreated by a tailor made computer software application to support the experimental studies undertaken. The standardized tasks included pointing at different sized targets, dragging with different mouse buttons, as well as steering and scrolling. This set of task were collected and adapted from previous studies [12, 13]. All 20 subjects (10 female and 10 male) used each one of the devices performing the standard tasks in the following order: pointing at large targets (pointing large), pointing at medium targets (pointing medium) and pointing at small targets (pointing small) at first. Then, dragging targets with the left button (dragging left), dragging with the middle button (dragging middle), dragging with the right button (dragging right), and, finally, steering targets inside a tunnel. The devices were randomly sorted and the participants performed the tests using the same device across the tasks in the sequence described above, and they then repeated the same sequence of tasks with another device after a resting period. A comparative overview of the graphical setup of the tasks is shown in Fig. 2. The pointing tasks

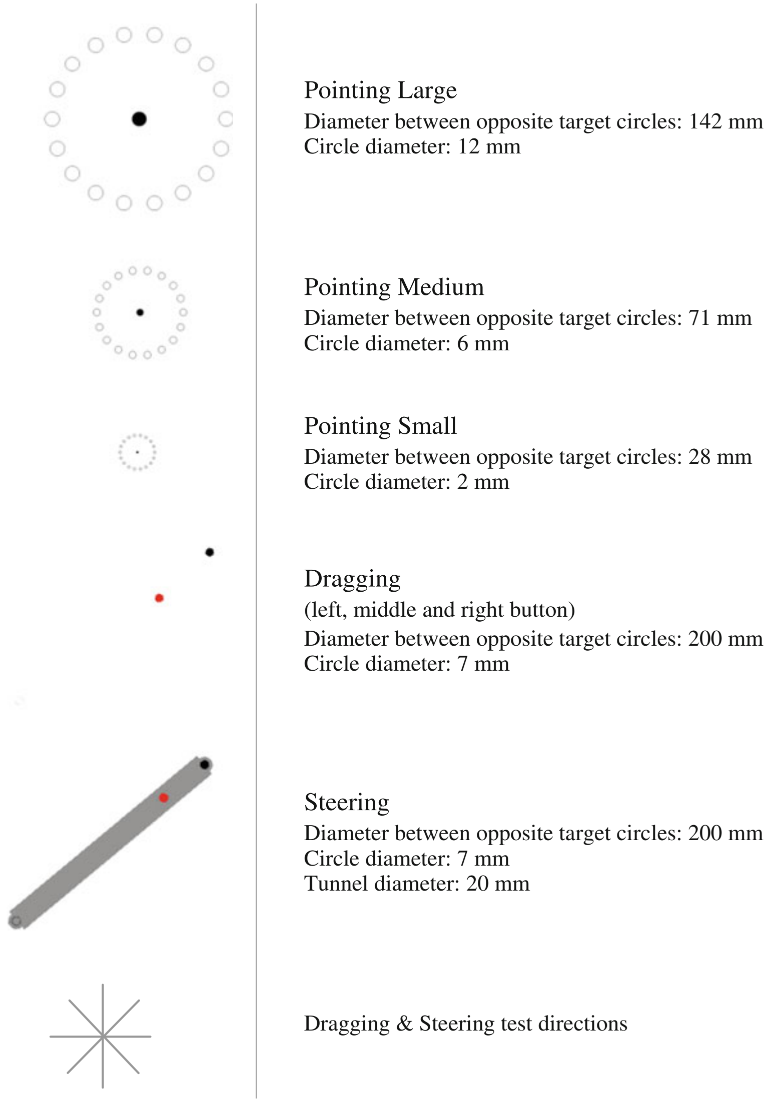

Fig. 2 Pointing, dragging and steering tasks (implemented by a tailor made computer software application); task sequence from top to bottom (pointing large to steering)

consisted of alternately clicking on 18 equally distributed round targets arranged in a circle (Fig. 2). Participants clicked on the center circle to start the task and then would move the cursor and click on the first active circle target (black-highlighted), if the click hit the target it would disappear, enabling the target on the diametrically opposite side of the circle, which when hit, would lead to the next target to randomly go active, and so on. The pointing task ran in pairs, one target was randomized and the next target stood opposite to it. The dragging tasks consisted of alternately dragging 8 equally distributed round targets arranged in a circle (Fig. 2) and participants would click and drag the circle to the diametrically opposite side matching the targets with another click. The steering task partially resembled the dragging task, it was necessary to hit the black-highlighted circle, release the mouse button, and then drive the circle to the diametrically opposite side matching the targets and trying not to get outside of the tunnel.

The purpose-built software collected several parameters of the trials including time to complete tasks and errors undergone, enabling calculation of effectiveness and efficiency usability parameters. The effectiveness for pointing and dragging tasks was calculated from Eq. (1) whereas for the steering task Eq. (2) was used. Efficiency was calculated from Eq. (3).

$$efa_{(point \wedge drag)} = 1 - \frac{No.FailedTargets}{No.TotalTargets}. \quad (1)$$

$$efa_{(steering)} = \frac{minimum\,mean\,deviation}{mean\,deviation(subject)}. \quad (2)$$

$$efi_{(point \wedge drag \wedge steering)} = efa \times \frac{minimum\,mean\,completion\,TIME}{mean\,completion\,TIME(subject)}. \quad (3)$$

Participants also assessed their discomfort and effort subjectively in the completion of the tasks using each one of the pointing devices, as well as rating the ease of use of each device in the course of the activity within the performance of the standardized tasks. Both subjective and objective evaluation parameters are compared across the sample between the two handheld devices under focus. Table 1 summarizes the comparative study performed. Subjects were given 3 scales (discomfort, ease of use and effort), each one composed of several items. Ratings were provided in 6-point Likert scales. Statistical analysis was carried out using IBM SPSS version 23.

Each session lasted between 10 and 12 min per device. An additional set of several non-conventional pointing devices was evaluated in the same experiment,

Table 1 Comparative study—tasks and evaluation parameters (scrolling efficiency and effectiveness are not reported in this paper)

PC mouse	Tasks	Usability evaluation		
		Objective		Subjective
		Measures	Calculations	(Subjects ratings)
Model A (0°) versus Model B (90°)	Pointing (different size targets) Dragging (different mouse buttons) Steering (scrolling)	Time (to completion) Errors (undergone)	Efficiency Effectiveness	Discomfort Effort Ease of use

and the order of evaluation was randomized for each subject across the several devices evaluated. This paper focuses only on two devices, a commercially available standard PC mouse and a commercially available vertical PC mouse.

3 Results

Participants ranged in age from 20 to 38 years old (mean = 25 years, SD = 4.8 years) and all of them were right handed. Hand width (hand breath) and hand length were measured using a retractable steel tape measure, resulting, respectively on female hand width with a mean of 79.9 mm (SD = 4.06 mm), female hand length with a mean of 177.3 mm (SD = 5.73 mm), male hand width with a mean of 88.8 mm (SD = 4.02 mm) and male hand length with a mean of 191.7 mm (SD = 4.67 mm).

The non-parametric Mann-Whitney U test was applied to the distributions of the four subjective evaluation variables (shown in Fig. 3 as mode bars, the mode is the value that appears most often in the data) across the two PC mouse models under study. As a result the null hypothesis stating that 'the distributions are the same across the two categories of pointing devices' was not rejected with statistical significance over the four variables under interest.

Figure 4 shows mean effectiveness of task completion using PC model A and PC model B and from these results it is observed, globally, that model A seems to be more effective than model B. The same applies in almost all the tasks performed by the subjects. The non-parametric Mann-Whitney U test returned rejection of the null hypothesis (equality of distributions across categories) considering a p-value lower than 0.05 for: effectiveness of pointing large (U = 290, $p = 0.014$), effectiveness of pointing medium (U = 302.5, $p = 0.005$), effectiveness of pointing small (U = 319.5, $p = 0.00$) and effectiveness of dragging right (U = 274, $p = 0.046$).

Likewise, the mean efficiency of task completion using PC mouse model A and model B is plotted in Fig. 5. The graphic shows that the mean efficiency of tasks completion is comparably greater in model A. The non-parametric Mann-Whitney U test supports these assumptions, since it returned rejection of the null hypothesis (equality of distributions across categories) considering a p-value lower than 0.05 for efficiency of pointing medium (U = 356, $p = 0.00$), efficiency of pointing small (U = 357, $p = 0.00$), efficiency of dragging left (U = 278.5, $p = 0.033$) and efficiency of dragging right (U = 323, $p = 0.00$).

The variables under focus were analyzed using non-parametric statistics [14] to statistically prove or disprove the differences among subgroups, such as those exemplified in Figs. 3, 4 and 5 giving good support relatively to objective evaluation parameters of usability. Particularly, the results of the Mann-Whitney U test did not support rejecting the null hypothesis (the populations are the same across the categories) with statistical significance over all the four focused variables from

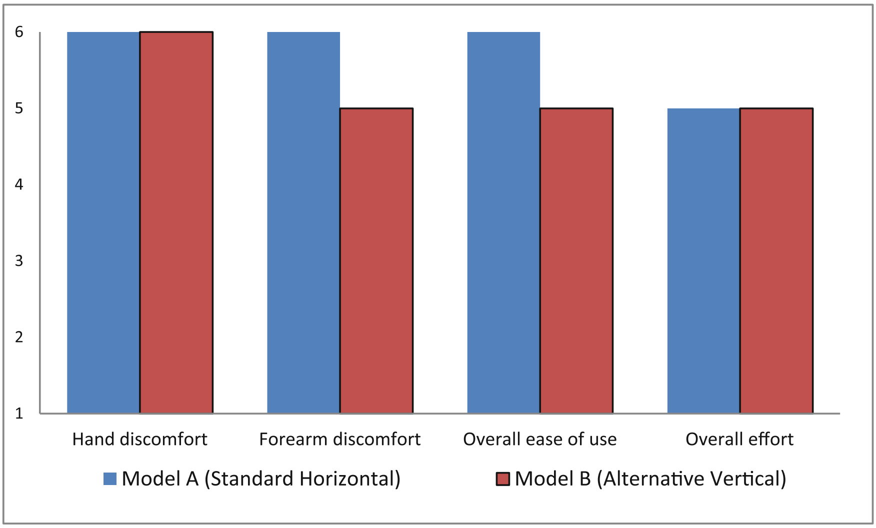

Fig. 3 Hand discomfort mode, forearm discomfort mode, overall ease of use mode and overall effort mode plotted against PC mouse models (All rated from '1' to '6'; Discomfort: from '1'—extreme discomfort to '6'—no discomfort; Ease of Use: from '1'—very difficult to '6'—very easy; Effort: from '1'—extreme effort to '6'—no effort)

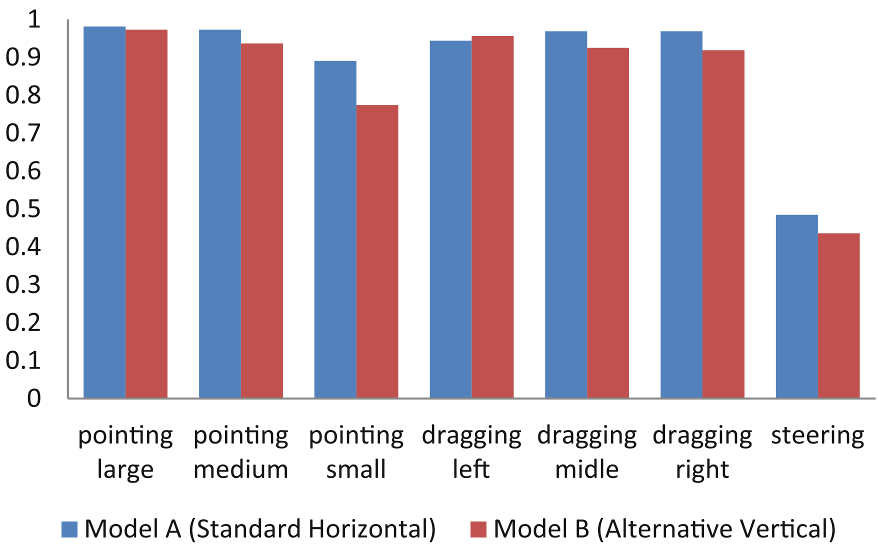

Fig. 4 Mean effectiveness of tasks plotted against the two PC mouse models considered in the study

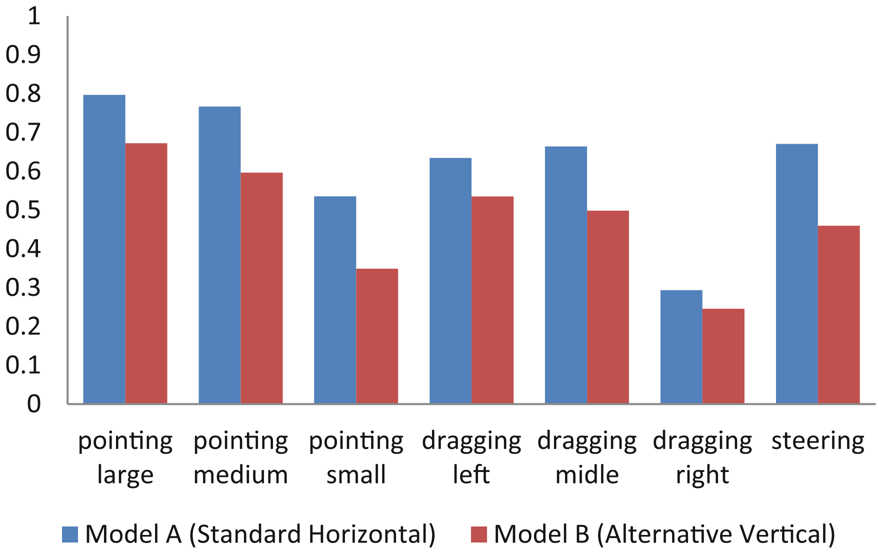

Fig. 5 Mean efficiency of tasks plotted against the two PC mouse models considered in the study

subjective evaluation, hand discomfort, forearm discomfort, overall ease of use and overall effort.

Additionally, the subjective usability variables depicted in Fig. 3 were correlated (Spearman rank order correlation, according to the approach described in [15]) with the objective variables depicted in Figs. 4 and 5, across the two categories of pointing devices included in the study. No significant correlations with objective indicators of usability were found involving hand and forearm discomfort. In what concerns overall effort, a significant moderate correlation was found with efficiency of the pointing at medium targets task (rho = 0.378, $p = 0.016$). Finally, the subjective variable of overall ease of use was positively and moderately associated to the following four objective usability indicators: effectiveness of pointing at large targets (rho = 0.42, $p = 0.07$), effectiveness of pointing at medium targets (rho = 0.386, $p = 0.014$), efficiency of pointing at medium targets (rho = 0.333, $p = 0.036$) and efficiency of pointing at small targets (rho = 0.343, $p = 0.030$). These results indicate the very expressive importance of the pointing tasks in formulating the subjective impression of overall ease of use.

4 Conclusion

An experimental set up with 20 participants was the basis on which to perform usability evaluation of two handheld devices (PC mice) geometrically and paradigmatically quite distinct. The first one is a standard, classic, horizontal and symmetric PC mouse and the second device is an alternative vertical PC mouse (supporting the adoption of a neutral forearm pronation posture by the user in the pointing activity). The study included both subjective and objective evaluation parameters of usability.

The difference reached in efficiency between model A and model B for the most tasks under interest, is statistically supported, in spite of the small sample size and short session time that may have benefited the classic device, show clearly better performance results for model A. Especially the tasks pointing at medium size targets, pointing at small size targets and dragging with right button of the PC mouse, all were simultaneously supported by Mann-Whitney U tests for efficiency as well as effectiveness, all together agreeing with the assumption taken above. The reported tasks play a key role in several computer aided design software tools, hence the present study may help users to better choose their PC mice.

Association between subjective and objective variables suggests the prominent role of pointing tasks in the subjective formulation of the concept of overall ease of use. This notwithstanding, discomfort subjective variables were not significantly associated to any of the objective usability parameters considered.

The results suggest that the envisaged health benefits in what concerns a lowered risk of musculoskeletal disorders of the hand, wrist and forearm proposed in the adoption of the vertical mouse are opposed by reduced efficiency and may increase effort and discomfort (hand and forearm) in the short term leading to the perception of lower ease of use. Hence, the results of the comparison reported in the paper suggest designing hybrid configurations of handheld pointing devices, in order to achieve a compromise between the expected long term effects on health and the objective and subjective task completion usability parameters.

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Cultural and Innovation Shaping of Human Systems Integration Path to Design

Denis A. Coelho

Abstract The paper develops on the Human Systems Integration (HSI) community notion brought forward by Norman [1]. 'Labeling and identity' is revisited, concerning various close disciplines sharing the encompassing aim of designing human systems integration. Problems brought about by the nature of academic disciplines in Implementing Human Systems Integration in the Design stage are contrasted to the solutions suggested by Norman in an effort to pave the path that leads to transformation from a reacting stance to a designing stance. These are juxtaposed to the diverse achievements and scope of innovation and design activities in EU countries with alternative innovation performance and national dimensions of culture, with implications for tailoring the solutions proposed by Norman. The paper concludes with an outlook on the differing rate of adoption of the solutions recommended and actual transformations envisaged within the HSI community, depending on cultural and innovation performance dimensions in 31 European countries.

Keywords Human factors · Human-systems integration · Cognitive engineering · National dimension of culture · Innovation performance · Europe

1 Introduction

The notion of a Human Systems Integration community and its "fire rescuing" stage was brought forward by Norman [1]. Two particular threads springing from Norman's thinking in this respect are approached and developed. On the one hand, the 'labeling and identity' issue is scrutinized, with an analysis of the commonalities and occasional lack thereof between the aims, scopes and approaches

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embedded in the not so distant disciplines of Human Factors and Ergonomics, Human Computer Interaction, Cognitive Engineering and Cognitive Systems Engineering, as well as Computer Supported Collaborative Work. This analysis supports the consideration that the aforementioned disciplines may be looked upon as domains springing from the encompassing aim of designing human systems integration. On the other hand, the problems brought about by the nature of academic disciplines (deep and narrow) in implementing Human Systems Integration in the Design stage are contrasted to the solutions suggested by Norman [1] in an effort to pave the path that leads to the transformation of the Human Systems Integration community from a reacting stance to a designing stance. These solutions are contrasted with the diverse achievements and scope of innovation and design activities in EU countries with alternative profiles of innovation performance [2] and of Hofstede's [3] national dimensions of culture, with implications for tailoring the solutions proposed by Norman [1] to the specific context. National Dimensions of Culture are associated to innovation clusters in the European Union (innovation leaders, innovation followers, moderate innovators and modest innovators), resulting in a further characterization of these clusters from a cultural dimensions perspective (e.g. individuality, masculinity, uncertainty avoidance, power distance, indulgence versus restraint, long term versus short term orientation).

2 Labeling and Identity

Human Factors and Ergonomics: Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people [4].

Human Computer Interaction, (there is currently no agreed upon definition of the range of topics which form the area of human-computer interaction; the following being a practical definition): Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them [5].

Computer Supported Collaborative Work: is a multi-disciplinary research field that focuses on tools and techniques to support multiple people working on related tasks. CSCW provides individuals and organizations with support for group cooperation and task orientation in distributed or networked settings [6].

Cognitive Engineering and Cognitive Systems Engineering: According to Lambie [7], the concept of cognitive engineering is not fixed and unequivocal, but in its various expressions certain common features are found. Norman [8] invented the term 'cognitive engineering' to emphasize cognitive aspects of human-machine interaction. Norman [8] stated: "(…) the aims of cognitive engineering are: to understand the fundamental principles behind human action and performance that are relevant for the development of engineering principles of design, to devise systems that are pleasant to use—The goal is neither efficiency nor ease nor power, although these are all to be desired, but rather systems that are pleasant, even fun: to produce what Laurel [9] calls 'pleasurable engagement'. (…) The critical phenomena of cognitive engineering include: tasks, user actions, user conceptual methods and system image. The critical methods of cognitive engineering include: approximation and treating design as a series of trade-offs including giving different priorities to design decisions."

In parallel to Norman's postulates on cognitive engineering, cognitive systems engineering was developed by Rasmussen, Hollnagel, Woods, among others, and was concerned with systems that were safety critical or complex [7]. As their work developed it attracted attention, because it offered better means to design. This version of cognitive engineering is forward looking to precision and testing of models and representations, rather than backward looking towards its epistemological roots [10].

"This group has too many names (see Table 1); so I will simply call it HSI, Human-Systems Integration" [1]. The analysis depicted in Table 1 supports the consideration that the disciplines therein depicted may be looked upon as domains springing from the encompassing aim of designing human systems integration. Moreover, Human Systems Integration is still in fire-fighting mode when it should be in fire-prevention mode [1].

Table 1 Depiction of commonalities and occasional lack thereof between the aims, scopes and approaches embedded in the not so distant disciplines of human factors and ergonomics, human computer interaction, cognitive engineering and cognitive systems engineering, as well as computer supported collaborative work

Discipline	Aims	Scope	Approach
Human factors and ergonomics	Understanding of interactions among humans and other elements of a system and design in order to optimize human well-being and overall system performance	Organizational, cognitive, physical	Understanding and design
Human computer interaction	Design, evaluation and implementation of interactive computing systems for human use	Computing systems and human use	Evaluation and design
Computer supported collaborative work	Research field that focuses on tools and techniques to support multiple people working on related tasks	Support for group organization	Task orientation
Cognitive (systems) engineering	Understand the fundamental principles behind human action and performance that are relevant for the development of engineering principles of design, to devise systems that are pleasant to use	Cognitive aspects of human-machine interaction	Understanding and design

3 Problems and Solutions Presented by Donald D. Norman

The problems brought about by the nature of academic disciplines (deep and narrow) in Implementing Human Systems Integration in the Design stage are contrasted to the solutions suggested by Norman [1] in an effort to pave the path that leads to the transformation of the Human Systems Integration community from a reacting stance to a designing stance.

Disciplines are deep and narrow; real problems are broad; so the practitioners must have broad, general knowledge, while employing narrow deep specialists. The university rewards expertise in a narrow topic, not broad general knowledge; thus, HSI requires knowledge from the social sciences, design, and engineering, but in the university they are separated by departments and by schools, by divisions and Institutes; the university reward system: Theory, not practice, even in engineering. Human-systems integration is essential; but it is difficult, difficult for fundamental reasons having to do with human psychology, organizational complexity, and the culture of people, groups, organizations, and society (after all, if the problem were easy, it would already have been solved). Large, complex systems are essential to modern civilization, but they entail huge problems: integration across the multiple domains necessary to pull it off, the ability to forecast the unpredictable—the unexpected outcomes of large systems and the compromises necessary for budgetary, aesthetic, social, and political needs. The requirements of each specialized discipline often conflict with one another, leading to yet more compromises or, in the worst case, fights, arguments, and dramatically suboptimal results [1].

Design, the discipline, is ideally suited to help solve these problems. Modern designers are problem solvers, relishing complex, wicked problems, developing creative, original solutions. They are broadly trained, experienced in a wide variety of disciplines; but these virtues come at a price: designers lack the necessary depth in each area. Combine designers and engineers, engineering training and design training, and we can create the people needed to solve the problems of the 21st century. Systems problems, integrating across disciplines, constrained by cost and existing solutions, psychology, sociology, and culture, political differences, and business needs. This is the real world: we need to rethink education to address it. Be less concerned with covering all the essential material and more concerned with teaching students how to think and how to learn on their own. The best students are capable of learning the material when they need it: So emphasize just-in-time learning, the complexity of real problems, the need to integrate across all disciplines, including non-engineering ones, and teamwork [1].

Norman [1] argues for the need of a professional discipline of HIS; commenting that we mostly have a research discipline. HSI must become an applied discipline, not just a research activity, not just a science (it needs all three: science, research, practice). "The problem is this: suppose, magically, HSI was asked to take part in all new projects from the very start. No more fire-fighting. Would HSI be able to deliver? I don't think so". HSI has to stop being an analytical field doing analysis after the fact and become a design field, synthesizing answers on the spot; providing answers in hours or days, not in six months. Doing quick and dirty experiments and quick calculations to ensure that the designs are "good enough"; practical designs look for large effects; traditional science looks for small differences. HSI has to change how it thinks; currently, HSI is not ready for real time. Universities need to change. Not only are they too narrow, but they keep disciplinary walls that inhibit cross-fertilization. Professors lack practical experience and usually feel that such experience is inferior in value to theoretical and research skills; so practice is not rewarded; only publications in refereed, research-based journals are recognized [1].

4 Innovation Performance and Cultural Dimensions

The solutions previously listed are to be contrasted with the diverse achievements and scope of innovation and design activities in EU countries with alternative profiles of innovation performance [2] and of Hofstede's [3] national dimensions of culture, with implications for tailoring the solutions proposed by Norman [1] to the specific context. National Dimensions of Culture are associated to innovation clusters in the European Union (innovation leaders, innovation followers, moderate innovators and modest innovators), resulting in a further characterization of these clusters from a cultural dimensions perspective (e.g. individuality, masculinity, uncertainty avoidance, power distance).

The European Innovation Scoreboards provide a comparative assessment of research and innovation performance in Europe. The scoreboards help countries and regions identify the areas they need to address. It is available from [2]. Table 2 shows in the last column the Innovation Scoreboard 2015 for the European countries where national dimensions of culture was available (the other columns concern national dimensions of culture).

The argument according to which culture exerts a profound influence on the innovative capacity of a society has been largely supported by empirical research. Barnett [12] postulated a positive correlation between the individualism of a society and its innovative potential: the greater the freedom of the individual to explore and express opinions, the greater the likelihood of new ideas coming into being. Hofstede [13] indicated that societies that score high on individualism and low on power distance tend to display higher growth and innovation rates. Shane [14] found that individualistic societies that accept uncertainty and exhibit a low level of power distance are those who attain better innovation performance. Hussler [15] introduced a culture based taxonomy of innovation performance. Societies that succeed by innovating on their own are those that possess a "culture of endogenous innovation". Vice versa, those countries with high uncertainty avoidance and high power distance can be defined as "cultures of imitation". The six measures of national cultures, initially identified by Hofstede [3, 13, 16], are summarized as follows:

Table 2 Hofstede's national dimensions of culture for the 31 countries included in the analysis [11], joined with the European Innovation Scoreboards 2014 data [2] (legend of headings given in main text in this section)

Country	pdi	idv	mas	uai	ltowvs	ivr	Innovation scoreboard 2014 (*100)
Austria	11	55	79	70	60	63	59
Belgium	65	75	54	94	82	57	62
Bulgaria	70	30	40	85	69	16	20
Croatia	73	33	40	80	58	33	31
Czech Rep	57	58	57	74	70	29	45
Denmark	18	74	16	23	35	70	74
Estonia	40	60	30	60	82	16	49
Finland	33	63	26	59	38	57	68
France	68	71	43	86	63	48	59
Germany	35	67	66	65	83	40	68
Great Britain	35	89	66	35	51	69	64
Greece	60	35	57	112	45	50	36
Hungary	46	80	88	82	58	31	37
Ireland	28	70	68	35	24	65	63
Italy	50	76	70	75	61	30	44
Latvia	44	70	9	63	69	13	27
Lithuania	42	60	19	65	82	16	28
Luxembourg	40	60	50	70	64	56	64
Malta	56	59	47	96	47	66	40
Netherlands	38	80	14	53	67	68	65
Norway	31	69	8	50	35	55	48
Poland	68	60	64	93	38	29	31
Portugal	63	27	31	104	28	33	40
Romania	90	30	42	90	52	20	23
Serbia	86	25	43	92	52	28	39
Slovak Rep	104	52	110	51	77	28	36
Slovenia	71	27	19	88	49	48	53
Spain	57	51	42	86	48	44	39
Sweden	31	71	5	29	53	78	74
Switzerland	34	68	70	58	74	66	81
Turkey	66	37	45	85	46	49	26

1. Power Distance Index (pdi)—Power distance is the extent to which less powerful members of organizations expect power to be equally distributed [13]. In low power distance countries there is limited dependence of subordinates on their bosses. Power is very decentralized as well as decision-making. In contrast, in high power distance countries, hierarchy is the fundamental principle on

which all relationships are based. Power is centralized as well as decision-making, leading to more emphasis on formal methods for gathering and analyzing external information [17].

2. Individualism versus Collectivism (idv)—Individualism is the degree to which people are oriented towards acting as individuals as opposed to acting as a group [13]. In individualist countries people tend to value individual success and achievement. Members of individualist countries are autonomous and confident, tending to rely primarily on their own ideas [18]. In collectivist countries, people are bound in groups such as the extended family or the village and are more likely to rely on information provided by others in formulating their opinions [18].
3. Masculinity versus Femininity (mas)—Masculinity is the extent to which success and aggressiveness are valued [13]. In high masculinity countries, high earnings, advancement through opportunities and challenging work are mostly emphasized. The use of information to support decision-making is dependent on its expected effectiveness in gaining advantage over competitors [17]. In contrast, in high femininity countries, relationships, concern for the others, inclusiveness and society's best interest are valued. Cooperation is often a visible feature. The use of information to support decision-making is very typical of a feminine national culture [19].
4. Uncertainty Avoidance Index (uai)—Uncertainty avoidance is the degree to which people feel confident about the future [16]. National cultures that score high in uncertainty avoidance have an emotional need for rules. Vice versa, national cultures that score low in uncertainty avoidance dislike formal rules, setting them only when it is necessary [17].
5. Long Term Orientation versus Short Term Normative Orientation (ltowvs)—Long term orientation stands for the fostering of virtues oriented towards future rewards, in particular perseverance and thrift. It's opposite pole, short term orientation, stands for the fostering of virtues related to the past and present, in particular, respect for tradition, preservation of 'face' and fulfilling social obligations.
6. Indulgence versus Restraint (ivr)—Indulgence stands for a society that allows relatively free gratification of basic and natural human drives related to enjoying life and having fun. Restraint stands for a society that suppresses gratification of needs and regulates it by means of strict social norms.

Geert Hofstede conducted one of the most comprehensive studies of how values in the workplace are influenced by culture. He analyzed a large database of employee value scores collected within IBM between 1967 and 1973. The data covered more than 70 countries, from which Hofstede first used the 40 countries with the largest groups of respondents and afterwards extended the analysis to 50 countries and 3 regions. Subsequent studies validating the earlier results include such respondent groups as commercial airline pilots and students in 23 countries, civil service managers in 14 counties, 'up-market' consumers in 15 countries and 'elites' in 19 countries.

In the 2010 edition of the book Cultures and Organizations: Software of the Mind, scores on the dimensions are listed for 76 countries, partly based on replications and extensions of the IBM study on different international populations and by different scholars.

In what concerns the current validity of Hofstede's cultural measures, criticisms addressed to the construct of national culture as a suitable variable for differentiation, apply directly to all four measures [20]. Different corporate, organizational, industrial and/or sector specific cultures may co-exist within the same firm and might as well conflict and counterbalance the national one [21].

Furthermore, in many countries, different ethnic or national cultures co-exist [22], as result of people mobility around the globe. Within the same country, different sub-cultures might persist, standing apart on religious, language or ethnicity grounds. As a consequence, the four measures of national cultures could be far from being reliable proxies for cultural homogeneity for a given national culture [21].

The data extracted from Hofstede's measures of national culture, that was used in the correlation analyses is presented in Table 2. The data has been cross-validated in an empirical study by van Oudenhoven [23] for Belgium, Denmark, Germany, United Kingdom, Greece, Spain and the Netherlands. The country scores on the dimensions are relative—societies are compared to other societies. It is thought that these relative scores have been proven to be quite stable over decades. The forces that cause cultures to shift tend to be global or continent-wide—they affect many countries at the same time, so that if their cultures shift, they shift together, and their relative positions tend to remain the same.

4.1 Analysis of Association Between National Dimensions of Culture and Innovation Score

Statistical analysis was performed on the data shown in Table 2, with the assistance of IBM SPSS software. The Pearson correlation factor was calculated for association between the Innovation Scoreboard values and the national measures of culture. Four significant and strong correlations were found as a result of this statistical analysis. No significant correlation was found between the innovation performance and the national dimensions of culture of masculinity versus femininity and Long Term Orientation versus Short Term Normative Orientation.

The national dimension of culture of Indulgence versus Restraint is the one more strongly associated to the Innovation Scoreboard from 2014, with a Pearson correlation factor of 0.77 ($p = 0.000$). Indulgent cultures place more importance on freedom of speech and personal control while in restrained cultures there is a greater sense of helplessness about personal destiny. Hence, countries scoring high in indulgence are bound to achieve higher scores in the innovation scoreboard, as this strong positive association indicates.

Power distance and uncertainty avoidance also show a strong association with the innovation performance of the country, albeit with an inverse proportionality. In the former case the Pearson correlation factor is −0.634 ($p = 0.000$), and −0.578 ($p = 0.001$) in the latter. Individuals in cultures demonstrating a high power distance are very deferential to figures of authority and generally accept an unequal distribution of power, while individuals in cultures demonstrating a low power distance readily question authority and expect to participate in decisions that affect them. The results of association support the consideration that low power distance cultures exhibit higher innovation performance. A low score on the uncertainty avoidance index indicates that the people in the country are more comfortable with ambiguity, more entrepreneurial, more likely to take risks, and less dependent on structure rules. Countries with high uncertainty avoidance scores desire more stability, more structured rules and social norms, and are less comfortable taking risks. The results of analysis of association support the consideration that countries with a lower uncertainty avoidance index exhibit higher innovation performance.

The individualism versus collectivism measure of culture was found to be positively associated with the Innovation Scoreboard 2015 in the sample considered ($n = 31$) with a correlation factor of +0.568 (p-value = 0.001). This result indicates that cultures that score high in individualism (where individuals are autonomous and confident) also tend to score high on innovation performance. On the contrary, highly collectivist societies (where people are more likely to rely on information provided by others in formulating their opinions) tend to show lower scores on the Innovation Scoreboard.

4.2 Where the Change in HSI Is Bound to Occur First

Strong associations were found between national dimensions of culture and innovative performance. Hence, it is reasonable to admit that in Europe, innovation performance is tied to the cultural fabric of a country, and hence that innovation leaders (Switzerland, Sweden, Denmark, Finland and Germany) are bound to be at the forefront of innovative developments in the path of the HSI community to design. Innovation followers (Netherlands, Luxembourg, Great Britain, Ireland, Belgium, France, Austria and Slovenia), moderate innovators (Estonia, Czech Rep., Cyprus, Italy, Portugal, Malta, Spain, Hungary, Greece, Slovakia, Croatia, Poland and Lithuania) and modest innovators (Latvia, Bulgaria and Romenia), respectively, will eventually follow with increasing time lags to the innovation leaders.

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Dynamic Gesture Analysis for Distinguishing Between Intentional and Unconscious Motions

Toshiya Naka

Abstract In human communication, nonverbal information such as gestures and facial expressions plays greater role than language, and it is known that gestures serve as a major channel when designing an intimate conversation systems between human and robots. However, one of the chief problem with such gesture-based interaction is that it's difficult to realize the effective actions and distinguish reliably between unconscious and intentional gestures: they tend to respond erroneously to unconscious movements, which impedes the natural communication. In this study, the authors propose a method for analyzing the mechanisms of effective gestures using dynamics: they have extended their analytical method to specifically identify intentional gestures, and found that they can be quantified by the value and slight changes in the torque of the main joints. Humans tend to add "preparation" and "follow-through" motions just before and after the intentional motion, and each behavior can be distinguished by using the "undershoot" or "overshoot" value if torque changes are measured with high precision. These proposed method has the potential not only to solve the problem facing the gesture-based interface but also to design human and robots communication strategy which can exceed the "uncanny valley" [1].

Keywords Gesture · Interaction · Dynamics · Unconscious motion · Communication robot · Systems engineering

1 Introduction

When designing many types of face-to-face interaction systems such as communication robots and virtual humanoid agents, the impression of user-friendly and intuitiveness are the important factors. Generally, the interaction with gestures has

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been an excellent choice as a way to easily use such intimate communication products. Also, it is well known that gestures serve as a major channel for revealing the true feelings within human communication. We frequently use gestures unconsciously, such as waving our hand when we say goodbye and beckoning with the hand when we want someone to come to us. Many studies of gesture analysis were aimed to examine the effects of human interactions. For instance, Knapp et al. [2] clarified the effects of gesture, posture, face and eye behavior on human communication and revealed how these nonverbal signals can affect to interact successfully. Cassell et al. [3] proposed an implemented system which automatically generates and animates conversations between multiple human-like agents with appropriate hand gestures, and Siegman and Feldstein [4] discussed the role of body movement in communication and action in human interactions. Many conventional research works on human-motion analysis have focused on the specific actions such as walking, running and special sports behavior like pitching and kicking. In such fields of sports kinematics, the dynamic analysis method has sometimes been used as a proven methodology [5, 6]. On the other hand, gestures may be made unintentionally when users naturally move their hands and body in daily life. In other words many gestures contain not only intended movements but also the several unconscious or emotional motions, and it is usually very difficult to distinguish both natural and intentional ones.

Given this situation, the authors investigated to quantify the roles of these characteristic gestures. One of the biggest problems with this kind of gesture-based interaction is that it is difficult to precisely distinguish naturally performed actions and gestures made with a specific intention, and sometimes gestures are in fact mistaken movements. These factors, in turn, cause the main difficulty in designing and implementing the gesture interface. Regarding this problem, they proposed a method of analyzing gesture-based interaction using a dynamical approach [7]. In general, human motion can be broadly classified into deliberate operation and unconscious behavior [8]. Furthermore, there is the tendency in which the more we try to make a gesture intentionally or precisely, the more it frequently deviates from natural motion. This tendency was also the basis of their previous analysis, which was focused on clarifying the mechanism behind gestures of emphasis in human communication. In authors previous approach, they found that “preparation” and “follow-through” motions were added unconsciously just before and after the main motion, and each of these behaviors can be quantified by the “undershoot” or “overshoot” of the value changes in torque. In the following section, they use these basic mechanisms of the gesture-analysis technique and extend them to distinguishing between intentional and natural motions.

2 Gesture-Analysis Model

We human tend to add force to the required anatomical parts, such as the arms and body mass, to emphasize certain actions, and these effects can be quantified by the value of torque applied to the main joint such as the hips, knees and wrists [9]. In Fig. 1, the authors show the typical exaggerated gesture model and the hierarchical definition of links structure of their proposed gesture-analysis model, in this case is depicted by movement of the right hand. As a typical example of the conscious gesture; when we are instructed to move accurately and quickly to the target position from the starting point, some kind of "preparation" or "follow-through" motions are usually added just before or after the start and target positions, and these motions will finally converge with subtle vibration. As a first basic approaches, authors tried to analyze these human characteristics by applying this model of exaggeration gestures.

In their previous studies, they found that there tended to be high correlation between the torque of torsion, such as that at the shoulder, elbow and wrist, and the degree of exaggeration motion of the upper arms. In Fig. 2 shows one of the typical dynamical analysis results of the relationship between the exaggeration motion and the torque changes at the main joints. In this figure, τ_7 shows the twisting torque of the wrist joint, τ_9 is the shoulder joint, and τ_{11} is the elbow joint of the right arm, respectively. There is a pattern of additional "preparation" and "follow-through" motions just before or after the "execution" motion. By collecting dozens of the characteristic gestures and applying them to this model, they found that most gesture could be quantified as the "undershoot" or "overshoot" value of torque, which was displayed by the gray zone in this figure.

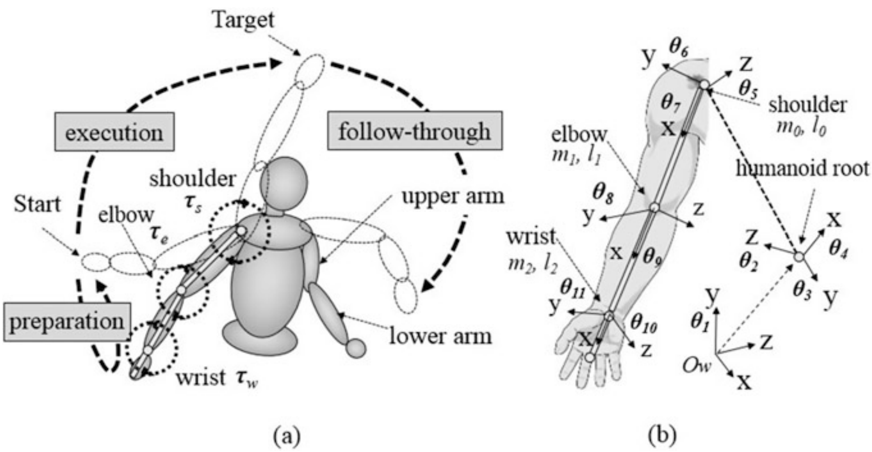

Fig. 1 Exaggeration gesture model and hierarchical definition of links, **a** shows the overall view of right hand exaggeration motion and **b** indicates the hierarchical structure and parameters of right hand

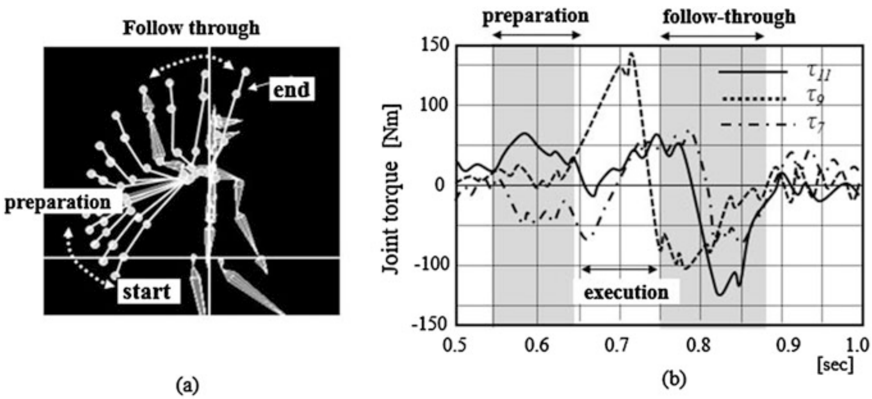

Fig. 2 Typical torque changes of τ_7, τ_9 and τ_{11} in intentional gesture, preparation and follow-through parts of motion are indicated by *gray regions* in (**b**)

3 Basic Idea and Experimental System

The authors extend their basic concept explained in the previous section to determine the difference in gesture behavior between conscious and unconscious behaviors. Figure 3 shows an overview of the experimental system, and (b) illustrates the image of GUI (graphical user interface) used to address the problem. In this experimental system, subjects were asked to stand in front of a large screen (one hundred inches size) and to track the target position exactly from some randomly displayed starting points by using hand gestures only. These user operations

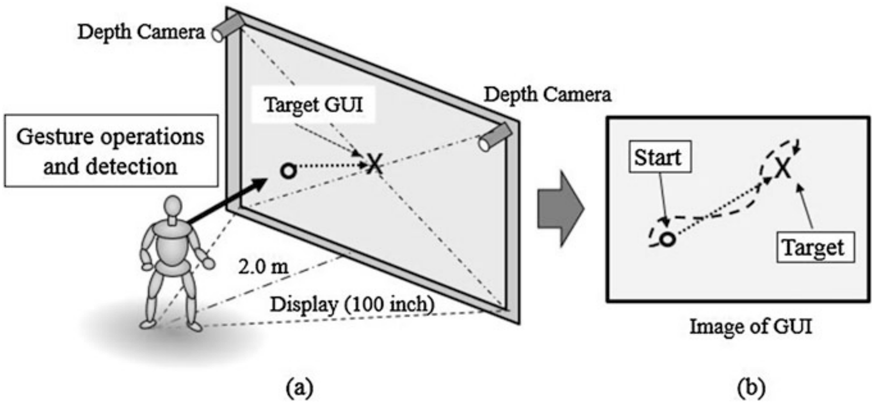

Fig. 3 **a** Shows experimental system overview for gesture behavior, 100 in. size large display with two depth functional cameras can detect any gestures of operator with no occlusion and **b** is an image of GUI, subjects are asked to move accurately the cursor to target position from the start point by using their gesture

were captured and tracked by two depth-functional cameras in real time. When users tried to manipulate the GUI more intentionally (precisely to the target position), a greater difference occurs at the start or target position, and this difference appears as “undershoot” or “overshoot” behavior.

4 Experimental Results

Typical experimental results of the torque changes in intentional gesture analysis are shown in Fig. 4. In this figure, τ_7 shows the twisting torque of the wrist joint, τ_5 is the shoulder joint, and τ_6 is the elbow joint of the right arm respectively. From these experiments, they can observe the same tendency of “preparation” and “follow-through” behaviors being applied to the intentional motion. In addition, this behavior can be quantitatively analyzed by the “undershoot” or “overshoot” value of torque in Fig. 4b. Moreover, there was no significant tendency of “undershoot” and “overshoot” observed in the change of torque value for natural behaviors that have the same start and end positions.

Furthermore, they show some results of the basic experiments to determine the intentional behavior of humans in Fig. 5. In these experiments, subjects are asked to perform user interaction such as that in Fig. 4: “Intentional motion” means to move from exactly the center circle to the cross point of area 1 in the GUI. In this operation, it is necessary to closely match the circle and the cross point, so the motion is usually more conscious. For comparison with this intentional action, “natural motion” means to move from the middle area to area 1 or 8. These tasks do not require the subject to match the point exactly but to enter the general area (much more large target circle and cross point), so it becomes a more unconscious

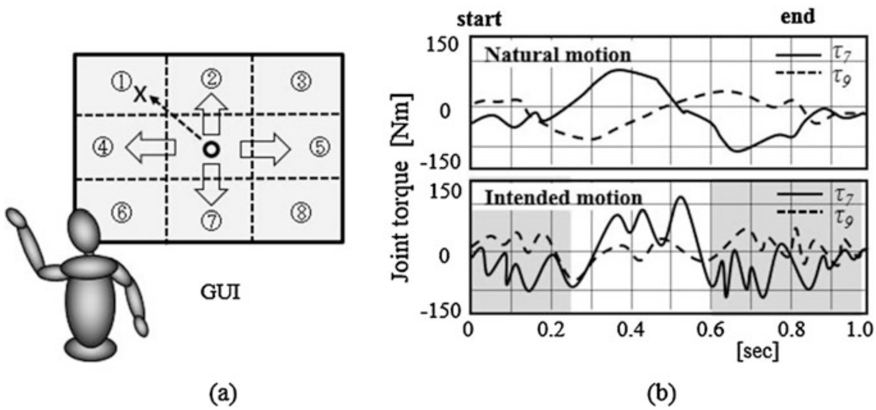

Fig. 4 Typical experimental results of gesture interaction

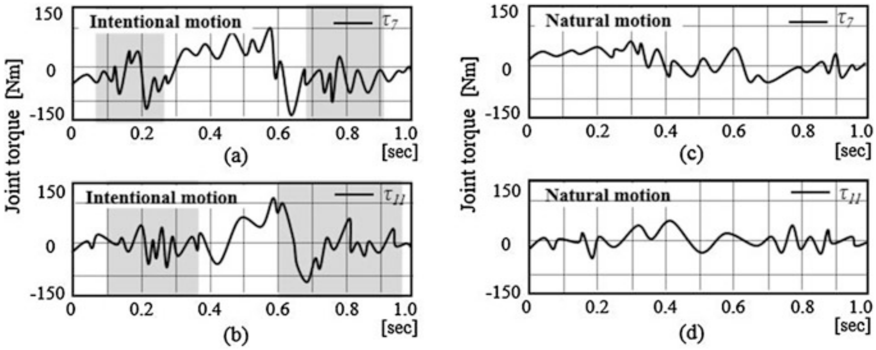

Fig. 5 Typical experimental results for determining intentional-gesture interaction

operation. In these experiments, they used a total of seven subjects who were twenty to forty years old.

Some typical experimental results are shown in Fig. 5. In these experiments, (a) shows an intentional operation from the center circle to the cross point in area 1, and τ_7 shows the twisting torque of the shoulder joint; (b) is also intentional operating results from the center circle to the cross point in area 8, and τ_{11} shows the twisting torque of the wrist joint.

Additionally, (c) is the natural motion extending from the large center circle to the cross point in area 4, and (d) shows the same natural motion from the large center circle to the cross point in area 5. As shown in (a) and (b) in Fig. 5, overshoot or undershoot occurs in the torque value generated in the apparently key joints when the subject performs conscious action, and these are indicated by the gray area. However, these values of the main joints were not remarkable for such unconscious close-approximation tasks in (c) and (d).

From this series of experimental results, it is possible to detect variation in the twisting direction of the torque that is generated in the shoulder, elbow and wrist joints. Furthermore, there is a high possibility of distinguishing between a conscious manipulation and an unconscious close-approximation operation. Based on this idea, authors additionally investigated how to estimate the conscious behavior and unconscious close-approximation action by using the torque generated in the major joints. The accuracy values of this estimation are listed in Table 1. In the experimental operation shown in Fig. 4, there is some difference in the dominant arm (i.e., right handed vs. left handed), but an accuracy rate of more than eighty percent was obtained. In this proposed system, the performances of subjects are captured and analyzed by the dynamical method to detect twisting torque of the main joints.

To determine the threshold value T_h of the operations that are evaluated as being either intentional or natural actions, we used the maximum value and amount of change in the torque values expressed by the integration shown in Eq. 1. In this equation, j shows the number of the main joints that had an impact on each action, and t_s and t_e show the start and end times, respectively. By using the proposed

Table 1 Experimental results of judgment on intentional and natural action

	Accuracy (left-handed) (%)	Accuracy (right-handed) (%)
Motion 1	78.2	90.1
Motion 4	80.3	93.1
Motion 6	84.7	91.6
Motion 2	82.1	88.2
Motion 7	88.7	89.2
Motion 3	90.1	80.3
Motion 5	93.7	77.2
Motion 8	89.2	83.8

dynamical approach, it is possible to reduce the detection of incorrect gesture performance for a given example by operating the GUI a little less consciously.

$$\mathrm{T}_h = \int_{ts}^{te} \sum_{j=1}^{m} \left(d\tau_j/dt\right)^2 dt \tag{1}$$

5 Application of Proposed Method

In this section, they examine the application by using the method proposed in the previous section. In this application, the user stands before a large wall screen (150 inches size) and operates the GUI using only hand gestures. Users can certainly perform the operation by adopting the conscious behavior described in before sections while holding up their left hand. After some exercises, it is possible to operate the GUI almost as intended with only a light consciousness due to the dynamical determination. Through performance evaluation with various objectives, it was found that subjects felt this kind of gesture operation was very easy to use (Fig. 6).

Fig. 6 Gesture interactions prototype. User is able to operate GUIs using gestures of her left hand standing in front of a large screen

6 Conclusion

In this paper, the authors focused on the gestures communication when designing an intimate conversation systems between human and robots and proposed a new intentional-gesture-analysis model. One of the biggest drawbacks of this kind of gesture interface is its inability to clearly distinguish between unconscious and intentional user operations. For this issue, they proposed an ergonomic method to analyze gestures using dynamics. From experiments using seven subjects, the following conclusions were obtained.

Humans tend to add “preparation” or “follow-through” motions just before or after an intentional motion, and each behavior can be distinguished by using an “undershoot” or “overshoot” value of torque changes with high precision. From their series of experimental results, it is possible to detect variation in the twisting direction of the torque generated at joints such as the shoulder, elbow and wrist, and more than eighty percent detection accuracy was obtained. Consequently, there is a high possibility that a system adopting this method can distinguish between a conscious manipulation and unconscious close-approximation operation. The proposed method can provide very important knowledge not only for distinguishing user intentions when interacting with simple operating interfaces using gesture control but also to design human and robots communication strategy which can exceed the “uncanny valley”.

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Reduction of Human Induced Uncertainty Through Appropriate Feedback Design

Marius Oberle, Eugen Sommer and Christina König

Abstract Due to the reduction of development periods and a concurrent increase of product complexity, knowledge about the usage and resulting strain of products becomes more and more important. Thereby the human impact on the uncertainty of usage is essential, yet hardly known or quantified. A first approach for the reduction of uncertainty could be the enhancement of information by means of additional feedback. Therefore, a laboratory study is conducted to investigate the amount of uncertainty as well as the impact of feedback on uncertainty, using a simple placement task. The study shows that by enhancing the amount of information given to the user, the systems strain and with this the uncertainty can be reduced significantly. Further an appropriate concept for the representation of information has to be developed, as the mere enhancement of information could also lead to an enhancement of uncertainty.

Keywords Uncertainty · Feedback · System design · Product usage · Information processing

1 Introduction

In recent years an increase of product recalls, e.g. in the automotive industry [1], can be determined. This is due to the reduction of development periods and product test phases by a concurrent increase of complexity [2]. Therefore, knowledge about the later utilization and the possible resulting strain on a product is crucial when planning and designing a product.

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Due to the variety and variability of the involved factors, prediction of the resulting strain on a product through usage is challenging [3]. In the case of load bearing systems, such as the landing gear of an airplane or a bridge, unexpected disturbances (e.g. natural variation of material properties) are identified as reasons for product uncertainty. Especially human interaction is crucial concerning product uncertainty, whereat the human performance variability can lead to the over-stressing of a system on one hand, but likewise represents a regulation for unexpected disturbances on the other hand [4]—both contributing to the extent of human uncertainty. Therefore, knowledge about the characteristics of human-machine interaction is vital.

Besides a method to further investigate and describe the human induced uncertainty during product usage, the question arises as to how human induced uncertainty can be reduced. According to [5, 6], lack of understanding on the part of the user, due to a lack of information, benefits human error and with this product uncertainty. Therefore, designing an appropriate feedback to enhance the amount of information given to the user by depicting the resulting stress on a product, seems a reasonable approach to reduce the human induced uncertainty.

Within this paper a laboratory study is conducted to further investigate the idea of using feedback to reduce uncertainty. Therefore, a simple placement task with defined weights and a tripod is used. The amount of uncertainty is assessed through the resulting force (impulse) on placing the weight on the tripod (dynamic) and the equality of force distribution (eccentricity) between the three legs of the tripod. The study compares two digital interfaces, one based on the measurement software at hand and the other especially developed according to the human-centered design process [7], regarding their feedback potential. Both feedback interfaces display the system's state, but use different mental models and visual means. They permit the user to improve the resulting system's stress through a second interaction (correction). Both feedback interfaces will also be compared to a task without additional feedback to quantify the reduction of uncertainty and with this the effect of the additional feedback.

This paper first presents the state of research with regard to the topics of uncertainty as well as the human uncertainty of man-machine interaction. Second, the applied method is described, focusing on the test hypothesis, the development of the two used feedback versions and the test setup. Then the conducted study and its results are presented and discussed with regard to the prior derived hypothesis. Finally, the findings and implications are summarized and further research steps indicated.

2 State of Research

This chapter covers a general definition as well as a concept to discern different types of uncertainty. Second, the topic of uncertainty in the context of human interaction, with regard to the utilization of products, is described.

2.1 Uncertainty

In the literature a wide variety of definitions for uncertainty, depending on the field of research, can be found. In the field of Mechanical Engineering a recent definition for uncertainty in the context of load-carrying structures states, that uncertainty only occurs within processes and when the process characteristics of a system cannot or only to a limited extent be determined [3]. Therefore, uncertainty generally describes a lack of information concerning a process.

Based on the above definition, uncertainty can further be subdivided into the three categories unknown uncertainty, estimated uncertainty and stochastic uncertainty [8]. Unknown uncertainty describes a state in which no information about the amount and effect of influencing factors on a process are known. Predictions about the process are therefore almost impossible, for which reason it represents the most severe type of uncertainty. If information about the influencing factors and their effect on a process are at least partially known, e.g. through boundary values of a certain effect, the category of estimated uncertainty applies. In the case of stochastic uncertainty influences and effects can be described through distribution functions, leading to the lowest amount of uncertainty. This means that by increasing the amount of verified information, uncertainty can be transferred from unknown to stochastic uncertainty.

The above definition refers to a technical point of view, focusing on the uncertainty of a technical process. Nevertheless, the definition can also be applied on the uncertainty of man-machine interaction, whereas the interaction is regarded as the considered process and the system involves both user and machine. In that case a new point of view concerning the uncertainty arises, as a constant exchange of information between the two participants is needed. If the user cannot discern the result of an interaction, he is kept unclear about the outcome and therefore the uncertainty for further interactions may increase.

A further inquiry of the uncertainty of man-machine interaction will be given in the following chapter.

2.2 Human Uncertainty of Man-Machine Interaction

Within this paper, human uncertainty describes the human impact on a process and therefore represents an influencing factor for the above stated process uncertainty. Currently, information about the human impact on the strain of technical systems/products is sparse. Human uncertainty can therefore be categorized as unknown uncertainty. Before going into detail, a definition of the context in which human uncertainty generally occurs will be given (see Fig. 1).

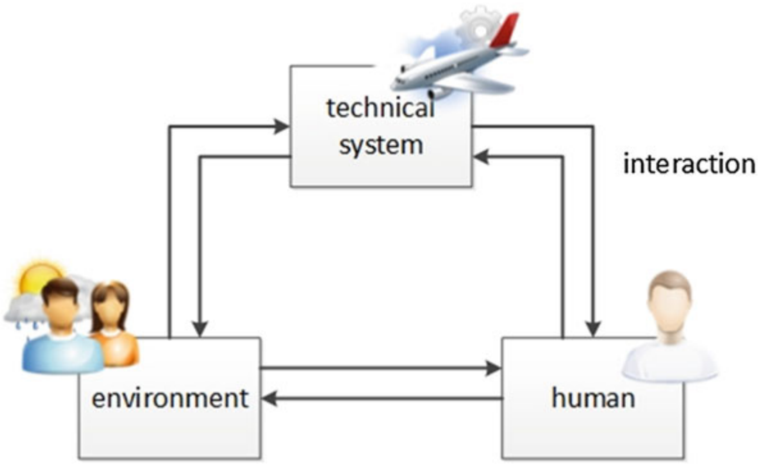

Fig. 1 Context of human uncertainty [9]. (A further development of the model for a detailed description of the interaction between user, environment and technical system is planned for future research.)

With regard to product usage, human uncertainty is characterized through the interdependency of the involved elements *technical system*, *environment*[1] and *user*. Initially the user as well as the technical system can be described through their system quantities. In the case of a technical system that could for example be its material properties or a certain work mode; in the case of the human being that could be attributes like age, gender or a certain set of qualifications and experiences. The initial quantities itself represent a first source for uncertainty, as they generally can't be quantified to a full extent, which leads to a lack of information.

A second source for human uncertainty is represented within the interaction itself, which can be subdivided into the two stages *choice of action* and *execution of action* [9]. Within the first stage, the user decides which specific type of action to use for the interaction. For example, this could be the decision to operate a switch with the left instead of the right hand or to not operate the switch at all. As this stage defines the general characteristics of the planned interaction, it is of major importance when considering human uncertainty. The second stage, the execution of action, describes the actual interaction and therefore how the prior chosen action is executed. Within this stage, human uncertainty focuses on the elementary variations of action execution, like the speed or force used to handle a switch. Consequently, the stage of action execution directly impacts on a system's strain and with this on the human uncertainty.

Information about the execution of action as well as its impact on the interacted system is always generated and can be perceived by the user through his senses. For

[1]As the paper focuses on the interaction between user and technical system, the environment will not be regarded any further.

example, the user could feel the amount of exerted force to handle a switch and a switch could emit a certain noise when latched correctly.

To reduce the uncertainty connected to the execution of action, a further enhancement of this natural feedback through appropriate feedback and system design is applied and investigated within the following chapters.

3 Method

In the following chapters the method to evaluate the effect of appropriate feedback design is presented. First the research hypotheses, which are validated within the following experiment, are defined. Second the experimental setup is presented before at last the two feedback designs, which were used throughout the experiment, are described.

3.1 Test-Hypotheses

As already stated within the introduction, lack of understanding due to a lack of information can lead to increase of human errors [5]. Applying this idea to the concept of uncertainty, leads to the assumption, that less information leads to an increase of uncertainty. As this assumption is directly in concordance to the above stated definition of uncertainty, following initial hypotheses is derived:

- H1[2]: Additional feedback results into a reduced system stress as well as a reduced amount of uncertainty in comparison to natural feedback.

Besides this general statement, it seems appropriate to investigate the amount and shape of the presented information and its impact on uncertainty. It can be assumed, that not only the mere increase of information leads to a reduction of uncertainty, but rather the manner of information representation, e.g. according to human information processing [6], will lead to a reduction of uncertainty. Therefore, following second hypotheses is derived:

- H2[3]: Appropriate feedback, designed with regard to the user, results into a reduced system stress as well as a reduced amount of uncertainty in comparison to feedback not designed with regard to the user.

Following the test setup for the evaluation of the above hypotheses is presented.

[2]For a better legibility the null hypothesis is not specified.

[3]For a better legibility the null hypothesis is not specified.

3.2 Experimental Setup

The formulated hypothesis concerning the influence of feedback variation on human uncertainty will be examined using a tripod as a loadbearing system which will be stressed by test persons. The complete experimental setup can be seen on the left of Fig. 2.

Centered on the table rests the tripod, arrested within small cavities to guarantee the same position throughout the experiment. On the end of each leg a dynamometer is installed, which enables the measurement of force applied to the system for each leg independently. Next to the tripod 2 weights, used by the test person to strain the tripod, are placed on fixed positions. Each weight weighs about 1.7 kg and is designed according to [10] to easily fit the 95th percentile of male and female hands within height and diameter. On a monitor, placed centrally on eye level behind the test table, the two different feedback designs can be presented to the subjects. The participants handling area as well as the handling height are adjusted with the help of a wooden, height adjustable pedestal. By using a measurement software, the force exerted by placing weights on the tripod as well as the location of the weights on the tripod can be recorded accurately.

The test participants are given the task of stacking the two identical weights on the tripod so as to minimize the resulting strain. The task can further be subdivided into two equal subtasks, as the strain depends on two parameters. On the one hand the weights have to be placed as gently as possible, with the goal to reduce the

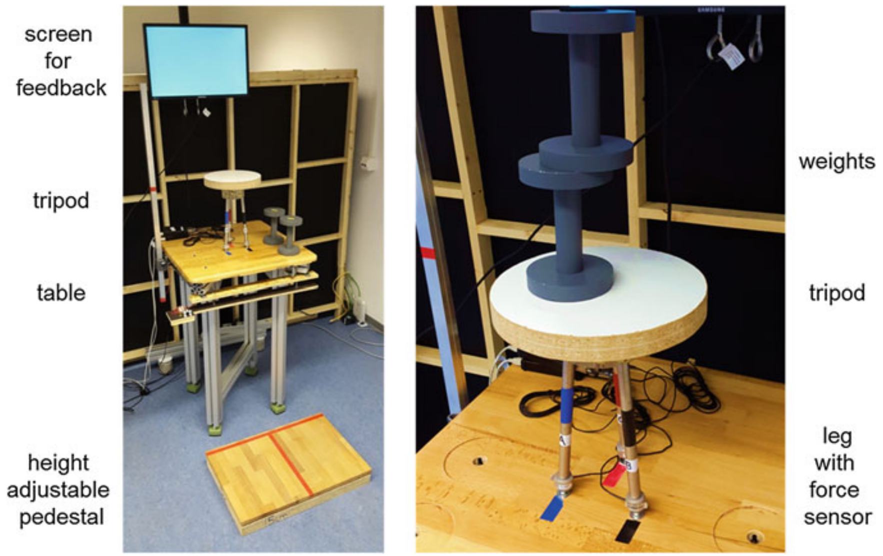

Fig. 2 Complete experimental setup consisting of a height adjustable pedestal, a table, the tripod and a screen for depicting the feedback (*left*) as well as the weights, the tripod at close with its three legs each with force sensor (*right*)

maximum force on touchdown. On the other hand, the weights have to be placed as centered as possible, with the goal to distribute the weight equally on all three legs.[4] Figure 2 (right) depicts a possible result after placing the weights.

The measured forces for each leg of the tripod represent the dependent variables. For the evaluation of the hypotheses two specific parameters are derived. One is the sum of the maximum force during touchdown of the weights (relating to the impact on the tripod) and the second is the force distribution across the three legs, specified by the eccentricity of the weight in relation to the center of the tripod. The independent variable represents the variation of feedback given to the subjects.

To eliminate or control external influences, the study is carried out in a separate room under laboratory conditions. To further control the influential factors the complete body of participants is restricted to right-handed men. To keep the effects of learning at a minimum, the sequence of feedback variations is permuted and each stacking task is preceded by two trial runs as well as repeated three times to account for outliers. In addition, demographic and complementary data is collected. For instance, each participant is asked to state the feedback version, with which he subjectively stressed the tripod the least and the most. Also the comprehension of the two digital feedback versions is assessed before and after each change of feedback through a questionnaire.

To ensure an identical procedure for every subject, every step is recorded using a checklist, which also contains prescribed phrases for instructing the subjects. Prior to the main study, the described experimental setup and procedure is evaluated within a pre-study.

3.3 Feedback Design

To investigate the second group of hypotheses concerning the effect of different designs and amount of the presented information, two different feedback versions are required as shown in Fig. 3.

Feedback1 (Fig. 3, top) provides continuous information about the tripod's stress by depicting the exerted force per leg across time using a curve chart. Right to the chart the last exerted maximum force per leg is given in numbers. *Feedback1* originates from the measurement software and was included with the dynamometers.

Feedback2 (Fig. 3, bottom) is separated into two charts, each developed to best support the user at one of the subtasks. Thereby the chart on the left provides information concerning the maximum force per leg on touchdown by the use of a bar chart. The chart on the right depicts the eccentricity of the placed weight in relation to the tripod surface as could be viewed from above. Other than *Feedback1*, the information on both charts is updated discreetly after every placement of a weight.

[4]The resulting distance between the center of the tripod in relation to the center of the weights is following referred to as eccentricity.

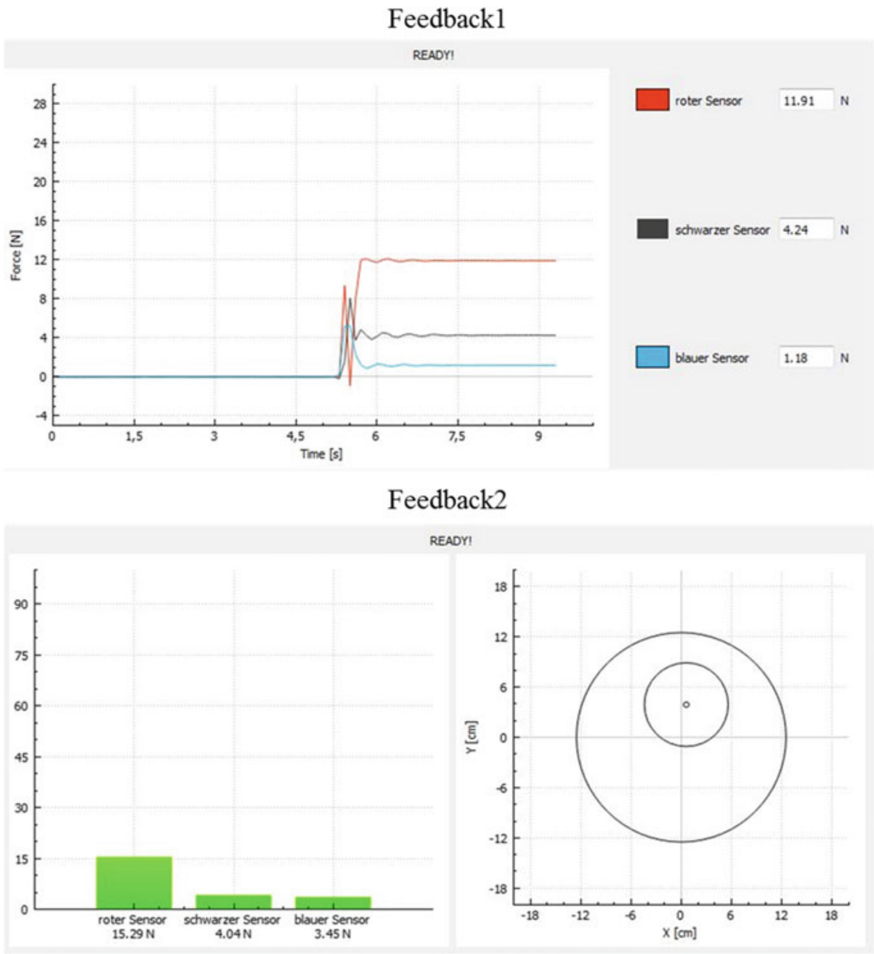

Fig. 3 *Top* Feedback1, consisting of a curve chart depicting exerted force per leg across time as well as maximum of exerted forces; *Bottom* Feedback2, consisting of a bar chart depicting force per sensor (*left*) and an optical representation of the position of the weights in relation to the tripod (*right*)

Feedback2 was specifically developed for this study according to the human-centered design process [7]. After the specifying of the context of use as well as the user requirements a morphological box was derived, containing a variety of different possible solutions. Through systematic variation three early concepts were derived and evaluated within a focus group by three usability experts.[5]

[5]All three experts were experienced research associates at the institute of ergonomics and human factors at TU Darmstadt. All experts had the opportunity to test Feedback1 prior to the focus group.

Thereby single elements of the concepts as well as the complete concepts were compared and rated. Finally, *Feedback2* was developed as a mix of the highest rated elements and implemented within the measurement software.

4 Results

A total of 32 participated at the study. All participants were right-handed men with an age ranging from 19 to 29 years (M = 23.8, SD = 2.5). Testing took about 45 min for each participant. Due to missing data, one participant had to be excluded, reducing the participants to 31.

Following the collected data will be presented and used for the evaluation of the hypotheses.

4.1 Descriptive Evaluation

In Table 1 the mean, median and standard deviation is given for all three feedback versions. Additionally, Fig. 4 depicts the results for maximum force (left) and eccentricity (right) of the placing processes in the form of box-plots.

As can be seen, the median for all three feedback variations as well as the mean value are nearly equal concerning the maximum force during the placement of the second weight, only differing less than 0.2 N. The variation of the standard deviation depicts small differences, especially for the highest deviation of *NoFeedback*. But with regard to the boxplot, an outlier can be identified, which is to blame for the higher deviation. Therefore, regarding the maximum force no tendency for differences between the feedback version can be found descriptively.

When regarding the data and the plots for eccentricity, a broader variation between the three feedback versions can be noted. Thus *NoFeedback* indicates the only negative mean value and a median directly at 0.00. In that case the subjects aggravated the resulting strain on the tripod by increasing the eccentricity with the second weight. Between *Feedback1* and *Feedback2* only small differences appear

Table 1 Mean, median and standard deviation for maximum force (in N) and eccentricity (in %) for all three feedback versions

	Maximum force			Eccentricity		
	Mean	Median	SD	Mean	Median	SD
NoFeedback	18.01	17.68	1.01	−0.03	0.00	0.32
Feedback1	17.84	17.57	0.75	0.24	0.22	0.30
Feedback2	17.94	17.75	0.89	0.29	0.31	0.19

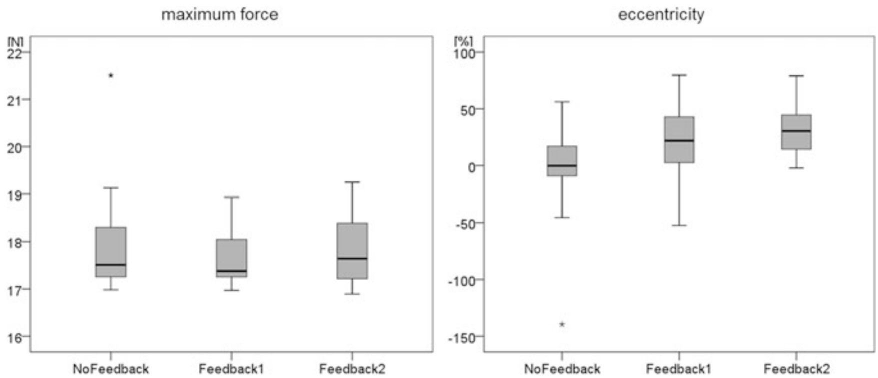

Fig. 4 *Left* Boxplot depicting the mean of the maximum force for each feedback variation for the placing of the second weight; *Right* Boxplot depicting the mean of the percentage improvement of eccentricity after placing the second weight. (Mean of the maximum force for all three legs summed across all three placings per feedback variation and subject.)

concerning median and mean value. Respective the standard deviation *Feedback2* depicts the lowest value compared to the other two feedback versions, which are more or less equal. Therefore, regarding the eccentricity a first tendency towards a reduced uncertainty for the additional feedback versions can be determined.

4.2 Evaluation of Hypotheses

To evaluate the impact of the feedback versions on the strain as well as on the uncertainty, the prior stated hypotheses are used. The hypotheses represent the general test idea and therefore have to be specified further. Respectively, testing of both dependent variables, maximum force and eccentricity, as well as each combination of feedback versions is desirable. In addition, the parameters strain and uncertainty are represented through mean value and standard deviation, which finally leads to a total of twelve sub hypotheses.

For evaluating the hypotheses concerning the impact of the feedback versions on the strain, a test to compare the mean values is needed. A first analysis reveals, that the data is not represented by normal distribution. Therefore, the Wilcoxon signed-rank test is picked as a non-parametric test for two dependent samples. Following the same assumptions, the Levene's test is chosen for comparing the standard deviations. All tests are rated against a significance level of $p < 0.05$ and Bonferroni correction is applied.

Table 2 depicts the resulting *p*-values for all twelve sub hypotheses.

With regard to the maximum force none of the four tested sub hypotheses for *H1* shows a significant *p*-value. Therefore, an impact of the feedback versions on the exerted maximum force is not verified, which confirms the results from the

Table 2 *P*-values for the tested hypotheses

		Maximum force		Eccentricity	
		Mean	SD	Mean	SD
H1	NoFeedback → Feedback1	0.681	0.146	0.000	0.502
	NoFeedback → Feedback2	0.710	0.631	0.000	0.504
H2	Feedback1 → Feedback2	0.652	0.289	0.327	0.058

descriptive data analysis. For the eccentricity, a highly significant ($p < 0.001$) difference of the mean values between *NoFeedback* and each of the two digital feedback versions is measured. Hence the impact of additional feedback on the strain of the tripod is confirmed. Besides this, again no further impact of feedback can be verified. Hypothesis *H1* is only confirmed in parts.

Hypothesis *H2* remains unconfirmed. All four tested sub hypotheses exceed the appointed significance level. Still, with a *p*-value of 0.058 the difference of the standard deviation for eccentricity draws near that level. The tendency from the descriptive data analysis remains a tendency.

4.3 Evaluation of the Questionnaire Data

In addition to the measurement, a questionnaire was used to assess a subjective rating of the different feedback types as well as their intuitive intelligibility by all participants.

Comparing the results for the intuitive intelligibility shows that the majority of the participants had difficulties to correctly interpret the factor eccentricity using *Feedback1*. In numbers, only 38.7 % before and 54.8 % of the participants after the study answered the question correctly. In the case of *Feedback2*, 83.9 and 87.1 % of the participants answered the question correctly. Therefore, *Feedback2* seems a lot easier to understand. The question for the factor maximum force is interpreted equally correct before and after participation by nearly 100 % of the participants.

Evaluation of the subjective rating of the feedback versions shows that 41.4 % of the participants thought to have achieved the lowest maximum force by using *Feedback2*. Furthermore, 86.2 % of the participants thought to have achieved the lowest eccentricity with *Feedback2*. With this a subjective preference of *Feedback2* can be perceived.

Due to the fact that no effect of the feedback versions on the maximum force could be measured, an additional questionnaire was send to each participant after the experiment. The goal was to settle the question whether the participants focused more on reducing the maximum force on touchdown or to reduce the eccentricity. A total of eight participants answered that questions, whereas seven of them stated to have solely focused on eccentricity by ignoring the maximum force.

5 Conclusion

This study shows that enhancing the amount of information given to the user concerning the resulting system state leads to a decrease of the systems strain and uncertainty. Additionally, it can be noted that different feedback types lead to different amounts of uncertainty. Whether the feedback concept, which was developed according to the human-centered design process, leads to an even further reduction of uncertainty, remains unclear.

Generally, the effect of additional feedback could be confirmed with regard to a reduced system strain. A direct connection of feedback to uncertainty could not be verified. Reasons could be an insufficient sample size or the application of an unsuitable test-method. Further, the missing effect of feedback on the maximum force can be explained by the fact, that the participants tended to solely rely on the feedback for the optimization of eccentricity. The task of reducing the maximum force was thereby accomplished only using natural feedback like vision and sound.

For future research the method of eye-tracking could be applied to further investigate to which extent specific features are employed by the user. Insights could be applied for the improvement of man-machine interfaces with the goal to further reduce human uncertainty. Therefore, an appropriate concept for the representation of information has to be developed, as the mere enhancement of information could also lead to an enhancement of uncertainty.

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The Effects of Extend Compatibility and Use Context on NFC Mobile Payment Adoption Intention

Pan Liu and Shu-ping Yi

Abstract The purpose of this research was to investigate whether devices compatibility, lifestyle compatibility and use context had an effect on the individuals' NFC m-payment adoption intention and the influencing mechanism. To implement this research, a questionnaire was carried out on the Internet based on sampling survey method, in order to test the developed research model towards NFC m-payment. Through SEM analysis we got four findings: (1) devices compatibility had an active influence on NFC m-payment adoption intention, while lifestyle compatibility did not show significant influence. (2) However, lifestyle compatibility had an influence on individuals' use context and thus indirectly influenced individuals' NFC m-payment adoption intention, (3) further, use context was a vital factor and had an active influence on individuals' NFC m-payment adoption intention, (4) finally, we found perceived risk had no effects on NFC m-payment adoption intention.

Keywords NFC M-payment · Extend compatibility · Adoption intention · Use context

1 Introduction

Following the development of "Internet +" in China, NFC m-payment will become an important application. Therefore, Following the development of "Internet +" in China, NFC m-payment will become an important application [1]. In China, NFC m-payment appeared in 2009, after seven years' development, NFC m-payment was still not universally accepted by consumers, therefore, understanding the factors

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influencing individuals' adoption intention was an urgent problem, as service providers, government and equipment suppliers had put into plentiful financial and human resources.

Reviewing the related studies, we found that many factors influencing user's adoption intention on m-payment had been studied. However, in China, few studies had pay attention on NFC mobile payment, especially the effects of relative advantage, extend compatibility (devices compatibility, lifestyle compatibility) and use context on individuals' adoption intention was a gap. In addition, its effects mechanism on NFC m-payment adoption intention was important for stakeholders, unfortunately it was a research blank as well.

Therefore, this study aims to understand the above-mentioned effects of devices compatibility, lifestyle compatibility, and service compatibility on NFC m-payment. The results of this study will help the stakeholders understand individuals' behavior well, and facilitate the diffusion of NFC m-payment in China.

1.1 Mobile Payment

In the era of mobile internet and internet of things, m-payment is a significant application. However, the definition of m-payment had different viewpoints, and the main accepted definition was proposed by Dahlberg, he thought that m-payment was to implement business transaction and capital transfer through communication network or other communication technology.

Previous researches indicated that unified theory of acceptance and use of technology (UTAUT) [2], innovation diffusion theory (IDT) [3] and technology adoption model (TAM) [4] were used widely by the investigators [5–7] for exploring the elements influencing adoption intention on m-payment. In addition, researches also focused on enjoyment as a main factor to reflect the individuals' adoption intention on m-payment [8], and perceived risk also was introduced as a negative element to response user's concerns on security during the process of financial transactions [9, 10], What's more, in the area of NFC m-payment [11], had proved its effect on NFC m-payment adoption intention. However, in Chinese Mainland, few studies had explored the effects of perceived risk on NFC m-payment adoption intention.

1.2 IDT

Based on the innovation diffusion theory (IDT), we knew that an innovation contained five traits, such as, compatibility, relative advantage, observability, complexity and trialability [12]. In some papers, relative advantage was thought to be similar to perceived usefulness, and complexity was semblable to perceived ease of use, compatibility was "the level in which innovation was believed to be agreement

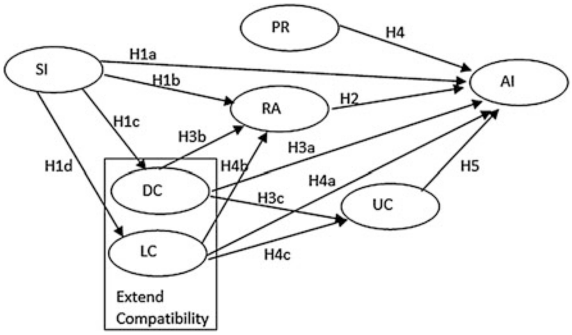

Fig. 1 Research model. Note: *SI* Social influence; *DC* Devices compatibility; *LC* Lifestyle compatibility; *RA* Relative advantage; *UC* Use context; *PR* Perceived risk; *AI* adoption intention

with the present values, past experiences and the needs of prospective users" [6]. In this paper, relative advantage (the advantages of NFC m-payment compared with remote m-payment) was thought to be an important factor on NFC m-payment adoption intention. While, in this study, compatibility contained device compatibility and life compatibility. Devices compatibility was defined as whether NFC m-payment service could apply to individuals' current mobile devices, while the life compatibility defined as the uniformity of an innovation with individuals' current lifestyles and experiences, and the system of NFC m-payment could be suitable to user's financial account system [13].

1.3 UTAUT

UTAUT was developed based on the theories of TAM, DOI, TRA, TPB [2], in this model, it described four independent variables, i.e., performance expectancy, effort expectancy, social influence, and facilitating conditions. Social influence was the degree of an individual perceived that momentous persons (e.g., peers or friends) thought he/she should done thing [14], and social influence had been verified influencing technology acceptance intention directly, furthermore, in remote m-payment area, it had been examined. In this paper, social influence also was thought to be a significant factor on NFC m-payment adoption intention. Therefore, based on the UTAUT and IDT theory, the research model was developed. As shown in Fig. 1.

2 Hypothesis

2.1 Social Influence

In different researches, environment had different classifications and meanings. Such as [15], split environment into physical environment and personal environment. In this paper, environment denoted personal environment (i.e., personal environment, social influence). Social influence was defined as "the degree to which a person trusted that people who were important to him thought he should finish the behavior in question" [16]. What is more, social influence directly affected technology acceptance [17, 18] had been examined. In addition, if friends got some advantages by using NFC m-payment, which will promote consumers to use it, what's more, friends' behavior will increased individuals' perception. Social influence had active influence to individuals' perceived ease of use and perceived usefulness on remote m-payment and NFC credit card [6], further, in many studies, they thought perceived ease of use was consistent with compatibility, and perceived usefulness stand for relative advantage. In this paper, compatibility contained devices compatibility and lifestyle compatibility. Therefore, we assume:

- H1a. Social influence was an essential factor in affecting user acceptance of NFC mobile payment.
- H1b. Social influence has an active influence to relative advantages in the process of adopting NFC m-payment
- H1c. Social influence has an active influence to devices compatibility in the process of adopting NFC m-payment
- H1d. Social influence has an active influence to lifestyle compatibility in the process of adopting NFC m-payment

2.2 *Perceived Relative Advantage*

Relative advantage [3] had been confirmed as a crucial factor of technology adoption. Such as, Dearing and Meyer proposed that innovations' saving money characteristics had been found to spread more rapidly than existing methods due to their perceived economic advantage. Tan et al. [19] found that perceived convenience forecast adoption decision on e-commerce activities. Besides [20] argued that the importance of providing a convenient payment way for consumers, and [21] also explained the benefit active influence individuals' perception on e-payment. In addition, the effects of relative advantage of remote m-payment had been examined [22]. In the NFC m-payment surroundings, NFC m-payment offered up the vital attributions (which can be used in the condition of no Internet connection) to the relative advantage. As NFC m-payment service could furnish any financial transactions in online environment, and it also cloud be used in the condition of no internet connection, therefore, we assume:

H2. Individuals' perceived relative advantage of NFC m-payment will actively influence individuals' intention to adopt them

2.3 Devices Compatibility

The mobile equipment compatibility was defined as the degree that individuals' current mobile facilities could fit the new mobile payment technology. According to previous studies, one of the barriers in the intention to adopt MCC was the cost of acquiring mobile phone [23, 24]. However, if individuals' mobile phone or mobile equipment could be used for NFC mobile payment, they did not need to buy a new NFC mobile phone. In addition, an individual's perception of devices compatibility would increase their perception on relative advantage, if the NFC m-payment had a better compatibility with their mobile devices, it would be easier for individuals to experience the NFC m-payment in special context, thus increased their perceptions of relative advantage and use context. Therefore, the devices compatibility of mobile equipment is important for individuals. Hence, we assume:

- H3a. Individuals' mobile devices compatibility has an active influence on the intention to accept NFC mobile payments.
- H3b. Individuals' mobile devices compatibility has an active influence to their perceived relative advantages during the process of adopting NFC m-payment.
- H3c. Individuals' mobile devices compatibility has an active influence to the use context during the process of adopting NFC m-payment.

2.4 Lifestyle Compatibility

Compatibility was one of the innovation characteristics, proposed by Rogers [12], and defined as the uniformity of an innovation with individuals' current lifestyles and experiences. Based on Rogers's studies [25], put forward a measurement scale for the innovation characteristics.

The influence of an innovation's compatibility on individuals' adoption intention had been studied in many areas, such as, the effects on mobile ticketing service [26], m-payment on public transportation [27], internet payment [22], etc. In addition, [28], found compatibility to be a crucial innovation characteristic driving consumer acceptance. However, in China, few studies focused the influence of the NFC mobile payment compatibility on users' adoption intention, although, in Taiwan, it had been studied [11], however, Taiwan could not represent the situation of whole China. In addition, an individual's perception of lifestyle compatibility would increase their perception on relative advantage, if the NFC m-payment had a better compatibility with their lifestyle, it would be easier for individuals to experience the NFC m-payment in special context, thus increased their perception of relative advantage and use context. Therefore, the devices compatibility of mobile equipment is important for individuals. Hence, we assume:

- H4a. Individuals' lifestyle compatibility has an active influence on the intention to accept NFC mobile payments.

- H4b. Individuals' lifestyle compatibility has an active influence to their perceived relative advantages during the process of adopting NFC m-payment.
- H4c. Individuals' lifestyle compatibility has an active influence to the use context during the process of adopting NFC m-payment.

2.5 Perceived Risk

Perceived risk meant that individuals felt the consequences' uncertainty when they used m-payment for purchase. A lot of research showed that perceived risk was thought to be a main factor baring users from accepting an innovation [29, 30]. In addition, [22] also explained that many users today were afraid of transaction risk. Moreover, in NFC mobile payment area, Pham and Ho [11] had explained that perceived risk had an influence on the adoption intention of NFC mobile payment. However, it was in Taiwan and could not represent the situation of whole China, Hence, we assume:

H4. Perceived risk will influence the adoption intention on NFC mobile payment.

2.6 Use Context

Use context was a situation that "users meet when they use mobile services in different places and times" [26]. Current studies about e-commerce had proposed that use context would influence consumers' choice of purchase channel [31], in addition, Mallat et al. [26] also had examined that use context influenced individuals' adoption intention on m-payment. Therefore, in the area of NFC m-payment, we assume:

H5. Use context has active effects on individuals' adoption intention on NFC m-payment

3 Method

3.1 Instrument

Seven constructs were included in the research model. All constructs were measured with multiple items and used five-point Likert-type scales ranging from (1) extremely disagree to (5) extremely agree, and most of the items were come from preceding studies but amended to suit our environment of NFC m-payment services. However, the items of devices compatibility were made by the study team.

Because the questionnaire used in Chinese, a translation work was conducted to guarantee translation effectiveness. In the first place, all the primordial items were translated into Chinese by an investigator, then we called for a professional English translator whose native language was Chinese to give us some advices. Based on his feedback information, we modified the questionnaire. Secondly, we invited 6 participants who came from our college and had used the AlipayPortal to finish the questionnaire, thereafter, we asked them whether the items existed indigestible or ambiguous words. According to their feedback, we modified some words to make them simple and clear. Meanwhile, an introduction about NFC m-payment [1] was given and aimed to help participants to understand the questionnaire easily, in order to test whether participants read this introduction carefully, and some testing items were given. Finally, 36 participants were invited to complete the preliminary investigation through WenQuanXing (a website of questionnaire test in China), then we examined the validity and reliability of this questionnaire by SPSS.

3.2 Sample

The formal testing was implemented among young people aged 17–48, as they were generally the early adopters of a new technology, moreover, most of the younger had used the remote m-payment. Therefore, they may have the ability and interest to use NFC m-payment. The questionnaire was tested in China, thus reducing the effects of culture. The questionnaires were collected through WenQuanXing. The total of 207 questionnaires were issued during a week of work, and the valid response rate is 91.8 % (190 of 207 is returned). The average age of the respondents was 26.8 years, 60.7 % of the respondents were male and 39.3 % were female.

3.3 Reliability and Validity Analysis

In order to test whether the scale suite do factor analysis, the KMO and Bartlett's test of sphericity were implemented. The results indicated that the value of KMO was 0.914 and greater than 0.5, and the spherical test chi-square values was 4891.618 and the degree of freedom was 253 ($p = 0.001$), therefore, the results manifested that the scale was fit for factor analysis. As shown in Table 1.

Using the principal component analysis method by SPSS21.0, based on the eigenvalue (more than 1) extracted factors, adopting the method of varimax made the factor matrix rotate, and a total of seven factors were rotated, and the total rate of variance explained reached to 87.176 %. In addition, all the indexes were greater than 0.5 and had a big load on the corresponding factors, and the factors of the crossed variable had a low load (lower 0.5), which indicated that the convergent validity and differential validity were suitable.

Table 1 The value of validity and reliability for the independent and dependent variables

Measure	Items	Factors loadings	KMO	Eigenvaule	Variance explained (%)	AVE	CR	Cronbach's a
Lifestyle compatibility	5	0.851–0.680		10.058	50.427	0.589	0.875	0.958
Use context	4	0.803–0.757		2.736	11.896	0.614	0.863	0.937
Perceived risk	3	0.950–0.898		1.992	8.661	0.672	0.800	0.934
Social influence	3	0.825–0.780		1.718	4.847	0.564	0.840	0.925
Relative advantage	3	0.810–0.614		1.644	3.851	0.762	0.833	0.875
Devices compatibility	2	0.685–0.667		1.115	3.089	0.755	0.853	0.899
Adoption intention	3	0.786–0.778	0.757	1.970	87.176	0.644	0.848	0.937

4 Results and Discussion

4.1 Structural Model Test

Testing the research model adopting the Smart PLS 2.0, and the results indicated that H1a, H1b, H1c and H1d got support, which demonstrated that social influence had positive effects on NFC m-payment adoption intention and the perceptions of relative advantage, devices compatibility and lifestyle compatibility. Further, H2 also was supported, which demonstrated that perceived relative advantage had positive effects on NFC m-payment adoption intention; H3a, H3b, were accepted as well, it illustrated that devices compatibility had active influence to the perception of relative advantage and adoption intention. However, H3c was not accepted, which indicated that devices compatibility had no effects on use context. In addition, H4a and H4b were supported, which manifested that lifestyle compatibility would active affect the individuals' perception on relative advantage and use context, while H4c was not accepted, which indicated that lifestyle compatibility had no significant effects on NFC m-payment adoption intention. However, H4 was not sustained, that is to say, perceived risk had no significant effects on NFC m-payment adoption intention; in addition, H5 also was supported, thus use context had an active influence on adoption intention. The results as showed in Fig. 2.

Fit indexes of the research model as shown in Table 2, which declared that the value of λ2/df (1.8) less than 3, and other indexes also were within acceptable limits, such as, NFI (0.94), NNFI (0.97), CFI (0.96), GFI (0.93), AGFI (0.85), and RMSEA (0.05), it indicated that the research model had better fit index.

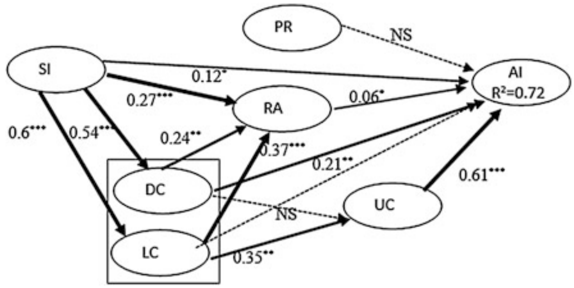

Fig. 2 The results of the research model (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$). Note: *SI* Social influence *DC* Devices compatibility *LC* Lifestyle compatibility *RA* Relative advantage; *UC* Use context *PR* Perceived risk *AI* adoption intention *NS* No significant influence

Table 2 Fit index of the research model

Index	Chi-square (p)	Degree of freedom	λ^2/df	NFI	NNFI	CFI	GFI	AGFI	RMSEA
Reference range	–	–	<3	>0.9	>0.9	>0.9	>0.9	>0.8	<0.08
Results	26.536 (p = 0.002)	6	1.8	0.94	0.97	0.96	0.93	0.84	0.05

4.2 *Discussion*

Through analyzing, individuals' perceptions of relative advantage, use context, devices compatibility and social influence add the NFC m-payment adoption intention strongly. Previous researches had indicated that relative advantage and compatibility had active influence on m-payment adoption intention [26], while we extended compatibility and confirmed that devices compatibility had an active effect on adoption intention, and lifestyle compatibility had no significant influences. That is to say, during the process of generalizing NFC m-payment, providers should think more about the devices compatibility, because it was an important factor for consumers. About lifestyle compatibility, it was not a main factor to individuals' behavior intention. However, it will influence individuals' behavior intention indirectly by use context and perceived relative advantages.

Secondly, several important results were found. Firstly, one extraordinary vital finding of this research was that use context was confirmed to be an important factor on individuals' adoption intention. It was consistent with prior researches in remote m-payment [24], that is to say, use context had active influence on users' m-remote m-payment adoption intention. However, individuals' perceived risk had no significant effects on their intention to adopt NFC m-payment, which was not consistent with pervious study on remote m-payment [22], maybe because their trust in remote m-payment services influenced the trust in NFC m-payment, and thus inactively affected the perceived risk, or most of the participants thought NFC m-payment could use under no internet, they trust this payment way would not suffer attacks of crackers or virus.

Thirdly, social influence had an active influence on individuals' behavior intention, therefore, some actions could be taken to increase the effects of peers and friends. In addition, social influence had an active influence to individuals' perception of relative advantage, devices compatibility and lifestyle compatibility, therefore, social influence was a vital factor in NFC m-payment adoption.

Finally, individuals' perceptions on devices compatibility had active influences on consumers' perceived relative advantages and use context, which, in turn, affected individuals' adoption intention on NFC m-payment. That is to say, if facilitators or administrations want to promote the adoption of NFC m-payment, increasing devices compatibility was necessary, which would increase individuals' behavioral intention.

5 Conclusion

In the first place, NFC m-payment was a different payment way compared with the existing and main m-payment (remote m-payment), and we paid attention to study the impact factors and its functional mechanism. We examined this effect and developed a model to explain its mechanism. The results indicated that positive factors (e.g., relative advantage, extend compatibility, use context) were the main factors during making decision to adopt NFC m-payment.

In the second place, although, some researches had proved the effects of compatibility in technology adoption, few studies focused on the context of NFC m-payment and distinguished the effects difference between devices compatibility and lifestyle compatibility. Therefore, we explored the effects of extend compatibility and its functional mechanism in the NFC m-payment context. The results indicated that devices compatibility had an active effect on individuals' NFC m-payment adoption intention, however, lifestyle compatibility had no significant influences.

Finally, we confirmed the relationship between extend compatibility and the adoption intention in NFC m-payment. We believed that our model provided a new and relatively complete view in the NFC m-payment decision process. In addition, we believed that our model laid a good theoretical foundation for researching the decision process of NFC m-payment. Maybe our model can extend other areas, such as, mobile ticketing and internet ticketing.

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Evaluation of Data Transfer Speed Between a USB Flash Drive and Laptop

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Abstract Transferring data between a PC and an external drive is an important task in today's life. The objective of the study was to determine factors affecting the file transfer rate and assess the statistical significance of each factor. Based on the literature review, three factors were determined: file size, file location, and available space in a USB 2.0 flash drive. Three levels were designed for each factor. There are three factors, each with three levels in a factorial experiment. So, 3-way Anova was used to understand the significance of each factor and their interactions. As a result, space availability in the USB flash drive has the most significant effect on data transfer rate. Furthermore, data transfer rate is also affected by the file size and file location. Hence, it is recommended that USB flash drives should have adequate free space to maximize the file transfer rate.

Keywords 3-way anova · File transfer rate

1 Introduction

Transferring data between a PC's storage and an external drive has become a very common task. Files containing photos, videos, important files, data backups are required to be stored in external storage. As technology advances, size of files also increases [1]. For example, a size of media file containing a high-resolution movie is more than 4 times the size of a file containing a low-resolution movie. Consequently, a simple task such as copying a file to another storage device could take a lot of time.

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2 Literature Review

The literature review was conducted to determine factors affecting the file transfer rate, as well as the processing speed. Limited literature was available regarding data transfer rate between a USB flash drive and the computer. As a result, additional literature reviews were conducted on factors affecting processing speed and data transfer rate in network. Based on the review result, factors to be included in the study were determined.

2.1 Processing Speed

The performance of a computer generally depends on its processor, memory and graphics card [2].

Processor. Processor speed is the major factor in a computer's overall performance. Activities like encoding video, encrypting files, or performing complex calculations require a lot of processor power. However, typing, reading email, or viewing web pages are common activities utilizing around 1 or 2 % of the CPU's total speed during the time [2].

System RAM Speed and Size. RAM is another important factor when it comes to Processing Speed. When all available RAM is utilized, the computer must uses the hard drive to cache data, which significantly decreases the processing speed [2].

Disk Speed and Size (**RPM's and Gigabytes**). The hard disk speed is also one of main factors affecting the processor speed. For example, a computer with SSD provides higher performance than a computer with a hard drive [2].

2.2 Data Transfer Speed

Bandwidth is the amount of data transferred over an internet connection per second. In other terms it is bits per second. Many factors contribute to limit the specified maximum bandwidth of an internet connection: Upstream and Downstream Bandwidth, Background Internet Usage, Wireless Bandwidth [3].

3 Design of Experiment

3.1 Equipment

The laptop and USB flash drive used in the experiment were a MacBook Pro and a 32 GB HP USB flash drive respectively. The laptop was a 2013 model with 16 GB memory and an Intel i7 processor. The laptop was selected as its powerful hardware would prevent factors limiting file transfer rate.

3.2 Experiment Design

Based on the literature review, three factors were determined for the study: file size, file location, and available space in USB flash drive. Some of the other factors considered were battery level, computer memory available, and processing power. These factors were not chosen as it was technically challenging to control them during the experiment. For example, available memory was one of main factors that affected both processing and data transfer speed. However, it was technically difficult to maintain the memory usage at a constant level during the course of this experiment. It should be noted that the file location denotes the number of sub folders in which the file is located.

Three levels were designed in each factor. File sizes of 0.5, 1 and 1.5 GB were deemed to be appropriate for our experiment. Multiple trials showed that it was difficult to measure time if the file size was too small, likewise it would take too much time to conduct each experiment if the file size was too large. Regarding the factor of available space, 0, 50 and 100 % were chosen. A space factor of 100 % represented that there was no other file in the USB flash drive besides the file being tested. Likewise, a space factor of 0 % denoted that there was no available space left in the USB flash drive, which included the file being tested. Lastly, file location factors of 0, 20 and 40 were determined.

To summarize, three factors were chosen for our experiment: file size, file location, and available space. Each factor is at three levels arranged in a factorial experiment. This is a 3^3 factorial design.

3.3 Data Collection

Based on the experimental design, data collection was conducted. Each reading was collected after restarting the computer and not running any additional applications to minimize the effect of other unknown factors. In addition, more than one team member recorded the data at the same time to verify the accuracy of the recorded data. The above measures were adopted to ensure that the data collection process and method was consistent, and the observations were random and independent to each other.

4 Analysis

A total of 81 measurements were recorded as presented in Table 1. Table 1 shows the time required for a complete file transfer under different conditions. The collected data was then processed to obtain the data transfer rate, shown by Table 2. Table 2 shows the data transfer rate, which was calculated by dividing the transfer time by the file size.

Table 1 Raw data: transfer time (seconds)

Space available	File location	File size								
		0.5 GB			1 GB			1.5 GB		
0 %	0	62.52	61.77	63.47	159.63	129.52	145.74	183.03	178.36	178.88
	20	71.49	71.47	66.72	123.54	133.84	143.38	205.35	193.5	191.26
	40	61.75	69.68	66.61	144.23	145.41	133.77	193.65	200.29	201.79
50 %	0	68.16	65.71	64.17	127.38	138.9	129.02	209.46	214.47	210.01
	20	71.62	82.96	66.88	137.21	164.5	161.31	237.22	224	257.8
	40	100.95	91.76	75.74	191.98	188.55	155.65	202.37	194.63	220.75
100 %	0	83.08	102.42	83.82	150.97	160.8	168.23	216.4	208.53	215.97
	20	77.88	82.86	89.78	169.06	154.89	133.59	320.27	216.77	247.02
	40	83.21	104.07	80.1	178.09	168.01	156.57	211.95	238.25	212.48

Table 2 Processed data—transfer rate (Mb/sec)

Space available (B)	File location (C)	File size (A)								
		0.5 GB			1 GB			1.5 GB		
0 %	0	8.189	8.289	8.067	6.415	7.906	7.026	8.392	8.612	8.587
	20	7.162	7.164	7.674	8.289	7.651	7.142	7.48	7.938	8.031
	40	8.291	7.348	7.686	7.1	7.042	7.655	7.932	7.669	7.612
50 %	0	7.512	7.792	7.979	8.039	7.372	7.937	7.333	7.162	7.314
	20	7.149	6.172	7.655	7.463	6.225	6.348	6.475	6.857	5.958
	40	5.072	5.58	6.76	5.334	5.431	6.579	7.59	7.892	6.958
100 %	0	6.163	4.999	6.108	6.783	6.368	6.087	7.098	7.366	7.112
	20	6.574	6.179	5.703	6.057	6.611	7.665	4.796	7.086	6.218
	40	6.153	4.92	6.392	5.75	6.095	6.54	7.247	6.447	7.229

ANOVA analysis was performed using Minitab 17 to understand the significance of each factor and its interactions. The results of the analysis are presented in Table 3. The analysis shows that file size, available space and file location are all significant factors. As a result, larger file sizes decrease the transfer rate. The transfer rate is also reduced considerably as the available space lowers. This could be explained by the inverted bath-tub curve of speed over time during data transfers. The rate remains low during the initial stage, and slowly climbs to reach its peak. It remains steady until its final stage, during which it starts to fall again. While transferring smaller files, speed is in steady state for a lower amount of time. During the transfer of larger files, less time is spent accelerating to constant speed initially, and decelerating from constant speed during the end. This explains the increased data transfer rate while transferring large files. Finally, the transfer rate decreases as the number of subfolders increase.

Table 3 ANOVA results

Interactions	16.919	20	0.846	2.816	>1.768
File size × Available space	2.318	4	0.580	1.929	<2.54
LA × LB	0.702	1	0.702	2.340	<4.02
LA × QB	0.339	1	0.339	1.130	<4.02
QA × LB	1.288	1	1.228	4.093	>4.02
QA × QB	0	1	0	0	<4.02
File size × Location	4.307	4	1.077	3.590	>2.54
LA × LC	0.561	1	0.561	1.870	<4.02
LA × QC	1.672	1	1.672	5.573	>4.02
QA × LC	0.115	1	0.115	0.383	<4.02
QA × QC	1.959	1	1.959	6.530	>4.02
Available space × Location	3.250	4	0.813	2.710	>2.54
LB × LC	0.094	1	0.094	0.313	<4.02
LB × QC	0.026	1	0.026	0.087	<4.02
QB × LC	3.010	1	3.010	10.033	>4.02
QB × QC	0.120	1	0.120	4.000	<4.02
File size × Available space × Location	7.059	8	0.882	2.937	>2.12
LA × LB × LC	0.004	1	0.004	0.013	<4.02
LA × LB × QC	1.513	1	1.513	5.043	>4.02
LA × QB × LC	3.127	1	3.127	10.423	>4.02
LA × QB × Qc	0.249	1	0.249	0.830	<4.02
QA × LB × LC	0.458	1	0.458	1.527	<4.02
QA × LB × Qc	0.012	1	0.012	0.040	<4.02
QA × QB × LC	1.304	1	1.304	4.347	>4.02
QA × QB × QC	0.379	1	0.379	1.263	<4.02
Error	16.224	54	0.300		
Total	66.746	80			

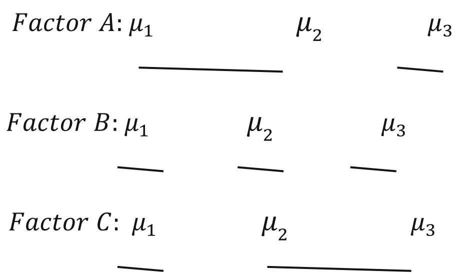

Fig. 1 Tukey test results

In addition, Tukey test was conducted to determine the significance of difference between levels. The results of the test are presented in Fig. 1. There is no significant difference between file sizes of 0.5 and 1.0 GB. When considering available space, there are significant differences between all levels. Finally, there is no significant difference between subfolders of 20 and 40.

5 Conclusions and Recommendations

This study was conducted to assess factors affecting the file transfer rate between a laptop and USB drive, and assess the statistical significance of each factor. It was found that space availability in the USB flash drive has the most significant impact on data transfer rate. Data transfer rate decreases with the decrease in space availability. Furthermore, data transfer rate is also affected by the file size and the location of file in respect to its subfolders. However, no significant difference was observed between file sizes of 0.5 and 1.0 GB. Similarly, there was no significant difference between subfolder levels of 20 and 40. To conclude, it is recommended to maximize free space in the USB flash drive to get the best file transfer rate.

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Diffusion of Knowledge Information to Industry Workers

Telma Tupy de Godoy, Elsa Cristina Giostri and Kazuo Hatakeyama

Abstract The cooperation between the knowledge industry and the foundry enterprise is an important element to become viable the access to the information and the acquisition of knowledge. This paper has an objective to report results obtained by analyzing the contributions of the knowledge industry project for the access of the worker to information and knowledge. In the methodological aspect, the research characterized as an exploratory, descriptive, quantitative, qualitative, making the use of the case study type. Utilized as data collection tool the annual reports of attendance, the borrowing of materials from the library and the personal questionnaire distributed to users, which allowed to identify the needs, the search and use of information in the perspective of the model of use of information. It has concluded that the implantation of the unit of project, in the foundry enterprise, resulted in the promotion of access to the information and knowledge of worker.

Keywords Knowledge industry · Knowledge diffusion · Needs of information · Use of information · Access to information

1 Introduction

The world society lives the transition period from the economic environment in which the proactive management of the knowledge assumes the central role for the competitiveness of enterprises and individuals. The resource "knowledge" acquires,

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in this context, core importance to the entrepreneur performance. According to [1] evidences found in several studies show that the open global economy imposed important challenges to the Brazilian enterprises increasing the needs of investment in technology, in education and in knowledge management (KM). The speed to identify and respond with efficacy the alterations of the world market reinforces the importance of the knowledge in the process of management of actual organizations.

The relevance of the information is universally accepted, whose management and profit seems related directly to the desired success. The information is also, considered and utilized as the tool of management [2]. According to [3] the access of information let the person to interact to build knowledge that contribute to generate new ideas, solve problems, take decisions and better the interpersonal relationships. In enterprises, the search for the knowledge, as the source of innovation and the obtaining the competitive differential, bring about the needs the environment for creation and share of knowledge [4]. Enterprises that act based in the knowledge, establish “their actions in the comprehension of the environment, the needs, and are leveled by the sources of available information and by the competence of the members” [5]. The knowledge of the enterprise built by the interactivity of the persons, sharing information and experiences that are transformed into knowledge, conceiving this way, the learning and the organizational development [6]. The diversity and co-existence of sources and means of access to the information bewildered the belief that the advent of the new Information Technology and Communication (ITC) becomes outdated the means and conventional printed matters, as is the case of the book. However, the experience has shown that the articulation of several media and supports opportune the enlargement of the space of the construction of knowledge. The act of reading as the process that facilitate the access to the information and appropriation of this in knowledge comprehend, among others, the reading of text and image that present more diverse media [7].

2 Use of Information

The search, the processing and the analysis of the needs and the use of information become important component of research in several fields, among them, the cognitive psychology, information systems, decision taking, social anthropology, organizational learning and diffusion of the innovation [4]. First studies on how the persons behave, when search and use information, presented in the conference on scientific information of the Royal Society, in 1948.

Two communications highlighted were paramount: one on the behavior of two hundred British scientists that worked in of the government bodies, universities and private research institutes in the search of information; and other on the use of the library of the London Science Museum. These studies sponsored by the professional association that needed to elaborate their programs to answer the explosion of scientific information and new technologies, and “also were initiated by the librarians, administrators of information centers and laboratories, which needed the data to plan the service …” [5].

The sources of information defined as any resources that respond the demand of information, product or service, one person or group of persons or one organization. Author [5] relates the use of information with one triad: necessity, search, and use of information.

The needs arise when one person recognizes gaps in his knowledge and his capacity to give the meaning to one experience. In the search for information, the person searches, intentionally, explanations that can change his state of knowledge. Persons when search and use the information make under several influences, in the scope of cognitive, affective and situational.

The cognitive influence has the origin in different strategies of the search of clarifying activated to fill different gaps of the knowledge. In the affective, the emotional state and psychological determine different preferences and methods of search of information. In the situational scope, as characteristics of the work determine the way to access and use the results acquired. The use of the information is the final stage, is the selection and the processing of information that result in new knowledge or actions.

Corroborating [6] KM is “the set of activities related to generation, codifying and transference of knowledge”. Authors state that KM bases in an existing resources as the management of information systems and good practices of human resources management to better the existing resources in the organization in form of oriented way to the knowledge. The KM seen as process in analogy with total quality, as who guarantee the quality is the person, in the execution of tasks in the day to day of work. For authors, the knowledge applied in the organizations but if not for this process imply in the formalized transference, being required the development of specific strategies.

3 Methodology

The research work presents as an exploratory, descriptive, quantitative and qualitative making the use of annual report of the frequency and of borrowing of materials between 2006 and 2011.

An individual questionnaire, elaborated based on the criteria of the “Proposal of diagnostics of knowledge management in libraries” of [8] and the model of the search and use of information of [5], for the data collection. It is a question of case study developed in the Tupy/SESI Library (TSL), unity of the SESI-IK project, installed in the Tupy Foundry S/A (TFSA), Joinville, SC.

4 Data Collection and Discussion

For the analysis of the objective: promote the access to information for the collaborators of the industry, were utilized the data of frequency of the users and borrowing of materials of the TSL, which were collected by the report in the period 2006–2011, as shown in the Table 1.

Regarding to the borrowing of the heap of the TSL it has noticed that the quantity of all types of materials consisting of the library, and access of the workers increased. Regarding to the utilization of the service of domicile borrowing of printed media, DVD and attendance of the users in the period 2008 until 2011 it has noticed in the analysis of the report that, in 2008, the quantity of borrowings and attendance not only increased related to 2007, achieved the apex of attendance.

Other issue that imposes is the gradual diminution or trends of decline of total obtained in the previous years. One of the factors that can explain this variation due to the implantation of the *Hour of the Tale* on Saturdays for the children of the collaborators that foment the interaction of their dependents—one entrepreneurial possibility to open the space for the inclusion of members of the families of their collaborators. This affirmative becomes explicit when analyze specific initiatives as the *Hour of the Tale* Project that was initiated in 2008. Deal with the count or the "telling" of story within the premise of the library, activity performed once a month for the children of workers in the foundry, from the age of three to twelve years old.

The "telling" of story characterized not only as an incentive to the reading this allowed even the integration of the child in the working space of progenitor and the strengthen of the relationship between the enterprise and the family of the workers. Besides, this functioned, also, as the way of the child to have major contact with heap of infant-juvenile literature, which contributed to increase the attendance related to 2007, in 754 % and the borrowings in 535 %. It worth mention, the promotion of the activities to stimulate the reading is also one of the principles of the SESI—IK project.

In 2009 had the decline for the search to the materials and the attendance in the library, which attributed to the collective vacation that TFSA conceded to the collaborators due to the slowdown of the Brazilian economy, also the suspension the activity of the *Hour of the Tale*. If the meaningful drop of the number of borrowings and users in 2009 can explained by the collective vacation of the enterprise, the phenomena of light recover in the following year does not keep as

Table 1 Identification of the sample. *Source* Authors

Year	Quantity of borrowing	Attendance of users
2006	1.470	609
2007	4.077	2.504
2008	25.921	21.396
2009	21.864	17.922
2010	22.221	18.163
2011	17.959	13.989

trend of growing noticed by the totals found in 2011. One of possible explanation was the end of the activity *Hour of the Tale* or the discontinuity of the dynamic aggregating practice of users.

To identify the type and level of needs of the search and use of the information obtained in the library, was elaborated the questionnaire based in the model of [5]. It has adopted this model, as this allowed the mapping of the needs, search and use of the information obtained by the users of services of information. From the analysis of the proposed model were defined the queries.

The questionnaire divided into two parts: being the first with the general characterization of the respondent: age, sex and educational level; and the second part “search and use of the information”, with 17 queries that allowed the identification of the needs the search and the use of information. The criteria of evaluation of answers of the second section encompassed: “always”, “many times”, “sometimes”, “rarely” and “never”. From the set of answer of the questionnaire, the analysis of the data was developed.

In the first section, characterization of the respondent, has noticed that the age range varied between 20 to more than 50 years old, being that 48 % are in the range of 31–40 years; in second section the age range of 21–30 years, representing 30 %, as shown in the Table 2.

Regarding to the level of education 40 % of the respondents have complete higher education, 30 % complete high school and only 10 % not completed higher education, as presented in the Table 3.

In the second part of the questionnaire, in the question search and use of information, looked for identify the pressing of knowledge according to the model adopted that consider yet levels of needs and classes of use of the information.

The queries developed with the proposal of mapping the needs, search and use of information.

Table 2 Age range of the respondents. *Source* Authors

Age range	Quantity	%
Up to 20 years	1	2
21–30 years	15	30
31–40 years	24	48
41–50 years	7	14
Over 50 years	3	6

Table 3 Respondents by the level of formal education. *Source* Authors

Level of formal education	Quantity	%
High school complete	15	30
Technical high school complete	10	20
Higher education complete	20	40
Higher education incomplete	5	10

Query	Questions
1	Do you attend the TSL?
2	Do you search sources of information in the TSL?
4	The material which you withdrawal from library is for professional needs?
6	The material that you borrow is for you?
8	TSL facilitated your access to the books and other sources of information?
10	Do you bought books before the implantation of the TSL?
12	Do you search information in the TSL to better the comprehension of private problems?
13	Do you search information in the TSL to determine what to do?

Fig. 1 Cognitive needs. *Source* Authors

The deficiencies or failures of knowledge for the performance of organizational tasks and the decision takings are the main generator of needs of cognitive information. To recognize these, have the answers of the queries 1, 2, 4, 6, 8, 10, 12 and 13, explicit in the Fig. 1:

In the social situations, the information that satisfy the affective or emotional needs, these are represented in the queries 1, 2, 3, 5 and 12, as presented in the Fig. 2.

The queries 1, 2, 3, 4, 5, 6, 8, 10, 12 and 13 deal of the needs that led the respondent the search of information in the library. The materials provided in the heap of the library searched by the users because of needs of information that varies according to the situation that can be one task that is performing, the needs of leisure, for the family, solve private problems and decision taking. To identify the level of needs of information, the following queries utilized:

(a) query 3—Do you withdrawal the material for leisure?
(b) query 4—The material which you withdrawal is for professional needs?
(c) query 5—The material which you withdrawal is for family?
(d) query 13—Do you search information in the TSL to determine what to do or how to do the thing?

These queries relate with the level of needs of the type “formalized” and “instrumental”. In the first stage the person succeed to do the description of the needs, and the second occur when the information is used for the user know how and what to do; is related with importance that he attributes to information to determine what to do or solve one problem.

	Query	Questions
Affective or emotional needs	1	Do you attend the TSL?
	2	Do you search sources of information in the TSL?
	3	Do you borrow the material of the TSL for leisure?
	5	The material that you withdrawal is for family?
	12	Do you search information in the TSL to better the comprehension of private problems?

Fig. 2 Affective or emotional needs. *Source* Authors

Perceive that by the result that the existing demand for literature books, magazines and cartoons (query 3) attended, as 48 % of the users of the library utilized the materials for leisure. Regarding to the search for professional needs (query 4) the majority rarely search information for these needs.

The demand for technical books, standards, and specialized periodicals, already provided by the Technical Library of Tupy, before the implantation of the project. Presently in the filling of the questionnaire, only 22 % searched information for explanation of professional problems.

The search for instrumental information to determine what to do, 30 % of the respondents go to the library with issue (query 13). Regarding to the formalization of the gap of knowledge can perceive that 42 % borrows books to attend the needs of information of the family (query 5).

The percentiles of the results of answers "always" or "many times" found in each one of queries are in the Table 4.

Among the types of needs are the "comprehension of the problem", the information is utilized to let better comprehension of determined problem and "explanation" is utilized to create one context or to give the meaning to a given situation.

Are associated with the type of needs of explanation and comprehension of the problem the queries listed in the Table 5.

Regarding to the type for comprehension and explanation of the problem, 24 % of the respondents search information in the BTS to better the comprehension of private problems (query 12), meanwhile highlights that 66 % find in the library the material which desire (query 7), and borrow the material for the proper use (query 6).

Table 4 Level of needs of information. *Source* Authors

Level of needs of information		% of participants that answered always or many times
Query	Instrumental and formalization	
3	Do you borrow the material for leisure?	48
4	The material you borrow is for professional needs?	22
5	The material you borrow is for family?	42
13	Do you search information in the TSL to determine what to do or how to do the thing?	30

Table 5 Type of needs of information. *Source* Authors

Type of needs of information		% of participants that answered always or many times
Query	Comprehension and explanation	
6	The material that you borrow is for you?	66
7	Do you find in the library the material that desire?	66
12	Do you search information in the TSL to better the comprehension of particular problems?	24

Table 6 Search of information. *Source* Authors

Search of information		% of participants that answered always or many times
Query		
1	Do you attend the TSL?	64
2	Do you search sources of information in the TSL?	54
8	BTS facilitated your access to the books and other sources of information?	86
9	Do you have already the habit to attend other libraries before the implantation of the TSL?	22
10	Do you bought books before the implantation of the TSL?	20
11	After the implantation of the project SESI knowledge industry you started to purchase books?	8

The search of information is the process in which the person search information in the way to change his state of knowledge, according to the precept of the model adopted. During the search manifested some typical behavior, among which to identify and select sources, extract and evaluate the information, extend, modify or repeat the search.

The user will search to provide the needs of information, based on two sources: the formal and informal. In this research, the collaborator of the foundry search information in the BTS. The queries that allowed identify the search are listed in the Table 6.

It noticed that 64 % of the respondents attend the library (query 1), 86 % recognize that the library facilitated the access to books and sources (query 8), 54 % search sources of information (query 2) in the TSL, how many does the research in the public or private library, 22 % attended other libraries to provide the needs of information (query 9).

Regarding to the contribution of the project for the acquisition of books “you purchase books before (query 10) and after” (query 11), 20 % purchase books before the implantation of the TSL and after the implantation 8 %.

By the analysis of the percentile of answers “always” and “many times” of the queries 1, 2 and 8 can be seen that the objective of the project SESI-IK to facilitate the worker and the family the access to the available information in printed or electronic media, in the Internet and the appropriation of the knowledge was achieved.

The use of information is the final stage of the model, from the recognition of the futile of knowledge, the person start search of information and will use it.

The use involves the selection and the processing; the user interprets the information found, that can answer one query, solve one problem, take decision, negotiate position or understand one situation.

The result of the utilization of the information is, thus, the change in the state of knowledge of the person and his capacity to act.

Query	Use of information
3	Do you borrow material from the library for leisure?
4	The material you borrow from the library is for professional needs?
12	Do you search information in the TSL to better the comprehension of private problems?
13	Do you search information in the TSL to determine what to do or how to do the thing?
14	Do you socialize knowledge that acquire by means of library with your colleagues in the workplace?
15	Do you have an opportunity to present your knowledge in the explicit way?
16	Do you participate in the systematic situation of exchange of knowledge?
17	Do you relate new knowledge to the previous and reorganize generating new knowledge?

Fig. 3 Queries on the use of information. *Source* Authors

Initially, from the answers of the queries 3, 4, 12, 13, 14, 15, 16 and 17, built the Fig. 3 and brought about to analysis to identify the use of information.

Regarding to the use of information obtained in the TSL, for the analysis was utilized the classes of use of the information extolled by [9]. It was evident that the users utilize for explanation, comprehension of the problem, instrumental, factual, confirmative, personal and motivational, as registered in Fig. 4.

Analyzing the percentile of the sum the answers “always” and “many times”, of the needs and associating the classes of use can notice that 68 % of the respondents had their needs associated to the use of information to clarify, i.e., “to create or give the meaning to one situation”. Choo [5], 48 % personal, 48 % motivational and personal, 32 % factual, 30 % instrumental, 24 % to the comprehension of problems, and 26 % confirmative. Highlight the utilization for explanation, personal and

Class of use	Query	Question
Personal. Creates relationships	3	Do you borrow material from library for leisure?
Explanation. Creates context or give meaning	4	The material you borrow from the library is for professional needs?
Comprehension of problem. Better the comprehension of problems, and **Personal**	12	Do you search information in the TSL to better the comprehension of private problems?
Instrumental. Determines what or how to do	13	Do you search information in the TSL to determine what to do or how to do the thing?
Motivational. Motivates, maintain personal involvement	14	Do you socialize the knowledge acquired by means of the library with your colleagues in the workplace?
Factual. Determine the fact of phenomena or event	15	Do you have an opportunity to present your knowledge in the explicit way?
Corroborative. Confirm other information	16	Do you participate in systematic situation of exchange of knowledge?
Explanation	17	Do you relate new knowledge with previous and reorganize generating new knowledge?

Fig. 4 Class of use of information. *Source* Authors

Table 7 Use of information with percentiles. *Source* Authors

Use of information		% of participants that answered always or many times
Query	Question	
3	Do you borrow the material from library for leisure?	48
4	The material you borrow from library is for professional needs?	22
12	Do you search information in the TSL to better the comprehension of private problems?	24
13	Do you search information in the TSL to determine what to do?	30
14	Do you socialize the knowledge acquired by means of library with your colleagues of workplace?	48
15	Do you have an opportunity to present your knowledge in the explicit way?	32
16	Do you participate in systematic situation of exchange of knowledge?	26
17	Do you relate new knowledge to the previous and reorganize generating new knowledge?	46

motivational, in the other classes, the information utilized in the similar quantities. In the Table 7 are listed the percentiles of queries that identified the use of information.

5 Conclusion

This study looked for to demonstrate the importance of projects as the SESI-IK is relevant to make possible the access to information and knowledge. The recognition of the needs of information that can be understood as the perception of difference between desired state of things and real situation that activate the process of search and decision of the use of information. The answers to the queries utilized to evaluate the level of needs show that the respondents recognize the gap in own knowledge and manage to describe its needs.

The emotional and psychological states determine different preferences and method of search of information. Regarding to the type of use of the information obtained in the library, outstand the utilization for the explanation, personal and motivational. Then, conclude that the projects as the SESI–IK shows relevant to make possible the access to the information and knowledge, so much the point of view of the enterprise as well as the community the investment can offer the results expected. It worth mention that the example of the *Hour of the Tale* the evidence is that is not enough to provide the access to the information. Is fundamental that promote activities of experiences destined to production and use of the information towards the knowledge; offer multiple possibilities of reading and, with this leading to the users to broaden their knowledge and their ideas.

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Increasing Control Room Effectiveness and Security Through Proximity-Based Interaction Technologies

Martin Boecker

Abstract In the context of ARTEMIS project HoliDes, a demonstrator was developed that employs the combination of novel proximity-based interaction technologies and adaptive support functionalities in order to increase the effectiveness and efficiency of emergency response operations. The paper presents five use cases for a border security control room.

Keywords Human factors · Human-Systems integration · Control rooms · User interaction technologies · Defence industries

1 Introduction

Emergency Response Control Rooms handle unplanned events that require an immediate response. Examples are Control Rooms of the fire department, of emergency call services ("112"/"911"), and of border security organizations. This paper describes how the effectiveness and security of Emergency Response Control Rooms can be increased with novel proxemics-based user interaction technologies.

The research reported here was carried as part of the ARTEMIS [1] project HoliDes (Holistic Human Factors Design of Adaptive Cooperative Human-Machine Systems) [2]. HoliDes addresses the "development and qualification of Adaptive Cooperative Human-Machine Systems (AdCoS) where many humans and many machines act together, cooperatively, in a highly adaptive way to guarantee fluent and cooperative task achievement" [2]. The focus of the project is to go beyond existing systems that adapt within the interaction between one human and one machine, and to extend this scope considering the cooperation between many machines and many operators. The project therefore investigates new ways of communicating system adaptations to human operators pro-actively, according to the operators' situation and capacities. Further aims of HoliDes are:

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- to reduce the cost of system development, in particular in particular with regards to compliance with human factors and safety,
- to reduce needed development cycles when applied to innovative and ambitious AdCoS,
- to foster Embedded Systems for AdCoS that are reusable in different safety critical domains.

The Control Room domain of project HoliDes realized by Airbus Defence and Space instantiates a number of use cases that employ novel interaction technologies based on image and IR technologies to enhance the organisation's overall effectiveness. The work is illustrated with the example of border security operations, but it applies equally to most other emergency response or command and control (C2) services.

Work in border security Control Rooms is characterized by phases with high activity followed by longer phases with little or no activity. The Control Room is organized to allow a 24/7 operation. The educational level of operators is often medium to low, and border security organizations may experience a high operator turnover. Border security is organized hierarchically. The Control Room sites are usually located close to the border and may be subject to assaults. The situation in other C2 or emergency response organizations has similar characteristics.

Currently, no mechanisms exist that ensure that operators are present at their workstations when the situation requires it. Neither are there adaptive and automatic functionalities for increasing the Control Room's effectiveness by (semi-) automatic workload handover.

Given the status quo, the AdCoS adaptation aims at increasing the emergency response organization's effectiveness and security by implementing new adaptation functionalities. The AdCoS focuses on the operators' physical and mental states, ensuring that they are present and effective when needed. Secondly, the organization's effectiveness can be increased by optimizing the workload of each operator.

State-of-the-art operator workstations consist of conventional office PC peripherals: two or three screens, a keyboard and a PC mouse (see Fig. 1). The AdCoS enriches the operator workstation with novel proximity-based interaction technologies (sensor equipment for capturing the operator's physical and mental state). Those sensors are part of the Microsoft Kinect and of the Tobii eye-tracking system.

It is worth noting that employing infrared sensors in workstations would probably not be acceptable for workplaces in a non-emergency context. In C2 or emergency response services, however, other people's lives may depend on the high effectiveness of the Control Room personnel, and the presence of sensors may therefore be justified (when dialing "112" or "911" in distress, people expect someone to be there to answer the call).

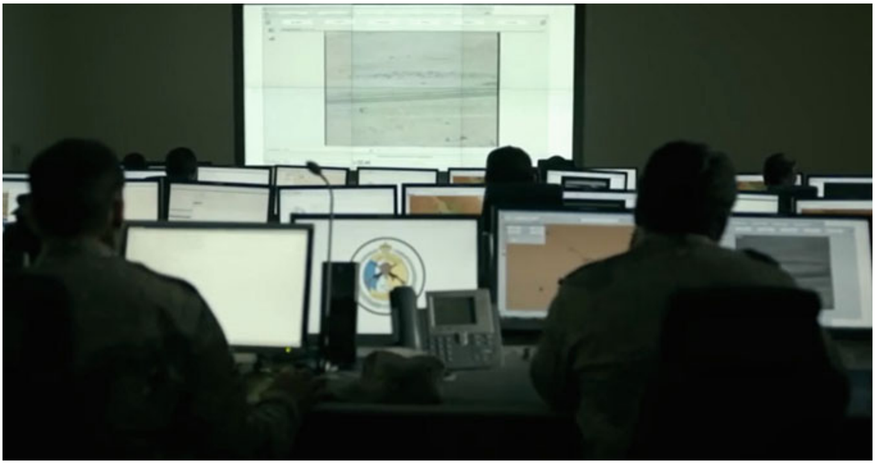

Fig. 1 Workplaces in a border security control room

2 Main Purpose of the AdCoS Demonstrator

The purpose of the AdCoS demonstrator is captured in three performance indicators:

- *Functionality*: The AdCoS provides functionalities that facilitate the operation of the Control Room and that hitherto have not been available.
- *Effectiveness*: The AdCoS increases the effectiveness of the Control Room operation by providing means that ensure that operators are available at their workstations and in a physical state that allows them to perform their duties in an effective and efficient way.
- *Security*: One specific feature of the AdCoS is the analysis of operator behaviors in order to identify suspicious patterns that can be exploited by perpetrators.

For each performance indicator and the associated use cases, a number of verification criteria has been defined that will be used in the evaluation activities.

3 Spatial Arrangement of the AdCoS Demonstrator

The demonstrator consists of two operator workplaces and one server workplace (see Fig. 2).

The two operator workplaces represent two roles:

- The Response Operator handles tracks or events that have to be monitored, this includes communication with mobile units;

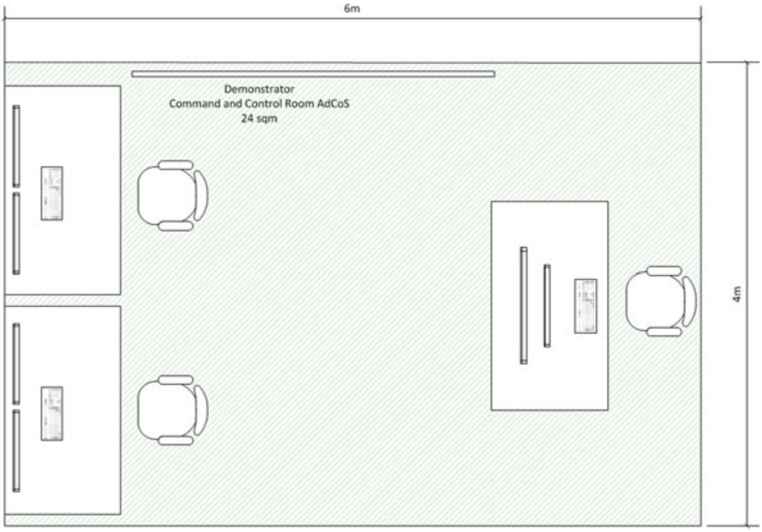

Fig. 2 Spatial arrangement of the AdCoS demonstrator

- The Response Supervisor coordinates the work of all Response Operators and assigns tracks or events to individual supervisors.

The server workplace is used for setting up the demonstrator network environment.

4 The Use Cases

The Control Room AdCoS is instantiated in six use cases, five of which have been implemented at the time of writing.

4.1 Use Case 1: Operator Presence/Absence

In longer periods of inactivity, operators may be tempted to spend longer times away from their workstations. In the case of an emergency, they may not be immediately available, thereby increasing the Control Room's response times to the emergency.

The use case adaptation uses infrared sensors in a Microsoft Kinect device to establish reliably whether an operator is present at his workstation or not. If his absence exceeds the permitted length of time (or in case of an incoming urgent case to deal with) the system will alert him discreetly by a vibration alert of his smartwatch to "nudge" him to return to his station (no colleague or supervisor needs to notice).

Table 1 System messages of different states of Use Case 1

State	Response operator activity	Response supervisor PC	Response operator PC	Response operator actuator
1.1	Is present	Indication operator present (green)	Indication operator present (green)	Idle
1.2	Leaves workstation	Indicator operator absent (red)	Indicator operator absent (red)	Idle
1.3	Is absentAbsent	Indicator operator absent (red)	Indicator operator absent (red), PC locked	Begin vibration, display text message
1.4	Returns (is present)	Indication operator present (green)	Indication operator present (green), PC locked	End vibration
1.5	Unlocks PC	Indication operator present (green)	Indication operator present (green)	Idle

For illustrating the functionality in the demonstrator, presence and absence are visualized on both the Response Operator PC monitor and the Response Supervisor PC monitor. In a real-life implementation, those visualizations would only be displayed in maintenance mode.

The following table describes the sequence of events for Use Case 1, with the operator returning upon being called back (Table 1).

If the operator is present, all indications are in neutral (see Fig. 3). If he remains absent for longer than the permitted time or in case of an incoming emergency, he is being called back by the actuator device (see Fig. 4).

The challenge in this use case is to define the range of detection such that it only covers the operator at his desk and nobody else walking by.

Fig. 3 HMI state 1.1 operator present, response supervisor PC, response operator PC, smartwatch

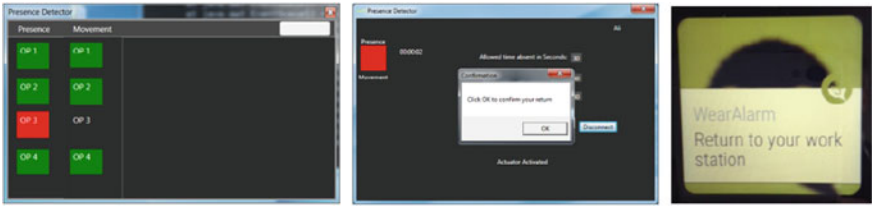

Fig. 4 HMI state 1.3 operator absent (>n minutes), response supervisor PC, response operator PC, smartwatch

4.2 Use Case 2: Operator Idle/Asleep

Another example of low Control Room effectiveness are operators that fall asleep during night shifts. The AdCoS adaptation recognizes sleeping operators (who are present at the workstation but display only minimum movements). If an operator has been identified as sleeping, the system will again activate an actuator to wake him up discreetly without anybody else noticing.

This functionality is also realized with the help of the Kinect IR sensor and the smartwatch actuator device. The engineering challenge in this use case is to define the range of body movement that can be expected from a sleeping person and only classify those as instances of “operator asleep”.

4.3 Use Case 3: Operator Tired at His Workplace

Another operator mental state that can negatively affect the C2 organization’s effectiveness is operator fatigue. The level of fatigue of an operator is captured by means of an eye-tracker system. The sensors observe the movements of the operator’s eyelid and interpret specific eyelid behaviors as indicators of fatigue (PERCLOS parameter). The position of the operator’s head is measured by the Microsoft Kinect’s optical camera to provide the system with the information, at which times the operator is facing the screens (and hence the eye-tracking system; see Fig. 5).

The indication of the operator status is for visualization purposes only. It would only be implemented in a product for maintenance purposes. The supervisor will not be informed about the operator’s level of fatigue (this is an optional feature).

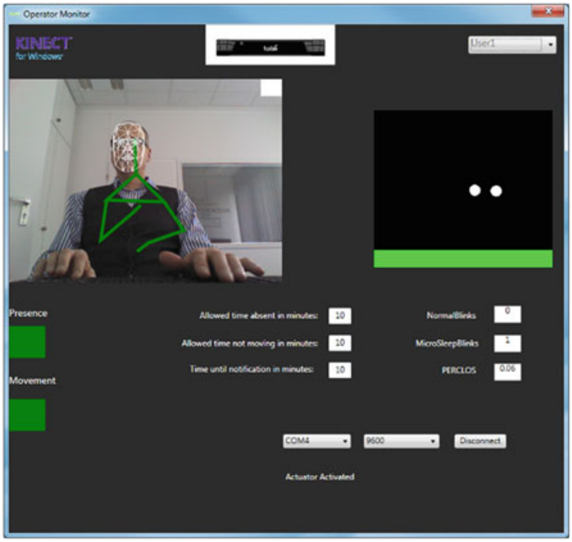

Fig. 5 Interplay of optical camera and eye-tracking system (maintenance mode)

4.4 *Use Case 4: Registration of Unusual Behavior Patterns*

Regular and observable behavioral patterns can be exploited by perpetrators for scheduling illegal activities. For example, they observe that the operators always sit outside of the station playing cards at two o'clock in the morning and exploit this knowledge. The automatic recognition of such exploitable behavior patterns can support the C2 Control Room management in identifying training needs for operators, focusing on behaviors that help maintaining the Control Room's security.

All instances of operator absent and operator idle (asleep) for longer than the permitted times are entered into the database of data related to operator absences. Instances of operator fatigue can optionally also be entered into the database, however, this is not supported by the AdCoS demonstrator implementation.

Similarly, in most cultures, it will not be accepted to store the operator ID. In those cases, the data will be registered anonymously, but still allowing the identification of operator behavior patterns (e.g. "An anonymous operator with the arbitrary label 'Operator X' displayed the following exploitable behavior: …").

The analysis for patterns in the database can be initiated automatically or manually. In automatic search, a control in the supervisor application can set a time (e.g. 0300 h every night) for the automatic search based on a range of parameters (e.g. all supported patterns). In manual search, a control in the supervisor application can initiate a search based on selected parameters (e.g. weekly patterns).

The patterns supported in the AdCoS demonstrator are:

- daily (e.g. regular absences every day between 0200 and 0300 h),
- weekly (e.g. regular absences every Tuesday and Thursday),

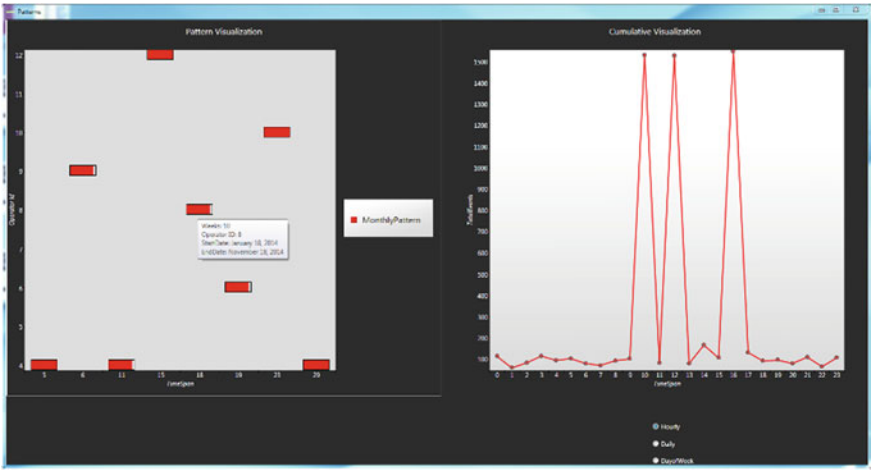

Fig. 6 Visualization of unusual behavior patterns

- monthly (e.g. operator is absent on every 15th day of month but at different times, i.e. absolute monthly pattern),
- complex time patterns (e.g. operator is absent on every second Tuesday between 0300 and 0400 h, i.e. relative monthly pattern), or
- complex correlational patterns (e.g. two individual operators absent together four times in a month at same time).

The resulting visualization indicates expected and unexpected regular patterns of specific behaviors such as absences (see Fig. 6).

4.5 Use Case 5: Load Balancing on Operator Level

One way of improving the effectiveness of a C2 Control Room is the optimum distribution of workloads among operators. To just consider "objective" parameters such as number of cases to be dealt with is not sufficient, as parameters related to the individual operator such as level of expertise, level of fatigue and level of stress also affect the workload experienced by an operator at a given time (see Fig. 7).

The use case workload handover demonstrates a functionality of the AdCoS that monitors the workload of each operator at any moment, visualizes the workloads to the supervisor, and pro-actively suggests the handover of individual cases from one operator to another if this improves the effectiveness of the operation as a whole.

In an example scenario, all Response Operators (RO) are working within an acceptable workload level, as indicated by green fields. Adding an event to Operator 5 leads to him reaching a workload above threshold (the workload indication for that operator turns red). The AdCoS suggests to the supervisor that an

Operator	Level of Expertise	Expertise Weighted	Level of Fatigue	Fatigue Weighted	N Hostile	N Hostile Weighted	N Neutral	N Neutral Weighted	N Friend	N Friend Weighted	Subjective Workload
1	1	1,2	1	0,5	2	10	4	12	2	2	14,4
2	2	1	1	0,5	1	5	4	12	2	2	9,5
3	3	0,8	1	0,5	2	10	2	6	4	4	8
4	1	1,2	1	1	1	5	1	3	3	3	13,2
5	2	1	2	1	2	10	2	6	1	1	17
5	3	0,8	2	1	3	15	0	0	2	2	13,6
6	1	1,2	2	1	1	5	2	6	1	1	14,4
7	1	1,2	2	1	0	0	2	6	2	2	9,6
8	1	1,2	1	0,5	1	5	1	3	1	1	5,4

Fig. 7 Computation of individual operator workload

event should be handed over to Operator 6 who will remain below threshold even if that event is added (see Fig. 8). The supervisor accepts the proposal and the indication for Operator 5 is displayed as green again.

5 Evaluation and First Results

At the present stage of the project, verification and validation activities are planned. Those are based on the previously defined verification criteria. First pre-tests have shown that the performance of the presence/absence detection is within an acceptable range (i.e. >95 % correct).

A second strain of evaluation activities will focus on the acceptance of the proposed solution by emergency response operators. This will be addressed with focus group sessions and questionnaire studies.

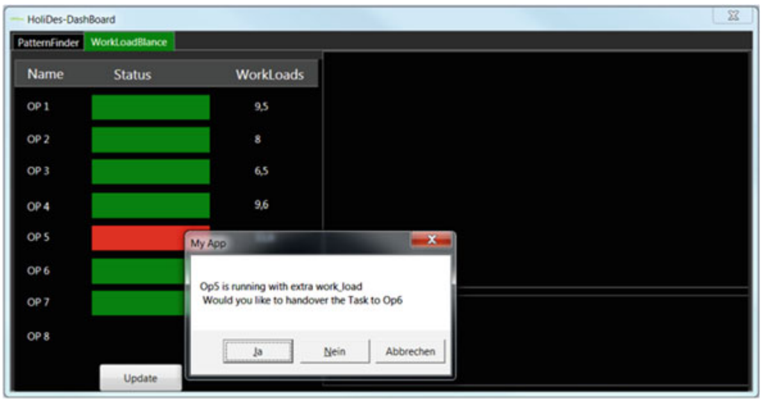

Fig. 8 The AdCoS suggests a workload handover

6 Summary and Outlook

The AdCoS demonstrator presented in this paper is an example of the potential for increasing the effectiveness and efficiency of emergency response operations by employing novel and adaptive interaction technologies.

The next steps of the work in project HoliDes will focus on the evaluation of the present demonstrator and the enriching of the demonstrator with additional functionalities.

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2. Project HoliDes (www.holides.eu)

Part II
Innovative Human-Machine Interfaces in the Automotive Domain

Use Your Brain (and Light) for Innovative Human-Machine Interfaces

Frankie Biondi and Lee Skrypchuk

Abstract The human machine interface (HMI) system of a vehicle is made up of a number of input and output devices that work in harmony to allow the driver to access a number of features and functions. The HMI of motor vehicles has evolved slowly up until the late 1990s when the first automation systems (e.g., Cruise Control) and touch screens were introduced. Since then, the amount of technologies being introduced into the car, especially over the last few years has sky-rocketed. Of these technologies none can be considered more challenging than that of the move towards vehicle automation. Given this push, new ways of interaction with the vehicle will be needed. In this paper we present two new innovative HMI techniques that will be key to addressing this challenge, namely brain-computer interfaces (BCI's) and ambient display technology aimed to make the driver (or passenger) interaction less demanding and more intuitive.

Keywords Human-machine interface · Automotive · Brain-computer interfaces · Ambient displays · User interfaces · Autonomous vehicles · Human factors

1 Introduction

Since the late 1800s when motor vehicles were firstly introduced, human operators have interacted with these by means of pedals, steering wheel, buttons and dials. Since the late 1990s and in the last 5 years in particular, the automotive industry and driving research community have witnessed an exponential growth in the number of different technologies that, over time, have become part of the current Human-Machine Interface (HMI) of many vehicles on the market. The introduction

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of touch screens for in-vehicle infotainment systems [1, 2], voice-recognition interfaces, Apple CarPlay© [3], Android Auto© [4] and gesture command systems [5] represent only a few of the large number of innovations that are part of the current in-vehicle driving experience.

Autonomous, self-driving vehicles are fast approaching a reality. The National Highway Traffic Safety Administration, along with other international institutions in the transportation domain (e.g., Society of Automotive Engineers) have created taxonomies for autonomous vehicles [6, 7]. In this progression towards autonomy, many automotive Original Equipment Manufacturers (OEM) have made public their intention to release NHTSA level-2 autonomous vehicles within the next three years and, along with other consumer electronics companies, NHTSA level-4 fully-autonomous vehicles by 2025. There are even cases of NHTSA level-2 vehicles already available on the public market. In 2015, Tesla Motors© released its Tesla Autopilot© software update [8] capable of allowing the system to take control of both the lateral and longitudinal behavior of the vehicle—by means, respectively, of a combination of Lane Keeping and Adaptive Cruise Control systems (see also Mercedes-Benz© Intelligent Drive© and Volvo© Intellisafe Autopilot© for similar NHTSA level-2 autonomous driving features). Although some of the NHTSA level-2 systems were designed to allow drivers to take their hands-off-the-wheel and feet-off-the-pedals for certain periods of time (e.g., 15 s), many users were found to abuse of these systems in many unforeseeable ways [9].

The advent of the autonomous vehicle has posed a large number of questions among researchers in the driving community and beyond. Transition of control is defined as that instance in which the control of the vehicle transitions between the driver and the autonomous system. One of the main issues associated with transition of control regards the driver's ability to take over from the autonomous system in scenarios where the autonomy is no longer possible [10]. With the autonomous system in control of driving, one likely consequence is indeed for "drivers" to fall out of the loop and reduce, or completely loose, their awareness of the driving task [11]. This of course is much more likely with "drivers" being engaged in non-driving related activities that tend to take their attention and eyes off the road [12]. One viable way to counteract this is to design warning signals capable of speeding the process of driver's re-engagement to the driving task [13] without being distracting or annoying [14]. This activity of handover is referred to continually in research in this area but is not the only challenge brought by the advent of autonomy. Another issue associated with autonomous vehicles regards how the wider HMI of these vehicles will change as a result. The steering wheel, pedals and dials represent means of control in a manual era. Whilst these may be required for sometime to come, thought has to go into how additional information is required to support the driver at times when they will be disengaged with the driving scene. This is especially important at points when the autonomy fails. There new interaction technologies may be required for users to interact with the vehicle begging the question how will future in-vehicle HMI evolve? This paper focuses on two concepts for innovative HMI concepts: Bike Sense and Mind Sense.

2 Bike Sense Concept

The visual and auditory channels are heavily taxed while driving. Many are indeed the tasks requiring drivers' visual and auditory attention [15]. As consequence, automotive OEM's are focusing their attention on haptics as an alternative sensorial modality for the HMI of warning and crash prevention systems [16], navigation systems [17] and infotainment systems [18]. Haptic can be distinguished based upon type (vibrations, pulses, counterforces), physical characteristics (amplitude, frequency, off and on time) and location where they are presented (steering wheel, backrest, pedals). Literature shows that different haptic signals are suitable to communicate different types of messages. Long duration vibrations presented on the steering wheel may be suitable for rear collision warning because of its ability to attract the driver's attention and trigger a corrective response very quickly [19]. However, the same signal may be perceived as annoying if presented too often by an infotainment system and, as a consequence, lead the driver to discontinue its use [20].

The Bike Sense concept utilizes a combination of visual, auditory and haptic signals to create an intuitive, easy-to-use HMI that enable the communication with the users in a fast and comprehensible way (Fig. 1).

The multi-modal components of the bike sense concept, visual, auditory and haptic, all working in harmony indicate a number of key aspects to the driver. The idea is to provide more detail of the threat posed by the object detected, but also the directionality and the proximity such that the driver is immediately aware and can thus consider an appropriate course of action. Recent surveys show that one of the main concerns associated with autonomous vehicles is related to the software misuse and safety [21], aspects that may likely reduce the level of users' trust toward the autonomous system [22]. In the context of autonomous vehicles, the

Fig. 1 Bike sense [34]

Bike Sense concept has the potential to keep the user aware of the vehicle surroundings through providing information about the presence and behavior of other selected road occupants. This will help users to increase their level of awareness and understanding of the system's capabilities to detect other road occupants with the potential and making them trust the system more.

Literature on the psychophysiology of redundant signals suggests that responding to redundant, multimodal stimuli is faster than responding to the same stimuli presented separately [23], a phenomenon observed within the driving context as well [13]. Nonetheless, one main issue associated with multimodal warning signals is that, because of the high level of perceived urgency associated with them, if presented too often they might become highly annoying [24]. This represents one of the main challenge for the Bike Sense concept as, although capable of expanding users' level of awareness of the surrounding road environment, it will not have to affect the overall level of user comfort.

3 Mind Sense Concept

A Brain-Computer Interface (BCI) is a device that uses the brain-activity of a person as an input to select desired outputs on a computer [25]. One method of obtaining a person's brain activity as a digital input is by using surface electrodes and an electroencephalogram (EEG) amplifier. The concept of BCI was proposed by Vidal [26] who suggested that consistent responses to stimuli in brain activity, called evoked potentials, could be used to convey information or intent that could be then used to control other devices.

Current BCI applications focus on assistive care. One of the main use cases for BCI in this field is to create alternative ways of communication for individuals with motor impairments who cannot use a keyboard or mouse for instance [27]. Because of the portability and commercial availability of BCI, these interfaces are being used in a number of other fields [28]. In the entertainment industry, BCI can be used to enrich the gaming experience by, for instance, making use of the users' cognitive and emotional state to control avatars [29]. Similarly, in the safety and security sector, BCI in combination with eye movement data can be used to detect deviant behaviors or suspicious objects [30].

The basis of Mind Sense in the context of autonomy is to observe whether a vehicle could read the brainwaves of the driver. This could be used for a number of purposes but one of the key ones would be to indicate that a user is beginning to daydream or feel sleepy while driving or, alternatively, when in autonomy is required to take control of the vehicle. The human brain continually generates four or more distinct brainwaves at different frequencies [31]. Delta waves (from 0.5 to 4 Hz) refer to a condition of deep sleep. Theta waves (from 4 to 8 Hz) refer to a state of drowsiness and a first stage of sleep. Alpha waves (from 8 to 14 Hz) refer to a state of relaxation yet characterized by alertness. Beta waves (from 14 to 30 Hz) refer to a state of high alertness. In a driving simulator experiment conducted on Jaguar Land Rover premises, participants drove two different scenarios. In the manual scenario, participants drove a manual vehicle for 45 min on a motorway road environment. They had control of the steering wheel, brake pedal ant throttle. In the autonomous scenario, participants were driven by a level-5 fully autonomous vehicle for 45 min and they were not required to operate it manually. Brain activity was recorded via a 14-channel EEG Emotive EPOC+ headset [32] throughout the two drives. Preliminary data showed that, in the manual scenario, the power of alpha wave slowly increased and became larger than the power of beta over the end of the 45-min drive. Interestingly, such pattern was even more prominent in the autonomous scenario with the power of alpha wave surpassing the power of beta in a much greater fashion. These data, although preliminary, suggest that in our experiment, when being driven by a highly autonomous vehicle, participants became more relaxed and, therefore, less alert over time as compared to when they were manually in control of the vehicle.

4 Conclusions

As standard automotive HMI become more outdated and autonomous driving features become a reality, the automotive industry has to provide innovative interfaces for future vehicles. In this paper we presented two different novel HMI concepts: Mind Sense and Bike Sense. Both these concepts aim to make the interaction between the user and the vehicle seamless and more intuitive. Bike Sense aims to reduce the cognitive processing stage typical of the stimulus-response tasks [33] through making the perceivable warning signal more self-explanatory and, therefore, faster to respond to the user. Similarly, the objective of Mind Sense is to directly “tap into the users’ brain” to detect its state and, therefore, have a more clear understanding of their capabilities and fitness to drive and, in an autonomous drive context, to take over control of the vehicle when required.

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Gesture-Based and Haptic Interfaces for Connected and Autonomous Driving

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Abstract While user interfaces for in-vehicle systems in the market are mostly button- and screen-based, advances in electronic technology provide designers with new design opportunities. In this paper, we propose applications of these novel technologies for several aspects of the current and future driving context. We explore opportunities for gesture-based and haptic interfaces in three different areas: establishing shared control between the driver and the autonomous vehicle; providing situation awareness to users of autonomous vehicles while engaged in other activities; connecting drivers to fellow drivers. We argue that these interface technologies hold the promise of creating richer and more natural interaction than the traditional vision- and audio-based interfaces that dominate the current market. We conclude by outlining steps for further research.

Keywords Human factors · Human-machine interface · Multimodal interfaces

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1 Introduction

The relation between the driver and the vehicle is rapidly changing, resulting in changes regarding the responsibility of the driver. Until twenty years ago, the driver was fully responsible for controlling the vehicle, so that poor control directly affected the outcomes, occasionally resulting in accidents. Over the last twenty years the number of driver assistance systems has greatly increased. As a result, state-of-the-art vehicles contain many electronic systems supporting the driver and aiming to increase safety, so that, even in cases of poor control, the system covers up for driver errors. Examples are Anti-lock braking system, Electronic Stability Control, Collision avoidance, Lane keeping and Blind spot detection. Systems such as Adaptive Cruise Control and on-board Navigation systems are more intended to support convenience and comfort and less to cover up for driver errors. Further changes in the relation between the driver and the vehicle are rapidly approaching with the advent of autonomous driving, which aims to narrow down the space for human error by reducing the involvement of the driver. Extreme visions are driver-less vehicles, where the only control that the passenger has is to enter the destination, and possibly the target cruise speed (as long as it does not violate the speed limit and is not beyond the capabilities of the system). In such a vision, the driver progressively changes from an error-prone operator into a passenger in a vehicle that is controlled by infallible technology.

The first tests with autonomous vehicles have led some to question the extreme vision of moving the driver/user completely out of the loop, and have inspired a different view on the relation between the driver and the vehicle. While reducing the involvement of the driver with low-level operational activities such as maintaining speed and steering, drivers may still be involved in higher-level control activities. In this vision, the driver is not taken out of the loop, but becomes an operator who is involved in strategic and tactical decisions and influences how the system performs, so that the decisions are better tuned to the needs, interests and preferences of the user. This way, the driver and the vehicle become companions who support each other in taking certain decisions and to reach a certain desired performance. Furthermore, advances in electronics and interaction technologies offer opportunities for new forms of interaction supporting such changes in the relation between the user and the vehicle.

In this paper, we will elaborate on this view and present examples of concepts representing innovative interfaces for assisted and autonomous driving. The first example is a concept that allows drivers to interact with an autonomous vehicle to influence decisions concerning tactical manoeuvres such as whether to take over and what speed to apply when taking over. The second example involves concepts that use different modalities (including haptics and audio) to provide situation awareness. The third example is a concept that allows the driver to give feedback to other drivers about their traffic behaviour by sending “likes” and “dislikes” by means of a gesture-based interface. The examples will be used to sketch perspectives about how novel interaction techniques may help to implement the reconceptualization of the relation between the driver and the vehicle.

2 Mixed Control: Keeping the User in the Loop

As mentioned in the introduction, the prevailing trend is to reduce the involvement of the driver. Arguments that are put forward to support this vision are safety, sustainability and convenience. With respect to safety, it is argued that the human error is the cause of the large majority of accidents, and that automation is needed to cover for human failure. With respect to sustainability it is argued that automated vehicles will have more sustainable driving styles than human drivers who exhibit speed variability, emergency braking and other driving behaviour raising fuel consumption. With respect to convenience it is argued that automation enables drivers to engage in other activities such as handling e-mail, texting, watching movies etc. People's need for engaging in such activities is clear from the fact that already now between 30 and 40 % of the drivers send text messages with their smartphone on a regular basis while driving [1]. Automation would allow them to do so in a safe manner.

In our work, we take a slightly different approach, which integrates a Companion view of the relation between the user and the vehicle, the model of adaptive automation by Parasuraman [2] and the levels approach by Michon [3]. In our approach, we enable the users to stay in the loop through a mixed initiative approach. On the system side, the system may invite the user to approve or veto certain intended manoeuvres, such as taking over or crossing a complicated intersection, or by approving the intention to speed up to meet the desired time of arrival after a delay occurred through a traffic jam. On the user side, the user may take the initiative to influence the way certain manoeuvres are executed, for instance by changing the driving style to be more defensive or more assertive, or by influencing the way a take-over manoeuvre is executed, so that the system may learn the preferences of the user.

In a project by Felix Ros, a haptic interface named Stewart was developed allowing the user to sense and influence the behaviour and intentions of the vehicle (Fig. 1). Stewart is a haptic interface for a fully autonomous vehicle. A form of haptic interaction was chosen since it was believed that it would be a non-obtrusive way to communicate the car's intention and also provide opportunities to indirectly influence the car's driving behavior. When driving, Stewart should enable people to do something else besides driving while providing a sense of control over the car's behavior.

Stewart strives for a satisfying driving experience by enabling a 'dialogue' or even discussions with an autonomous vehicle. This dialogue can have multiple levels of intensity, depending on the car's judgment of the traffic situation and the driver's intention. Changing direction or increasing/reducing speed should be easy to influence when the human driver chooses to do so. In this case, there will be

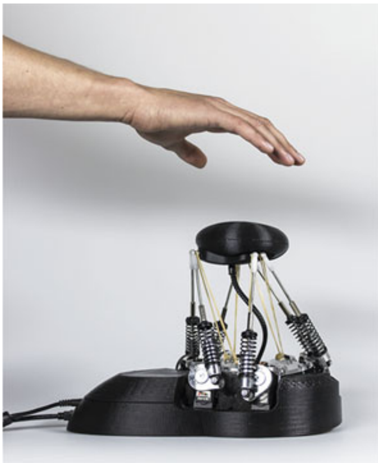

Fig. 1 Stewart uses software designed for a platform that uses six servos controlled by an Arduino. The transition of the six degrees of freedom is calculated and the information is fed to Arduino, controlling the servos

barely any dialogue depending on how much effect this action has on parameters like arrival time and fuel consumption. However, if the human driver deliberately intends to break the law, the car will (re)take control and communicate this through an intense haptic discussion. When a decision has to be made fast, the vehicle will always make this decision for the driver. Any decision taken by the vehicle is rational—and essentially better thought-through—which will lead to safer transportation for the driver and its surroundings.

Stewart will always provide feedback of the car's intentions and current actions to the driver if needed. Stewart's interaction is focused on building and achieving trust between the car and its driver. The driver can choose to be in the driving loop by touching or looking at Stewart, or stay out of the loop and ignore Stewart and do something else. Stewart should not be obtrusive; the vehicle is self-reliant and does not need the user to reach its destination.

So why would one want to control a vehicle that drives itself? Learning to trust a (new) technology takes time. A feeling of control can help building a mutually trustful relationship. Humans are unpredictable creatures who tend to change their minds frequently. Interfaces like Stewart are very much needed to communicate our human intentions to intelligent technologies like autonomous vehicles in order to create satisfying user experiences, given the difficulties associated with a relationship where one entity is human and the other is not.

A similar view on the relation between the user and the vehicle is being explored in a project by Sergej Zwaan (Fig. 2). The system called the "Comrade" embodies the vehicle's condition through a light in the steering wheel The user can push the light aside to take over control or pull the light to the steering wheel to hand over control. While the user is in control, the vehicle can indicate a willingness to take over control, indicated by the light sneaking into the direction of the steering wheel. Likewise, while the system is in control, it can indicate willingness to hand over control to the driver; this is indicated by the light sneaking to the right, or it can

Fig. 2 The "Comrade" system, a tangible interface for negotiating control between driver and vehicle

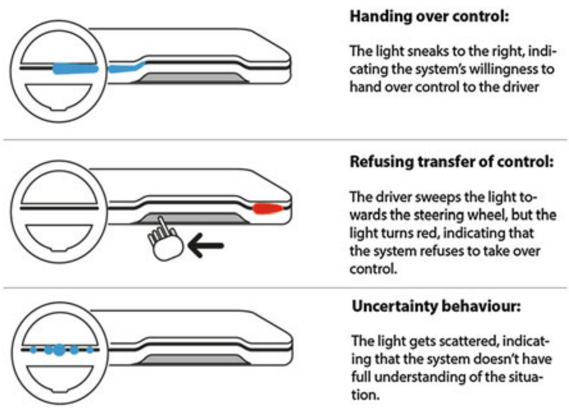

Fig. 3 Examples of the negotiation dialogue for handing over control

refuse to take back control again, because it thinks the situation is too dangerous for autonomous driving (for example when driving through snow) (Fig. 3). Finally, the system can show uncertainty when driving in a situation it does not fully understand. These interactions could make driving an autonomous car more understandable by translating technical issues into visual behaviours.

3 Multimodal Interfaces for Situation Awareness

Keeping the user engaged in the control loop requires that s/he should remain aware of the situation. Situation awareness has been most thoroughly investigated by Endsley [4]. In the context of driving, situation awareness refers to the process of perceiving and understanding the current state of the world and predicting the evolution of the situation in the immediate future. This includes the position of other vehicles and other road users, but also what manoeuvres will be required in the immediate future (braking, accelerating, taking turns, which objects/events will require attention in the near future and so forth). At a higher level, situation awareness may also apply to matters such as the progress of the trip: how are we doing in view of the estimated time of arrival (how long will it still take, is there a delay and so forth). Often, we notice that passengers also look outside the window to build situation awareness, and some passengers state that it keeps them from becoming car-sick, as it helps them to anticipate the forces the vehicle's manoeuvres will exert on the body [5, 6].

We believe that the need for situation awareness will not disappear with self-driving vehicles. Possibly the precise information that users would like to have is not as detailed as the information that drivers currently require to perform adequately. But we believe that users will at least want to have the same information as passengers do currently, also in view of preventing motion sickness. It is estimated that between ten and thirty percent of the occupants of autonomous vehicles will become car-sick if they engage in other activities such as reading e-mail, watching movies or just relaxing with eyes closed [7, 8], certainly if autonomous vehicles will evolve and their driving style will become more self-confident and assertive than the very defensive driving style of current autonomous vehicles [9].

In the near future, we will investigate the needs of occupants of autonomous vehicles for situation awareness when they are engaged in other activities. It appears that motion sickness becomes particularly likely if users are engaged in other visual tasks so that their visual information does not match the information from their vestibular system. Requiring people to look outside will keep them from enjoying the convenience of autonomous driving. Thus, we need to look for other solutions to enable people to build a model of the world and remain situationally aware, allowing them to anticipate the forces to which their bodies will be subjected.

In several projects, we are exploring multimodal interfaces to provide users with information to build situation awareness. Currently, drivers and passengers alike need to predict the immediate future from the current situation, in order to react appropriately to upcoming situations. With autonomous vehicles, this task is relayed to the vehicle. This means that the vehicle will know how it needs to act in the near future, and this enables us to present the intentions of the vehicle directly to the users rather than requiring the users to infer the future actions based on information about the current situation. In other words, we explore how to provide information about the intentions of the vehicle to the users through different modalities, both visual, auditory and tactile. Taking into consideration that users are engaged in other activities, we need to explore peripheral displays for the different modalities, so that the information is provided in a subtle manner and the interference with the current activity of the users is minimized. An early prototype for a haptic interface is shown in Fig. 4.

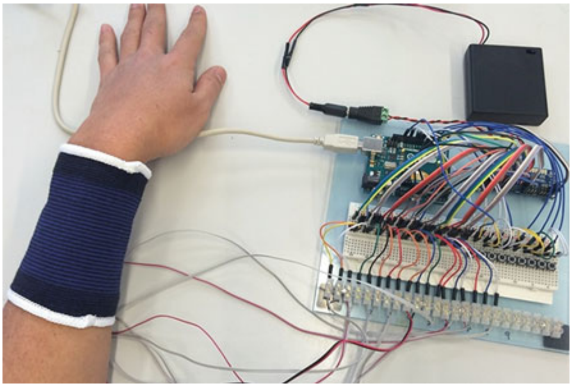

Fig. 4 Prototype of first concept to provide vibrotactile feedback to enhance situation awareness in autonomous vehicle

4 Facebook on the Road: Giving Feedback to Fellow Drivers

Social media have become omnipresent, enabling people to stay connected with their social relations. In the automotive domain, connectivity usually has one of two meanings: either it is about vehicles connecting to each other to exchange information; or it is about drivers/passengers being connected to the internet. It is not about drivers being connected to each other. The anonymity that prevailed between drivers before the internet era still largely remains. It has been argued that such anonymity increases the likelihood of undesirable behaviour, since anonymity impedes empathy and tolerance and counters accountability [8, 10].

This observation was the inspiration for a series of research and design studies aiming to build systems that enable drivers to connect to each other and research their effects on driving behaviour [11, 12]. In a first series of studies it was investigated how people feel about providing feedback to other drivers about their driving behaviour, and how they feel about receiving feedback from other drivers on their own driving behaviour. In different studies employing a driving simulator, it was investigated whether people would like to give and receive both positive and negative feedback, or only positive, and whether the feedback should be made available in real time or only after the trip (Fig. 5).

An interface was created allowing drivers to provide positive or negative feedback by making a thumb-up or thumb-down gesture and select a nearby vehicle as the recipient of the feedback by a pointing gesture, as shown in Fig. 1. In the setup shown in Fig. 1, the gestures are recognized using a Leap motion sensor. The interface enables a much more natural and less distractive interaction than a traditional screen-based interface.

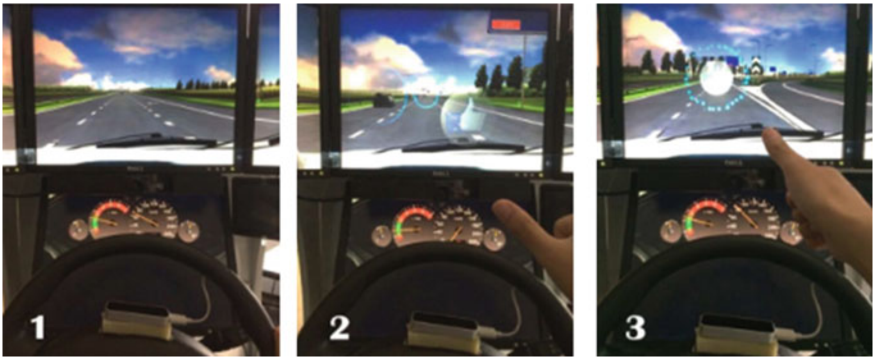

Fig. 5 Providing feedback to fellow drivers. *Panel 1* The setup, showing a Leap motion sensor for gesture recognition. *Panel 2* Making a thumb-up gesture to express "Like". *Panel 3* Selecting the recipient vehicle of the "Like" gesture through a pointing gesture

5 Conclusion

In the previous pages we have summarized three projects exploring novel interaction techniques for the driving context. While mainstream interaction technology for the driving context is mostly button- or screen-based, novel interaction technologies enabling gesture-based and haptic interaction hold the promise for creating a more natural and less distractive interaction. These interaction technologies may be applied both to the interaction between the driver and the environment and the driver and the vehicle. These novel technologies allow for a more subtle interaction that appears to be particularly suited for autonomous driving, where users may be engaged in other activities such as texting or watching a movie. Elsewhere we have argued that a vision where drivers are progressively removed from the control loop and have no control over the behaviour of the vehicle is bound to run into problems of user acceptance [13]. We favour an approach where the driver can do other things, but is still in the loop, and the driver and the vehicle build a companion relation where they support each other in reaching a result that is satisfactory for both parties. Such a situation requires interfaces that are unobtrusive and allow for subtle interaction. We argue that the novel interaction techniques are particularly suited to build interfaces that meet these requirements.

Next steps are to validate the ideas and concepts outlined here. Will people appreciate the companion relation that establishes a social relation between the user and the vehicle, or will they be satisfied with being removed from the interaction loop, where the vehicle is still a social agent but one that they cannot influence at all? What type of communication is best and how detailed does this 'dialog' need to be? Also, we need to investigate what users' requirements are for situation awareness, and how we can satisfy those through peripheral displays using multiple modalities. Answering those questions will enable to shape the social relation between the users and the vehicle. Finally, the promises and limitations of gesture-based and haptic interfaces deserve further exploration.

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Somatosensory Interactions: Exploring Complex Tactile-Audio Messages for Drivers

Maria Karam, Rebecca Wilde and Patrick Langdon

Abstract We present early results of a study on tactile acoustic devices as a somatosensory communication system for drivers. A series of studies were conducted to explore this alternative mode of tactile communication and to illustrate some of the perceptual differences between tactile audio and haptic vibrations. Results from this research suggest that speech and other sounds can express information to the body with little or no advance training, and that tactile acoustic signals can function as an augmentation to haptics, leveraging the complexity of human somatosensory interactions (HSI) to increase driver's awareness of their environment using sound as a tactile sensation.

Keywords Human factors · Human-systems integration · Systems engineering · Haptic and tactile interactions

1 Introduction

Haptics for in-vehicle information displays are aimed at increasing safety, awareness, and response times to emergency situations for drivers. Human machine interface (HMI) systems often include haptic displays to provide information and notifications on lane departures, road hazards, or for autonomous vehicle take over and navigational instructions [1–4]. Haptic signals may however be over used, as when they startle or annoy drivers with a sudden or steady vibration [5]. A more

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subtle option is to target cutaneous stimulation with lower intensity and more varied vibrations that can represent an effective alternative to structured haptic messages. Tactile acoustic systems are sound displays for the body, using the subtle vibrations of sound to express emotional or characteristic information of an audio signal [6]. Tactile acoustic devices (TAD) were developed to support tactile experiences from sound by leveraging the skin's highly sensitive information detection mechanisms.

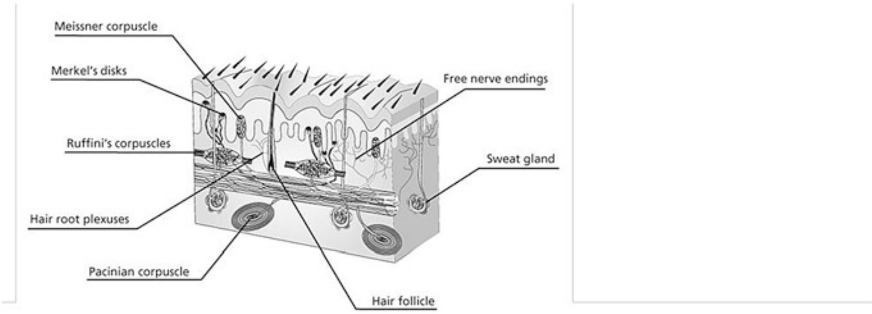
2 Background

2.1 Physiological Literature

Vibration actuators are used routinely as a general-purpose interaction device for haptic displays as they are robust and inexpensive [7, 8]. Research into Tactile or haptic displays focus on electro-stimulation, electro-cutaneous stimulators, and mechanical pin arrays or forces, thereby allowing compact, powerful stimulations to be delivered to skin surfaces or experienced as kinaesthesic force. Considerable work has explored augmenting visually impaired use of computers through vibrotactile 2D displays [9], or for signalling information; for example, using cross-modal tactile icons or "Tactons" [10, 11]. Evidence is accumulating that combining auditory and tactile information is effective and advantageous for both vision impaired and sighted individuals [12–14]. The passive vibrotactile stimulation of receptors in the skin and muscles allow cost-effective and straightforward methods of generating a haptic stimulus. However, the use of an audio amplified signal through a purpose-designed transducer array largely subsumes this approach and adds the further possibility of varying frequency, amplitude and the presentation of complex signals.

2.2 Discriminability, Spatial and Temporal Masking

Vibratory discrimination thresholds for touch sensors are dependent on both frequency and amplitude of stimulation. Sensations are dependent on rapidly adapting and slow adapting mechanoreceptors (RA I, SA I, RA II, SA II), embedded in the skin, sensitive to frequencies between 0,5 and 1000 Hz and with receptive field sizes varying from 1 to 1000 mm^2. Touch sense has been identified with Pacinian Corpuscles; the RAII receptors, but in fact, is known to be associated with all the glabrous skin afferents, including Meissner corpuscles, Ruffini corpuscles and the Merkel complex cells. Amplitude in such studies is measured in mm. of displacement rather than work done (power), and thresholds vary from 0.01 to 40 mm. The contact discrimination threshold (receptive field size) on the body varies from 0.7 to 100 mm but this is undoubtedly modified by amplitude or vibratory power in psychophysical functions, as is illustrated in Fig. 1. This implies, in particular, that greater sensitivity is obtained at increased power at the extremes of the



Human mechanoreceptors and their corresponding sensory modalities

Receptor	Class	Sense modality	Frequency range (most sensitive at)	Receptors (cm^2) at fingertip
Meissner corpuscle	RAI	Stroking, fluttering	10–200 Hz (200–300 Hz)	140
Merkel disk receptor	SAI	Pressure, texture	0.4–100 Hz (7 Hz)	70
Pacinian corpuscle	RAII	Vibration	40–800 Hz (200–300 Hz)	21
Ruffini ending	SAII	Skin stretch	7 Hz	9
Hair follicle	RA	Stroking, fluttering	?	–
Hair	–	Light stroking	?	–
Field	–	Skin stretch	?	–

Fig. 1 Tactile displays: overview and recent advances [8]

frequency-amplitude-area envelope [8]. Discrimination (Just Noticeable Differences—JND) results have been found to confirm the psychophysical functions for both vibration (frequency and amplitude) and mechanical displacement. Notably, however, frequency changes have been detected when vibration amplitudes are varied [7]. Discrimination frequencies of less than 5 Hz have been reported at around 25 Hz but these also increase with frequency.

Spatial and temporal masking effects before and after the stimulus exist, with minimal effects after an ISI of 200 ms. Previous studies have taken work on two-point discrimination as a guide to Tactor spacing, adopting a minimum spacing of around 100 mm [15]. However, traditional research suggests that glabrous skin is most sensitive during active exploration and the assumption has been that non-glabrous or hairy skin (back, legs, arms) is therefore not sensitive to tactile information presented in a passive mode. Despite this, passive hairy skin sensitivities are thought to range from ~5 to ~1000 Hz, and tactile acoustic displays have effectively exploited a wider range to avoid damaging the audio signal. In particular, complex sound information such as music can be divided into multiple tactile channels coding parts of the frequency spectrum and perceived in this way. This is the approach taken by the TAD system based on the Model Human Cochlea (MHC) theory [16].

3 Experimental Design

The study examines the potential to display HMI sounds thorough a seat in an automobile using a tactile acoustic device, and presents preliminary insights into the use of sound vibrations to notify drivers of information within in and outside of the vehicle. The research is divided into a pilot study for exploring perceptions and responses to using sound as physical information, and a set of experimental trials to evaluate the tactile signals for detection, identification, localization, intensity, and perceptual responses of participants.

3.1 Methodology

A 12-channel TAD was added to the chairs used in the experiment. An 8-channel Spinal TAD system was secured to the back of a chair, with a 4-channel pad placed on the chair seat [17]. Each of the 12-channels are calibrated to ensure they can be detected on the body, and different sounds are presented through the tactile system. Participants are asked to provide feedback for each trial relating to the factors: detection, identification, intensity, location, in addition to comments on comfort and preference. Five people took part in the pilot test, and another ten in the experiment, for a total of 15 participants. Each participant was seated in the chair so that they could make contact with all 12 channels. Trial signals were presented to each participant without prior training, with or without background music playing, and at different intensities (in the calibration trials). Trials were conducted across two locations: a university research lab in the UK, and a coffee shop (Café) in Canada [18]. The pilot study was conducted entirely at the Café, with 8 participants recruited in Toronto. The remaining 7 participants were recruited from a university and automotive research departments in the UK. Results were combined for our analyses. Data was collected using a series of questionnaires, interviews, and observations.

3.2 Apparatus

A Spinal TAD [17] was hung on the back of a chair to allow us to position it on the seat to make contact with the back, arranged as 4-pairs of mono signals along the 8-transducer array. Two rows of transducer pairs were used in the seat cushion, with individual signals presented through each channel. The uses a stereo signal, or tones generated through audio processing software as input to the transducer arrays. The sample files used are 320kbp/s mp3 files comprised of sound bites, organized into three groups: emergency signals, environmental sounds, and voice.

The TAD setup is shown in Fig. 2, illustrating the portable system in an SUV (left), and the Café chair (right). Tactile acoustic signals for the calibration trials were generated in real time for each channel using a signal generator in the development kit. We used the default sound distribution model to process the sound files for the 8-channel system [16].

Fig. 2 TAD systems setup in a car (*left*), and the Café chair (*right*)

4 Experimental Design

4.1 Pilot Study

Five participants were recruited from the Café for the pilot study, based on a 15-min introduction session to tactile sound. The system calibration tests runs through each of the channels, activating them individually until the user notices the vibrations. This is followed by an exploration session, using the opening 10 min of the film Star Wars IV [19]. The soundtrack is redirected to the TAD, and the video portion is hidden from view. Participants were asked to describe their first impressions of the experience, and then were shown the video to provide context to the signals. The sounds in the café served to mask most sound leak from the tactile system, although there were quite moments when the sounds could be detected.

Observations. Participants reported a range of responses, ranging from an immediate recognition of the sounds of gunshots, explosions, and the voice of the robot R2D2 without having seen the video. Another participant could not identify the vibrations as sounds, but did note that she felt hungry, like her stomach was rumbling. Once the video was shown, she also became very astute at recognizing the other sounds in the film on the vibration display, even while wearing a heavy winter coat, which could have reduced sensitivity initially. None of the participants had prior experience with the tactile displays, and each expressed interest in taking part in the upcoming experimental trials. Table 1 summarizes observations from the

Table 1 Overview of Pilot study results from Toronto

user ID	Sex	Clothes	Comments
P1	F	Thick	Not sure what the signals were until the video is displayed. This leads to recognition of sounds as vibrations throughout the 10 min scene
P2	F	Thin	Vibrations feel rumbly, made her stomach rumble like hungry. Felt a flight or fight reaction from the signals, which were fight scenes in the movie, with explosion sounds 5 min test
P3	M	Light jacket	Couldn't identify movie. But when switched to music, was instantly noticed. Wen't back to movie, and noticed. Noticed R2D2's voice in the vibration, surprised him that he could feel the beeps, very distinct. Very sensitive to vibrations, jumpy at times
P4	F	Jacket	Could not identify movie. Showed screen, then understood. Switching between sounds while movie played was noticed
P5	M	Thin	Sound audible, could identify changes in the action of the film, and noted the rumbling felt like being hungry

pilot, suggesting that even without knowing the content, change in signal can be detected, as can some of the characteristics of voices (R2D2 vs Princess Leah).

Preliminary findings are in line with previous work on the perception of tactile sounds, primarily music and speech [16], which also suggested that this first use of a portable TAD as an external seat cover would be sufficient for running tests with the technology outside of a theatre environment, to support development of the car seat prototype.

4.2 *Calibration Study Method*

Tones were generated and presented to each of the 8-channels in the TAD seat. For the calibration trials, tones were initially presented at 200 Hz and output level set to 0.75 of maximum output. The participant was queried for discomfort or unpleasant sensations at this point. From the 200 Hz start the frequency was raised until the participant could not perceive any tactile stimulation and this point was established by a series of sweeps above and below the threshold frequency. The same procedure was then repeated for the lower threshold, yielding an upper and lower detection threshold.

Trial Factors. The Independent Variables (IV's) were

- Factor A: Body Position (Channel 1–8)
- Factor B: Threshold Frequency (HI 200 Hz+, LO 200−)

The measured dependent Variables were:

- Upper threshold, Lower Threshold

- Perceived Position, Perceived Intensity

The subjective measures were:

- subjective sensations, comfort, clothing

4.3 Procedure

Participants were asked to seat themselves in the chair or on the automotive buck, with personal adjustment in order to ensure normal transmission. Participants wore normal indoor apparel for the experimental trials. Practice and familiarization was made by playing a series of audio tracks of tones and noises through the system without headphones. Each was instructed in the reporting procedure for body location (shoulder, ribs, kidney, butt L, Butt R and Thy L and Thy R; intensity (High, Medium, low) and threshold (can perceive some/no touch sensation). Participants wore headphones to attenuate external noise and for each channel in turn the threshold procedure was followed and a note made of upper threshold, perceived body location and intensity. After each channel presentation participants were asked about subjective sensations.

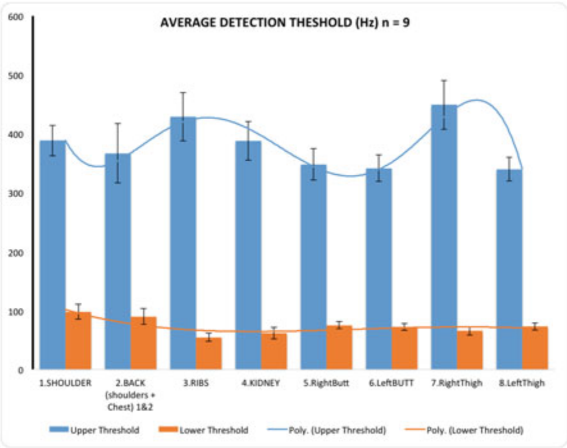
5 Results and Discussion

All participants experienced no difficulty in performing the task and none found the sensations aversive.

5.1 Calibration Results

Results of the calibration trials with the signal data (Sine waves at 50 and 500 Hz to the individual channels) showed that each of the frequencies could be detected consistently at comfortable amplitude levels ($\sim$ 60 db), on each of the haptic regions of the lower seat (RB/LB, RT/FT), and on the pairs of TAD channels along the back (S, C, B, K). Most participants could distinguish the haptic touch sensations from the audio leakage through the headphones and all precisely identified the threshold level at high and low frequencies. All participants could localise the sensations accurately, often to the left or right side of the body. The average levels were calculated with a correction for missing data on Channel 2 that occasionally gave intermittent output during trials. The detection thresholds were highly consistent across subjects and the Standard Errors show that they were highly accurate for both the higher and lower thresholds. However the average higher thresholds

Fig. 3 Upper and lower thresholds for the 12 channels



show greater variability than the lower (range 6–12). Figure 3 shows the averages and highlights with a polynomial fit a tendency to greater sensitivity at "modes" in body position for the upper threshold. These could be described as "Mid back" and "buttock-thighs". No such effects were found for the lower thresholds suggesting an even spread over the body area affected by the transducers. Clothing, body shape and body position appeared to have little effect on thresholds.

Finally, some participants experienced some "synaesthesia" between the audio leakage and the vibrations sensation although they were instructed to attend to the vibrations touch sensations. This suggest that the sensory fusion developed by the TAD system approach is a strong cognitive effect, as has been established elsewhere [3, 10]. A bi-modal sensitivity was detected relating to body location of the perceived sensations for the high frequency thresholds. This is highlighted by a polynomial fit in Fig. 3 showing that sensitivity is perceptually centered around the ribs and kidneys, buttock and thighs.

Haptic Signal Detection. Participants were very sensitive to the frequency of vibration touch sensations and were able to accurately report upper and lower detection thresholds and body locations, varying little across subjects. The distribution of reported sensations across conditions varied significantly between body locations.

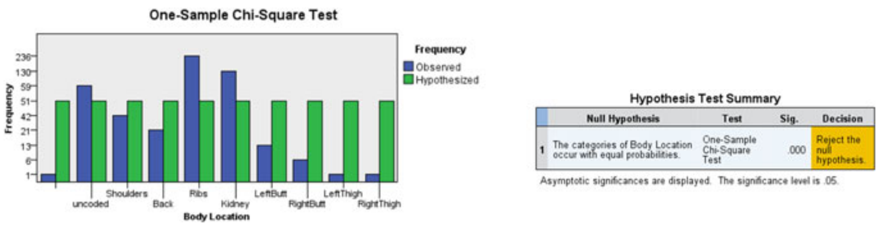


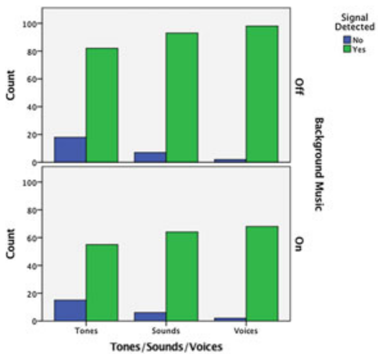
Fig. 4 Results from location detection

Results of detection of body location of the tactile signal (Fig. 4) show that participants reported sensation for some body locations significantly more often than expected by chance. In addition the distribution suggests that the most reported body locations were shoulders, ribs and kidneys and to a lesser extent back. Butt and thighs were less frequently reported and a significant proportion of trials were not located at all.

5.2 Preliminary Experimental Results Analysis

Experimental data were recorded as binary (yes/no) or ordinal (hi/med/lo; body locations) formats and converted into frequency counts by conditions. Sound track stimuli were presented in random orders, in the presence or absence of background music played through headphones. Participants were required to identify the tactile signal and identify it from a set played to them during a training stage at the beginning of the experiment. In the absence of a long term study, the order of the conditions with or without background music were not counterbalanced, the musical condition always occurring last, in order to maximize the learning effects of the differences in sensation. Our analysis uses a series of one-sample chi-squared tests of deviation of a sample from a distribution. We note that signals were distributed across transducers at different body locations using the MHC for the compressions channeling and the distribution of frequencies in the original sound sample. However, given the sensitivity the data revealed during the calibration study, we can say with some confidence that human sensitivity is likely to be higher in these body sites, as suggested by the threshold data. The relative lack of stimulation in the buttocks and thighs can be accounted for by the infrequency of bass component in the signals presented on the lower seat. Despite occasional signal bursts, there was little sign of aversive sensations. Clothing, seat position and body fat levels had minimal effect on the results.

Test 1. TAD signal detection irrespective of background sounds (Fig. 5) results show that for both the background sound and no background sound, participants



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories defined by Signal Detected = Yes and No occur with probabilities 0.5 and 0.5.	One-Sample Binomial Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Fig. 5 Detection results with/without background music

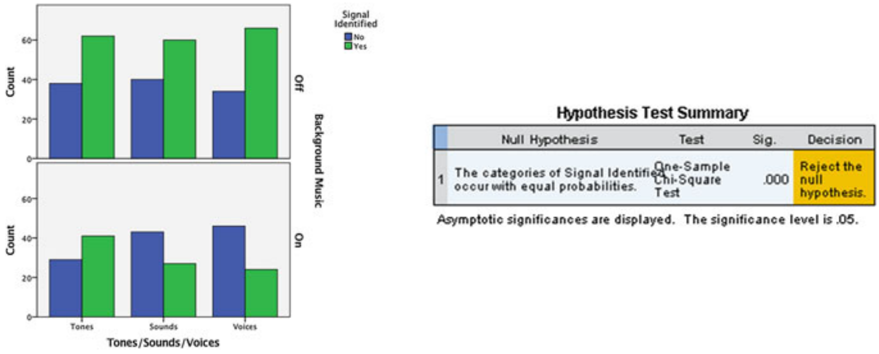


Fig. 6 Signal identification results

detected the TAD sensation significantly more often than would be expected by chance.

Test 2. Signal identified irrespective of background sounds (Fig. 6). The results show that for both the background sound and no background sound, participants identified the TAD sensation significantly more often than would be expected by chance. In addition, the distribution suggests that of the three categories of sounds tested, daily sounds and voices were less easily identified in the background music condition than pure tones.

Test 3. Signal audible irrespective of background sounds (Fig. 7) shows that for no background sound, participants perceived as audible the TAD sensation significantly more often than would be expected by chance. For the background sound condition the distribution suggests that signals were predominantly not audible sensations, particularly for the voices category.

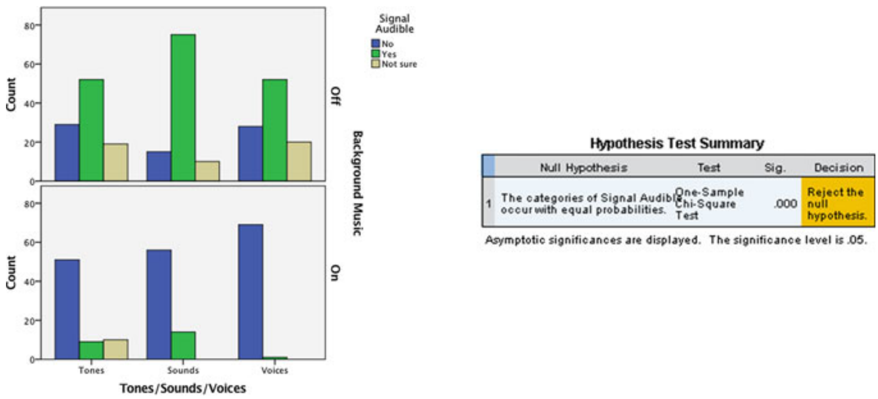


Fig. 7 Results for signal being audible

5.3 Discussion and Analysis

As we are not focusing on the haptic capabilities of TAD devices, we have shown that the system has the potential to run multiple somatosensory signals through the body. The calibration study demonstrated that a range of 9 users with varying body types, genders and clothing arrangements were all able to detect signals across all body positions with very similar levels of accuracy and upper and lower frequency thresholds. Standard errors were extremely small suggesting very little variation between individuals in their ability to detect the transformed acoustic signals. Preliminary analyses suggest that users can detect tone, daily sounds and voices as tactile signals using the MHC encoding, irrespective of background noise music.

A significant proportion of users could identify these signals as part of a remembered set, and this was still possible, though harder, in the presence of background sounds. For most participants tactile signals were sometimes perceived as linked to an audible sound, but this occurred infrequently in the presence of background sounds, and was reported as a synaesthesiac (multimodal) percept of sound and feeling. The distribution of sensations across body locations appears to have had little variance between individuals, irrespective of sound type and mapping and this was confirmed by the thresholds study. It was still see evident that users were able to identify both haptic, and sound signals simultaneously, suggesting a potential for more bandwidth to the somatosensory system than previously considered for physical communications.

6 Conclusions and Future Work

The TAD system showed support of both haptic style vibrations and tactile sounds ranging from mechanical sensations to human speech using the MHC theory. This initial investigation suggests that both haptic sensations, and cutaneous stimulation can coexist as detectible and identifiable, in addition to the localization of individual frequency vibrations directed to a specific contact point on the body. Results extend to an upcoming in-car study using the MHC in real world, long-term studies of tactile communication for drivers. Sound, system, and signal design modifications are being explored towards improving and refining tactile communication using the TAD system, and to extend our results into actual in-car scenarios to help improve somatosensory interactions for automotive applications.

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Information Model for Intention-Based Robot-Human Interaction

Daniel Schilberg and Sebastian Schmitz

Abstract Safe robotic-based systems gain more and more importance in an aging society. To enable all members of society to continue participation in social live, private and professional, robots are required to identify the intentions of people and the robots must be able to convey their intention to the people who use it. In this paper, an information model is introduced which matches the robot's atomic capabilities like rotational or translational motion or grasping which must be aggregated to more complex skills. These skills must be associated with an application context. Furthermore, the mapping between the robot's capabilities must be transparent and comprehensible to the human user, so that in fact intentions can be derived from an actual handling procedure. The information model is based on the following steps: 1st system design, 2nd gather, 3rd recognition and evaluation and 4th response.

Keywords Human-machine-interaction · Safe HMI · Intention-based interaction · Robotics · Mechatronics · Cyber-physical systems · Industry 4.0

1 Introduction

In 2011 the expertise "Challenges of Demographic Change" was issued by the German Council of Economic Experts [1]. The expertise's objective was to take a look at demographics and growth potential in an aging society from the viewpoint of labor, goods and financial markets. Parallel to the development of the age structure, there are technological advances in the field of information technology, which will have a significant impact on the world of work. To explore the ensuing social potential, we have to focus on two requirements. On one hand the disciplines of mechatronics still have to continue to grow together, and on the other hand other

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mostly non-technical disciplines, such as medicine or the social sciences, have to be integrated. In Germany, this development is called “Industrie 4.0” [2] and in the United States its name is “Cyber-Physical Systems” [3].

Based on the performance gains of autonomous and semi-autonomous technical systems in the past 10 years the range of applications of technical systems in general and robotics in particular will be greatly expanded. The documents “The German Standardization Roadmap” [4] and “A Roadmap for US Robotics—From Internet to Robot” [5] show how the professional and private life will be effected by robotic systems, which are based on a strong information network.

Fundamental research on human-machine interaction is needed if we want to create robotic systems that support elderly people at home and at work to keep them independent, productive and enable their social participation. In 20 years a robot, similar to the mobile phone today, will be our constant companion. To reach that goal, not only the fields of mechanics and energy must continue to develop. Such a robotic system must also recognize intentions of people to support them and it will have to reveal its behavioral intentions to allow secure interaction, which consists largely of non-verbal communication. For this purpose, an information model for robotics must be developed. The robot’s atomic capabilities like rotational or translational motion or grasping must be aggregated to more complex skills and these must be associated with an application context. Furthermore, the mapping between the robot’s capabilities and functions of the product must be transparent and comprehensible to the human user, so that in fact intentions can be derived from the procedure. In order to achieve the outlined objective, a robot has to gain knowledge about its own functionality and environment as well as about the interaction with it. The approach to reach this goal is divided in four steps:

1. System Design

The system design is based on methods which can describe human-machine interactions (HMI). The description of the HMI is the origin of the derivation of context-sensitive robot configurations that allow the fulfillment of aggregated function. An essential point to achieve user acceptance of the system is transparent and comprehensible robot operations.

2. Gather

The robot must capture his environment, including acting persons. The detection of the environment in which the robot is operating is done by sensor data. Sensor values must be correlated against each other in order to provide comprehensive and verified information.

3. Recognition and Evaluation

The detection of the robot’s environment is followed by a recognition and an evaluation of the environment. For this purpose objects and obstacles must be identified. Each recognized scenario must be analyzed concerning its actual state in comparison to the target state.

4. Respond

Depending on the results of the evaluation of the actual state an action must be performed to achieve the target state and to fulfill a function.

This paper will show an information model of an intending robot system. The starting point is the formulation of an information model for a generic robot system that stores information about the four aforementioned steps in their origin context and enables further data processing by correlation, aggregation and analysis.

To achieve the mentioned objectives the requirements of the system must be collected and they have to be transferred into the specifications. After that a robot system is developed. The first structure of the system architecture comes into use, followed by the information integration model and the integration of additional sensors. The information integration model is the formal self-description of tasks, functions and capabilities of the robot. The atomic functions are aggregated to higher skills and communicate with their environment based on this model.

2 Related Work

Over the last decade the research area of robotics has made a great leap forward. It is the aim of many projects to increase the capabilities of robotic-systems. There is a huge range of varying approaches to achieve the goal to make robots smart. Approaches can be assigned to different main objectives. These objectives are related to the robots behavior and to the models that are used to match the behavior for a certain situation. To build up the above-mentioned information model we have to combine some existing technologies and develop them furthermore. In this section we take a closer look on the most important technologies for the information model.

2.1 Information Modelling

The core of this research work is how to connect the movements of joints to complex operations and how to explicate intentions via movements. An information model should fulfill these operations. To build this information model we have to use methods from information retrieval and the semantic web. Furthermore, we have to look at existing information models in other application domains.

Information retrieval (IR) is marked by vague requests and insecure knowledge. Oddy et al. [6] describe the retrieval strategy in the following way: "The goal of information retrieval is to resolve those anomalies in a person's state of knowledge, which induced him or her to seek information from literature. Our approach is to select search strategies with explicit reference to characteristics of the enquirer's ASK structure." [6]. The challenge of intentions is that the state of knowledge

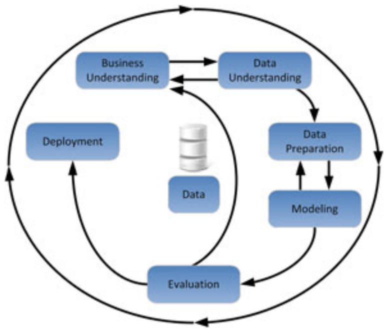

Fig. 1 Dataflow according CRISP-DM industry standard [8]

concerning the intention of a person is uncertain and that makes it complicated to derivate a decision. Manning et al. [7] gives an comprehensive introduction to IR. For our work Fig. 1 describes how the system has to work for our approach.

However, IR is the way to process the information, but for that we need a representation of the robot's capabilities, the robot's tasks, the intentions and their relationships. Therefore, the method must enable the possibilities to discover and exploit domain specific knowledge. The concept is based upon ontologies and planning algorithms from artificial intelligence. According to (Gruber [9]) an ontology is an explicit specification of a conceptualization [9]. The used ontologies are expressed in OWL, which is the ontology language recommended by the W3C [10]. The matching between capabilities and intuition is related to the semantics of concepts. These concepts are implemented in diverse projects, but the most important project for our implementation is the Cluster of Excellence "Integrative production technologies for high wage countries". During the project a framework was developed that facilitates the semantic integration and analysis of measurement and enterprise data according to real-time requirements. Semantic technologies are used to encode the meaning of the data from the application code. Herewith the data is automatically annotated using terms and concepts taken from the application domain. Furthermore, a semantic integration and transformation process is facilitated. Thus subsequent integration and, most importantly, analysis processes can take advantage of these terms and concepts using specialized analysis algorithms [11–13].

2.2 *Behavior and Intention*

Behavior and intention are psychological topics that must be taken into account to develop an information model that should enable a robotic system to explicit its intention and be able to derivate the intention of a human being out of its behavior. There are a lot of empiric studies concerning behavior and intention. These studies will be the base for the connection between human behavior and human intentions that are represented in the ontology.

Our assumption is that the human-machine interaction will be purposeful, so that we will ignore unplanned behavior and focus on the following theories. The theory of reasoned action (TRA) [14] and the theory of planned behavior (TPB) [15] are the psychological background for the derivation of the intention to reach a certain goal through the behavior. The psychological studies will also help to predict the behavior. The aim of study [16] is to show "that discovery of the role of intentions depends on the statistical power of test procedures, the reliability of measures of intentions, and the nature of the processes intervening between intentions and behavior." (Bagozzi et al. [16]) and the study by Budden and Sagarin (2007) "Many individuals intend to exercise, but fail to link this intention to behavior. The present study examined the impact of an implementation intention intervention (i.e., instructions to form specific if–then plans) on an exercise intention–behavior relationship among working adults who varied in reported occupational stress levels. Results indicated that implementation intentions backfired, such that participants who did not form an implementation intention exercised significantly more than participants who formed an implementation intention." That focus on the implementation of intentions and the influence of boundary conditions like stress [17]. We want to sort out side effects of human behavior that are related to "bad habits" of the interacting humans. We presuppose a mindfulness when it comes to the relation between behavior and intention like it is examined by Chatzisarantis and Hagger [18]: "These findings suggest that mindfulness is a useful construct that helps understand the intention-behavior relationship within the theory of planned behavior." [18].

2.3 Robotics

The information model is the "brain" of the interaction system that is able to derivate intentions out of the behavior based on the before mentioned psychological knowledge. The next step is to take a look at the behavior of the robot. A human coworker should be able to derive the objective of each operation from the robot‘s actions. Therefore, the robot must act as the human expected it. The movements of an industrial robot are very efficient but not always understandable for the human user. To achieve that the robot moves exactly as the user expected it we have to add kinematic constraints to the information model. The research of Dragan et al. takes a look at misleading robot motion. The robot should hide its intention [19]. The results of this study are very interesting for the definition of the bandwidth of acceptable movements out of the human perspective that are implemented in the information model. In another work of the authors one predicts an initial state due to previous experiences and use them for trajectory optimization [20]. The mapping from machine movements to human movements and vice versa is a basal function of the information model with the goal to enable the human to predict what the robot will do and vice versa [21]. The publications [22–24] refer to a planning algorithm that is used to self-optimize the problem-solving strategy of a robotic system. This algorithm will be used to adopt the robot system to a known situation that is directly derived from an unknown situation. Vieritz et al. [25] shows a human centered design approach for the development of automation systems that is used in this work.

3 Method

3.1 System Design

In the system design the robot configuration as well as the security evaluation of robots and applications will be considered. Methods must be developed for safe human-machine interaction and the way of description of the interaction has to be determined. Based on these descriptions and configurations a secure robot configuration must be derived in order to detect reliable risks and unwanted interactions properly.

3.2 Gather

For a safe human-robot interaction it is necessary that the machine can detect the human and the environment. The robot's detection of its environment is done by sensors and their data recording. Sensor values must be mutually correlated to provide comprehensive and verified information. The detection should be as good and efficient as possible, even under unfavorable conditions (for example lighting conditions, surfaces, fouling), to guarantee the safety of the human. Since a few years, optical sensor systems are also available to help monitoring the common working space of humans and robots in order to avoid collisions. However, this working area surveillance from a fixed perspective is the origin of general limitations such as masking the visible area. It can't be excluded that the worker is hidden behind a sensor. The robot can solve this fundamental problem by detecting obstacles in its range of motion by itself, so the "source of danger" is fitted with sensor technology. In this case spatial resolution and real-time capability of the sensor are special challenges for technical integration.

3.3 Recognition and Evaluation

Based on the sensor data a detection and an evaluation of the environment in which the robot and the human are is done. For this purpose, we need a reliable distinction of humans from other objects. Starting from the recognition of a scenario each situation must be evaluated with regard to whether this is an intentional interaction or a risk to humans. It must be sure that the algorithms that are used recognize and rate situations correctly. This project will implement a model that automatically transmits a movement shown by a person to an arm and a hand of an industrial robot. In the collaboration with robots, the people's safety is most important. Safety aspects of the generated robot programs are based on the individual workspace of various robot kinematics, the configuration of the robot motion commands avoid singularities and discontinuities. The human movements are divided into movement patterns. Motion analysis calculates all parameters of the robot commands in order to prevent dangerous situations. The robot learns movements and can apply these to any object. The movements are not copied but adapted to each task. The trajectory is adjusted in relation to the object location. The general object manipulation requires haptic understanding in order to quickly create a trajectory and handling movements for complex components in the required location.

3.4 Respond

A reaction of the robot is the response to a certain situation. How the robot reacts depends on the situation evaluation result. The reaction always has to happen in a way that no danger to humans arises. The robot also has to react to misbehavior of the people so that there is no danger to him, or at least threads should be minimized. The reaction is related to the actuators which have to make sure that the control signals are error-free, i.e., when the expectations have been met, to start the reaction. During the movement, the path planning determines which reaction takes place in order to avoid collisions. In this case, however, the ability of the actuators must be known and considered.

Unlike robotic systems in production the direct interaction between humans and robots is an essential part when it comes to service robots. Especially while using mobile service robots, for example assistive robots in industrial or domestic environment, people must be safe while moving in their vicinity. Wherein the insertion of separated safety guard-devices is generally not possible. Mobile service robots with manipulators must frequent people's environments safely. The robot's workspace must be monitored three-dimensionally and its movements must be adapted to existing static and dynamic obstacles. The information model provides a method to generate an obstacle model out of the three-dimensional sensor data. This model is used for the trajectory planning of the manipulator and the mobile platform of the robot. The model includes all degrees of freedom of the robot system that includes the platform and the manipulator in order to enable simultaneous movements of manipulator and platform and avoid collision.

4 Model

The architecture of the framework is based upon a service-oriented approach. In the framework, sensor data is propagated by applying the service bus pattern. In addition, application information is distributed along this bus. Therefore a resource-oriented approach has been implemented following the enterprise service bus pattern. Figure 1 illustrates the architectural basics of the framework and its main components [13] (Fig. 2).

Sensor nodes are connected via sensor node gateways. The linking of measurement systems is realized via measurement system gateways supporting access via application programming interfaces (API), databases and screen scraping. Further, data can either be pushed by the measurement system or pulled by the gateway via scheduling. Data is semantically annotated by annotation services and routed to further services, either by an event-based publish/subscribe mechanism or by triggering configurable processes. The framework implements a semantically enabled data consolidation for further analysis, simulation or reporting purposes. The query processor realizes the access to the underlying data storage. Required data is automatically provided by using the adaptive information integration technique mentioned before [13].

The semantic annotated data will be stored as information in the system ontology. The ontology holds information about the concrete transformations, features and applications used in the context of a specific domain. Besides, information about the domain specific data schema is stored [12].

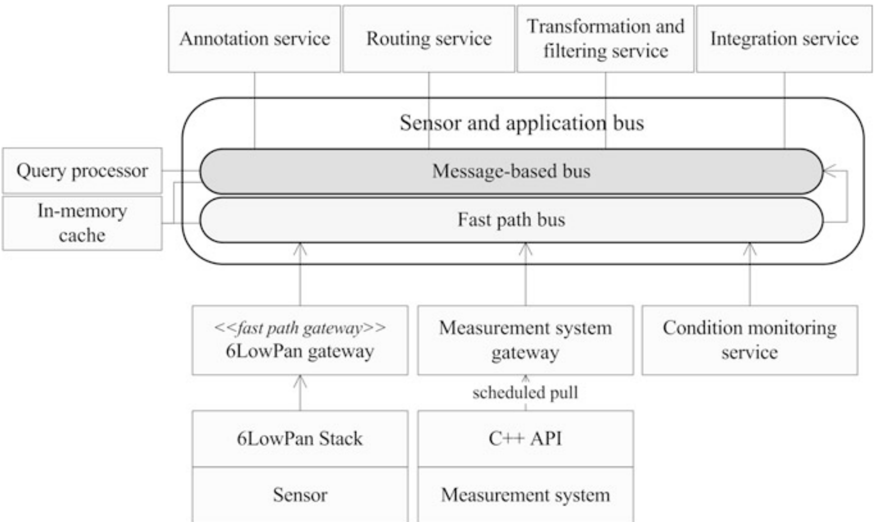

Fig. 2 Framework architecture by Tobias Meisen et al. [13]

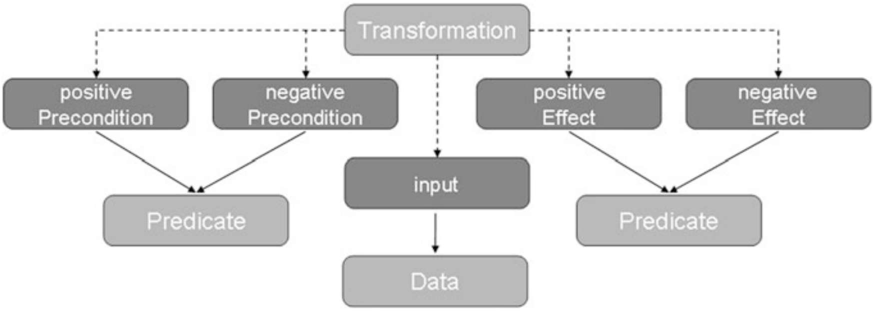

Fig. 3 Fragment of framework ontology—transformation concept by Tobias Meisen et al. [12]

The ontology has to specialize the concepts of the framework ontology in order to specify the conceptualization of the domain. These main concepts are data, feature, application and transformation, which are introduced shortly.

The concept data is the generalization of all data concepts used in the domain. More precisely, each concept in the domain ontology used to describe the data schema of the domain has to be a specialization of the concept data.

To define domain specific features, the concept feature is used. A specialization of the concept feature is a listing of the requirements that have to be satisfied by a set of data. If these requirements are satisfied, the feature is fulfilled by the given data.

For each definition of applications and their requirements, instances of the concept application have to be expressed in the domain ontology. Besides the requirements that are expressed using features, an instance of the concept application can have additional object properties to express domain specific information of an application. Similar to an application, a transformation has requirements that have to be satisfied. Otherwise, the transformation cannot be used. Therefore, each instance of the concept transformation has to outline the requirements by defining instances of feature concepts. In addition, a transformation changes the features of the data. This is realized by expressing the effects of the transformation in the ontology. The concept transformation and its main relations are depicted in Fig. 3 [12].

5 Conclusion

In this paper an approach of an information model as an integrative concept for safe human-robot interaction reconsidering nonverbal communicated intentions was given. The information model is shown in Sect. 4 and is based on the previous works summarized in Sect. 2. Section 3 depicts the steps that must be done to build up a robotic system that fills the information model with sensor data, so the system can derivate intention related information from the data based on the relations that are represented in the ontology. The next step will be to implement the information model on a robotic system in an industrialized environment.

The aim is to lay the foundations for assistance systems that allow a safe and efficient interaction between people and robots in the same workspace. The information model can increase efficiency. In addition to production the application of robotics in other areas such as medicine, disassembly, workshop and household will be more and more suitable. Sustainability plays an increasingly important role in the disposal of the products. The products are as inexpensive as possible to dismantle. In order to carry out the dismantling economically in high-wage countries safe human-machine interaction is also necessary in order to use the strengths of humans and robots optimally. In this example, the combination of the human flexibility in recognizing unions and the human experience concerning the order of the actions combined with the power of a robot while holding heavy components complements the skills optimally. Such safely designed interactions will also contribute to the acceptance of assistance systems. The demographic change leads to an ever-greater retirement age. Secure assistance systems can especially help older but very experienced people.

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Augmented Reality for the Support of Space Exploration Missions and On-Ground/On-Orbit Operations

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Abstract The work presented in this paper is the result of two different but connected studies related to the adoption of Augmented Reality (AR) technologies in the field of space exploration and operations scenarios. During the first three years study an innovative Graphical User Interface (GUI) utilizing Augmented Reality technologies (GUI-AR) have been developed for space exploration scenarios and relevant interaction methods and metaphors have been conceived. The second study, named EdcAR, commissioned by ESA and currently ongoing, has always to do with AR technologies but this time in two different operational scenarios. In the first scenario the AR system is used to support on-ground operators during telecommunications satellites integration and testing activities while the second scenario deals with on-board training and the ground control remote support to the crew during malfunction and recovery activities onboard the ISS. The final AR system demonstrator will be delivered to ESA on October 2016.

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Keywords Human factors · Interaction design · Graphical user interface (GUI) · Augmented reality (AR) · Space exploration · Space operations

1 Introduction

The work presented in this paper falls under the Human-Machine Interface (HMI) domain and is about the development of a wearable Graphic User Interface (GUI) and Operational Support System (OSS) using Augmented Reality (AR) technologies.

Over last years Augmented Reality technologies are powerfully getting more and more into the human spaceflight applications area, providing support to operators during tasks performance and taking the place of the more traditional Graphic User Interfaces devices shown on 2D displays.

The study described here focuses mainly on aspects of interaction between the user and the technology rather than on the system technological features or implementation methods.

The first study has been initiated within the STEPS "Sistemi e Tecnologie per l'EsPlorazione Spaziale" research project funded by Piedmont region with the participation of the "Fondo Europeo di Sviluppo Regionale" and led by Thales Alenia Space Italia.

The STEPS project was aimed at studying existing technologies and analyzing new solutions for space exploration missions that, with a highly growing trend, involve the presence of both humans and robotic systems. The STEPS Human-Machine Interface (HMI) work package had two different but conjunct aims. The first aim was to develop HMI devices permitting, among other things, the local/remote control of rovers equipped with robotic arm. The second aim was to enhance the user capability to control the system through the provision of tools designed to augment the decisional and planning capability of the operator and increase as well system autonomy in order to allow humans a greater supervision instead of execution role. This HMI system was originally conceived as human-robot collaboration in austere and tough environments where the usage of common control systems, as keyboard, mouse, joystick/joypad, and optic systems would have been impractical if not unbearable. In fact astronaut suits and gloves in Extra Vehicular Activity (EVA) typically hinder user movements and decrease fingers precision; moreover we'd like the astronaut to be able to move freely during his/her task without carrying around any external control/monitoring device.

The result of the study was a modular HMI system in which ten different autonomous subsystems have been developed and integrated into a final demonstrator covering monitoring, control and decisional support aspects related to the given scenario.

Recently the European Space Agency (ESA) issued an ITT for the development of an Augmented Reality system to be used in the field of space AIT/AIV and Operations applications. The winning project, named EdcAR, is currently under development and is conducted by Thales Alenia Space Italia and France, the Finnish research Centre VTT and the Greek research Institute ICCS.

Two use cases have been utilized for the definition of the user requirements, the first for on-ground operations and the second for the International Space Station (ISS) onboard training and ground control remote support to the crew.

The on-ground scenario deals with the AR support to operators during the mounting of a thousand coax cables on telecommunication satellites payload's panels while the on-orbit scenario deals with the provision of AR onboard training lesson and also with the support the space control centre personnel has to provide in real time to the crew during the performance of malfunction and recovery activities onboard the ISS.

2 HMI for Human Planetary Exploration Scenario

The user scenario considered for the development of the HMI system was a human planetary exploration scenario in which three astronauts are collaborating with each other and are supported by robotic systems, in particular by a pressurized rover and by a small rover having a robotic arm mounted on. Several crew EVA tasks have been foreseen to be accomplished on the planet surface as for example the assembly/repair of some mechanical and/or electrical devices, perform tests/experiments on materials/resources, carriage of objects/materials on the planet surface, and so on. The following picture represents the storyboard realized for the description of the human planetary exploration mission use case (Fig. 1).

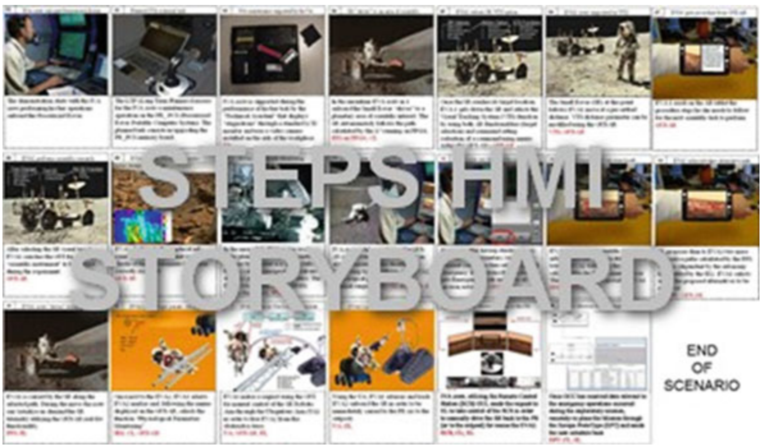


Fig. 1 Storyboard for HMI planetary exploration scenario

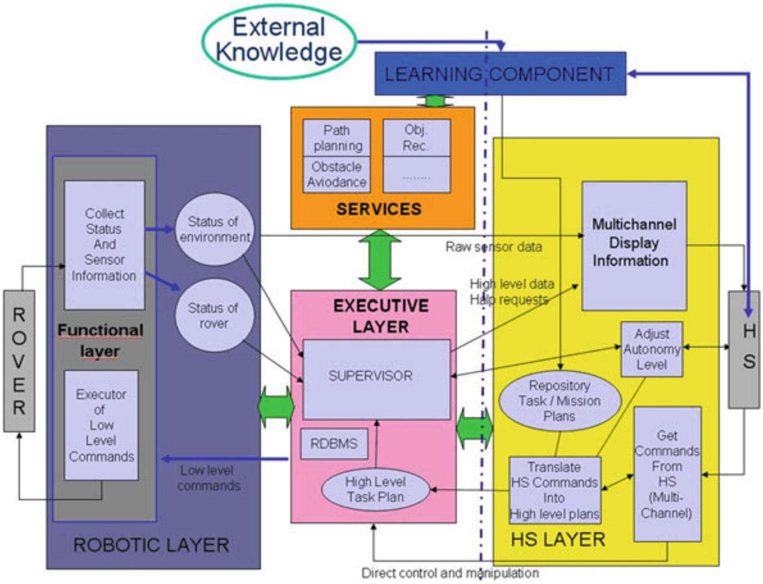


Fig. 2 HMI system general architecture

After having identified User and System requirements associated to the mentioned scenario, we developed a modular HMI system architecture as shown in the following graphic (Fig. 2).

In this architecture the "HS (Human Supervisor) Layer" provides the crew with the robotic system monitoring and control functions; the "Executive Layer" establishes the sequence of actions to perform for reaching a set of goals according to the current system autonomy level; the "Services" block contains various and specific applications (e.g. path planning, visual tracker,…); the "Learning Component" exploits system external knowledge for supporting the user during the execution of procedural tasks; the "Robotic Layer" represents the physical robotic system itself and all layers are connected to each other by means of a common "Communication Layer".

Here below the list and a brief description of the ten subsystems developed during the study.

1. *Augmented Reality—Graphical User Interface* (*GUI-AR*): all graphical information is provided to the user through the exploitation of Augmented Reality technologies.
2. *Communication Layer* (*CL*): communication among the different HMI subsystems is managed by a common actor facilitating integration between modules.

3. *Executive Layer* (*EL)*: coordination and decisional aspects of the overall HMI scenario are managed by this focal actor adopting the “sliding autonomy” approach.
4. *Enhanced Path Planner Service* (*PPS*): preferences based on several settable parameters can be applied by the user for the calculation of the path.
5. *Europa ProtoType* (*EPT*): discrepancies between the planned and the real operative scenario will automatically drive to a tasks scheduling re-planning.
6. *Planner Service on FPGA* (*PS*): FPGA technology has been tested for the execution of A* algorithm during a nominal path planning request.
7. *Remote Control Station* (*RCS*): the rover mobility can be commanded and controlled by remote operators through this control station.
8. *Technical Assistant* (*TA*): the operator is aided during the execution of a technical task through the automatic recognition of performed steps and suggestion of the next ones.
9. *Ubiquitous Arm* (*UA*): the positioning and the functions of a robotic arm and its end effectors are intuitively controlled by simple movements of the user arm and fingers.
10. *Visual Tracking System* (*VTS*): a supporting rover automatically follows at a chosen distance the user during his/her walking on the planet.

Besides User Review sessions performed for each of the different subsystems in order to evaluate from the user point of view the functionality and the usability of the subsystems under development, the integration of the resulting overall HMI structure has been then tested and evaluated throughout a joint demonstration leaded by the previously defined user scenario. The assessment results were good with regard to both users and usability requirements defined at the beginning of the study.

Let’s have now a closer look at the Multimodal Display Information subsystem (named GUI-AR).

2.1 The Augmented Reality GUI (GUI-AR) Subsystem

In order to allow the astronaut to monitor and control the mission supporting systems at any time and contemporaneously move freely during his/her task without carrying around any external device, an immersive Graphical User Interface (GUI) unit that uses Augmented Reality (AR) functionalities has been designed and a prototype has been implemented as system demonstrator. Information to be presented to the astronaut is expected to be directly projected on the visor of the EVA helmet so to augment crew knowledge of the real environment with the addition of relevant textual and/or graphic data. The GUI-AR concept and related demonstrator has been developed and integrated with the overall HMI system so to provide the user with a complete ubiquitous and wearable command and control device. Different GUI elements and functions have been developed in this prototype so to demonstrate how the user can for instance manage with the GUI-AR system the execution of scientific experiments and visualize relevant results; receive information about mission and operations status; visualize 3D maps; monitor rover and environmental data; …

The GUI-AR Demonstrator. The immersive GUI-AR demonstrator has been composed by an acquisition camera device grabbing images at 30 Frame per Second (FPS) at 640 × 480 pixel resolution. Marker based tracking technology has been then used to extract objects position and orientation (Fig. 3).

Interaction with the overlaid data is achieved with a wearable finger mouse while the head movements, detected thanks to a 6 Degree of Freedom (DoF) gyros device, has been used to hide/show GUI elements out of the user Field of View (FOV). The display device is a Head Mounted Display (HMD) with 1024 × 768 pixel resolution and can be worn also with eyeglasses. Even if low cost equipment has been used, the system is ready for high-end See-Through devices too (Fig. 4).

In order to maintain the EVA's FOV as clear as possible different strategies have been studied for presenting the information. Most of the functionalities can be recalled by the user through the head movement; raising the head will show up an actions menu, while looking right will provide contextual data (Fig. 5).

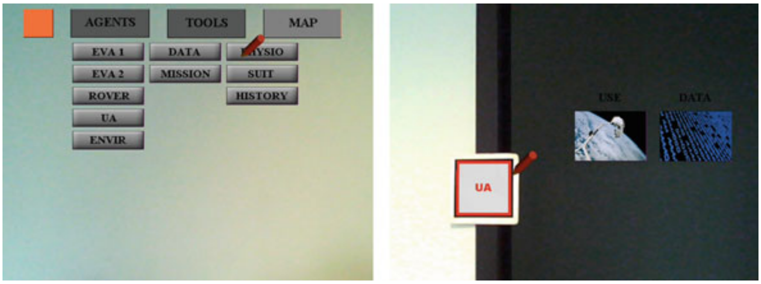
At any time the EVA can look at its wrist to know agents position on the map or read incoming messages. Other information, strictly connected with Agents, is only available when the EVA looks at them.

Data are then presented to the EVA crew in three different forms:

- Data outside EVA's FOV can be recalled only by head movements

Fig. 3 Marker based AR objects position and orientation

Fig. 4 Head mounted display and 6DoF gyros



a) b)

Fig. 5 Data (**a**) recalled with the head movement, (**b**) overlaid near the tracked object

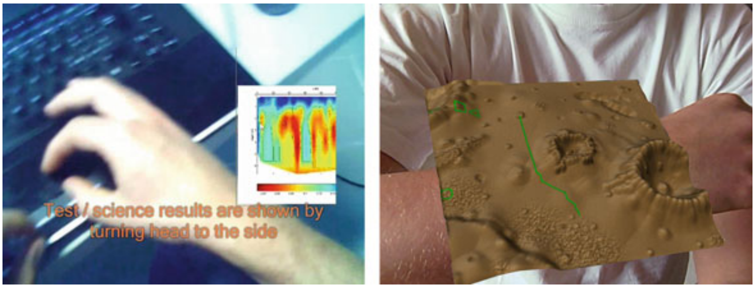


Fig. 6 Head movement recall and 3D map on wrist

- Two dimensional data overlaid nearby the tracked object
- Textual and graphical information aligned to user wrist (Fig. 6).

3 From Planetary Exploration Towards On-Ground and On-Orbit User Scenario

The system has been designed keeping in mind the real-time constraints of an immersive GUI. In order to keep the usability of the GUI the system provides frame rates near to 30 FPS and interaction response times around 40 ms. Tracking technology resulted to be quite stable considering the low camera input quality and the reduced size of markers. There is nevertheless to point out the fact that the demonstrator realized during this project has the only aim to demonstrate the concept feasibility and test the relevant functions. For an EVA space exploration scenario the hardware to be utilized needs of course to be customized to the crew EVA suit.

A consideration came up while developing the system: the same approach utilized for the human planetary exploration scenario may also be exploited for terrestrial and/or on orbit space applications. A concrete opportunity to verify the assumption occurred recently with an ESA ITT concerning the development of an Augmented Reality system to be used for AIT/AIV and space operations activities. TAS Italia together with TAS France, the Finnish VTT and the Greek ICCS have submitted a proposal that has been selected by ESA at the end of 2014.

The study named 'Engineering data in cross platform AR' (EdcAR) is currently under development and integrates the AR visualization system with an Engineering Data Layer and an AR Authoring Tool. The Engineering Data Layer shall be able to abstract the different engineering data sources used by the Space Applications and provided in a heterogeneous and domain-specific format so to be 'transparently' utilized as data input for the AR system while the AR Authoring Tool is in charge of developing a user friendly workbench intended to map the engineering data to the AR visualization layer.

Two are the use cases selected to be implemented for the EdcAR system demonstrator, one for an on-ground integration scenario and one for an on-orbit training and malfunction-recovery operations scenario.

3.1 The EdcAR Project Use Cases

The first use case we're developing is in the context of Assembly Integration and Testing (AIT) activity for telecommunication satellites. During this task a thousand coax cables have to be mounted on the payload's panels during the assembly phase. The installation of a single coax lasts approximately one hour and includes the preparation of the installation, the assembly and the documentary aspects related to traceability.

During current activity, operators have to move back and forth frequently from the payload to a TV set that displays instructions on the task to perform. In the case they have to operate inside the payload, as shown in the Fig. 7, these transfers can be time-consuming and difficult. With EdcAR system will be able to get all information needed to perform his/her task just in time and right in place.

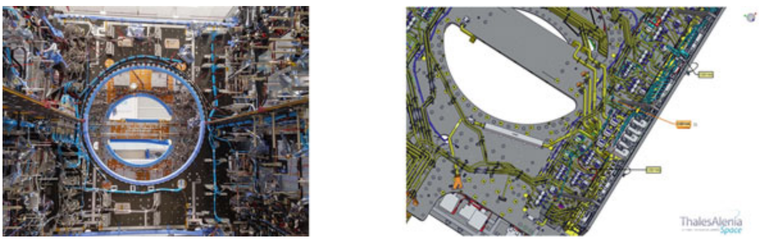


Fig. 7 Coax cables assembly on payload's panels

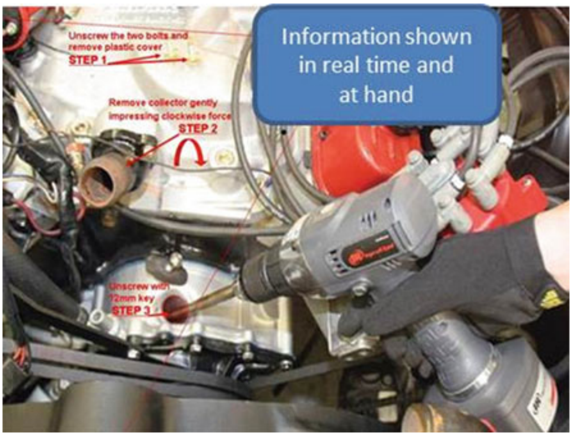


Fig. 8 AR showing procedural steps during on-board training as well as on-ground experts hints during remote support of ISS crew during malfunction operations

The second use case selected is about space Ground Control Centres support to the crew on-board the International Space Station (ISS) during their malfunction and repair activity as well as the delivery of on-board training.

Systems experts on ground currently support the crew activities on board the ISS utilizing voice loops and monitoring the video images taken by a camera in use on the space module. They indicate equipment or parts to be operated and explain the type of actions the crew has to perform for a specific operation by using voice communication and by uploading to the ISS pictures or graphics or textual information related to the task. AR functionalities under development in the EdcAR project will greatly improve ground/on-orbit communication and collaboration thanks to the fact that ground expert will be able to indicate devices or parts to be operated by pointing arrows or highlighting areas of interest and will be able to describe the operation to be performed by showing graphical information that will aid the crew, step by step, during his/her duty.

All this without any encumbrance for the crew, except for wearing a pair of AR glasses. Information will be displayed directly superimposed to the hardware and additional graphic or textual info will be shown in real time and at hand (Fig. 8)

We are confident that these new AR application scenarios have the potential to be adopted in the context of space domain already in the near future.

The final AR system demonstrator will be delivered to ESA on October 2016.

4 Conclusions

Ten different HMI concepts and relevant subsystems prototypes have been developed during the STEPS project led by TAS-I under the human planetary exploration missions common user scenario. Each subsystem, evaluated through User Review sessions, has been implemented following the user centered design approach.

A final HMI system demonstrator has been delivered at the end of the project integrating the ten subsystem into an overall HMI architecture aimed at supporting the users—the IVA and EVA crew—during their activities within the given planetary exploration user scenario. The HMI demonstrator has been tested and evaluated during and at the end of the study throughout joint demonstrations leaded by the previously defined user scenario, obtaining good results with regard to both users and usability requirements defined at the beginning of the project.

The GUI-AR subsystem in particular had the aim of providing the user with a complete ubiquitous and wearable command and control device. Different GUI elements and functions have been developed for this subsystem prototype utilizing AR technologies so to demonstrate how the user can manage, using the newly developed GUI-AR system, for instance the execution of scientific experiments and visualize relevant results, receive information about mission and operations status, manage 3D maps, monitor rover and environmental data, manage resources settings… all this utilizing intuitive control interaction methods and avoiding encumbrances that common user-system interaction devices usually have.

The positive results obtained during user evaluation sessions of this system have driven to the consideration that similar approach utilized for the GUI-AR in planetary exploration mission scenario could also be applied to other space activities such as crew training, AIT/AIV, malfunction and recovery tasks, on-orbit scenarios….

Acknowledgments This consideration have had the chance to be verified with the ongoing development of EdcAR project funded by ESA under contract AO/1-8100/14/NL/MH "Augmented Reality for AIT, AIV and Operations".

Appendix: Acronyms

AIT	Assembly Integration and Testing
AIV	Assembly Integration and Verification
AR	Augmented Reality
DoF	Degree of Freedom
EVA	Extra Vehicular Activity
FOV	Field Of View
FPS	Frames Per Second
GUI	Graphical User Interface
HMD	Head Mounted Display
HMI	Human Machine Interface
ICCS	Institute of Communications and Computer Systems
ISS	International Space Station
IVA	Intra Vehicular Activity
TAS-F	Thales Alenia Space France
TAS-I	Thales Alenia Space Italia

UA	Ubiquitous Arm
VR	Virtual Reality
VTT	Technical Research Centre of Finland

Part III
Human-Machine Interactions and Emergency Management Applications

Teaching Usability to Industrial Engineering Students

Isabel L. Nunes

Abstract Industrial Engineers determine a better way to do things and work in varied professional areas, which includes Ergonomics. Usability is a key topic in Ergonomics, related with the effectiveness, efficiency and satisfaction of human-system interactions. Usability impacts companies' productivity and economic success since, e.g. the occurrence of errors can lead to incidents and/or accidents; to do unnecessary operations increases the load and/or the gestures repetition, with potential for the development of work related musculoskeletal disorders; and users' dissatisfaction can become a risk factor for the development of stress, with all the consequences associated with it. In this context the thematic of Usability was initiated in the Master program of Industrial Engineering. A learn-by-doing approach was introduced in order to assist students' reach the defined learning outcomes. The paper offers some insights on the benefits of the adopted methodology, analyzes results of the last four years and discusses some observed trends.

Keywords Learn-by-doing · Human-system interaction · Learning outcomes · Student-centered learning

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1 Introduction

Industrial Engineering (IE) is the engineering branch that deals with the design, improvement, installation, management and control of complex processes or systems (involving people, materials, information, equipment and energy). The Industrial Engineers work to eliminate waste that does not add value (e.g., time, money, materials, labor, machine time, energy), i.e. they engineer processes and systems to improve quality and productivity. In a simply way IE determine a better way to do things and work in a wide array of professional areas, including management, manufacturing, logistics, health systems, retail, service and ergonomics [1].

Taking in consideration the aforementioned 'job description' of Industrial Engineers, and recognizing the growing importance of information systems to EI, the topic of Usability has been considered an important competence for these professionals and included in the educational program of Industrial Engineering, ensuring an adequate set of learning outcomes in this field of Ergonomics to the future practitioners.

The European Qualifications Framework [2] defines 'learning outcomes' as statements of what a student knows, understands and is able to do on completion of a learning process. The learning outcomes are defined in terms of knowledge, skills and competence:

- knowledge—means the outcome of the assimilation of information through learning;
- skills—means the ability to apply knowledge and use know-how to complete tasks and solve problems;
- competence—is described in terms of responsibility and autonomy.

Armed with such competences Industrial Engineers can play an important role in improving the usability of the products or services that companies offer or of the production systems they use, both in small businesses—where they may be the only human capital with knowledge in this domain, and in large companies—integrated into multidisciplinary working groups that combine complementary perspectives, but where still their knowledge can help to achieve better final results [3].

In fact, nowadays technological progress has led to the proliferation of a variety of information systems for all types of applications (industrial, domestic and leisure) that makes human society increasingly exposed and dependent of ever more complex systems. In truth, it is easy to realize that all the vital services that modern societies depend upon (e.g., power and water distribution networks) and trust (e.g., hospitals, security and emergency, transportations, production and supply chains) base their activity on a myriad of complex and interdependent systems.

The most commonly accepted definition for Usability is the one provided in ISO 9241-11 standard: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [4]. As Krug notes, in practical terms Usability ensures that a person of average (or below average) ability and experience can use a product (independently of being a web site, a jet aircraft or a revolving door) for its intended purpose without being deeply frustrated [5].

Usability is also a measure of the ergonomic quality since: (i) effectiveness translates the existence of conditions for users to perform their duties without errors; (ii) efficiency indicates that tasks are performed engaging the minimal amount of resources (e.g., time and number of operations); and (iii) satisfaction reveals the subjective perception that users have regarding the product or system they are using. In the work environment all these dimensions have a direct or indirect impact on workers' health and safety. Usability also impacts companies' productivity and economic success since, depending on the type of system concerned, the occurrence of errors can lead to incidents and/or accidents; performing unnecessary (inefficient) operations increases the load and/or the gestures repetition, with potential for the development or worsening of work related musculoskeletal disorders; and users' dissatisfaction can become a risk factor for the development of stress, with all the consequences associated with it.

The importance of Usability, for society in general, is particularly significant in the current context of fast pace technological progress, where it is expected tasks to become simplified by the introduction of new systems. However, this is not always the case. In fact, because of design problems, it is relatively common to face difficulties in the interaction with new systems. An anecdotal example is the autocorrect functionality introduced in smartphones' SMS writing. Although this feature was meant to be a facilitator, it often leads to "despairing" situations of sending wrong messages due to modifications on the text that one is trying to write. Unfortunately, there are many examples of situations where the problems of human-system interaction have much more serious consequences resulting, for instance, in environmental disasters, aircraft crashes or fatalities in medical practice.

This reality forces a careful consideration of the usability problems, which requires the application of systematic and structured scientific principles in systems interfaces development, sometimes referred to as Usability Engineering. One approach to ensuring a high usability when designing interfaces and interaction is User-Centered Design (UCD), which can be characterized as a phased problem solving cycle (see Fig. 1) where user needs are taken into account during the development and validation of the design solutions [6, 7].

Modern pedagogical methods tend to divert focus from teacher to student looking to respond to the needs of the learner; assuming that student-centered learning does not have a *one size fits all* solution. This new education paradigms, focused on the development of competences, require that schools act as facilitators for student's motivation and engagement, which lead to the design of educational programs that encourage students to take an active role in the learning process, being responsible for planning their own learning process and achieving learning outcomes [9]. Higher Education Institutions that embrace such methodology have to adopt student teaching and assessment methods, which are coherent with this approach, and ensure that students receive timely feedback on their progress, in order to adjust their learning methods.

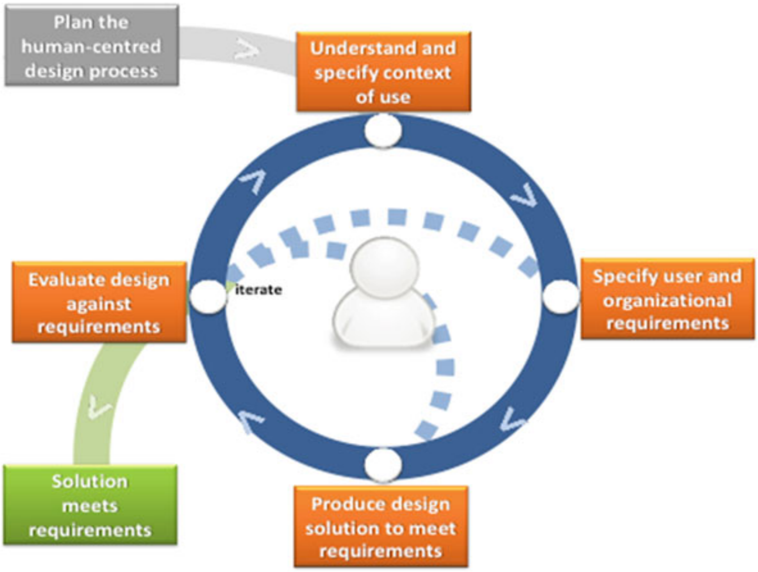

Fig. 1 User-Centered Design cycle (adapted from [8])

This paper discusses the importance of teaching Usability to graduate students of Industrial Engineering, describes the experience of a course offered at a Portuguese Faculty, identifies learning outcomes, refers the merits of the learn-by-doing approach, which was adopted as a method of student-centered learning. If also offers an overview on the results obtained in the last four years of activity and analyzes the growing interest of this course among the student community.

2 Materials and Methods

In order to achieve the learning outcomes defined to the Usability classes the pedagogical methodology chosen was based on the learn-by-doing approach, in which theoretical classes are complemented with practical work done by student teams. The goal of the practical work is to design the interfaces of a digital product requiring a significant amount of human-system interaction. Such practical work begins with each student team engaging in a brainstorming session for developing an idea, which is supposed to exploit a market opportunity by creating a new product or significantly improving an already existing system. The practical work proceeds with the design, prototyping and usability evaluation of the digital product (websites or apps) interfaces and interactions, following the UCD approach. The activity cycle of the practical work (subsequent to the initial brainstorming) is described below and shown in Fig. 2.

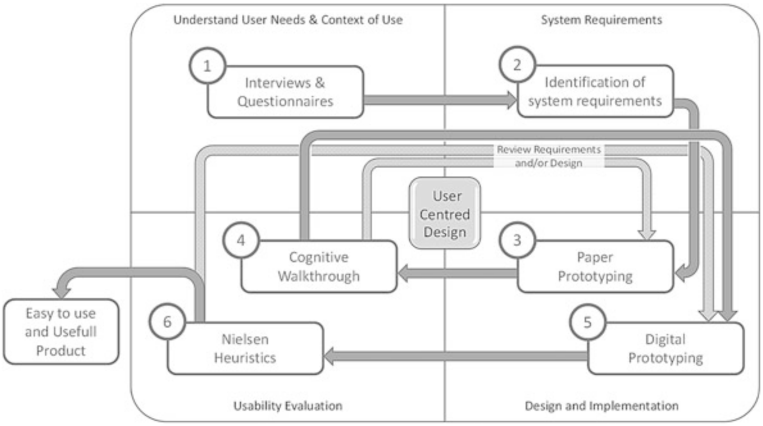

Fig. 2 Graphical representation of the cycle of application of the learn-by-doing paradigm in teaching the User-Centered Design approach to Industrial Engineering and Management students (adapted from [13])

The process of work, according to the UCD approach, begins with the identification of the context of use and of the user needs (step 1 of Fig. 2). The technique used for eliciting detailed information on user, task and environment is the context of use analysis [10]. Students gather information using structured interviews or questionnaires to potential users. The elicited information about users needs is converted into product requirements (step 2), which define the functionalities and interactions that the interfaces must provide.

The work evolves with the creation of a paper prototype (step 3), whose usability is evaluated using the cognitive walkthrough method [11] (step 4). This methodology is based on exploratory learning, where a group of untrained individuals (selected so as to be representative of the universe of users) is asked to perform a set of predefined tasks. The aim is to assess how intuitive the product is (learnability), evaluating the extent to which users can use the product and achieve their objectives without having had any training. These evaluations also serve to assess users' satisfaction. Users' feedback is analyzed and the need for design improvements is established.

The next iteration of the development cycle corresponds to the creation of a digital prototype (step 5) using freeware simulation software (e.g., Balsamic Mockups, Justinmind).

These digital prototypes are subject to usability evaluation by experts (step 6), which adopt a holistic vision, based on Nielsen Heuristics (NH) [12]. This methodology analyzes the compliance of the interfaces against the principles of usability (as defined in NH). The experts (which are role played by students from other teams) assess the digital prototype using a self defined NH-based protocol. These "experts" have to classify the severity of each detected problem in terms of product operation (interaction) impact and must recommend improvement measures. The last iteration corresponds to the solving of the problems identified on the digital prototype, converging to a product that ensures a complete satisfaction of the user needs.

3 Results and Discussion

Over the years students' interaction design interests gradually shifted from websites to apps. The trend in terms of product design typology is presented on Fig. 3.

This evolution is consistent and is closely related to the change of interfaces' technological paradigms, which evolved from interaction environments exclusively based on keyboard and mouse devices and Windows-Icons-Menu-Pointer Graphical User Interfaces (also called WIMP GUI) to other user interface paradigms (e.g., Natural User Interfaces—NUI) and user interaction models (e.g., based on touch or gesture). In fact the types of equipment based on this technology (e.g., smartphones, tablets) are becoming increasingly used in professional and educational applications, leading to a practice that has been called BYOD (bring your own device); in 2015, the number of tablets sold exceeded the number of traditional computers (desktop and mobile); and the forecast for 2016 is that the number of apps for mobile devices will exceed the number of Internet domain names [14].

The domains of application of the projects developed are quite varied, e.g. apps for selling clothes, traditional food or cookies, for managing house bills or to reserve a restaurant. Regarding websites the projects were also varied, e.g. aiming at car sharing or the music sharing among friends.

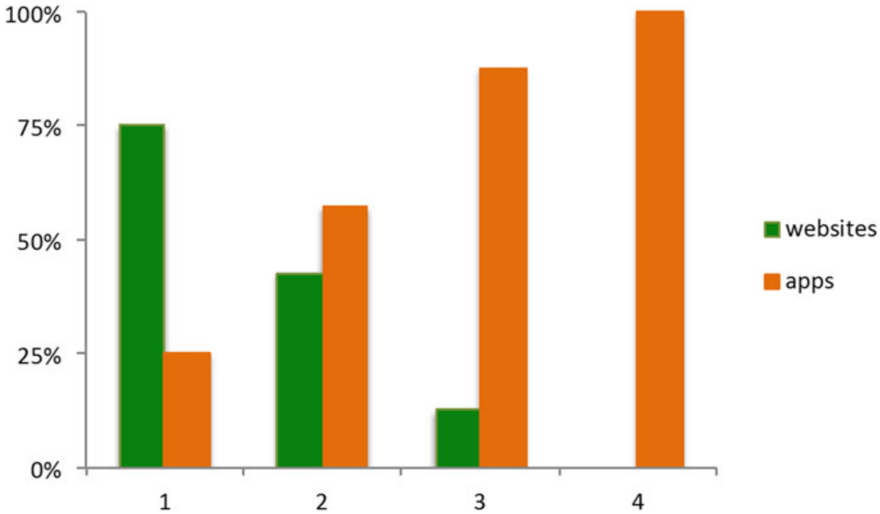

Fig. 3 Trend of the students' product design typology

In summary, introducing Usability in the educational program of Industrial Engineering and the adoption of the learn-by-doing model were a success. The course, being optional, has consistently great demand from students, who turn out to be his great ambassadors regarding the usefulness of acquiring knowledge, skills and competences in this domain.

4 Conclusions

The inclusion of Usability thematic in the curriculum of Industrial Engineering course was intended to offer students an opportunity to acquire skills in the field of Ergonomics, notably through the knowledge of structured scientific principles that enable them to be, on the one hand, agents that promote Usability principles, and, on the other hand, valuable skilled assets that can be engaged in design processes that define the human-system interactions. The course goals include developing a practical project, where students have to establish user needs to solve a problem and have to design interactive interfaces, implemented in digital prototypes, which allow the analysis and validation of the interactions' usability. The outcomes and adherence of students to this course along the last years confirm the merits of the learn-by-doing approach. In fact, this is an adequate methodology to help students achieve the established learning outcomes, which included the elicitation of user needs, conduct usability evaluations, exploit a digital prototyping tool. This methodology is also in accordance with the conclusions presented on [9], which state that an approach based on student-centered learning, where students are involved in active learning and active participation, can encourage deeper learning. Such approach provides (1) higher knowledge retention rate than traditional forms of learning; and (2) more learning motivation, because the challenges set to students require original thought and increase interest in the subject-matter.

Of note are also other consequences of the teaching of this subject, namely the development of various Master's degree dissertation projects under the topic of Usability whose context of application were real work environments. This last aspect is, in itself, also quite relevant, since it is revealing that companies are beginning to wake up to the importance of the thematic. Furthermore, several EI course alumni became employed in the software industry, as responsible for ensuring the Usability of their products.

Finally, it is worth emphasizing the role that Universities should have in the effort of qualifying professionals in areas relevant to the Society, including in matters relating to the quality of human-system interactions and their impacts on Occupational Health and Safety. These are areas where Ergonomics, in general, and Usability, in particular, have a prominent place.

With the implementation of what is designated as the Bologna process, in the European Higher Education system, the teaching-learning paradigm has evolved, from a traditional education model, based on the transmission of knowledge to students, to a student-centered learning model, by which students retain more of the information they learn where there is an aspect of active learning and active participation.

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Comparing the Effectiveness and Accuracy of New Usability Heuristics

Freddy Paz, Freddy Asrael Paz and José Antonio Pow-Sang

Abstract Nielsen's usability heuristics are the most recognized assessment tool to conduct heuristic evaluations. However, in a previous study we demonstrated these principles fail to cover all aspects of usability in the emerging categories of software products. The current generation of applications is embedded of special features that are not considered by the conventional principles. For this reason, we have developed a new set of usability heuristics that provide accurate results when are used to evaluate transactional Web applications. In this paper, we present a comparative study, in which the effectiveness of our new proposal and the Nielsen's approach are contrasted. For this purpose, two groups of students were trained in a different set of principles. Subsequently, they were requested to conduct a heuristic evaluation using the approach that was assigned. Then, the results were compared. The analysis establishes that our new proposal covers more features, is more understandable and is perceived as easy to use. Although the promising results, some improvements and more experiments are required in other scenarios.

Keywords Human computer-interaction · Heuristic evaluation · Usability heuristics · Comparative study · Experimental case study

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1 Introduction

Usability is considered one of the most important factors in the development of software products. This quality attribute establishes the degree in which end users of a specific application believe that using a particular graphical interface would be free of effort. Nowadays, usability is a necessary condition for the success of any product, especially in the context of Software Engineering. Many companies have failed in developing applications by not considering usability guidelines. The lack of a user-centered approach has led to the demise of numerous software products, because of their complexity, difficulty to use, unclearness or hardness to understand.

Given the current importance of usability in software products, several evaluation methods had emerged as a result. These techniques were developed to determine if a graphical user interface meets appropriate levels of usability. One of the best known and widely used techniques for this purpose in HCI is the heuristic evaluation. This usability inspection method involves the participation of three to five specialists who judge whether each dialogue element follows established principles called "heuristics" [1]. According to this method, evaluators must use a list of heuristics to identify usability issues of the user interface design that need to be solved. The ten usability heuristics proposed by Nielsen [2], are considered as the most recognized assessment tool to conduct a heuristic evaluation. However, these principles provide inaccurate results when they are used to evaluate non-traditional software applications [3].

Nowadays, there are new categories of systems such as mobile-based applications, videogames, augmented reality applications and virtual worlds. This new generation of products is embedded of special features that were not considered during the development of the conventional principles [4]. Nielsen's approach fails to cover all usability aspects that are currently present in the new emerging types of software products [5]. The transactional Web applications are not the exception, and for this reason, we have previously developed fifteen new specialized heuristics that are capable of providing more accurate results in this domain [6].

This paper describes a validation process of the new heuristics in an academic environment. The intention of this work is to provide specialists with a tool which can be used to evaluate effectively the usability of transactional Web applications. For this purpose, we conducted a comparative study, in which the results of both proposals, the new heuristics and the traditional Nielsen's approach, are compared.

2 Usability and Heuristic Evaluation

Usability is a quality attribute that extends its concept not only to software products but also to electronic devices. The ISO 9241 standard provides a broad definition that can be applied to any technological interface: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [7]. Similarly in the context of Software Engineering (SE), the ISO 9126-1 standard provides another definition of usability: "the capability of a software product to be understood, learned and liked by the user when it is used under specified conditions" [8]. Although these concepts are oriented to different types of products such as hardware and software, both emphasize the design of an intuitive interface that allows users to achieve their purposes easily. User satisfaction is usually the result of a successful interaction. This positive user experience (UX) can only be achieved by employing user-centered design techniques and usability evaluation methods during all phases of the development process.

The relevance of usability has led to the emergence of several techniques that allow specialists to evaluate this quality attribute in software products. These usability evaluation methods are defined as "procedures composed of well-defined activities to collect data related to the interaction between the end user and a software product, in order to determine how the particular properties of this application contribute to achieving specific goals [9]." According to Holzinger [10], these methods can be classified into two groups: inspection methods (which involve the participation of usability specialists), and test methods (which involve the participation of end users).

The purpose of the usability evaluation methods is to identify aspects in the interface design that can negatively affect the usability of a software system. These issues can be directly identified by specialists, or by observing the interactions between the software and the end users. A test method can be always supplemented with interviews in which users are asked about their opinion on the interface [11].

Heuristic evaluation is an inspection method that was developed by Nielsen [12]. This technique involves the participation of a small group of evaluators who examine all graphical user interfaces (GUIs) of the software application to determine if all elements of the design follow usability principles called "heuristics" [1]. This method must be conducted by professionals in HCI. In case a heuristic is infringed by the user interface design, the issue is classified as a usability problem. There are many protocols to conduct a heuristic evaluation. However, we have considered the following proposal [11]:

STEP 1: Each evaluator works independently for one or two hours. During this time interval, these specialists should examine all graphical user interfaces of the system to determine if all heuristic principles are followed. The result of this phase is an individual list of usability issues per evaluator, in which each design problem is related to one heuristic that is infringed by the interface.
STEP 2: When all specialists have completed their individual list of usability issues, they should come together to elaborate a single list. In this activity, there should be a consensus between all inspectors to determine if all issues, that were identified, indeed represent a usability problem. Additionally, the team should establish the best way to describe each issue. Finally, they should determine the correct association between the identified problem and the principle is not meet.

Table 1 Rating scale for severity and frequency

Rating	Severity	Frequency (%)
0	I do not agree that this is a usability problem at all	<1
1	Cosmetic problem only: need to be fixed unless extra time is available on project	1–10
2	Minor usability problem: fixing this should be given low priority	11–50
3	Major usability problem: important to fix, so should be given high priority	51–90
4	Usability catastrophe: imperative to fix this before product can be released	>90

STEP 3: Once the single list of usability issues is established, it must be sent to each specialist. In this phase, all evaluators should individually estimate the severity and frequency of each problem that was defined in the single list. The severity is related to the impact of the design problem in the use of the system: in case it occurs, will it be easy or difficult for users to overcome? Likewise, the frequency is related to the number of times each problem becomes visible in the interface. For this study, the scales proposed by Nielsen were considered. The ratings for severity and frequency are presented in Table 1.

STEP 4: As a final step, a member of the team must calculate the criticality (severity + frequency) of each usability problem, and average the individual scores in order to analyze the results. All the evaluation team should elaborate a final report. In this document, specialists must propose possible solutions to the identified issues.

3 A Comparative Study

In heuristic evaluations, the ten usability principles proposed by Nielsen are the most commonly used approach [2]. This list of broad rules is considered a traditional assessment tool by specialists. However, there is enough evidence in the literature stating that these heuristics provide inaccurate results when they are used to evaluate the new categories of software products that are available nowadays [13–15]. Current applications are embedded of emerging features that were not considered during the development of the traditional heuristics. In Web domain, systems incorporate new attributes such as sophisticated designs, extra functionality, and real-time processing. Software products are constantly evolving, and for this reason, an updated assessment tool, that could cover all the new aspects of usability, is required.

In a previous work [16], we conducted a heuristic evaluation to a transactional Web site with the participation of recognized specialists in the field. The purpose was to identify important aspects related to usability that are not considered by the conventional heuristics in this specific domain. The results demonstrated that Nielsen's approach fails to deal with usability issues related to culture, design, transaction, and functionality. In this way, we developed a new set of principles in order to provide specialists with a tool that will consider all the embedded features of the transactional Web applications for a successful evaluation.

In this paper, we compare the effectiveness and accuracy of both proposals. These two different approaches are presented as follows.

3.1 Nielsen's Usability Heuristics

Nielsen's principles are the most known guidelines to perform heuristic evaluations. According to the author of this approach, these principles are relatively broad and can be applied to any user interface [17]. Given that these heuristics allow specialists to find usability problems during early phases of the software development, these issues can be solved as part of an iterative design process. Nielsen's usability heuristics are [2]: (N1) Visibility of system status, (N2) Match between system and the real world, (N3) User control and freedom, (N4) Consistency and standards, (N5) Error prevention, (N6) Recognition rather than recall, (N7) Flexibility and efficiency of use, (N8) Aesthetic and minimalist design, (N9) Help users recognize, diagnose, and recover from errors, and (N10) Help and documentation.

3.2 New Heuristics for Transactional Web Sites

The new set of heuristics was developed because of the need for a tool that could provide accurate results when it is used to evaluate the usability of transactional Web applications. Although Nielsen's principles are still valid in this domain, there are aspects of usability that are not considered by this traditional approach. We used the methodology proposed by Rusu et al. [18] that defines a systematic procedure to establish new heuristics for interactive systems. After two iterations in which a literature review and some experimental case studies were performed, we obtained a list of fifteen usability principles: (F1) Visibility and clarity of the system elements, (F2) Visibility of the system status, (F3) Match between system and user's cultural aspects, (F4) Feedback of transaction, (F5) Alignment to Web design standards, (F6) Consistency of design, (F7) Standard iconography, (F8) Aesthetic and minimalist design, (F9) Prevention, recognition and error prevention, (F10) Appropriate flexibility and efficiency of use, (F11) Help and documentation, (F12) Reliability and quickness of transactions, (F13) Correct and expected functionality, (F14) Recognition rather than recall, and (F15) User control and freedom. A more detailed description of our proposal can be found in previous works [6, 16].

4 Research Design

4.1 Participants

This study involved the participation of forty-five undergraduate students in their final year of Engineering in Computing at the National University "Pedro Ruiz Gallo" (UNPRG). They were randomly chosen from two different sections of the same course (*Usability Engineering*). As part of the program activities, students had to learn the main concepts of usability as well as the methods to evaluate this quality attribute. This fact allowed us to train students in heuristic evaluations. Although students were from two different sections, they were not mixed. In order to perform a comparative study, the assessment process was explained using a different tool in each section. The traditional Nielsen's proposal was used in Section I. In the same way, the new set of heuristics for transactional Web applications was employed in Section II. This distribution is presented in Table 2. Students had little or no previous experience in this topic. Given that they attended the same courses of the academic program, we can establish they had a similar background.

Students were informed about this research. All they agreed voluntarily to participate without expecting any compensation. Before conducting the experiment, students were notified that the quality of their reports and answers would not affect their grades in the course. The experiment was performed in January 2016.

4.2 Study Design

Our empirical study was focused on a comparative analysis of the results of both approaches. For this purpose, we have considered the experimental design illustrated in Fig. 1.

First, all participants were trained in the main concepts of usability and heuristic evaluations. In order to avoid personal preferences, we described the method using a different assessment tool in each section. Section I was trained with the ten traditional Nielsen's heuristics. Similarly, section II was trained with the new fifteen usability heuristics for transactional Web sites. Subsequently, participants examined

Table 2 Instrument-Subject Distribution

Section I	Section II
Nielsen's usability heuristics	New usability heuristics for transactional web sites
Total subjects: 21 (3 Teams of 7 participants)	Total subjects: 24 (3 Teams of 8 participants)

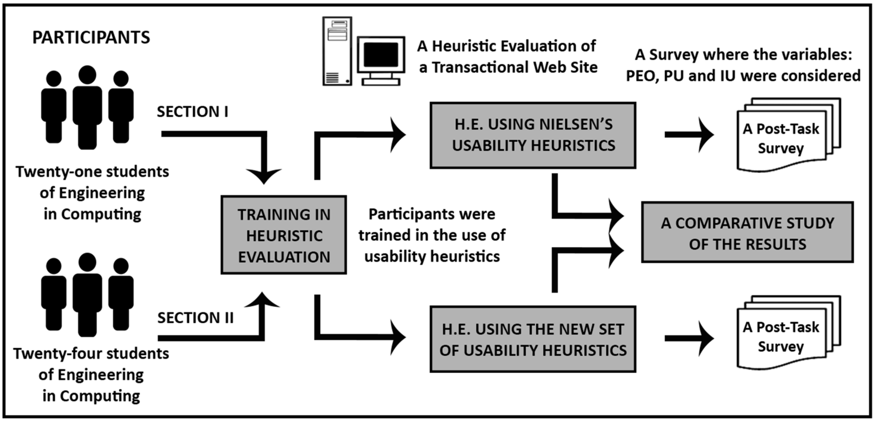

Fig. 1 Experimental design

all the user interface design of an e-Commerce Website using the heuristics that were assigned to their section. For this activity, *HotelClub.com*, an online Web site for hotel booking was selected. Students spent about two hours inspecting the graphical user interfaces of the system. As a result of this process, each student reported a list of usability issues. Each problem was detailed according to following parameters: (a) problem ID, (b) problem definition, (c) comments/explanation, (d) occurrence examples, (d) infringed heuristic, and (e) screenshots.

Next, several teams were randomly organized in both sections. Three teams of seven students were formed in Section I. Likewise, three teams of eight students were formed in Section II. The purpose of each team was to elaborate a single list of issues into a final report. In this document, each group had to specify the average rating for severity, frequency and criticality of each identified issue.

Finally, a post-task survey was employed to identify the students' perceptions about the use of heuristics with regard to the following variables: PEO (perceived ease of use), PU (perceived usefulness) and IU (intention to use). The items of the survey were formulated using a 5-point Likert scale, where 1 was referred to a negative perception of the construct, and 5 to a positive opinion (see Appendix A).

5 Data Analysis and Results

In this section, we present the results of the comparative study. Both approaches were contrasted in the following categories: (1) number of identified issues, (2) errors in associations, and (3) students' perceptions.

5.1 Number of Usability Issues

We consolidated all reports to determine the number of usability issues that were identified by each approach. The results are illustrated in Fig. 2.

The conclusions of this analysis are:

- A total of 25 usability problems were identified by the participants who used the Nielsen's usability heuristics.
- A total of 39 usability problems were identified by the participants who used the new set of usability heuristics for transactional Web sites.
- There are 10 usability problems that can only be identified by the use of the Nielsen's usability heuristics.
- There are 24 usability problems that can only be identified by the use of the new set of usability heuristics for transactional Web sites.
- There are 15 usability problems that can be identified by both approaches.

According to the validation process proposed by Rusu et al. [18], if more usability problems are identified with the new proposal in a comparative study (with Nielsen's heuristics), the results can be considered favorable. However, it is still necessary to analyze the quality of the problems that were identified by our new approach. In Table 3, we present the five most critical problems that only were

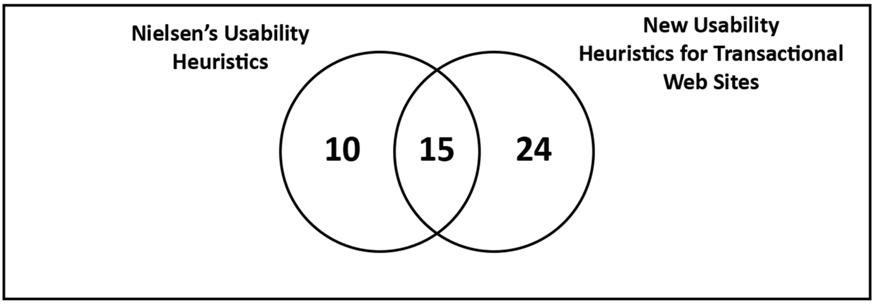

Fig. 2 Number of usability issues identified by each approach

Table 3 Five most critical problems that were only identified by the new approach

Problem ID	Problem definition	Criticality
P18	Limited payment options	5.6
P12	The Website does not display the hotel prices in the local currency of user	5.0
P24	Places of error are no easily recognizable	5.2
P14	Few currency types available	4.4
P25	Recommended destinations are not optimized to user's preferences	4.0

identified by the new usability heuristics. Considering that the maximum score for criticality is 6.0, then the identified issues by the new heuristics are relevant.

5.2 Errors in the Associations

Another aspect that we considered in this comparative analysis was the percentage of wrong associations. When the evaluators identify usability issues, they must specify the heuristic has been infringed. However, in some cases, the heuristic is misunderstood by the inspectors. They establish that a particular principle is not followed, when in fact, the heuristic that was infringed is another. To perform this analysis, we have defined the following concepts:

Valid association: When the inspector associates correctly the identified usability issue with the heuristic that is infringed by the graphical user interface.
Wrong association: When the inspector specifies the infringement of a heuristic that is not actually related to the usability issue that was identified. In Tables 1 and 2, this category represents how many times participants chose this heuristic incorrectly to justify the finding of a usability issue.

The percentage of wrong associations are presented in Table 4 for Nielsen's usability heuristics, and Table 5 for New Heuristics for Transactional Web Sites. The results show that fewer errors are made when our new proposal is used. Possibly, the descriptions of our principles are more understandable than the established ones by Nielsen. However, more case studies are required to generalize these conclusions.

Table 4 Errors in the associations for the Nielsen's usability heuristics

Usability heuristic	Total number of problems	Valid associations	Wrong associations	Percentage of wrong associations (%)
N1	2	1	1	**50**
N2	2	0	2	**100**
N3	1	1	0	0
N4	13	6	7	**54**
N5	2	1	1	**50**
N6	1	0	1	**100**
N7	1	0	1	**100**
N8	2	1	1	**50**
N9	1	1	0	0
N10	0	0	0	0
Total	**25**	**11**	**14**	**56**

Table 5 Errors in the associations for the new usability heuristics

Usability heuristic	Total number of problems	Valid associations	Wrong associations	Percentage of wrong associations (%)
F1	4	4	0	0
F2	1	1	0	0
F3	3	3	0	0
F4	0	0	0	0
F5	3	3	0	0
F6	6	5	1	**17**
F7	1	1	0	0
F8	3	2	1	**33**
F9	4	4	0	0
F10	6	1	5	**83**
F11	1	1	0	0
F12	1	1	0	0
F13	5	5	0	0
F14	0	0	0	0
F15	1	1	0	0
Total	**39**	**32**	**7**	**18**

5.3 Perception Variables

The last aspect we examined in this comparative study was the post-survey. In this questionnaire, we evaluated three variables:

Perceived ease of use (PEU): The extent to which an evaluator believes that using a particular set of usability heuristics would be free of effort.
Perceived usefulness (PU): The extent to which an evaluator believes that a particular set of usability heuristics will achieve its intended objectives.
Intention to use (IU): The extent to which a reviewer intends to use a particular set of usability heuristics in the future. This construct is an intention-based variable for predicting the adoption in practice of the heuristics.

The results are presented in Table 6. Although there is an improvement in all aspects regarding the Nielsen's traditional heuristics, the differences were not highly remarkable. Therefore, further studies are needed.

Table 6 Comparison of the perception variables between the nielsen's approach and the new usability heuristics

Approach	PEO	PU	IU
Nielsen's usability heuristics	3.02	3.74	3.62
Heuristics for transactional web sites	3.37	3.71	3.64

6 Conclusions and Future Works

Heuristic evaluation is a widely used method to determine the usability of software products. This technique involves a group of specialists judging if all elements of a graphical user interface follow specific guidelines called "heuristics". Nielsen' usability heuristics are the most recognized tools to perform heuristic evaluations in all domains. However, these principles fail to cover all aspects of usability that are currently embedded in the current generation of software products. Transactional Web applications are not the exception. Therefore, a new proposal was developed.

A new set of fifteen heuristics was developed in a previous study. In this paper, we present a contribution of experimental nature which describes the validation process in the e-Commerce Web domain of the new heuristics. The purpose of this study was to perform a comparative analysis of the conventional Nielsen's approach and our new proposal. Forty-five students from two different sections were requested to perform a heuristic evaluation. The traditional heuristics were used in Section I by twenty-one students, and in the same way, the new set of heuristics for transactional Web sites was employed in Section II by twenty-four students. The accurate of the results was compared.

The results show that the new heuristics cover more usability aspects of this new specific domain of software. The number of issues was higher in the evaluations in which the new proposal was used. However, there were usability problems that were only detected by the traditional approach. Although the results are promising, some improvements and more experiments are required in other scenarios. This work is intended to provide specialists with an effective tool to support heuristic evaluations in the context of Transactional Web Applications.

Appendix: Survey Instrument

For each usability heuristic, please mark a cross [X] over the square which most closely matches your opinion. There are no "right" answers to this survey. For this reason, just give your honest opinion based on the experience that was gained in the case study.

(A) **Ease of Use of the Usability Heuristics**: How easy to use was each usability heuristic? (Table 7)

(B) **Usefulness of the Usability Heuristics**: The same pattern of question A was employed to measure the usefulness of each usability heuristic. How useful do you consider each usability heuristic is? (Table 8)

(C) **Intention to Use the Usability Heuristics**: Would you use these heuristics in future evaluations to measure the level of usability of transactional Web applications? (Table 9)

Table 7 Form to measure the ease of use of each heuristic

Heuristic	Very Difficult	Difficult	Neutral	Easy	Very Easy
NX			X		

Table 8 Form to Measure the Usefulness of Each Heuristic

Heuristic	Completely useless	Useless	Neutral	Useful	Completely useful
NX					X

Table 9 Scale to Measure the Intention to Use the Heuristics in the Future

Definitely not	Probably not	Neutral	Probably yes	Definitely yes
			X	

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When to Interrupt: A Comparative Analysis of Interruption Timings Within Collaborative Communication Tasks

Nia Peters, Griffin Romigh, George Bradley and Bhiksha Raj

Abstract This study seeks to determine if it is necessary for a software agent to monitor the communication channel between a human operator and human collaborators to effectively detect appropriate times to convey information or "interrupt" the operator in a collaborative communication task. The study explores the outcome of overall task performance and task time of completion (TOC) at various delivery times of periphery task interruptions. A collaborative, goal-oriented task is simulated via a dual-task where an operator participates in the primary collaborative communication task and a secondary keeping track task. User performance at various interruption timings: random, fixed, and human-determined (HD) are evaluated to determine whether an intelligent form of interrupting users is less disruptive and benefits users' overall interaction. There is a significant difference in task performance when HD interruptions are delivered in comparison with random and fixed timed interruption. There is a 54 % overall accuracy for task performance using HD interruptions compared to 33 % for fixed interruptions and 38 % for random interruptions. These results are promising and provide some indication that monitoring a communication channel or adding intelligence to the interaction can be useful for the exchange.

Keywords Interruption management · Collaborative communication · Turn-taking · Human-human-computer interactions

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1 Introduction

The primary focus of this work is on exploring when to disseminate system-mediated interruptions within collaborative multi-tasks in auditory environments. In this work, an interruption *is the intention of a 3rd party to convey new information to a member participating in a collaborative communication task, which aids in one task but disrupts another*. Imagine a military operation in which an Unmanned Aerial Vehicle (UAV) operator is communicating with team members on the ground. In this operation, an example of a collaborative communication task between the operator and the teammates is a task in which the UAV operator and human teammates are coordinating the location of a particular ground object based on the teammates' perspective as well as the UAV's location and perspective. In conjunction with this task, the UAV operator may also be tasked with keeping track of various UAV state changes.

Figure 1 illustrates a generic representation of this specific scenario for the focused collaborative, communication task where an operator is communicating with human teammates and a machine teammate simultaneously.

In Fig. 1 notice there is bidirectional communication between the operator and human teammates as well as the operator and her machine teammate, but the human teammates are oblivious to the communication between the operator and the machine teammate. Here you have the collaborative communication between the operator and human teammates and another task between the operator and machine teammate. In this dual-task scenario, we would like to determine whether the machine teammate should monitor the communication channels between the operator and the human teammates before it communicates information to the operator. If monitoring the communication channel prior to an interruption is beneficial, when is the most optimal time to interrupt the operator that is the least invasive to the overall exchange and results in the operator performing all tasks quickly and effectively.

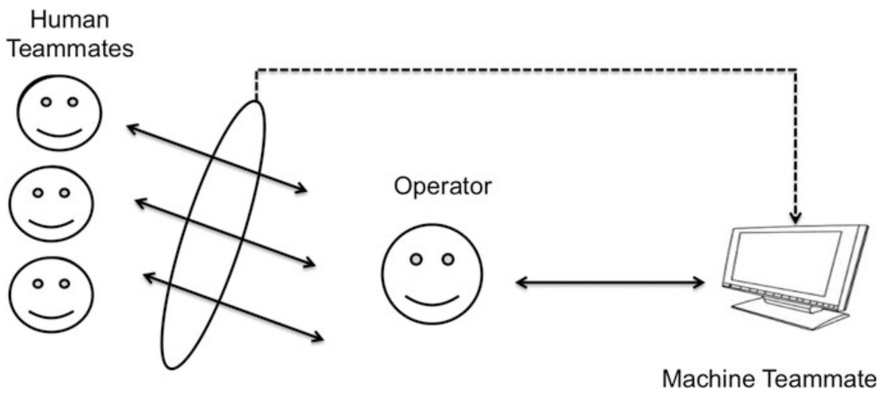

Fig. 1 Collaborative communication & monitoring task

There is empirical research dedicated to manipulating time on the delivery [1–3] of system-mediated interruptions [4] in multi-task environments [5]. There is also literature that explores immediate interruption or notification dissemination [6–8] within dual-task scenarios. Studies have shown that delivering interruptions at random times can result in a decline in performance on primary tasks [1, 6, 8–10]. Additionally, studies have illustrated that interrupting users engaged in tasks has a considerable negative impact on task completion time [2, 3, 6, 9, 11, 12].

It is imperative that system interruptions are delivered at moments of minimal cognitive workload [13] to avoid information overload and maintain task efficiency. Miyata and Norman [14] argue that delivering notifications at moments of lower mental workload would lower the cost of interruptions. Coordinating interruptions within a dialogue is an important factor in maintaining efficient communication and preventing information overload [15].

Much of the current literature is focused on one user engaged in a primary task interrupted by a peripheral task. This study differs in that the primary task is a collaborative task between two or more users and the secondary task is presented to one of the collaborating users. This work aims to determine if monitoring a collaborative communication task will improve overall task performance and time of complete (TOC) within collaborative, goal-oriented exchanges. In this study *monitoring* refers to listening to a communication exchange between two users prior to distributing an interruption. The monitoring method used in this report is referred to as human-determined (HD) interruptions where a human interrupter listens to or monitors a collaborative communication channel between two users and decides on appropriate times of interruption. The hope is that humans use cues while monitoring a communication channel prior to interrupting that could be less disruptive to the exchange between collaborating participants. If humans monitoring the communication channel prior to interruptions are indeed valuable for the overall exchange, this could help justify designing an interruption system that mimics optimal human interruption cues in collaborative exchanges. In this study, there is a significant increase in operator task performance when the communication channel is monitored and human interruptions are disseminated in comparison to random and fixed times interruptions.

The rest of this paper is arranged as follows: Sect. 2 illustrates the methods used in this work. In Sect. 3 the evaluation process is explained. Section 4 presents the results, which are further discussed in Sect. 5. Finally, Sect. 6 is the conclusion.

2 Methods

A collaborative, goal-oriented task is simulated via a dual-task of a dyadic collaborative communication scenario (primary task) in conjunction with a keeping track task (secondary task). Data are collected through a series of exercises undertaken by a team of three individuals: an interrupter, an operator, and the operator's teammate. In the primary task, the operator and teammate perform a collaborative communication task in an effort to accomplish a common goal similar to that illustrated between the UAV operator and his human teammates. In the secondary task, the operator simultaneously performs a keeping track task. Within this task the operator must keep track of various UAV states where the state information is disseminated via the experimenter sending interruptions at varying interruption timings: fixed, random, and human determined (HD). Finally, human performance on the secondary task and the time of competition (TOC) on the primary task are evaluated to determine the implications of interrupting at different times. The assumption is that a human monitoring the communication channel (HD interruptions) will result in interruptions sent at a less disruptive time allowing the operator to complete the primary task at a faster rate and improve secondary task performance.

- Research Question I: Is there a difference in the time of completion (TOC) for the primary task for different interruption timings?
  - H_{01}: There is no difference in the TOC for the primary task for different interruption timings.
  - H_1: There is a difference in the TOC for the primary task for different interruption timings.
- Research Question II: Is there a difference in the performance of the secondary task for different interruption timings?
  - H_{02}: There is no difference in the secondary task performance for different interruption timings.
  - H_2: There is a difference in the secondary task performance for different interruption timings.

2.1 Data

The goal of the data collection is to characterize how different interruption strategies affect task performance in a team communication task. The overall data collection consists of 30 teams engaged in a collaborative task. In the data collection, a team is defined as two users participating in a communication task with one team member acting as an operator. If there is a team consisting of User1 and User2, User1 as the operator is one team and User2 as the operator is another team. This setup is used because the evaluation is done with respect to the operator, not the team. All teams are chosen randomly from a total of 23 participants. From the 23 participants, 2 are selected randomly to participate as human interrupters in addition to one person not participating in the collaborative communication task. In total 3 human interrupters were used in this data collection.

2.2 Tangram Task

The Tangram Task is a collaborative communication task where users communicate over a push-to-talk communication channel to rearrange Tangram shapes on their individual screens until the shapes in the corresponding color columns correspond correctly. One user has an interface similar to Fig. 2. The other user has the exact same interface except the columns and objects in the columns are rearranged.

Two member teams are instructed to speak across a push-to-talk communication channel and collaborate with one another to arrange their Tangram shapes so that the shapes in the color column correctly correspond. Each team has an unlimited time to complete this task, but participants are instructed to complete the task as quickly as possible without jeopardizing task performance. Since one of the team members is the operator and simultaneously completing the keeping track task, there are three types of human-human communication interactions during this task between the team members:

- The non-operator describes the Tangram shapes and asks for feedback from their partner
- The operator describes the Tangram shapes and asks for feedback from their partner
- Both of the teammates describe the Tangram shapes and request feedback

This experimental task is inspired by the task described in [16] and used because it is a close simulation of the collaborative communication task described in the afore-mentioned UAV scenario.

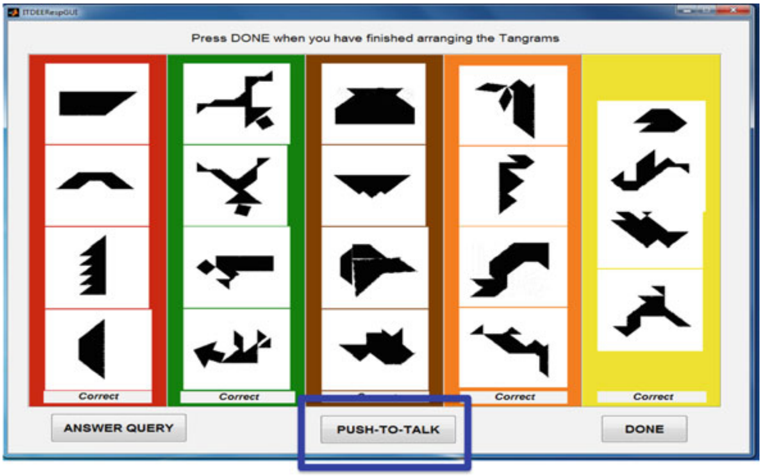

Fig. 2 Interface of tangram task

2.3 Keeping Track Task

In the keeping track task, the operator is interrupted by the experimenter with updates about various objects and their attributes and then queried about the state of a particular object while simultaneously performing the Tangram task. Random, fixed, and human-determined (HD) interruptions (updates and queries) are communicated to the operator at various timings:

- *Fixed Interruptions*—interruptions (updates and queries) automatically disseminated every 9 s
- *Random Interruptions*—interruptions automatically disseminated randomly between 5 and 13 s
- *Human Determined*—interruptions disseminated based on a human interrupter listening to the collaborative communication channel and determining based on the activity on the channel when to execute an interruption.

Human interrupters were instructed to send interruptions during times when they think their interruptions would be the least disruptive to the overall communication task. Human determined interruptions are being used to determine if an intelligent monitoring mechanism is necessary for interruptions.

Users must respond to queries via a push-to-talk communication mechanism. The operator was instructed to respond to the most recent state update of an object prior to a query. Multiple updates are sent to the operator followed by a query pertaining to information presented in the updates. The interruptions are presented as *blocks* of sizes 3–5 where 3, 4, or 5 updates were presented before a query. For example, an interruption block of size 3 presents 3 updates before a query. The query corresponds to information within the current block. The *lag* is how far a query is from its corresponding update. Below is an example of an Update/Query block:

```
{Update I}: Hawk-88' LOCATION is Point Bravo
{Update II}: Raven-3's FUEL-LEVEL is 30%
{Update III}: Falcom-11's ALTITUDE is 1900 ft.
{Fourth[Query I}: What is Raven-3's current FUEL-LEVEL?
```

This example illustrates an update/query block with a block size of 3 and a lag of 2 meaning there were 3 state updates before the user is queried and the attribute in question is two positions away from the query. All interruptions are communicated via a synthesized human voice. The keeping track task is motivated by [17].

3 Evaluation

The outcome from the data collection is used to determine if the operator performs the Tangram task faster when a human is listening in on the task and interrupting in comparison to automatically sent interruptions. The data is also evaluated to determine if the operator is able to perform better on the keeping track task when a human interrupts in comparison to fixed and randomly disseminated interruptions. Using the results from the data collection, we evaluate two metrics: the primary task time of completion (TOC) and the secondary task performance.

As described in Sect. 2.2, the primary task or the Tangram task required a two-member team to communicate and complete a collaborative task. Note that one of the participants in the team is the designated operator and simultaneously performing the keeping track task. Since we would like to see which interruption mechanism: random, fixed, or HD is least disruptive and results in a faster completion time over the primary task, we extract the TOC or how long it takes a given operator to complete the Tangram task with his partner. For each interruption-timing category, we average over all of the operators' TOC (in minutes) for the primary task.

Additionally, as described in Sect. 2.3, the secondary task or the keeping track task required the designated operator of a team to respond to queries when presented with a block of updates about UAV objects and their varying states. The experimenter annotated the results of this task. The percent correct served as the secondary task performance metric. The percent correct was calculated as the number of queries answered correctly divided by the total number of queries presented to a given operator. For each interruption-timing category, we average over all the operators' percent correct on the secondary task.

4 Results

A one-way analysis of variance (ANOVA) was conducted to evaluate the relationship between interruption timings and time of completion (TOC) on the primary task. The independent variable, interruption-timing factor included three levels: random, fixed, and human-determined (HD). The dependent variable was the average time it took the operators to complete the Tangram task (TOC) in minutes. The ANOVA was not significant at the 0.05 level, $F(2, 174) = 0.96$, $p = 0.39$. The 95 % confidence intervals for the differences, as well at the means and standard deviations for the three interruption timing groups are reported in Table 1.

Although on average operators completed the primary task in less time when HD interruptions were administered, the TOC averages are close across interruption

Table 1 Primary task TOC (minutes) results

Interruptions	Mean	Std. error	95 % confidence	
			Lower	Upper
Fixed	3.32	0.19	2.94	3.70
Random	3.45	0.19	3.07	3.83
HD	3.087	0.19	2.70	3.46

timings and there is no significant difference in the completion times. Here we can accept the H_{01} null hypothesis.

A one-way ANOVA was conducted to evaluate the relationship between interruption timings and user performance on the secondary task. The independent variable, the interruption-timing factor, included three levels: random, fixed, and HD. The dependent variable was the percent correct of queries operators answered correctly on the keeping track task. The ANOVA was significant at the 0.05 level, $F(2, 174) = 7.52$, $p = 0.001$. The strength of the relationship between the interruption timings and the percent correct on the secondary task, as assessed by the η^2, was average, with the interruption-timing factor accounting for 8 % of the variance of the dependent variable.

Follow-up tests were conducted to evaluate pairwise differences among the means. The Levene's Test results in a significance of 0.45, supporting our assumption of homogenous variances among the three groups. We then conducted post hoc comparisons using the Tukey HSD, a test that assumes equal variances among the three groups. As illustrated in Table 3, there was a significant difference in the means between the HD interruptions and fixed timed interruptions as well as a significant difference in the HD interruptions and the randomly timed interruptions. The 95 % confidence intervals for the pairwise differences, as well at the means and standard deviations for the three interruption timing groups are reported in Tables 2 and 3.

As summarized in Tables 2 and 3 and Fig. 3, the average accuracy for the primary task of all 30 teams is 54.7 % for Human Determined interruptions, 38.4 % for randomly timed interruptions, and 33.5 % for fixed-timed interruptions. These results indicate that there is a significant difference in user performance when the operator is interrupted with HD interruptions. These results suggest that we can reject the H_{02} null hypothesis.

Table 2 Secondary task performance (percent correct) results

Interruptions	Mean	Std. error	95 % confidence	
			Lower	Upper
Fixed	33.47	4.05	25.47	41.47
Random	38.38	4.05	30.38	46.38
HD	54.70	4.05	46.70	62.70

Table 3 Task performance (percent correct) comparison across interruptions

		Mean diff.	Std. error	Sig.
HD	Fixed	21.23	5.73	0.001
	Random	16.32	5.73	0.014

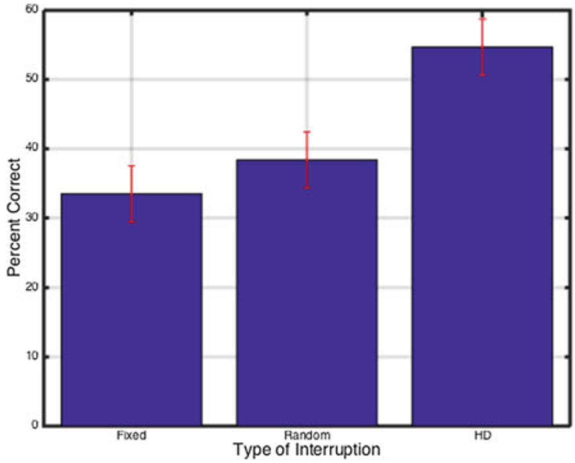

Fig. 3 Secondary task performance results

5 Discussion

The aforementioned results illustrate that monitoring the communication channel can improve task performance since the interruptions are probably being allocated as points that are less disruptive. This does not necessarily result in a lower time of completion for the primary task. This work did not directly evaluate the influence of interruptions on the TOC of a task [2, 3, 6, 9, 11, 12], but focused more on the how the TOC of a task was affected by various interruptions timings. From these results, various interruption-timing disseminations do not have an impact on the time of completion of a task.

The current results do however corroborate current literature that has shown that delivering interruptions as random times can result in a decline in performance on tasks [1, 6, 8–10]. The current work augments this claim by not only showing that randomly timed interruptions can be detrimental to task performance but in comparison HD interruptions are an improved mechanism of disseminating interruptions. There is no difference illustrated in this work between fixed-timed and randomly-times interruptions. Human-determined interruptions on the other hand significantly improve task performance over both of these alternative mechanisms.

In future work, we would like to use these results to justify the necessity of an intelligent interruption management system that can be used in collaborative, goal-oriented tasks. It was illustrated that the user task performance was degraded when fixed and random interruptions were sent. If monitoring the communication channel before interruptions indeed provide some improvement in the overall task performance within collaborative tasks, then there is justification for proposing an intelligent mechanism that also monitors a communication channel before interruptions. The next step in this work is developing a baseline model of what cues to monitor within a communication channel before an interruption. We could begin by exploring human interruptions (in this work stated as human determined interruptions) to determine if there are optimal human cues that could be integrated into an interruption management model. The long-term goal of this work is to design an intelligent interruption agent whose performance exceeds the performance of a fixed, random, and human interruption performance in collaborative, goal-oriented tasks.

6 Conclusion

In conclusion, in this work a collaborative communication and keeping track task to simulate a collaborative goal-oriented interaction between an operator and his human and machine teammates was developed. In evaluating the time of completion and performance on an experimental dual-task, the results suggest that although there is no significant differences in the effect interruption timings have on the time of completion of a task, the performance of the task in influenced by the time at which interruptions are disseminated. These results show that there could be some benefit to monitoring a task prior to sending interruptions in a collaborative communication task, that supports how well the task is performed.

The benefit of fixed timed and randomly timed interruptions is that they can be integrated into collaborative tasks between users and disseminate interruptions automatically. If the benefits of automatically sent interruptions could be merged with the benefits of a monitoring system, there is the potential for developing an intelligent interruption management system in collaborative communication task environments. Such a system would be beneficial in any interaction in which two or more users are collaborating to accomplish a common goal and there is peripheral information coming in that supports the current exchange or an additional task.

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The Impact of False and Nuisance Alarms on the Design Optimization of Physical Security Systems

Alisa Bandlow, Katherine A. Jones, Nathanael J.K. Brown and Linda K. Nozick

Abstract Despite the known degrading impact of high nuisance and false alarm rates (NAR/FAR) on operator performance, analyses of security systems often ignores operator performance. We developed a model to analyze the impact of nuisance alarm rates on operator performance and on overall system performance. The model demonstrates that current methods that do not account for operator performance produce optimistic estimates of system performance. As shown in our model, even low NAR/FAR levels and the associated alarm queueing effect can increase operator detect and response time, which in turn reduces the amount of time the response force has to interrupt the intruder. An illustrative analysis shows that alarm processing times can be higher than the assessment time due to queue wait times and that systems with only one or two operators can become overwhelmed as NAR increases, decreasing system performance.

Keywords Human-systems integration · Physical protection systems · Nuisance alarms · Operator performance

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1 Introduction

Identifying an optimal design for a physical security system is critical to mission performance. Facility or system owners are sometimes willing to invest millions of dollars to increase intruder delay times by a few seconds. In most systems, a human operator assesses the alarmed sensors and then calls on the response force to investigate. With limited budgets, sites are searching for technologies that can reduce the number of staff employed, thereby reducing the overall cost of the security system. However, more technologies and sensors will usually increase the nuisance and false alarm rates (NAR/FAR), which in turn may require additional operators to respond to the increase in alarms.

Standard physical protection system (PPS) assessment methods include red team exercises [1], adversary sequence diagrams, design basis threat and fault tree analysis [2]. Analyses of physical security systems primarily focus on the intruder delay times due to physical barriers, the reliability of sensors, alarm assessment, and the response times of the protective force [1–5]. These methods typically assume that the operator is ready to begin assessment as soon as the intruder alarm is generated and that the operator behavior never deviates from policy and training, such as ignoring alarms.

As the rate of nuisance and false alarms increases, a system's perceived reliability decreases, causing the operator to lose trust in the system. Moray et al. [6] found that trust was impacted the most when system reliability fell below 90 %. This loss of trust can result in delayed response to alarms (the "cry wolf" effect) [7, 8]; probability matching response rates [9, 10]; and, in extreme cases, failure to respond, ignoring or disabling alarms [11, 12].

Despite the known degrading impact of high of NAR/FAR on those monitoring the alarms, analyses of security systems often ignore operator performance. Thus, an operator who is slow to respond to an alarm or who simply ignores or disables the alarm can weaken security systems that are considered highly reliable. Without including a more realistic human response and assessment time, current system performance estimates may be overly optimistic.

We previously developed a model to optimize the design of a PPS [13]. Building on that model, we developed a new model to analyze the impact of nuisance alarm rates on operator performance and overall system performance. The NAR/FAR level and the associated alarm queueing effect for a proposed system design impact the speed at which the operators will respond to alarms, which in turn affects the amount of time the response force has to interrupt the intruder.

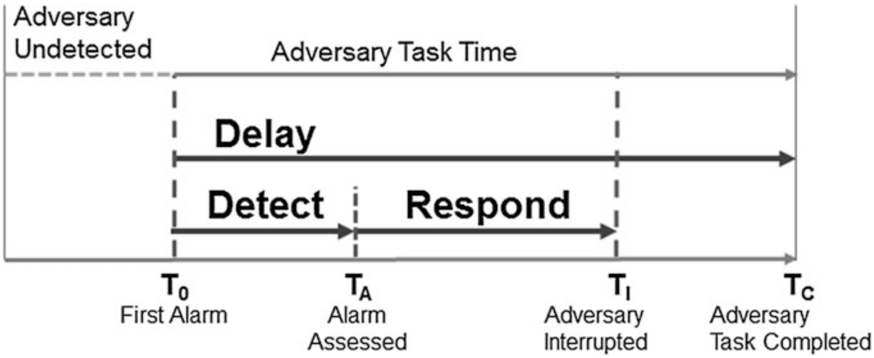

Fig. 1 Relationship between PPS functions (delay, detect, respond) and the adversary task timeline

2 Physical Protection System (PPS)

The goal of a physical protection system (PPS) is to use detection, delay and response to prevent an adversary from reaching a target [2]. *Detection* is the discovery of an adversary when a sensor detects an abnormal event. A person assesses the alarm to determine if it is valid (an adversary is detected) or invalid (a nuisance or false alarm). *Delay* is the use of obstacles to increase the adversary task time. Obstacles can be passive barriers (e.g., locks, fences, and Jersey walls) or active barriers (e.g., engagement by the response force, pop-up vehicle barriers). *Response* is the actions taken by the response force to prevent adversary success.

Figure 1 shows the adversary task timeline and the relationship to the three PPS functions. The total time for the adversary to accomplish their goal is labeled Adversary Task Time. The Adversary Task Time is impacted by the delay provided by the PPS. Any delay provided by the PPS before detection (the dotted line labeled Adversary Undetected) does not count towards system effectiveness. After the first alarm at time T_0, the alarm information is assessed to determine if it is valid or a false or nuisance alarm. If the alarm is assessed to be valid at time T_A, the alarm information is communicated to the response force. Additional time is required for the response force to deploy and respond to the adversary. The time at which the response force interrupts the adversary is T_I. If the adversary is not interrupted, they will complete their task at time T_C.

3 PPS Design Optimization Model

We previously developed a model to optimize the design of PPS [13]. We use probability of detection, probability of interruption, delay time, and response time as defined by [2] as elements in our model. We represent the problem as an attacker-defender model, in which the attacker (adversary) has perfect knowledge of the security measures in place. The attacker's goal is to reach a specific target which is protected by a physical security system. In this model, the defender is the designer and operator of the security system. The defender's goals are to minimize investment cost, minimize the nuisance alarm rate and false alarm rate (NAR/FAR), and maximize the probability of interrupting the adversary. The probability of interruption (P_I) is the probability that the travel time of the security response force will be less than the travel time remaining for the attacker once they have been detected, allowing interception before the target has been reached. We use the P_I given detection as the relevant measure of interest for the quality of the path from the perspective of the attacker.

The model is not a simulation of the attacker attempting to reach the target. Instead, the model performs an implicit enumeration of all attacker paths [4, 5]. For each PPS design solution, an algorithm explores the paths the attacker can take to calculate the worst (lowest) P_I [3]. This P_I is then assigned to the solution. Increasing the P_I is accomplished by adding detection and delay security measures (such as cameras and fences). Each technology investment has an associated cost and NAR/FAR.

The goal of the optimization is to suggest which technologies to place at which locations. The model only places barriers and sensors outside and on the exterior of buildings. The final output is a Pareto frontier that identifies a collection of efficient solutions. This allows a decision maker to identify an acceptable trade-off between the probability that the intruder is interrupted, investment costs, and NAR/FAR.

4 Operator Performance Model

We developed an operator performance model to begin including a more detailed representation of operator behavior with a goal of analyzing the impact of alarm rates on operator performance and on overall system performance. We chose to focus on two impacts of alarm rate on performance. First, dependent on the alarm assessment time, there is a maximum number of alarms a single operator can assess in a day. Second, the alarm rate can affect the operator's trust in the alarm system's reliability.

4.1 Alarms as a Queue

Standard PPS assessment methods typically assume that the alarm station operator is ready to begin assessment as soon as the intruder alarm is generated. However, the operator may be busy assessing other alarms, thus delaying detection. There is also a maximum number of alarms that can be assessed in a day. When the alarm rate is high enough, the operator(s) may not be able to assess all of the alarms in the queue, which can lead to missed detections.

To model the arrival and assessment time of alarms more realistically, we use a queueing model. Our approach is to shift the mean of the response time distribution by adding the steady state results of a queuing model which assumes there are k independent servers and that all alarms generated are examined in the order received. We assume that the alarms are independent of one another and arrive via a Poisson process (*M*). We also assume that the service time for an alarm is arbitrarily distributed (*G*) and that there are k operators examining the alarms. In queueing notation, this implies an *M/G/k* queue.

Gans [14] gives a classical result that a reasonable approximation for the average waiting time per alarm in the queue is as follows.

$$E\left[W^{M/G/k}\right] = \frac{C^2 + 1}{2} E\left[W^{M/M/k}\right] \tag{1}$$

where C is the coefficient of variation of the service time distribution, and the $E\left[W^{M/M/k}\right]$ is as follows.

$$\frac{(1 - P_0)}{k\mu - \lambda}. \tag{2}$$

where $\rho = \lambda/k\mu$, λ is the arrival rate of the Poisson process, k is the number of operators, and μ is the mean of the service rate distribution.

P_0 is the probability that there are zero alarms in the system and is computed as follows.

$$P_0 = \frac{1}{\left[\sum_{i=0}^{k-1} \frac{(k\rho)^i}{i!}\right] + \frac{(k\rho)^k}{k!(1-\rho)}}. \tag{3}$$

Generally, this approximation works well for operators in the tens, which we assume to be a plausible range for this application.

Strengths of this approach are that it is tractable and allows us to represent investment in the operators that examine alarms. The weakness is that there may be priorities among the alarms, which this approach ignores.

4.2 Operator Trust in the Alarm System

In the standard PPS assessment methods, the operator performance can be included in the probability of detection (P_D) as follows.

$$P_D = P_S \times P_A. \tag{4}$$

where P_S is the probability that a sensor detects the abnormal event, and P_A is the probability that the cause of the alarm is accurately assessed by the operator. P_A does not include the operator's response rate, so these methods do not account for operator behavior that deviates from policy and training, such as ignoring alarms.

To better represent operator behavior, we allow the system NAR/FAR to effect operator response time. First, since the original PPS design model focuses on the optimization of technology investments, operators are added as an investment item with an annual cost per operator. More operators can deal with higher alarm rates, but this will increase investment costs. Second, system NAR/FAR rate affects operator response times. Operator distrust in the system is quantified as a delay in response time. Since the original model uses P_I as a measure of quality for solutions, we include delay in response time in our calculation of P_I in order to better anticipate the true performance of a design in practice.

The operator performance model requires the following inputs, to be provided by the site physical security expert. Each sensor type has an alarm rate (which includes correct detections, NAR and FAR) per day. The sensor alarm rates are aggregated to obtain the system alarm rate per day. The site will have a maximum number of operators that they are willing to hire k. The operator has an average assessment time for a single alarm AT. Many alarm station operators perform a primary task in addition to monitoring alarms [2, 15], so there will be an average lag time, LT, when the operator has to switch tasks to respond to an alarm.

As the sensors' P_S increases, the NAR also increases, and the operator's trust in the system decreases. This causes an increase in response times [10, 16–18], which we call the trust delay time TDT. We bin the alarm rates into categories of low, medium and high, based on acceptability levels in industry standards EEMUA Publication 191 [19] and ANSI/ISA-18.2 [20], which result in proportional trust delay times. We define the alarm rate levels for a single operator. The low category signifies the maximum alarm rate deemed to be acceptable, with high operator trust. The medium category signifies the maximum alarm rate deemed to be manageable. The high category contains alarm rates above the medium category and is deemed to be over-demanding.

The operator's total response and assessment time OAT for a single alarm is calculated as follows:

$$OAT = AT + LT + TDT. \tag{5}$$

where the TDT value is selected based on the system NAR/FAR category. OAT is used to calculate μ in the queueing model.

We did not include the trust delay time or allow variability in P_S or P_A in the original model. Since each solution on the Pareto frontier represents a unique PPS design solution, the inclusion of additional variables would make it difficult to quantify the impact of each variable on the probability of interruption. Instead, the operator performance analysis begins with a single PPS design solution generated by the original model. The number of operators is varied from 1 to *k*. The P_S for each sensor type and the P_A for operators are varied across a range provided by the site physical security expert. The alarm rate is calculated as a function of P_S in lieu of actual performance data.

The goal of this second model is to identify the acceptable trade-off between the system performance P_I, cost of employing more operators, P_S, and the NAR.

5 Illustrative Analysis

For our analysis, we assume a site size of 400 m × 400 m, with a single target at the center of the site. The baseline architectures are generated using the PPS design optimization model, using a single barrier type (fence), a single sensor type with $P_S = 0.9$, and $P_A = 1.0$. We selected the PPS design option with the highest P_I.

Since we did not have access to actual operator performance data, we looked for data in the literature. We found a small set of studies that looked at changes in response time due to system reliability [10, 16–18, 21], but the target identification tasks were not analogous to alarm station operator tasks. Due to lack of data, the values used are notional (see Table 1).

We calculated the NAR/FAR categories based on an operator assessment time of 45 s, which gives a maximum possible rate of 1920 assessments performed per day. The queueing model showed this value to be too high, even with no trust delay. We set this as the medium category threshold and set the low category threshold to half

Table 1 Notional values used in all of the operator performance model experiments

Input	Variable	Notional values for experiments
Max number of operators	*k*	5
Operator assessment time	*AT*	45 s
Coefficient of variation in assessment time	*C*	0.1 (assume standard deviation is 10 % of a mean with Gaussian distribution)
Probability of assessment	P_A	Range from 0.6 to 1.0 in 0.1 steps
Lag time for task switching	*LT*	1 s
Trust delay time categories	*TDT*	Low: 0 s (high trust, immediate response) Medium: 10 s High: 20 s
Alarm rate categories		Low threshold: 960 alarms/day or 40 alarms/hour Medium threshold: 1920 alarms/day or 80 alarms/hour High threshold: >1920 alarms/day
Sensor alarm rate		$12 * (P_S)^2$
Sensor probability of detection	P_S	Range from 0.3 to 0.9 in 0.05 steps
Response force time		70 s (assume standard deviation is 10 % of a mean with Gaussian distribution)

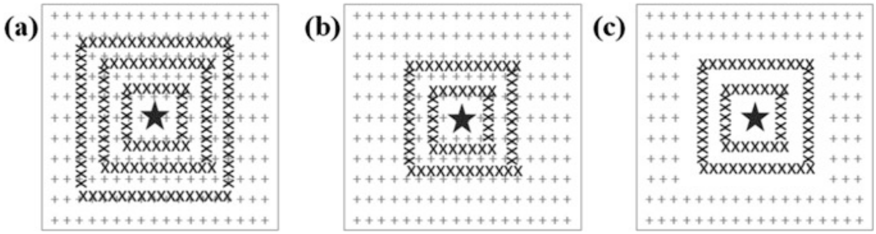

Fig. 2 The PPS architectures for Trust/No Trust Delay (**a**) and Low Sensor (**b**) High Sensor (**c**) experiment conditions. The target is protected by fences and sensors

of that value. Increasing sensory sensitivity increases the rate of nuisance alarms [2], so we created the sensor alarm rate function (Table 1) to generate a range of alarms based on the P_S, from 1 alarm at $P_S = 0.3$ to 10 alarms at $P_S = 0.9$.

We performed two experiments: one which included trust delay in the assessment time and one that did not. First, the highest P_I PPS architecture with no trust delay was generated (Fig. 2a) and was used to compare the impact of no trust delay versus trust delay on system performance. Second,, the highest P_I PPS architecture with trust delay was generated (Fig. 2b) and compared to a second design with fewer sensors (Fig. 2c) to analyze the trade-offs in system performance P_I, ten-year cost, number of operators, P_S, and the NAR.

5.1 No Trust Delay Versus Trust Delay

The baseline architecture for this experiment is three fences surrounding the target with 272 sensors (NAR/FAR range 272–2720 alarms/day) across the site (Fig. 2). The best $P_I = 0.9992$ with 3 operators. The operator performance model varies the number of operators, P_S, and P_A. The step effect seen in the graph in Fig. 3 is due to

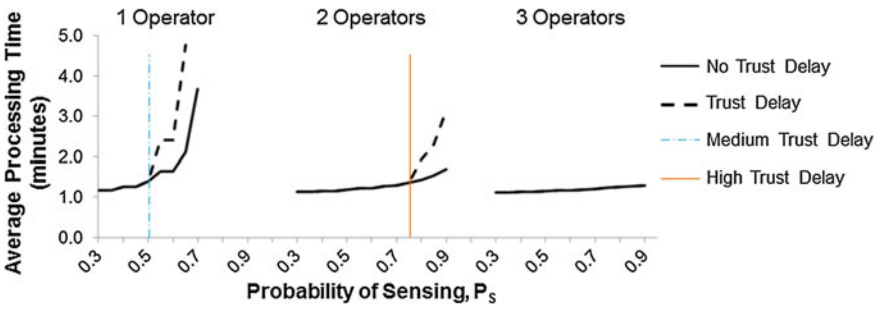

Fig. 3 Average processing times for a single alarm (in min) for the no trust/trust delay conditions. No trust/trust delay have the same values for the three operator group. Four and five operator groups have similar results to the three operators, so they are not shown

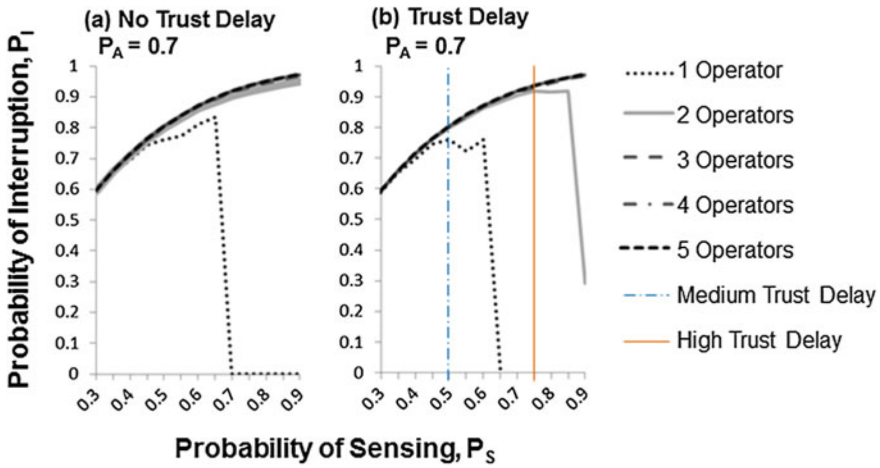

Fig. 4 System performance for operator P_A = 0.7 improves as the P_S increases. The higher NAR levels have a negative impact on one to two operators. In both conditions, three to five operators have the same values

increases in P_S that are not significant enough to raise the NAR per the sensor alarm rate function (see Table 1).

No Trust Delay Condition. This experiment excluded the trust delay time from assessment times to establish a baseline and to show the impact of the queueing model. Figure 3 shows the average processing time for a single alarm, which includes the queue wait time and the operator assessment time. The higher times indicate a longer queue. The queueing model shows that even at the low alarm rates, the average processing time is higher than the operator assessment time due to queue wait times. With the notional values used, one to two operators are most sensitive to increasing P_S (which increases the NAR), with minimal impact on operator groups of size three to five.

The higher alarm processing times negatively affect system performance in terms of P_I. Higher P_S lead to higher P_I for all P_A, as seen in Figs. 4a and 5, a for three to five operators. However, the increased alarm processing times for one to two operators reduce the maximum P_I that can be achieved. When P_I drops to zero, the NAR level overwhelms the operator, who can no longer clear the queue.

Trust Delay Condition. The effects of the trust delay are seen for one to two operators (Fig. 3). For one operator, the processing time jumps when the medium trust delay time is added. For two operators, the processing time jumps when the high trust delay time is added. Trust delay has no impact on three to five operators, which have the same processing times as the no trust delay condition.

As in the no trust delay condition, the increase in alarm processing times impacts the maximum P_I that can be achieved. The dip in the one operator P_I curve in Fig. 4, b is caused by the addition of the medium trust delay and occurs for all P_A. The decline in the P_I curve for two operators is caused by the addition of the high

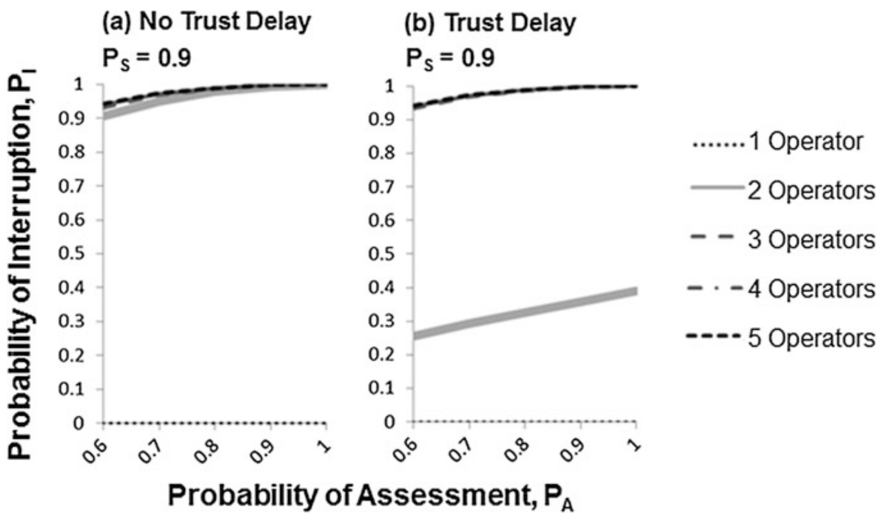

Fig. 5 Comparison of system performance P_I when $P_S = 0.9$ for the no trust/trust delay conditions as operator P_A increases. $P_I = 0$ for one operator. In both conditions, three to five operators have the same values

trust delay and is most visible for the lower $P_A = 0.6$ and 0.7. Figure 5, b shows that for the highest NAR level ($P_S = 0.9$), the longer processing times for two operators (Fig. 3) greatly reduce the system's P_I for all P_A.

5.2 *Low Versus High Number of Sensors*

The baseline architecture for this experiment is two fences surrounding the target (Fig. 2b, c). The high sensor architecture has 324 sensors (NAR range of 324–3240 alarms/day) across the site and has a ten-year cost of \$115 M. The best $P_I = 0.9995$ with five operators. The low sensor architecture has a sensor gap around and within the fences to simulate a work area that is not alarmed in order to avoid nuisance alarms. The best $P_I = 0.9898$ with three operators, 184 sensors (NAR range of 184–1840 alarms/day) and has a ten-year cost of \$67 M.

Let us assume a goal of $P_I \geq 0.8$. Initially, we assume an operator $P_A = 1.0$. We exclude the single operator (Fig. 6a) because he can only achieve the target P_I for a narrow band of P_S. In the low sensor solution, two operators can achieve $P_I \geq 0.8$ (Fig. 6b). The high sensor solution achieves better system performance at lower P_S, but eventually the two operators' P_I declines to zero. For the low sensor with two and three operators, the performance curves are almost identical. Therefore, the low sensor solution with two operators appears to be the better choice since it is significantly cheaper and has lower NAR than any high sensor solution.

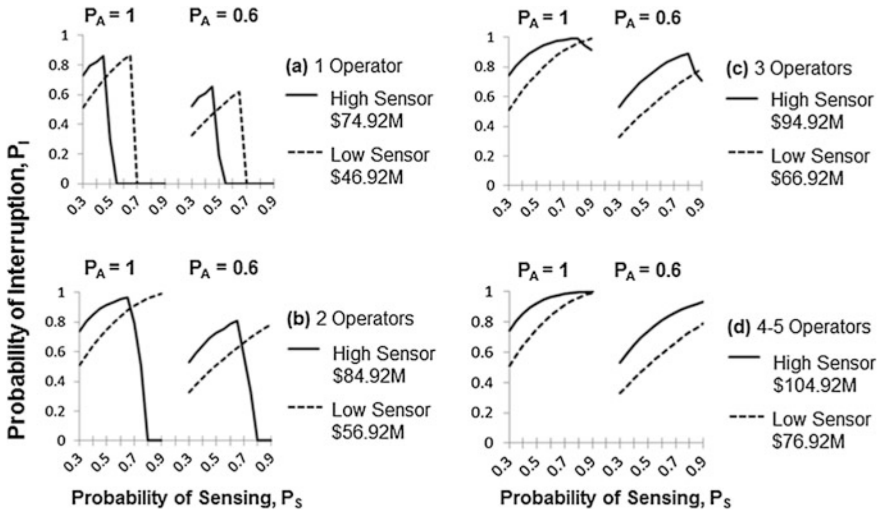

Fig. 6 Comparison of system performance P_I for the low/high sensor solutions when operator $P_A = 0.6$ and 1.0. In both conditions, five operators have similar performance to four operators

What if operator $P_A = 0.6$? The low sensor solution can never achieve $P_I \geq 0.8$. With three operators, the high sensor solution meets the target, but P_I eventually drops below the target (Fig. 6c). With four operators, the high sensor solution meets the target (Fig. 6d). The high sensor solution with four operators achieves the best system performance, but costs $105 M. The system owner will need to decide if the increased performance warrants the increased cost and higher NAR.

6 Conclusion and Future Work

With limited budgets, sites are searching for technologies that can reduce the number of staff employed, thereby reducing the overall cost of the security system. However, more technologies and sensors will increase the nuisance and false alarm rates (NAR/FAR), which in turn will require more operators to maintain current system performance levels. While analyses of security systems often ignore operator performance, its inclusion is important to improving the accuracy of system performance estimates. Our illustrative analysis demonstrates that current methods that do not account for operator performance produce optimistic estimates.

First, the queueing model shows that even at the low alarm rates, the average alarm processing time can be higher than the operator assessment time due to queue wait times. In our illustrative analysis, the lowest processing time was well above the assessment time, even for the larger groups of operators.

Second, system owners need to consider the current alarm rate generated by their system and the additional alarms generated by new technologies. There is a maximum the number of alarms that can be assessed during a day, which can lead to missed detections when the system alarm rate exceeds this threshold. Our model can help system owners understand where these thresholds occur.

Third, operator assessment performance can have a major impact on system performance. If we assume an overly optimistic assessment performance when analyzing architectures, then the system performance will also be lower than anticipated.

Future work will include adding alarm priorities in the queueing model and adding response rate to the probability of assessment in our model, which adds the scenario where operators silence alarms without assessment. There are many more details that can be added, but adding more realism to the operator's probability of assessment requires more studies. There is limited data on how well alarm station operators can detect a target against various backgrounds on a video monitor. Studies are needed to obtain a baseline of operator assessment performance, including the impact of factors such as the vigilance decrement, the work environment, and the psychophysical characteristics of the assessment tasks.

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Facing Disasters—Trends in Applications to Support Disaster Management

Mário J. Simões-Marques

Abstract Disaster Management is a complex process, usually dealing with a large amount of uncertain, incomplete and vague information, which normally requires the coordination and collaboration among a variety of actors. Technology offers new and exciting opportunities to deal with these challenges, but also may create new types of challenges that can overwhelm decision makers. The paper will offer insights on the innovative trends that can be found in applications designed to support disaster management addressing, in particular, the approaches that address preparedness and response stages. The work will look at the characteristics of different types of human interaction proposals considering applications, such as "serious games" for the preparedness phase or collaborative distributed intelligent systems for the response phase.

Keywords Emergency management · Serious games · Crowdsourcing · Information sharing · Multimodal interfaces

1 Introduction

Disasters are a constant threat to human society, causing millions of victims and billions of US dollars of economic damages. Statistical reviews, like the one by Guha-Sapir et al. [1] based on data compiled on the International Disaster Database (EM-DAT), offer a perspective about the dimension of this problem. According to these authors, considering the decade 2004–2013, there was an annual average of approximately 200 million victims (i.e., the sum of deaths and total people affected) and of US$162.5 billion of economic losses, resulting from an annual average number of 384 reported natural disasters around the world (excluding biological disasters). The number of reported victims peaked in 2010 (342 million and 297,598 deaths), the year of Haiti's earthquake. The estimated economic losses

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from natural disasters were as high as US$382.5 billion in 2011, year of the tsunami in Japan. The economic impact of a disaster usually consists of direct consequences on the local economy (e.g. damage to infrastructure, crops, housing) and indirect consequences (e.g., loss of revenues, unemployment, and market destabilization). This is, however, just part of the picture since, besides natural disasters, there are also man-made disasters (e.g., fires, transport accidents, industrial accidents, oil spills and nuclear, biological, chemical or radiological events) which are also source of high number of victims and economic losses. Quarantelli et al. [2] while trying to categorize all disasters and crises into a systematic conceptual framework, note that man-made disaster can be accidental (e.g., technological disasters triggered by natural hazards) or deliberate (e.g., conflicts, terrorism, criminal).

According to the United Nations International Strategy for Disaster Reduction [3] disaster means "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" and emergency management means "the organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps."

Such disruptive impacts justify that a large number of actors (civilian, governmental and non-governmental) combine efforts to prevent the onset of a disaster, and plan and implement the reaction to disasters.

Most organizations and literature[1] concur with the existence of an emergency (or disaster) management cycle composed of the four phases—Mitigation, Preparedness, Response and Reconstruction (or Recovery). In the present paper the author will focus mainly on the Preparedness and Response phases. Preparedness is the stage where strategies are put into place to prepare the community and to allow the implementation of a successful operational response should one disaster occur. Response is the stage immediately after the strike of a disaster, corresponding to the employment of resources and emergency procedures to preserve life, property, the environment, and the social, economic, and political structure of the community.

Disaster Management is a complex process, usually dealing with a large amount of uncertain, incomplete and vague information, which normally requires the coordination and collaboration among a variety of actors. There are many non-technological issues, for instance organizational [5], political (e.g., lack of trust and effective partnership with the business community [5, 6]), cultural (e.g., see [7, 8]), gender-related (e.g., see [9, 10]), or inclusion of people with disabilities (e.g., see [11]) that complicate disaster management. These issues are particularly common in the context of large international disaster relief operations, but exist also at national level. A study by the U.S. National Academy of Sciences notes that

[1]For instance, Baird wrote an interesting overview which provides some insight for each phase of emergency management, the temporal versus functional distinctions, and the importance of interrelationships and responsibilities for each phase [4].

> During the Tsunami in Tamil Nadu, strong internalized values of nudity and shame prevented women from running to safety as their *sarees* had been removed by the sheer force of the waves. The women preferred to drown rather than come out of waters without their clothes. Since the incident many of them have started using inner wear as it will provide minimal cover in case they have to discard or raise their *saree* and run.

Fig. 1 Example of amplified disaster consequences due gender-related cultural values (*Source* [9])

"*disaster response faces several organizational themes, such as the strong tension between central authorities with hierarchical control over disasters, and the distributed nature of most disasters; or building trust among the various actors involved in responding to a disaster. Organizations must be able to form quickly and work well together across space and time; and they must be able to adapt and resize easily as the disaster develops*" [5].

Therefore, disaster response decision-making complexity is multidimensional: ad-hoc organizations have to cooperate in a stressful environment to hastily process large amounts of imprecise information, considering many constraints inherent to innumerous factors. Some of these constraints result from the location, type and impacts of the events, and the resources' characteristics and scarcity; while others, often forgotten, result of incorporating cultural sensitiveness factors in the decision process (e.g., gender equality and equity, policy barriers). In fact, gender issues are very important in some cultures (for instance, medical caregivers acceptability is gender dependent). Figure 1 highlights the reason for existence of more casualties among women in a disaster that stroke the southeast of India. As noted in [9] there is the need to always wear a gender lens while Assessing and Analyzing, Planning and Designing, Implementing, Monitoring and Evaluating.

A totally different example are policy-related constraints, such as the existence of operational caveats imposed either by or towards disaster responders. For instance, there were reports from the Katrina Hurricane disaster relief operation, pointing that foreign medical personnel deployed to the area was not authorized to practice medicine and to assist victims' needs, since they didn't had the formal certification of US health authorities required for regular medical practice on US soil.

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Nevertheless, technology offers new and exciting opportunities to deal with the aforementioned complexity challenges, but also may create new types of challenges that can overwhelm decision makers, which need to be considered.

The paper will offer insights on the innovative trends that can be found in applications designed to support disaster management addressing, in particular, the approaches that address preparedness and response stages. The work will look at the characteristics of different types of human interaction proposals considering applications, such as "serious games" for the preparedness phase or collaborative distributed intelligent systems for the response phase.

2 Foresight

Many national, international, non-governmental and civil society organizations devote efforts to gain insights on what the future holds, to define strategies, reduce risks, ensure resilience and business continuity and prepare courses of action to respond in the event of disruptive situations. Example of prospective studies are the ones produced by the United Nations (UN) [3, 12], the North Atlantic Treaty Organization (NATO) [13], the European Union [14], the OECD [15] the U.S. National Academy of Sciences (NAS) [5, 16], or by the U.S. Federal Emergency Management Agency (FEMA) [17].

All such studies point to a future of transition (from a unipolar world to a quite unstructured relation of powers) characterized by a rapid changes, uncertainty, globalization and complexity. This scenario brings many dangers (e.g., political tension, ideological polarization and fractured identities; impacts of changing demographics, migrations and increased urbanization; disruptive social effects of technologic evolutions on human employment and the risk of advanced technologies accessibility by malicious non-state actors; increased resource scarcity and economic inequality; devastating impacts of natural disasters exacerbated by environmental and climate change) which in a globally networked world tend to spread rapidly. However, technological innovation, behavioral change, and globalization also offer exciting opportunities to leverage digital technology, share ideas, and discover new resources.

Baubion argues that dealing the novel crises requires different approaches when compared with traditional crisis management [15]. For instance, considering the Response Phase traditional crisis management, is based on command and control systems, standard operating procedures, strict lines of responsibilities, sectoral approaches. However, dealing with novelty calls for expertise in crisis identification/monitoring, flexible and multi-purpose crisis management teams and facilities, common concepts across agencies to inform leadership with high adaptive capacities, similar tools and protocols that could be utilized for multi-crisis, international cooperation, and the management of large-response networks.

FEMA recognizes that emergency managers will need to optimize resources, anticipate events, or deal with complex and/or unprecedented problems, and in the domain of innovative models and tools identified opportunities [17], for instance, for the: (i) adoption of new risk management tools and processes in order to manage cascading consequences of interactions among infrastructure and all hazards; (ii) employment of alternative surge models to meet the challenging confluences of social, technological, environmental, economic, and political factors and conditions; (iii) establishment of flexible frameworks that optimize emergency management interoperability across all boundaries; (iv) planning and coordination around shared interests and interdependencies to exercise the entire range of emergency management capabilities.

The same FEMA foresight study elaborates on the importance of building and strengthening partnerships, considering all society levels [17]. This requires empowering individuals (both as volunteers and in social networks as information producers and consumers), engaging communities to play a greater role throughout all phases of disasters, and intensifying inter-agency and international disaster-response collaboration and planning, and fostering increased collaboration to ensure appropriate use of the military to provide specialized capabilities or to augment capacity in complex, overwhelming disaster incidents.

Regarding the last topic, it is worth noting that emergency management personnel has to be prepared to use military assets that are appropriate for emergency situations and, conversely, military personnel needs to be proficient in emergency response [5, 17, 18], since there is a strong relationship between the roles of supported and supporting actors, considering the crises/conflict spectrum continuum, which is illustrated in Fig. 2. Notice that disaster relief operations may either

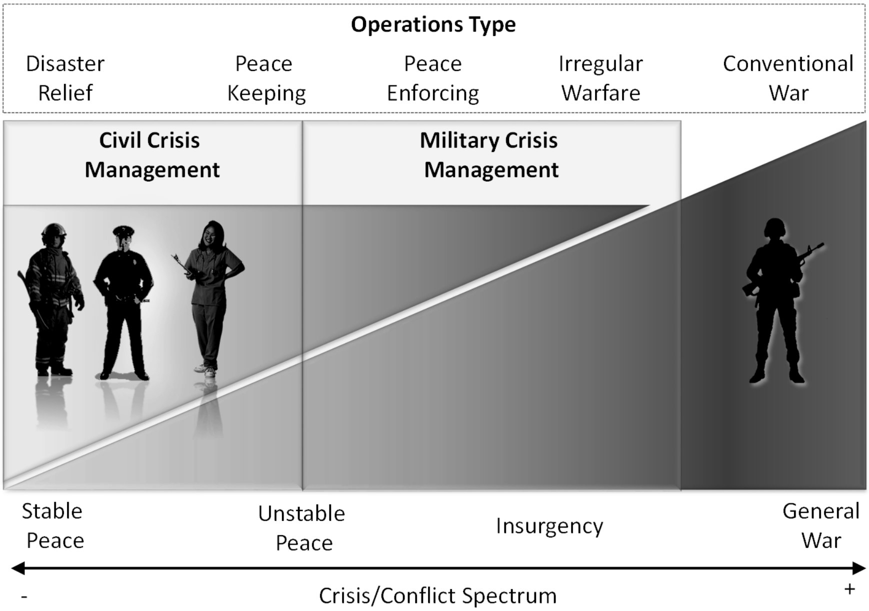

Fig. 2 Roles and response operations types versus the crisis/conflict spectrum

occur in a permissive environment (e.g., disaster relief operations or peacekeeping, stabilization, reconstruction and development operations) or may have to be conducted in a non-permissive environment, as is the case of peace enforcement operations [19].

In fact, the military ensure an organizational model for managing extremely complex and distributed activities, which reflects the development over many years of a clear sense of what to centralize and what to decentralize [5]. From the technological standpoint, the military have the means and the experience of conducting distributed network-centric operations where the flow of information through the different level of the hierarchical chain is central.

3 IT Opportunities and Challenges

About a decade ago, in the aftermath of Hurricane Katrina, a report produced by US National Academy of Sciences [5] stressed the importance of disaster management and highlighted the role of information technology (IT) in disaster management. The same report stated that "*IT provides capabilities that can help people grasp the dynamic realities of a disaster more clearly and help them formulate better decisions more quickly*"; and concluded that "*IT has as-yet-unrealized potential to improve how communities, the nation, and the global community handle disasters" and "disaster management organizations have not fully exploited many of today's technology opportunities*." The report authors produced and elaborated on ten recommendations for improving disaster management, which included the pursuit of six key IT-based capabilities [5]:

- More robust, interoperable, and priority-sensitive communications
- Improved situational awareness and a common operating picture
- Improved decision support and resource tracking and allocation
- Greater organizational agility for disaster management;
- Better engagement of the public;
- Enhanced infrastructure survivability and continuity of societal functions

The implementation of such capabilities was pointed in [5] as enabler of a flexible strategy of resilience and adaptability to the dynamics and inherent complexities of disasters. This also requires the adoption of simulation systems to support the training disaster management professionals; the capturing and dissemination of lessons learned; the use of credentialing and identification tools for managing the flow of personnel in and out of incident areas to improve the efficiency of response and recovery operations; the evolution of information sharing towards distributed processing of continual messaging-streams fed by pervasive sensors, providing real time situational awareness data; the shift from command models of resource management toward negotiated "brokerage" approaches; coping with a "managed ad-hoc-racy" of disaster management and responder organizations that can evolve seamlessly and continuously over the entire course of a disaster; and leveraging the public as providers of information and sources of valuable technology tools [5].

On the same lines, FEMA refers some emerging technologies that advance emergency management capabilities such as the Unmanned Aerial Vehicles (UAVs) and robots (which provide powerful search and rescue capabilities) or the pandemic sensors (which offer early warning of disease outbreaks); and identifies the need of a common set of standards that allows maximizing interoperability and asset sharing in disaster relief operations [17].

National Academy of Sciences four state-of-the-art technologies and methods that relate directly or indirectly to disasters informatics issues: computing and communications technologies; geospatial and temporal methods; modeling and simulation; and laboratory or field gaming experiments [16].

It is possible to observe that research and industry is somehow confirming the foresight and is providing solutions that can be used in support of disaster management, particularly considering the response phase. The following lines address some examples of relevant domains and initiatives that illustrate this trend, without the intention of being particularly exhaustive and well structured.

3.1 Information Sharing and Computing and Communications Technologies

Information sharing is a problem domain that is at the crossroad of many others.

Information sharing requires data sharing which implies technical capabilities (including data standardization, collection and analysis, archiving, and sharing) to disseminate findings in "user-friendly" ways and through multiple media [16]. This issue is related with a variety of issues that encompass the existence of platforms for sharing information, ensuring interoperability between different systems, the ability to source data, to collectively extract information and knowledge, and to support distributed and ad-hoc disaster management organizations.

Standardization is a quite specific area of expertise, which benefits the entire community. Considering the work done by the International Organization for Standardization (ISO) in the specific domain of Emergency Management is it possible to identify a series of standards that include ISO 22320, ISO 22322, ISO 22324, ISO 22351, and ISO 22951.

Some of the emerging domains in the information sharing domain are crowdsourcing, and collective intelligence [20–25]. For instance, Gao et al. [21] describe the role that crowdsourcing played in the response to the catastrophic events such as the 2010 Haiti earthquake, and the 2011 Japan earthquake and tsunami. Since then many other examples can be accounted, such as the recent terrorist attacks in Paris and Brussels.

Table 1 Synthesis of examples of websites and references that refer to a set of relevant emergent technological disaster management topics

Topic	Websites	References
Apps	http://prepared-housewives.com/emergency-apps-that-might-just-save-your-life/	
Crowdsourcing/collective intelligence/knowledge	https://www.ushahidi.com/ http://quakemap.org/ https://www.google.org/crisisresponse/ https://geofeedia.com/ http://www.un-spider.org/	[20–25]
Emergency management systems	https://www.alert.sa.gov.au/map http://emergency.copernicus.eu/	[5, 16, 37]
Information sharing/platforms	https://www.ushahidi.com/ https://data.hdx.rwlabs.org/ https://humanitarian.id/ http://reliefweb.int/ http://www.gdacs.org/ https://www.humanitarianresponse.info/ http://digitalhumanitarians.com/ https://ftsbeta.unocha.org/	[25]
Modeling and simulation	http://i2sim.ece.ubc.ca/ http://www.sandia.gov/nisac/	[16]
Serious games/multimodal interfaces	http://www.gamesgames.com/game/red-cross-emergency-response-unit http://www.stopdisastersgame.org/	[27–30] [31–33]
UAVs/drones		[34–36]

Regarding web-based platforms, a host of international, non-governmental, and private organizations, directly or indirectly engaged in humanitarian assistance and disaster relief, are offering web platforms intended for use by disaster responders and the general public. Table 1 offers a list of internet addresses that can be accessed to find examples of different types of platforms already available.

Information sharing is critically dependent of computing and communications technologies. During the past decades there was notorious changes in this area that combine increased computing capacity and portability with affordable and ubiquitous access. In fact, the tablets and smartphones of today, are as powerful as desktop computers were a decade ago, and the virtually ubiquitous internet is shifting social, educational, organizational and laboral paradigms. As noted in [26] the generalized use of mobile devices is leading organizations to allow their collaborators to use personally owned devices to access business information and applications, with significant gains in productivity. This practice is designated BYOD (bring your own device). Another new trend related with this, is the one where people use applications which are obtained in the cloud (and not necessarily provided or defined by the organization responsible for the activity—e.g., employer). This practice is designated BYOA (bring your own applications).

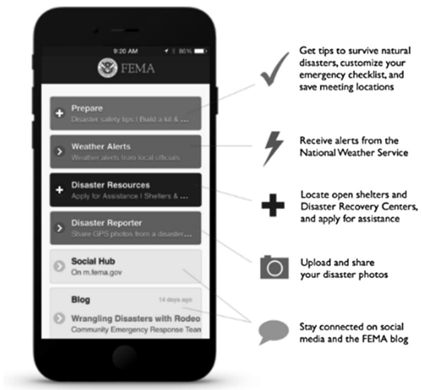

Fig. 3 FEMA App, available for Apple, Android, and Blackberry mobile devices

Therefore, disaster/emergency management is increasing evolving from traditional information systems to an "ad-hoc" mix of traditional systems and BYOD/BYOA tools.

Crowdsourcing and BYOA is possible as a result of the development of mobile apps that explore the ubiquity of mobile devices. There are cooperation initiatives such as the Global Disaster Alert and Coordination System (GDACS), combining United Nations, European Commission, and disaster managers and disaster information systems worldwide. GDACS aims at filling the information and coordination gap in the first phase after major disasters, by providing real-time access to web-based disaster information systems and related coordination tools. An integral part of the system are the iGDACS and GDACSmobile apps which are dedicated to provide automatically geo-located photos and text messages designed to perform over both low and high bandwidths, allowing for a *combined* crowdsourcing and "bounded crowdsourcing" approach to data collection and curation. Figure 3 illustrates another example of mobile app, in this case made available by FEMA.

As the report [16] from the National Academy of Sciences stresses modelling and simulation is another topic that is quite relevant for the design of the different elements of this system.

3.2 Serious Games and Multimodal Interfaces

Other very active IT domain is the field of simulation, training, gamification.

For instance, the United Nations International Strategy for Disaster Reduction (UNISDR) provides the Stop Disasters game, where players attempt to build disaster-resilient communities while also achieving development goals (e.g., building infrastructure).

There is a significant amount of literature addressing the thematic of serious games (e.g., [27, 28]) namely in the context of disaster management (e.g., [29, 30]).

The development of serious games is closely related with the development of applications that call for mixed reality (i.e., augmented and/or virtual reality) and multimodal systems.

Virtual reality are applications which immerse the users in a virtual world, while augmented reality overlays digital information onto an image of the physical world. On January 2016, Goldman Sachs under the series "Profiles in Innovation" published a report named "Virtual and augmented reality have the potential to become the next big computing platform", where the authors argue how mixed reality applications can reshape existing ways of doing things.

In the disaster management domain, an example of mixed reality games is the one presented by Fischer et al. created to investigate coordination in disaster response [31].

Multimodal systems base their human-system interactions on the recognition of human speech, gaze, gesture, and other natural behavior. Therefore the conventional "windows, icons, menus, pointer" graphical user interfaces (WIMP GUI) are evolving to natural user interfaces (NUI) which accommodate alternative types of interaction, such as the reaction to multi-touch or gestures.

Gouin and Lavigne offer a very interesting overview on the trends in human-computer interaction, in the context of Command and Control systems, which addresses multimodal systems in a quite thorough way [33].

3.3 UAVs/Drones

There are many emergent domains that can contribute to raise situational awareness in the period immediately after the onset of a disaster and also to provide fast logistical support for emergency response.

Despite very brief, among all such emergent technologies is particularly worth of mention the UAVs and drones, which use is becoming quite generalized.

In fact, the technological evolution of UAVs and drones is offering unprecedented opportunities for the application of this type of systems in support of disaster relief operations.

Some of the category characteristics, payloads, applications, and types of control are discussed in [34–36].

4 Conclusions

Disaster Management is a complex process, usually dealing with a large amount of uncertain, incomplete and vague information, which normally requires the coordination and collaboration of a variety of actors. Technological evolution offers new and exciting opportunities to deal with the overwhelming challenges that decision makers have to face, particularly during the disaster response phase.

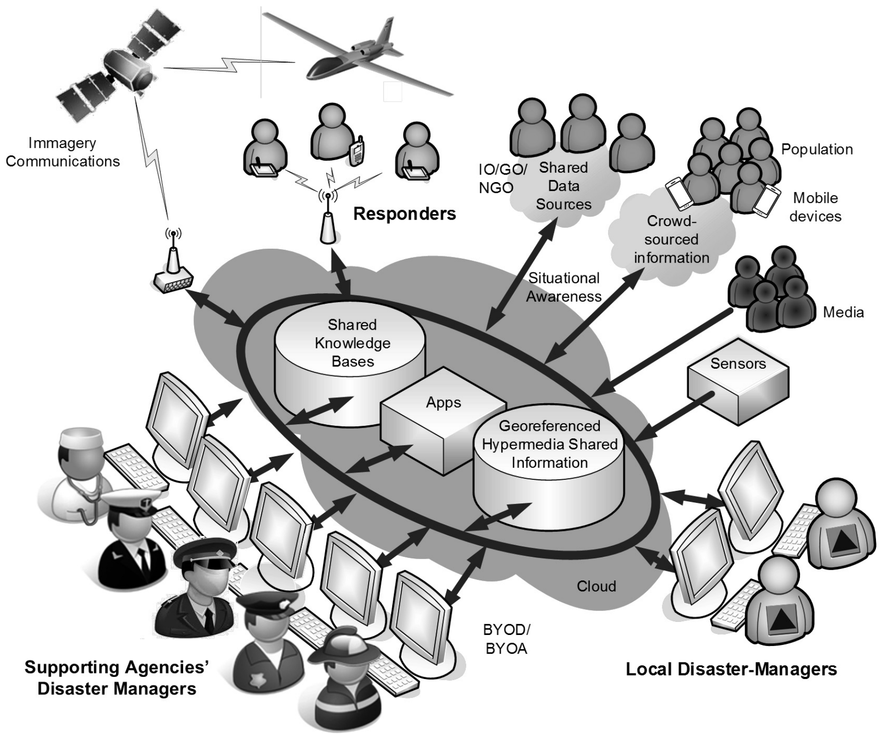

Fig. 4 High level view of the virtual network used to support the disaster response cooperative decision-making process

The introduction section characterized the disaster management context.

The following section presented the foresight of several international organizations, particularly regarding the opportunities and challenges of information technology in disaster management.

The third section offered a brief overview of topics which were grouped under the following thematics: (i) Information Sharing and Computing and Communications Technologies collaborative; (ii) Serious Games and Multimodal Interfaces; and (iii) UAVs/Drones. Table 1 complements the text with examples of websites and a synthesis of references that refer to a set of relevant emergent technological disaster management topics.

Finally, since "a picture is worth a thousand words", Fig. 4 presents a conceptual image of a distributed intelligent systems to support the disaster response phase.

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Part IV
Computing Technologies for Teams Dealing with Dynamic Environments

Accessibility, Adaptability, and Extendibility: Dealing with the Small Data Problem

Travis Bauer and Daniel Garcia

Abstract An underserved niche exists for data mining tools in complex analytical environments. We propose three attributes of analytical tool development that facilitates rapid operationalization of new tools into complex, dynamic environments: accessibility, adaptability, and extendibility. Accessibility we define as the ability to load data into an analytical system quickly and seamlessly. Adaptability we define as the ability to apply a tool rapidly to new, unanticipated use cases. Extendibility we define as the ability to create new functionality "in the field" where it is being used and, if needed, harden that new functionality into a new, more permanent user interface. Distributed "big data" systems generally do not optimize for these attributes, creating an underserved niche for new analytical tools. In this paper we will define the problem, examine the three attributes, and describe the architecture of an example system called Citrus that we have built and use that is especially focused on these three attributes.

Keywords Human factors · Text analysis · Data mining · Analytical tools

1 Introduction

Data mining needs for national security are complex. The industry has seen analytical tool capabilities evolve quickly over the years. A decade ago, the ability to perform modest text analysis over several thousand documents on an individual desktop was considered an accomplishment and large scale distributed computing

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required highly specialized hardware and staff with engineering degrees. Today, a high-end but still stock laptop can process millions of documents and a bright high school student can set up a basic Hadoop cluster.

Current conventional wisdom has led many information technology departments serving analytical environments to focus on building large scale, distributed computational systems. There are advantages to this. Consolidating analytical capabilities into a centralized, shared location reduces the need for individual deployments of software and distribution of data. Consolidating makes the system and data easier to manage. Having a single location to "update everything" makes it easier for an IT department to deploy new capabilities on a wide scale.

It might seem that this would lead to rapid deployment of new analytical capabilities. After all, if an IT department can put new capabilities in a single place and have them immediately widely available, this should improve the rapid operationalization of new analytical capabilities.

On the one hand, this approach may work for certain computing technologies such as web-based email. In these kinds of situations, the solutions offered are generally "one size fits all" and there are a predictable number of identical operations needed by each user. For analytical needs that fit this description, such engineering solutions work.

On the other hand, in analytical computing contexts where questions and data sets change rapidly, centralization of computing capabilities can be problematic. Individual analysts have unique and rapidly changing requirements. In order for tool developers to address unique aspects of new problems, high degrees of customization are necessary but not practical with a centralized application.

Analytical tool development for a rapidly changing environment needs to have a high degree of accessibility, adaptability, and extendibility.

- Accessibility: Rapid operationalization of analytical tools requires that a user, who is usually a subject matter expert in the data but not necessarily in the tool or the algorithms, be able to analyze new data quickly in their environment as a normal part of their day-to-day work.
- Adaptability: A tool needs to cover a wide range of use cases that the developers might not be able to anticipate. If the range of use cases supported is too small, the tool may have very limited use. If the range is too large, the tool could be difficult to use and it may not get used at all.
- Extendibility: To cope with a complex dynamic environment and evolve with the data and needs, an analytical tool must have the capability of being easily extended "in the field." This means that a developer or a "power user" could add new functionality to the tool where it is deployed.

Because large, distributed shared systems do not optimize on these attributes, a niche is open for software that excels in these three areas. A properly engineered rich client application has these attributes. We present a way of engineering a rich client library and suite of applications with these attributes.

2 Analytical Environments Can Be Complex and Dynamic

In complex analytical environments, analysts are often confronted with more data than they can manually analyze and questions that they cannot easily address with a small set of queries. Analysts must do their job by assembling bits and pieces of information from multiple sources, none of which may be obvious.

In addition to being complex, these environments are also dynamic. The questions and focus can quickly change; what was an important question yesterday might not be important today.

In these kinds of environments, it has to be possible to operationalize new ideas quickly in the form of analytical tools. The team may not have a long time to determine if a new analytical idea is going to be of any use. Imagine that during a team's brainstorming meeting, someone comes up with the idea of applying a particular algorithm to some data. If, before the idea can be tried, the team has to draft requirements, those requirements have to be checked against a host of tool development efforts to see if anyone else might be able to implement the requirements, a team has to design a user interface, algorithms have to be implemented, testing has to be done, the prototype tools has to be tested for an extended period of time in a "qual" environment, vetted against the original requirements, and signed off by administrative leads before the tool will be of any use, the team may have already moved on to a new problem. An idea for new analysis might have a short half-life.

3 Distributed Computing Leaves a Niche

We would like to suggest that the community's current focus on building "big data" systems is part of the problem. There has been a major emphasis over the last decade in building large distributed systems to help deal with "big data."

In the last several years, high performance, distributed computing became more accessible due to systems like Hadoop [1]. It used to be that in order to do high performance, distributed computing, you needed specialized hardware, proprietary software, and a lot of money. It is now the case that a bright high school student can build a distributed computing cluster using open source software. You could even build a small cluster on something as small as a Raspberry Pi.

Centralized computing makes configuration management easier. It is much easier, more manageable, and arguably safer to put your software in one place and have a whole institution access it, rather than having everyone acting independently. When you update your web interface, everyone who uses that interface instantly gets the latest version of your software.

While on the one hand, those are valid and useful arguments, what makes large scale distributed computing useful also creates problems. Those problems become especially apparent in contexts like the ones we are emphasizing here. Complex, dynamic environments require that new tools be operationalized quickly.

One problem is that the modularity inherent in large scale distributed computing can create the illusion of a finished product. One group of people might focus on data ingestion independently of how that data is going to be used. Another group might build an interface using small amounts of simulated data. Another group might focus on efficient networking among the computers without having tested where the chokepoints are going to be in practice. Each of these activities—data ingestion, user interface, and networking—is important and difficult to tackle. However, when there is no single, complete product, it may be possible for one group to finish their job successfully without having a clear idea of how it connects to the other parts of the engineering process. All this is taking place while the user is waiting to try new ideas. In a complex dynamic environment, this means delays in trying new ideas, which means that many potentially valuable ideas are never tried.

Another problem for a large, shared, distributed system is the cost of downtime. If a critical server goes down, quite a few people can be affected as it can stop work for whole teams. A natural response to this is to prevent developers from experimenting with new algorithms on the system because of the risk of instability. This inherently limits what people can do and makes it harder to adapt in a complex, dynamic environment.

Finally, a large, shared, distributed system also lends itself to a lowest common denominator mentality. Building an expensive shared resource will naturally focus on things that are common to the largest number of users of that system. Things that are most common are usually also the most obvious and easily anticipated.

4 Rich Clients

Rich clients, on the other hand, do not by nature have these problems. With a rich client, it is much clearer what the product is and what it does. No one would argue that a rich client analytical tool was completed if it was not possible to get data into it or if it did not have a user interface. It would be much easier, up front, to determine if the tool was usable.

Proximity to the user is critical for working in complex, dynamic environments. It should be apparent fairly quickly whether the tool is going to be useful or not and it should get out of the way if it isn't.

A tool running locally on a machine also has the opportunity to be dynamic. Because it is serving one person, it is possible for a locally run application to adapt or be reconfigured without affecting the whole office environment.

Our solution to improving the ability of new analytical tools to be rapidly operationalized in complex, dynamic analytical environments is rich clients engineered with accessibility, adaptability, and extendibility at their core. The rich clients have to be written in such a way that they have the attributes we have discussed.

5 Accessibility

It is common for an analyst to have some identified cache of data available locally. In a complex, dynamic environment, it is critical for it to be possible to load this data quickly into the tool. Situations are common where an analyst has some data that they want to analyze and to be sitting next to a large distributed system with no ability to load the data themselves. Therefore, there is plenty of computing horsepower, but effectively no ability to add data. However, if the user has the ability to get data into their analytic system on demand, then it is possible to rapidly adapt to changing problems and circumstances.

Neither the data import nor the analysis capability has to be perfect. The goal is not to have a perfectly finished product. Rather, the goal is to have something quick and reliable. Having the ability to ingest common office document formats such as text, PDF, HTML, RTF, and CSV files, and common office suite files is often sufficient to cover a significant number of use cases.

Secondly, having the ability to search through the documents and split them into different categories with some autonomous, manual, and semi-autonomous methods can let the user support a surprisingly large number of use cases. As with document import, this does not have to be perfect. It has to have sufficient ease of use that an analyst can use it with minimum training and the algorithms have to act in a predictable manner. The algorithms also have to function quickly enough that the user does not have to wait for results.

6 Adaptability

The software also has to be adaptable. By adaptable, we mean that it must be possible to recombine existing capabilities "in the field", in ways that were not anticipated "in the lab" when writing the software to address new use cases. It is ok if this recombining of capabilities requires programming expertise, but it also has to be the case that it must be possible to do this programming in the field. A scripting language is ideal for this kind of activity.

7 Extendibility

Over time, as the scripts harden and certain processes and algorithm combinations emerge as being particularly useful for the long term, it becomes important for more carefully thought out, permanent solutions to be developed. These more permanent interfaces will be less flexible, but easier and faster to use with the GUIs focused on specific applications. By writing the software with a careful modular structure, it should be possible to add new features, modules, specialized algorithms, and domain specific knowledge so that the analysts can be more efficient in highly specialized tasks without compromising the ability to ask the new kinds of questions as the environment inevitably keeps evolving.

8 Overall Architecture

We have designed, implemented, tested, and currently use a tool called "Citrus" as an example of an accessible, adaptable, and extendible tool. Citrus is a text analysis and data mining library written in Java. This library is packaged with a range of applications. Some of these applications are easy-to-use, requiring little or no understanding of data mining and text analysis. Also included are two scripting languages that require a fair degree of expertise, but allow use within a broad range of different applications.

Citrus provides accessibility by virtue of being able to easily ingest a broad set of different kinds of documents, including common office document formats, email, and CSV files. In its most basic form, users can point Citrus to a directory tree of many different kinds of files. Citrus will scan the directory tree, parsing and ingesting all the files it recognizes along the way. Common document sets' sizes are in the tens of thousands, although in specialized cases, such as Tweets, users can productively manipulate tens of millions.

Citrus provides adaptability by virtue of its scripting languages. Citrus comes with a custom language called "Pulp" which serves as a kind of "bash for text analysis." With Pulp, a user who is comfortable with a command line can create document analyses and perform various kinds of analyses. Citrus also comes with Groovy [2] built in. Groovy is a superset of Java, but works in a scripting manner. With Groovy, a user can write full pieces of software in Citrus because the full API is accessible. Scripting can be done "in the field," which means that on an analyst's desk or for an analyst, we are able to deploy new scripted capability quickly, which in turn lets us adapt to complex dynamic environments where new tools need to be operationalized quickly.

Citrus is also extendable. When a script starts to "harden" and its uses become clearer, it is possible to write full Java plugins. These plugins can then be added to Citrus in a variety simple and fast ways. There are various points of integration so that these modules function as part of Citrus itself, providing everything from extensions to the scripting language, to new menu items, to full-blown applications and new interfaces.

9 Framework

At the heart of Citrus there is a set of state-of-the-art, well tested, libraries that have general utility for data mining and text analysis. The centerpiece among these libraries is Lucene [3], a Java-based indexing and search library. It includes a well-established capability for tokenizing text and creating an index, which can then be searched using a query language.

Because we want Citrus to support a wide variety of different kinds of data formats, we have also integrated Tika [4]. Tika is a Java-based library that advertises it can extract text from over 1000 different file formats. This provides the core of the text document creation process, although it is not the sole means by which documents are prepared for ingestion.

For certain algorithms, Citrus relies on the Foundry [6], a Sandia-developed Java library of various machine-learning algorithms. Citrus also integrates a number of third party support libraries for various purposes, such as parts of Apache Commons' libraries [7] and Google guava [8].

10 Library

Although all of these libraries (most notably Lucene) have a variety of different analysis capabilities, none of these capabilities can serve as a full-blown text analysis and data mining application. In addition, although some of them (most notably Groovy) contain internal user interfaces, all of them are designed to be used by other applications or integrated into a larger application.

We have built on top of Citrus additional algorithms and analysis capabilities. For instance, Lucene does not provide basic text analysis data structures such as Log/Entropy vectors or mutual information computation over terms. However, it does, through its Java API, provide direct access to underlying data structures that make it easy to ask questions about how many times terms occur and their locations in documents. Citrus builds a layer on top of many of these data structures, implementing these more advanced computations.

Citrus has, at its core, a combination of an event-driven bus-like infrastructure so different parts of the application can talk to one another as well as a global application configuration and "engine" that ties together all the different parts of the system at runtime. They are engineered in such a way that developers can write isolated sections of code, such as how to display a particular class instance to a user or a particular algorithm. By registering it into the larger runtime, the new capability is automatically integrated and exposed to the rest of Citrus. This engine is also in charge of loading and integrating the various plugins. For this reason, developers can write specialized modules that might not get distributed with the system as a whole, but still get loaded into particular runtime environments. That way, a developer can write new algorithms and capabilities that integrated with the rest of Citrus without necessarily having to change or even have access to the core codebase itself.

11 Applications

If it were just infrastructure and algorithms, systems like Citrus would be like a variety of different text analysis libraries already in existence. Having algorithms and an infrastructure is a beginning, but it is not enough for operationalizing such capability in complex dynamic environments. To support that, we have a variety of user interfaces. Basic indexing, search, and other kinds of analysis capabilities are available "out of the box." Our goal is that with 20 min of tutorial, we can have the software installed on a person's computer, have them using basic capabilities analyzing their own data, and they can be functional in the software without us.

We do this through two interfaces built on top of Citrus. The first, called Clementine, is a basic search application. It is designed for a use case where someone wants to do basic searches on a corpus and does not want more sophisticated features cluttering up the environment. This is particularly helpful as an initial application for people who are averse to using complicated analytical tools. Even if a person does not spend a significant amount of time in this application, it is a great way to introduce people to the broader analytical suite. Anyone who can use an Internet search engine can use this application. Because Citrus can quickly analyze a user's own documents, users have a sophisticated search tool out of the box.

Clementine also offers one feature that starts to take people out of "search only" mode; a graphical display of relationships among terms and documents that they can grow by "expanding" a term or a document. The terms and documents selected are based on mutual information.

A second application, Durian, forms the "workhorse" of the suite for non-developers. This application encodes a workflow that we commonly observe among analysts working through an analytical problem with a large number of documents. The first stage in the workflow is to split the documents into subsets. The second stage is to browse the documents looking for those that help answer their analytical problem. The third stage is to sort or label the documents, often into some combination of "interesting," "uninteresting," and "need to ask more questions about this later" categories. Durian allows analysts to work through this kind

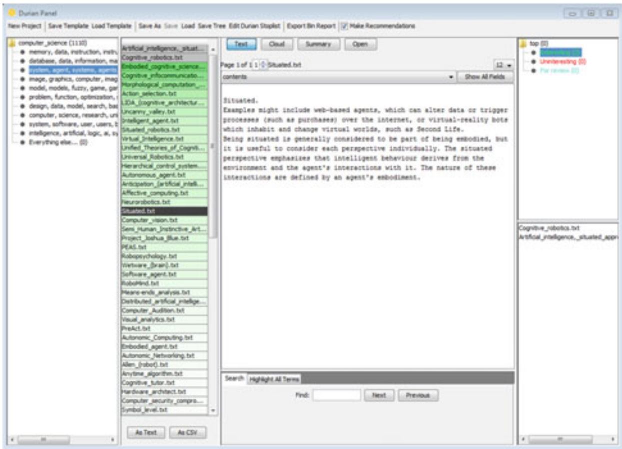

Fig. 1 Durian is an application that supports a workflow commonly observed among analysts

of workflow iteratively. To facilitate each of these stages, the interface lets users apply more advanced algorithms such as Latent Dirichlet Allocation, document comparison sorting algorithms as well as word clouds for document summarization. Users can use this without any particular expertise in the algorithms themselves or in the mechanics behind how the software works. It provides a powerful and intuitive way to sort through and examine documents (Fig. 1).

12 Scripting Languages

There are three common use cases where these easier-to-use interfaces are not enough. This is where scripting languages come in. The first is where developers are testing new functionality and want to try something quickly without generating new versions of the software or modifying the underlying code base. This may be for a "one-off" request, for debugging purposes, or an initial implementation of an algorithm for which we do not want to invest all the rigor we put into modifying Citrus itself.

The second use case that goes beyond existing interfaces is where we are "in the field" and want to quickly implement a new feature or do something nonstandard with Citrus. In earlier forms of this software, it was common for us to see a customer problem and know we were 20 lines of code from really being able to help. However, in order to accomplish those 20 lines of code, we would have to go back to our lab, modify the software, run all the release tests, and come up with a new version. With a scripting language, we can implement those 20 lines right on the spot. That can sometimes be a prelude to a new version of the software down

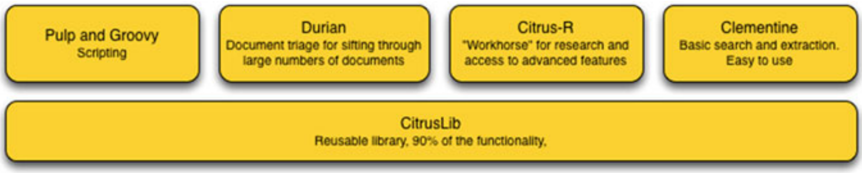

Fig. 2 Citrus diagram

the road with a better, more hardened user interface. Sometimes that script might be enough.

The third use case that is especially common has to do with data ingestion. It is common for raw text extracted from documents to contain some kind of internal structure or format. This format allows for custom parsing of the data which allows for better analysis. A section of each document may contain a date, for instance, or fields such as author, subject, keywords, etc. Tweets have hashtags. Other times there may be specific codes (e.g. serial numbers) commonly used among the documents that may need to be treated separately. These specialized formats are often idiosyncratic to each customer (Fig. 2).

13 Case Study

The following example explains how the system described in this paper offers the accessibility, adaptability, and extendibility needed to adjust to a complex, dynamic environment.

We were asked to look through a corporate network to try to find a certain category of information. "Look through the network" could mean a variety of different things, such as scanning databases, shared drives, web applications, etc. This category of information had data in some predictable formats, but was defined generally enough that although we certainly needed to do searches, we needed more than that; but exactly what we needed wasn't yet clear.

Because Citrus had a scripting language and a broad ability to ingest different kinds of documents, within 24 h we had written a script, applied it to parts of the network and had sample output. Although there were no significant findings, the output provided a good opportunity for us to discuss with the customer more specifically what kind of information they were looking for and the overall nature of the data through which we would be sifting. Already, with only a small amount of work, data was in the tool and accessible for analysis because of the adaptability of the tool.

Having discussed these early findings, we improved the script and performed a larger scale analysis. This yielded a significant cache of information. This new finding showed that a larger effort was worthwhile. It also raised questions about procedures and policies for what to do when we discovered more relevant information.

Having done this, we had a much better idea of what we were looking for, what kinds of data we would be searching through, and, for this particular problem, the very high false positive rate we would have when sifting through the data. We spent more effort developing a more sophisticated user interface, focused on this particular sifting problem, to make it easier to work through the false positives. We put this user interface to work and expanded the kinds of information we were looking for.

At that point, the customer had a good idea of the nature of their data, what they expected to find, etc. So they invested in a commercial product as a permanent solution. The relatively modest investment in using a tool like Citrus to explore the data initially helped them to understand the requirements for the commercial tool they would use later on.

In the course of doing this project, another analogous effort came up for which there was no good commercial software solution. At that point, a staff person from the customer started using Citrus on their own, with mostly email assistance from us, to perform this analogous task. He wrote his own extensions to Citrus and reported bugs back to us.

Finally, years later, we integrated a new advanced algorithm and released it with a new version of Citrus. It did not occur to us that the customer might be interested in this algorithm. To our surprise, we got an email, unexpectedly, stating that this algorithm was something they needed and Citrus provided an easy way for them to start exploring that space.

14 Conclusion

Our ability to quickly get data into Citrus and run initial tests with minimal investment, our ability to adapt Citrus to new situations which it was not originally designed for, and our ability to hand it off to others for use in ways we did not expect has yielded a useful ecosystem of software, users, and developers that has been helpful to our customers and provided a useful pipeline for software and ideas from the lab to the desktop.

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Unconstrained Biometric Identification in Real World Environments

Marios Savvides, Felix Juefei-Xu, Utsav Prabhu and Chandrasekhar Bhagavatula

Abstract In this work, we introduce four topics that cover the most important problems and challenges for unconstrained face biometrics identification in real world environment. They are (1) off angle and occluded face recognition, (2) low resolution face recognition, (3) full craniofacial 3D modeling, and (4) hallucinating the full face from the periocular region. We will show the state-of-the-art results accordingly.

Keywords Unconstrained face recognition · Unconstrained biometric identification · Off angle face recognition · Occluded face recognition

1 Introduction

In this paper, we describe the challenges faced in developing unconstrained biometric identification algorithms that work in real-world environments. Facial recognition is one of the most ubiquitous biometric modalities, however pose, occlusion, low resolution are all real world challenges [1–32] faced by law enforcement every day. We overview our approach to handling one of the most seen challenges which is facial occlusion. Facial occlusion is a commonly seen challenge when examining any type of video footage involving a committed crime. Criminals try to hide themselves by occluding their faces, with scarfs, masks, hoods

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or hide behind objects to avoid the camera's line of view. We show our approach to solving this challenge by utilizing the available part of the face biometric to extract a consistent biometric signature. We turn the problem into a heavily under-sampled problem where we only are able to observe or sample a very minute portion of the signal, but we must be able to reconstruct the full facial signal in order to be able to enter the workflow of current commercial matchers. We show that in fact we take the challenges of occlusion, pose and low resolution and frame all these very different problems in a common framework of signal recovery from sparse sampling. We show how off-angle pose can be turned into a missing data problem with our 3D Generic Elastic Models (3D GEMS) which can model 2D faces in 3D. By using our robust facial landmarking algorithms which are key for defining a consistent facial structure from which to extract features that are pose tolerant. Additionally, we show how low resolution images are in fact very sparsely sampled signals of the originally high resolution faces. By borrowing ideas from compressed sensing signal processing and optimization, we overview a formulation that can address this challenge. We overview in extreme masking of the face a dictionary-weighted approach for facial recovery from just the visible periocular. We will focus on the following four topics: (1) off angle and occluded face recognition, (2) low resolution face recognition, (3) full craniofacial 3D modeling, and (4) hallucinating the full face from the periocular region. We will show the state-of-the-art results accordingly. Due to page limit, we cannot mention everything under the dome of unconstrained face recognition. We think the four topics we cover in this work are the most important ones and hopefully the readers can benefit most from it. Topics (1) and (2) illustrate the three most important factors (off angle, occlusion, and low resolution) when dealing with unconstrained face recognition. Topic (3) provides a capability to model the full craniofacial shape and texture, which allows us to generate 2D facial images with any 3D pose more accurately, and allows us to de-rotate any off angle faces to frontal pose. Topic (4) provides a capability to remove heavy facial occlusions, or equivalently, hallucinate the full face from just the periocular region, which can be of great help for existing commercial facial matchers to deal with masked faces.

2 Off Angle, Occluded Face Recognition

2.1 A Brief Introduction of the Face Representation

The representation of the face is a critical element in the design of any system; a poor representation can impede subsequent tasks significantly, and could prove to be the weakest link in the processing chain. In our representation, both intensity values and x, y, and z locations are extracted from a set of dense correspondences that mark the same locations on every face. A flowchart of this process is shown in Fig. 1.

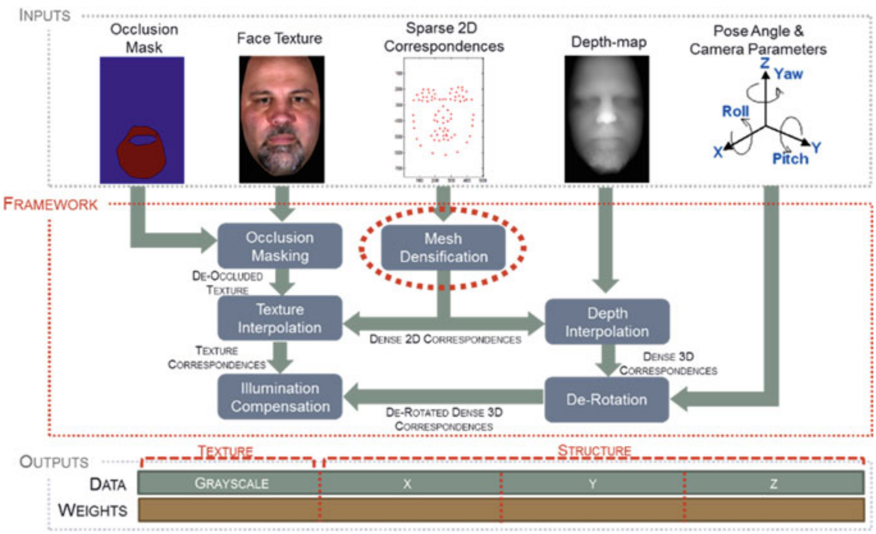

Fig. 1 Flowchart of representation extraction process

In this representation, not all points will always be visible due to degradations to the face. Degradations can include things like low resolution, occlusions, and off angle faces. In the cases of these degradations, the points that are not visible can be treated as missing data in the representation. We can use our missing data completion techniques like Weighted Generalized Hebbian Analysis (WGHA) [33] and Weighted KSVD (WKSVD) [24] to recover the whole representation. This allows us to generate facial images that can be used by any face matcher for matching, ideally at a better rate than the original, degraded images.

2.2 *Off Angle, Occluded Face Recognition*

We have shown in previous work [33] how we handle both occlusions and off-angle faces in our framework by utilizing known occlusion masks and information about the 3D head pose to determine which vertices of the face are visible. By utilizing this information, we can correctly specify which portions of our representation need to be weighted accordingly for our data completion techniques to recover the entire representation vector. We have also shown experiments performing face recognition under both of these factors as shown below. Figure 2 shows the ROCs for recognition using various matching techniques on our representation at a yaw of $\pm 45°$ using the CMU MPIE dataset [34]. The results are good especially when compared against commercial systems as shown in Fig. 3. There is a marked improvement over using commercial systems on the raw images.

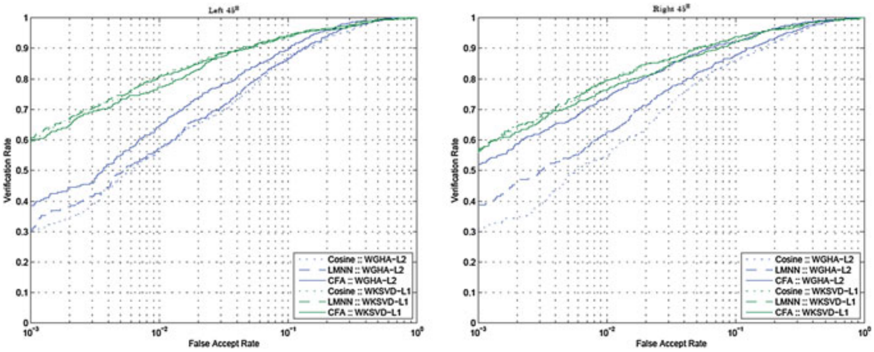

Fig. 2 ROCs for yaw angles of 45° for both left and right angles using several different matching techniques on our feature representation. Even at a yaw angle of 45°, the recognition is favorable

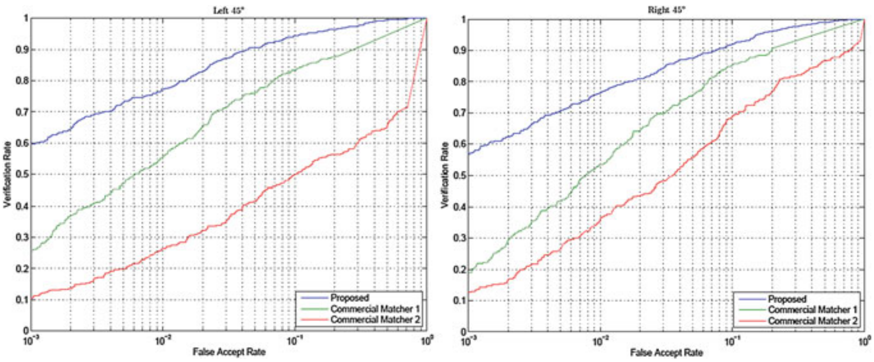

Fig. 3 Comparison of commercial matchers (Pittpatt in *green* and Identix G6 in *red*) to our system (*blue*) at 45° of yaw

We also compared to two commercial matching systems. The results show that adding this reconstruction as a preprocessing step allows us to greatly improve the matching performance as the pose gets more extreme.

We have also run experiments seeing how a combination of pose and low resolution together impact face recognition. We accomplished this by running the Labeled Faces in the Wild (LFW) [35] unsupervised recognition experiment. The results are shown below. As can be seen, we very well with only two methods outperforming us. Both of these methods, Pose Adaptive Filters [36] and MRF-MLBP [37], extract very fine tuned features from the data. With an additional feature extraction step, it is possible that our method would perform better (Fig. 4).

However, due to the nature of the LFW dataset, it is difficult to tell where the algorithm fails. In order to have a deeper understanding of the capabilities and limits of a system that uses our method, we have begun performing experiments on controlled combinations of these factors. So far, we have run experiments using the

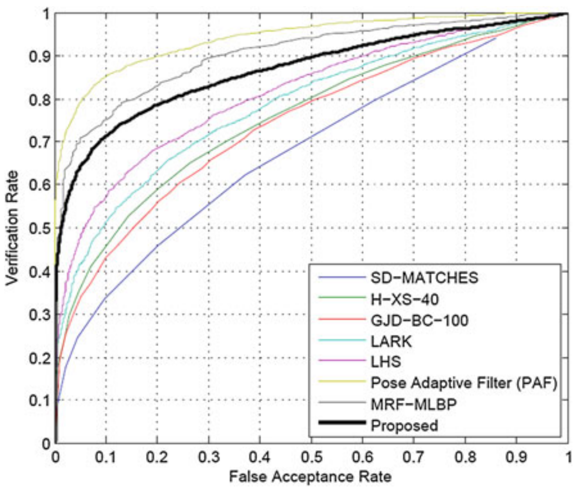

Fig. 4 ROC for LFW using our method (*black*) and many state of the art methods

CMU MPIE dataset combining off-angle face recognition and synthetic occlusions. Since the MPIE dataset has fixed poses at which the face was captured but no occlusions, we need to synthetically add occlusions into the image. Since our representation does not use any region that is marked as occluded, we just need to set the mask for our weighting appropriately. However, to ensure there is no possibility of error, we artificially add another image in place and set the occlusion mask to the same location. Varying levels of occlusion are added from 5 to 50 % of the face region covered as seen in Fig. 5.

In our experimental setup, the representations from the un-occluded frontal images are enrolled as a gallery set while the recovered representations from the occluded images at a specific pose are used as a probe set. With only the normalized cosine distance as the metric for matching two images, we see in Fig. 6. Though we would prefer to be invariant to angle and occlusion, we can see that there is a graceful degradation in performance as more of the face becomes occluded and at different angles. This means that the algorithm will not dramatically fail just because a face under both conditions is given though there is a limit.

Fig. 5 Varying levels of synthetic occlusion added to frontal image

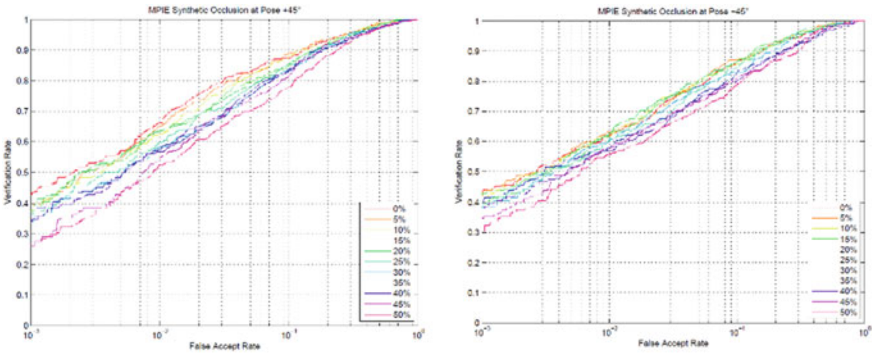

Fig. 6 ROCs for verification at varying yaw angles of ±45° and different levels of synthetic occlusion

We plan on experimenting more with a combination of low-resolution, off-angle, and occluded faces by artificially down sampling these images and computing ROCs for all possibilities. We also plan on running more experiments showing whether the algorithm can match off-angle faces to other off-angle faces with occlusions.

3 Low Resolution Face Recognition

By using the same representation, we can also super resolve face images by treating low resolution images as high resolution versions with many missing pixels. By setting the weights in the representation appropriately, we can generate super resolved versions by completing the feature vector. Some examples of super resolved versions from the MPIE dataset are shown in Fig. 7. In order to verify that these super resolved images are indeed useful for recognition, we ran both the Pittpatt matcher and the Identix G6 matcher on the low resolution images and the super resolved images. The gallery set were the original high resolution images while the probe set was either the low resolution version or the super resolved version. As seen in Fig. 8, Pittpatt shows a very dramatic improvement in using the super resolved faces for recognition while the Identix G6 matcher does not show the same improvement. This is possibly because Pittpatt must first be able to detect a face which is easier on the super resolved images. However, we can also see that when we use our own CFA matcher, we outperform both commercial systems on the low resolution scenario. However, it is difficult to compare all of these fairly as we cannot control the face detection step in Pittpatt whereas our method assumes some user input as to the location of the face. This helps demonstrate, however, the importance of having some human interaction in this process as fully automated systems cannot currently handle such cases.

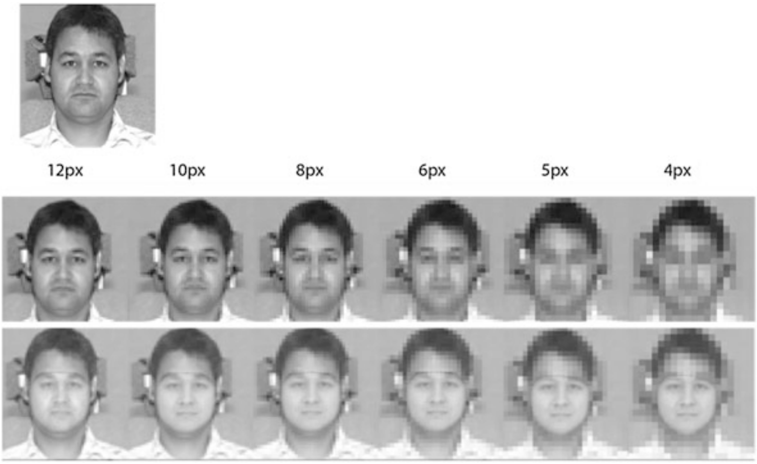

Fig. 7 Example of super resolution applied to various levels of downsampling to approximate low resolution inputs. Original image (*top*), downsampled images (*middle row*), super-resolved versions (*bottom row*)

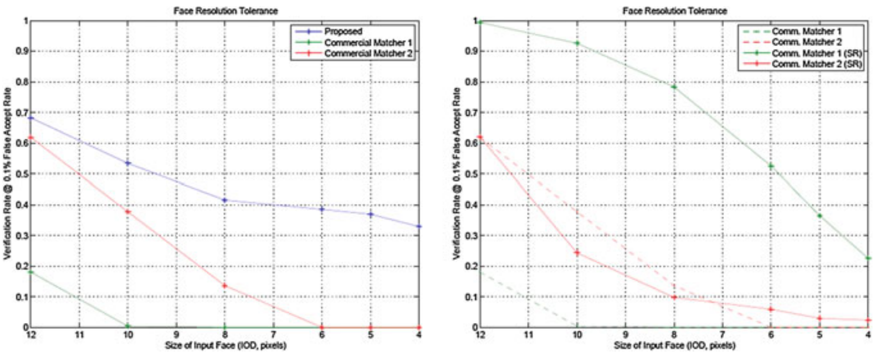

Fig. 8 Proposed system versus commercial systems (*Left*). Running from the original low resolution images, we outperform both Pittpatt *green*) and Identix G6 (*red*). Improvement to commercial systems using super resolution technique (*right*). Pittpatt (*green*) shows a large improvement when using the super resolved images (*solid line*) over the original images (*dashed line*). Identix G6 (*red*) does not show an improvement

4 Full Craniofacial 3D Modeling

Our current representation works well for the interior portions of the face which is what is mostly used by commercial applications as well as our own internal matchers. However, there is a possibility that more information is needed by another system or by an end user who wishes to visually inspect the 3D models. To that end, we have started work on developing a full craniofacial 3D modelling technique that will allow us to use as much information as possible from the original images.

4.1 Generating Shapes

Our approach is based on using a generic full craniofacial 3D model and computing a camera projection matrix from the 3D space to the image. In order to compute the projection matrix, **M**, we need to have a set of correspondences between the 3D model and the 2D image plane. We accomplish this by hand selecting 79 vertices on the 3D model corresponding to the 79 landmark points we can automatically detect on a 2D image of a face. By using these as correspondences between the 3D model and the image plane, we can formulate the relationship between the homogenous versions of these points as

$$\mathbf{p}_c \cong \mathbf{M}\mathbf{p}_w, \tag{1}$$

where $\mathbf{p}_c$ is the homogenous point in the camera's image plane, $\mathbf{p}_w$ is the homogenous point in the world coordinate system (i.e. the 3D model coordinate system) and **M** is the 3×4 camera projection matrix. Since these are all in homogenous coordinates, the equality can only be defined up to a scale change. Since both sides represent vectors in the same direction however, we can show the cross product of the two must be equal to 0 exactly. This allows us to rewrite the set of equations as

$$\mathbf{P}\mathbf{m} = \mathbf{0}, \tag{2}$$

where **P** is a $2N \times 12$ matrix containing the coefficients from rearranging the cross product of the vectors and **m** is a vector containing all elements of **M**. From this we can compute **M** as the row null space of **P**. However, since we have more than 12 rows, there will most likely not be a null space. This occurs because we have more than the minimum number of points needed but this does allow us to be tolerant to some noise in the measurements of the landmarks. By computing the SVD of **P**, we can find the singular vector corresponding to the smallest singular value. This is the solution that gets us closest to satisfying all constraints. This gives us the camera projection matrix. Once we have computed **M**, we need to readjust the 3D model to properly fit the points on the subject in the image. Otherwise, every subject would have the same 3D model in the end. To accomplish this, we can use **M** to compute a ray in 3D space from the camera origin through each landmark point in the image plane. The camera center is embedded into the camera projection matrix as $\mathbf{C} = -\mathbf{P}_{3\times3}^{-1}\mathbf{p}_4$ where $\mathbf{P} = [\mathbf{P}_{3\times3}|\mathbf{p}_4]$ or $\mathbf{P}_{3\times3}$ is the first 3 columns of **P** and $\mathbf{p}_4$ is the last column of **P**. The optical ray through the camera center and any image point, $\mathbf{p}_c$ is

$$\mathbf{R} = \begin{pmatrix} \mathbf{C} \\ 1 \end{pmatrix} + \lambda \begin{pmatrix} \mathbf{P}_{3\times3}^{-1}\mathbf{p}_c \\ 0 \end{pmatrix}, \quad (3)$$

By adjusting λ we can compute all points on this ray. For each landmark on the 3D model, we can compute the closest point on the corresponding ray and use that as the new point that the 3D model should have. This way, all landmarks will image onto their correspondences exactly. Once we have these new 3D points, we use a thin plate spline interpolation to generate the new full craniofacial 3D model that is specific to this image.

4.2 Generating Texture

In order to texture the new 3D model, we use the camera projection matrix to project all 3D points onto the image plane. We can then determine the texture value by interpolating it based on the pixel values in the image. To account for the self occlusion problem, for each vertex in the model, we look at the points that projected to a close region around it and find the triangles in the 3D model comprised of those points, excluding any containing the original vertex itself. We then compute a ray-triangle intersection test for each of these triangles and the ray going from the camera center to the vertex. If any of them intersect, we know that the point would be occluded in the projection and so we can fill it with black instead. When we do this, the new 3D model makes much more sense. The original image along with landmarks and the resulting 3D model from various views are shown in Fig. 9.

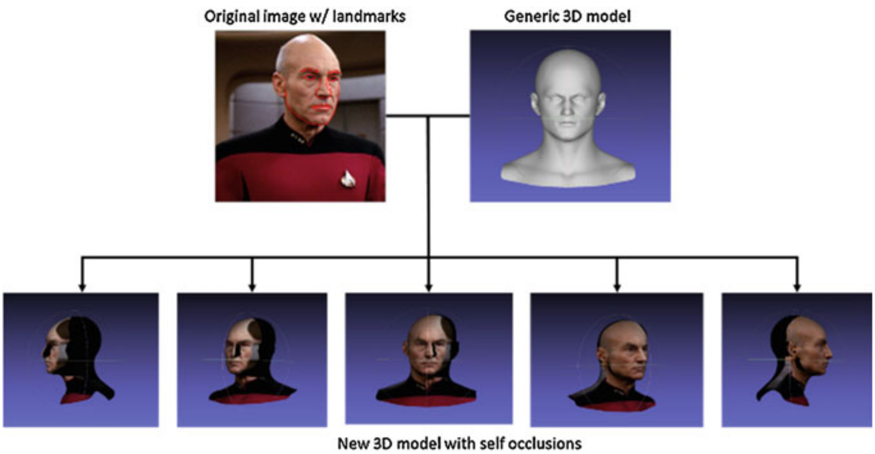

Fig. 9 3D model at various views (*bottom*) generated from original image, landmarks, and generic 3D model (*top*)

As can be seen, the missing regions need to be filled in. This can be accomplished with techniques we have already laid out previously. We plan on investigating the best way to fill in the missing portions in the future.

5 Full-Face Hallucination from the Periocular Region

When the faces are heavily occluded, it is extremely difficult for commercial face matchers to detect the face, and to match them properly and accurately. In our previous work [24], we have proposed to hallucinate the full face from just the periocular region—the region around the eyes. This application is important for recovering the faces under facial occlusions, such as masks. The method is based on a weighted joint dictionary learning with sparse constraints. The reconstructed full face will show high fidelity within the periocular region which is visible to the algorithm, as well as other facial regions outside the periocular region which is not visible to the algorithm. Figure 10 shows some visual results for the full face hallucination. The first row of Fig. 10 is the original full face images, the second row shows the cropped periocular region which is assumed to be the only visible region to be fed into the algorithm, and the third row shows our full face hallucination. It can be seen that the reconstructed full face shows high fidelity as compared to the original full face. A natural byproduct is that the hallucinated faces show neutral expression, which is actually an asset for the commercial face matchers. This is largely due to the fact that our training data sets contain most of the faces under neutral expression. For the rest of the paper, the term hallucination and reconstruction will be used interchangeably.

Here, we want to motivate the use and application of the hallucination of the full-face from the periocular capability on the basis of the case of the masked

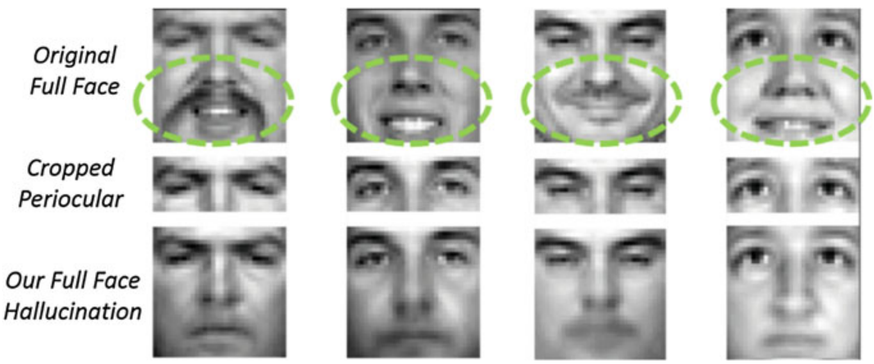

Fig. 10 Visual results of the full face hallucination from the periocular region using the proposed DW-KSVD [24] method. A natural byproduct is that the reconstructed full face shows neutral expression

executioner (ISIS member) of James Foley. By using our algorithms, Dimensionally Weighted K-SVD (DW-KSVD) [24], which heavily utilizes the sparse signal processing theory, we were able to generate a full face reconstruction of the ISIS suspect from the periocular region. We also proposed a novel sparse coding method called Hierarchical Orthogonal Matching Pursuit (OMP). The key advantage of Hierarchical OMP over OMP is the fact that it does not require retraining of a dictionary given a periocular mask. We also re-run the experiment of identifying the ISIS suspect out of a million mugshot images with the true identified suspect. We show that our reconstructions using DW-KSVD can match the suspect at **Rank-1** and **Rank-2** out of three independent reconstruction attempts.

5.1 Experimental Results (Original Jihadi John)

As shown here, we were able to match the real suspect using this technique and the commercial matching system known as Pittpatt very accurately.

Full Face Hallucination from Heavily Occluded Face. Figure 11 depicts the process flow to reconstruct the full face from the periocular region.

The DW-KSVD [24] method is used to reconstruct the full-face from the small periocular region that is depicted in the figure as the "usable periocular region". A total of three independent attempts were made to choose a trust region leading to three reconstructions; however, we find that the three reconstructions are similar to each other. This shows reproducibility of our method. The three sparse dictionaries were trained on a separate database of 200,000 faces all of whom were cropped with the same mask as the three independent periocular masks.

Face Identification. Once we have the three reconstructions from the previous experiment, we re-run the face identification experiment, this time with the true

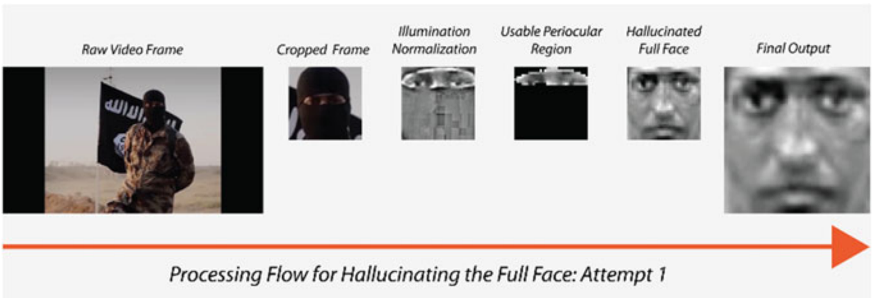

Fig. 11 Process flow for the reconstruction/hallucination of the full face of the suspect from just the sample video frame. The frame is first cropped and then de-rotated to obtain a near frontal orientation. Illumination normalization then helps in removing some of the effects of shadow. We identify a small usable periocular region which seems to contain the most amount of biometric identity. We then hallucinate the full face using DW-KSVD

Table 1 Retrieval rankings of 3 reconstructions on 3 mugshots data sets with varying sizes

Ranks	10,000 Faces	100,000 Faces	1,000,000 Faces
Reconstruction A	1	1	1
Reconstruction B	1	1	2
Reconstruction C	1	1	1

suspect (confirmed from other sources) Mohammad Emwazi. To create the gallery set we add in the suspect's frontal image available on the Internet, into the database of 10,000, 100,000, and 1,000,000 mugshots respectively. Following the previous work, we re-run a commercial face matcher (Pittpatt) with the three independent reconstructions as the query images (Reconstruction A, B, and C) and the aforementioned three sets of mugshot images of varying sizes as the gallery database. The retrieval rankings are tabulated in Table 1.

As can be seen from the table, we are able to identify the suspect in **Rank-1** from a database of 1 million images. Moreover, the other two attempts matched at **Rank-2** and **Rank-1** respectively illustrating the robustness of the method.

6 Conclusions

In this work, we have shown four important topics under the dome of unconstrained face biometric identification in real world environment. They are (1) off angle and occluded face recognition, (2) low resolution face recognition, (3) full craniofacial 3D modeling, and (4) hallucinating the full face from the periocular region. We have also shown the state-of-the-art results accordingly. We believe that these four topics cover the most important problems and challenges in unconstrained face biometric identification in real-world environment.

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Predicting Team Performance Through Human Behavioral Sensing and Quantitative Workflow Instrumentation

Matthew Daggett, Kyle O'Brien, Michael Hurley and Daniel Hannon

Abstract For decades, the social sciences have provided the foundation for the study of humans interacting with systems; however, sparse, qualitative, and often subjective observations can be insufficient in capturing the complex dynamics of modern sociotechnical enterprises. Technical advances in quantitative system-level and physiological instrumentation have made possible greater objective study of human-system interactions, and joint qualitative-quantitative methodologies are being developed to improve human performance characterization. In this paper we detail how these methodologies were applied to assess teams' abilities to effectively discover information, collaborate, and make risk-informed decisions during serious games. Statistical models of intra-game performance were developed to determine whether behaviors in specific facets of the gameplay workflow were predictive of analytical performance and game outcomes. A study of over seventy instrumented teams revealed that teams who were more effective at face-to-face communication and system interaction performed better at information discovery tasks and had more accurate game decisions.

Keywords Humatics · Serious games · Human-system interaction · Instrumentation · Teamwork · Communication analysis · Information theory · Operations research · Decision-making

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1 Introduction

From network operations control centers to expeditionary military detachments, teams of humans interoperate with complicated systems to create complex sociotechnical enterprises. Within these enterprises, the most critical component of overall performance is that of the human, yet their contribution is often the least understood. For decades, social science has provided the foundation for the study of humans in these contexts through the observations of ethnographers and anthropologists, yet these traditional methodologies have significant limitations. Human observation is often subjective and anecdotal and can suffer from biases and differences in interpretation. Additionally, existing tools to measure human behavior can be qualitative and are insufficient in capturing intricate intra- and inter-individual dynamics. Lastly, the collection of these data is time and human intensive and does not scale to large organizational studies. These limitations hinder the ability to draw objective conclusions and understand the parameters influencing team success. Recent technical advances in sensing and instrumentation can be used to augment human observation and enable quantitative, persistent, and objective measurements of human behavior. By jointly processing these multi-modal data, a more complete characterization of human-system interaction can be made, increasing the ability to modify behavior and improve performance. The fidelity and granularity of these data can be very revealing, and in some instances be used to predict performance in related aspects of the activities being measured.

2 Humatics Assessment Methodology

Over several years, we have developed a data-driven research methodology and technical framework, *Humatics*, to address the challenges outlined in Sect. 1 by quantitatively measuring human behavior; rigorously assessing human analytical and cognitive performance; and providing data-driven ways to improve the effectiveness of individuals and teams. Humatics incorporates three major areas of research including system-level, physiological, and cognitive instrumentation; assessment methodology and metrics development; and performance feedback and behavioral recommendation. In this paper, we describe an instantiation of this approach, shown in Fig. 1, and its application to the study of teams' abilities to effectively discover data, make sense of that data, and make decisions during a serious game.

The development of an instrumentation and data collection strategy for a given human-system research effort requires careful consideration of the specific learning objective for the process being studied and identification of observables to be measured in order to enable insight. A measurement strategy can then be developed based on which method and phenomenology is best suited to directly or indirectly

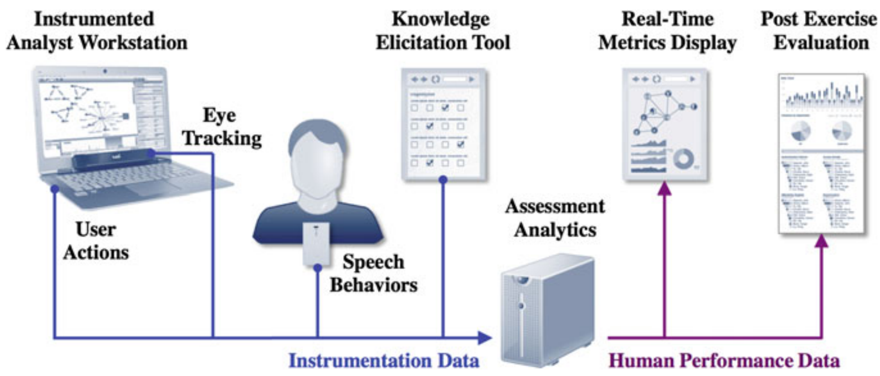

Fig. 1 Humatics performance assessment framework

measure those observables. For this research effort, specific instrumentation modalities were chosen to augment qualitative human observations with near continuous collection to enable analysis of dynamic low-level behavioral signals.

The first element of the framework in Fig. 1 is the instrumented analyst workstation, where both system-level and physiological instrumentation are used to characterize human-system interactions. System-level instrumentation is accomplished through the insertion or enabling of software code that logs graphical user interface interaction events, queries to and transactions with databases, what data is visible to the user, and more. To add context to the data, screen recordings are continuously captured and a research-grade eye tracker is employed to detect the user's location of gaze on the screen. This physiological information is used for cross-referencing the system-level data.

The next element in Fig. 1 is cognitive instrumentation, which is used to measure behaviors associated with the cognitive processing of information. To quantify the comprehension and situational understanding of teams during scenario-based training or serious games, knowledge elicitation techniques are employed [1, 2]. In addition to gaze following, the eye tracker is also used to perform pupillometry in order to noninvasively estimate human cognitive load [3].

The last framework instrumentation modality involves the use of wearable sensors, called Sociometric Badges [4], to record non-linguistic metadata of speech behaviors, body movement, and other data. Originally developed by the MIT Media Laboratory, the badges have often been employed to perform longitudinal studies of the communication patterns of large organizations. For this application, badges with modified firmware and custom post-processing software are used to increase granularity for small group dynamics within hierarchical teams.

Collected instrumentation data is processed with specialized metrics and are used for real-time diagnostic displays or post-experiment assessment. Real-time displays allow for immediate team evaluation to enable behavioral redirection, while offline post-processing supports in-depth analysis and process improvement. The team assessments in this document are an example of the latter.

3 Network Discovery Serious Game

In 2009, researchers at MIT Lincoln Laboratory developed a serious game to better understand how analysts use multisource textual and geospatial data to make risk-informed decisions [5–7]. In the game, competitive teams of varying size from 3 to 8 players analyze the scenario data to make expected decision outcomes. The teams self organize their roles and responsibilities; teams were provided with one less game client than the total number of players, generally causing hierarchies to form with one leader and the rest workers. The game scenario is based around a scripted storyboard where an organized crime network is operating in a city to incite violence (kidnappings, attacks) and then quickly disperses into the background populace of the city. From this storyboard a probabilistic vehicle traffic model produces vehicle movements, or tracks, for the scenario vehicles the teams are tasked to find. Those tracks are embedded into realistic background tracks from the same model that simulate the normative movements of the city population. Using this combined track dataset as input, video modeling and simulation tools are used to produce a simulated airborne video dataset rendered over the city's geospatial extent for each time-step in the scenario storyboard.

Teams are given news and police reports of varying relevance to cue them to observable events in the video. Teams then analyze the video to follow suspect vehicles from overt events to their sources and destinations in order to unravel the network of facilities used by the crime organization. Teams are given 90 total minutes to accrue evidence (discovery phase) and then to codify what they know (decision phase) by identifying which facilities (sites) should be interdicted by law enforcement to disrupt the network. All scenario data are displayed, manipulated, and acted upon in a software game client that was purpose-built for this research and is instrumented for post-game analysis as described in Sect. 2.

4 Team Assessment Case Study

To assess human performance during the game, each major step of the workflow is decomposed and mapped to instrumentation data and performance metrics that characterize their behaviors. As seen in Fig. 2, three major facets of performance emerge including client interaction, information triage, and discovery and decision performance. Additionally, the performance of this entire workflow is underpinned

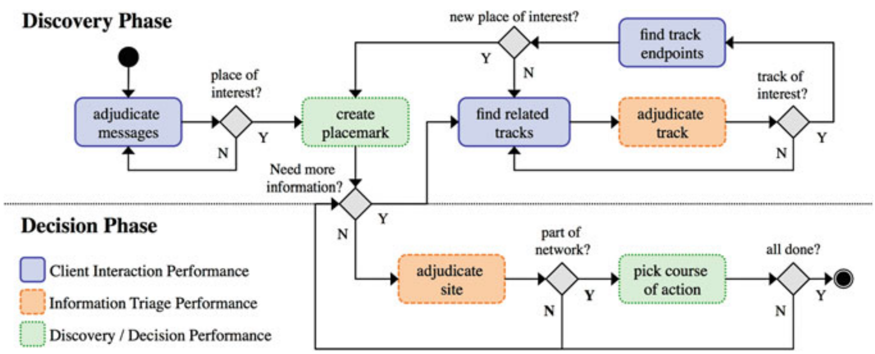

Fig. 2 Gameplay workflow and performance metric mapping

by a team's ability to effectively organize and collaborate through face-to-face communication. In this section, a case study of four 5-member teams illustrates how system-level and physiological instrumentation can be used to better characterize a team's performance during gameplay.

4.1 Game Client Interaction Performance

Software instrumentation built into the game client records various user interactions both on-demand and at specific intervals. These data can be used to understand macro behaviors like the volume or rate of interactions with specific tools in the client. For example, in the game teams use placemarks, geo-spatial annotations, to codify the site discoveries they have made and to later code their courses of action (decisions). By recording placemark creation and modification attributes we can quantify team analytical behaviors in the workflow as a function of time. These data can also be used to analyze micro behaviors, such as the geospatial data currently being viewed by the user, known as the viewport [5]. Viewport data are recorded each second and include the current time of gameplay, the time in the scenario being displayed, and the geospatial bounding-box of the video footprint in the map tool. An example of viewport instrumentation is shown in Fig. 3.

4.2 Scenario Information Triage Performance

After the viewport data are logged as described in Sect. 4.1, they are correlated with the scenario ground truth and processed using specialized information theoretic metrics [5, 8] to determine which relevant (scenario crime network) and irrelevant (background population) tracks or sites are being viewed at each scenario time-step.

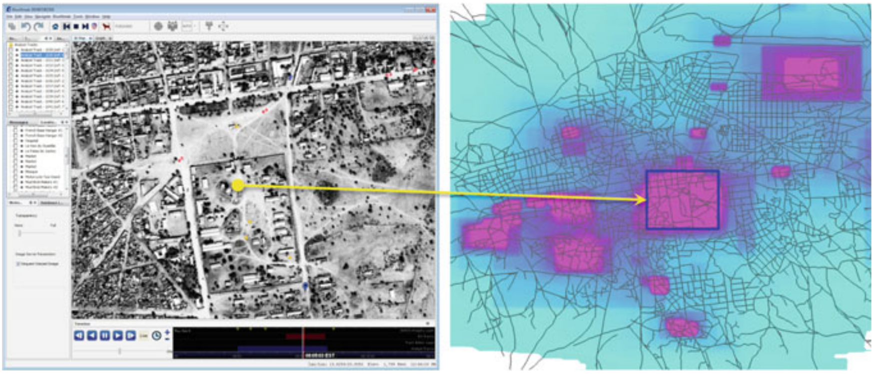

Fig. 3 An illustration of viewport instrumentation. The game client (*left*) is viewing a portion of the scenario video, whose viewport extents are represented by the *blue box* on the heat-map (*right*), as indicated by the *yellow arrow*. Viewport heat-maps can be used to understand a team's geospatial analysis strategy

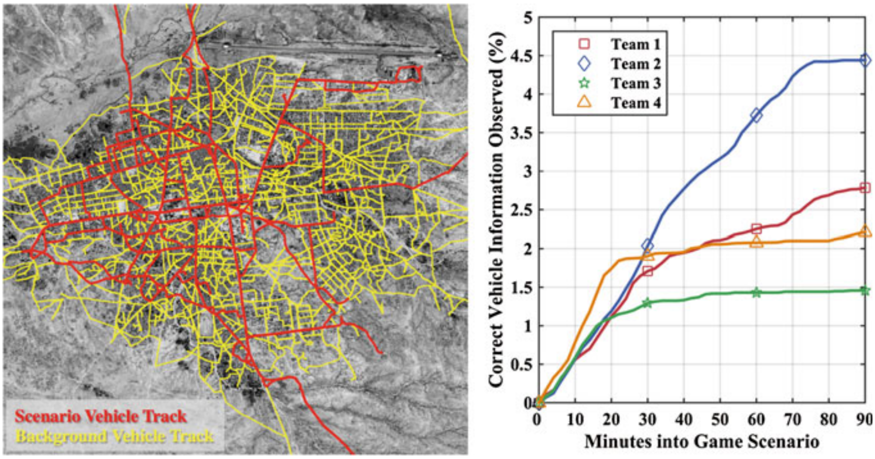

Fig. 4 Team vehicle triage performance. The *left* plot shows the extents of all vehicle track data in the game, with the *red lines* denoting tracks associated with the criminal network vehicles and the *yellow tracks* of background population tracks. The *right* plot shows the team triage performance, with the y-axis representing the percentage of total red tracks observed in the video and the x-axis representing the number of minutes elapsed since the start of the game

A graphical representation of the scenario and background track information is shown in Fig. 4, which illustrates the teams' ability to effectively triage vehicle track data. If players are properly interpreting the information in the report messages they should focus only on the red scenario vehicle tracks and not the yellow background population tracks. As shown in Fig. 4, Teams 3 and 4's performance

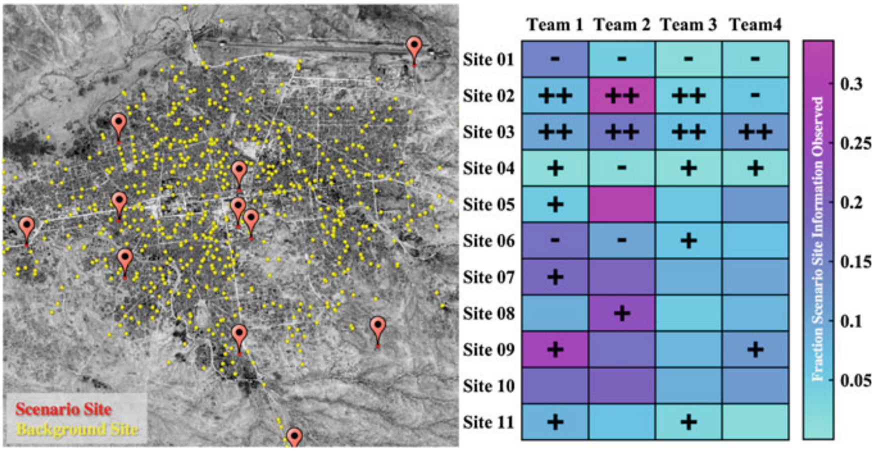

Fig. 5 Team site triage performance. The *left* plot shows the scenario sites to be discovered, as annotated with the *red icons*, and the background sites, denoted with a *yellow dot*. The *right* plot shows the performance of the teams at accumulating information at each of the scenario sites, as indicated by the fill color of each *box* and *color bar scale*. Decision outcomes for sites are also plotted (*right*), with a + or − representing a correct or incorrect decision respectively

plateaus as the scenario evolves, whereas Teams 1 and 2 continue to find and analyze more relevant (red) scenario tracks throughout gameplay.

Similarly, Fig. 5 illustrates the teams' ability to effectively triage video of site-related activities. As shown in the figure, Teams 1 and 2 spent substantially more effort observing scenario site information as compared to Teams 3 and 4. In many cases teams, spend a lot of time analyzing sites but ultimately chose an incorrect action or take no action at all.

4.3 Team Discovery and Decision-Making Performance

Because the scenario was constructed to have the crime network activities completely separated from the background activity, the game can be analyzed from the perspective of signal detection theory. Essentially, the teams are considered to be detectors of criminal network activity in that they are attempting to extract these signals from the noise of the normal activities of the rest of the population [6]. The Receiver Operating Characteristics (ROC) measurements of detection theory can be used to assess the teams' performance, as shown in Fig. 6.

Results from two different tasks are plotted: the discovery of scenario sites as measured by team placemarks at those sites, and the declaration of scenario sites which are the subset of the total placemarks that are given a course of action

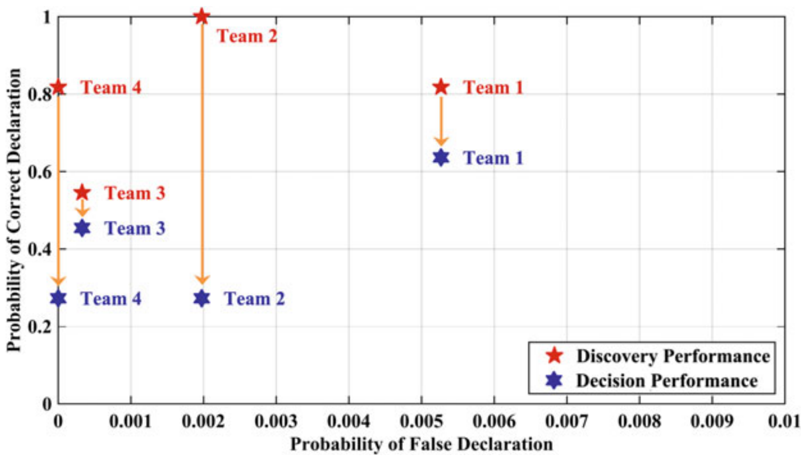

Fig. 6 Team discovery and decision ROC plot. The y-axis represents the *Probability of Correct Declaration*, or the fraction of correct sites found and acted upon by the teams. The x-axis represents the *Probability of False Declaration*, or the ratio of incorrect sites declared divided by the total possible discoverable sites. The *blue* icons represent decision performance for sites that were declared to be associated with the network. The *red* icons show the fraction of all sites that were correctly discovered before the course of action selection process

decision. Decision actions are directly related to the teams' comprehension of the scenario storyboard and their confidence in that understanding. For example, it can be seen that Team 2 had placemarks on 100 % of the crime network sites, but only had the confidence to declare 30 % of those sites. They also declared sites not part of the network, resulting in a 0.2 % probability of false declaration. Team 4 had similar discovery performance as Team 1 and 0 % probability of false declaration. Team 1 had the highest detection probability, but at the expense of more false declarations.

4.4 Team Verbal Communication Performance

Face-to-face communication is known to be a key factor in overall team performance for highly cooperative tasks [9–12]. Traditional methods to characterize these communications have largely focused on speech content, however more recent methods center on the collection of non-linguistic speech features that enable the characterization of team dynamics without having to analyze the linguistic content of a team's utterances [4, 10].

To collect speech metadata, Sociometric Badges are given to each player during gameplay. The badges continuously record the time, duration, and identity of each player's speech, and post-processing software provides measurements of when

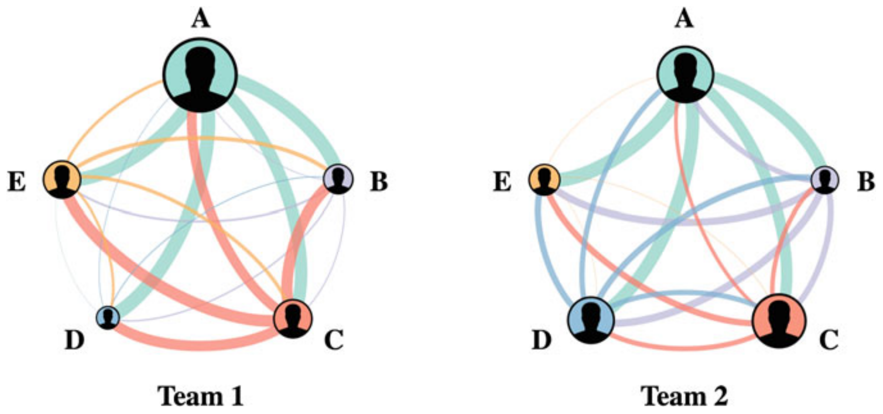

Fig. 7 Face-to-Face communication network graphs. *Vertices* represent players and edges represent directed communication from one player to another. Vertex size is proportional to total participation for a player, edge thickness is proportional to directed speech time to each teammate, and edge color indicates directionality by matching the source vertex color

players spoke alone, when speech overlapped with another player, which players were listening, and when players were silent. These data naturally form a directed graph of communication between players as shown in Fig. 7. For simplicity, only Teams 1 and 2 are shown.

Previous studies of face-to-face communication behaviors of small teams in a collaborative setting have found that balanced participation and speaking time along with increased turn-taking are associated with better team performance [13]. In Fig. 7, Team 1 players A and C are dominating the conversation as seen by their edge thickness, while the rest of the players are less engaged with lower participation (smaller vertices) and less speaking time (thinner edges). Conversely, Team 2 has a much more balanced distribution of both speaking time and participation than Team 1, with player A acting in the role of team leader. Analysis of group influencers and team role estimation using these data is a promising area of active research [14].

For deeper insight into the communication network, a Social Network Analysis approach to characterizing player interaction is explored. By computing the directed, normalized Closeness Centrality of each player [15], an estimate of the connectedness of players can be derived. Larger centrality magnitudes indicate a player's graph "closeness" to all other players. One useful application of this measure is to inspect the time-varying behavior of player centrality [16] during game play, as shown in Fig. 8. In the figure, the visual representation of Teams' 1 and 2 closeness centrality can be very useful for identifying team dynamic attributes, such as leader emergence. For Team 1 we see the same effect of players A and C communication dominance as seen in Fig. 7. For Team 2 we see the clear emergence of player A as the leader of the team during the discovery phase of the

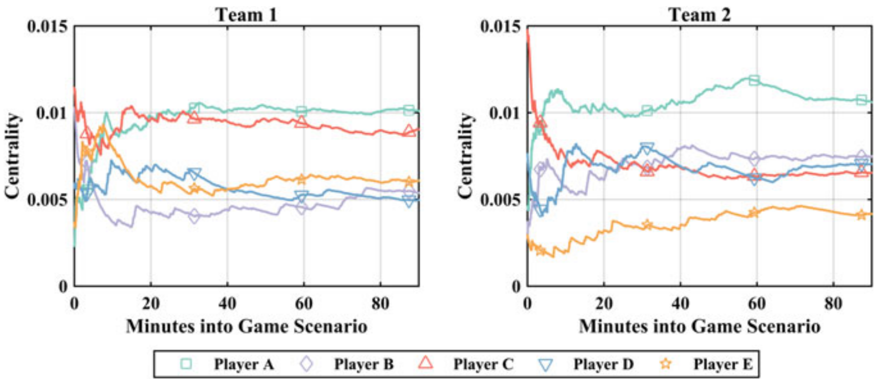

Fig. 8 Time-varying player communication centrality. In both teams, Player A is considered the leader and transitions to gain the highest *Centrality* midway through the game. Qualitative observations during gameplay support these findings

game with A's centrality reducing towards the end as the team moved into the collective decision-making phase of the game.

In addition to Social Network Analysis, Recurrent Pattern Analysis was also performed using the Sociometric Badge data. First, speech patterns are coded into symbols according to various speech behaviors and are then analyzed as a time series [17]. The strength of the recurrent structure within these code sequences is called determinism (DET). In a strict turn taking situation the DET will be high (near 100 %) as the conversation is highly structured. In a situation with random speech intervals, the DET will be low (close to 0 %) indicating that the conversation is highly unstructured. DET scores were comparable for the four teams, with local maxima near 60 % and local minima near 30 %. There were fluctuations in the values over time, indicating that the structure of the communication ebbed and flowed throughout gameplay. Further analysis showed a high correlation between DET magnitude and the percentage of time an individual spoke while all others listened (r = 0.47–0.53, $p < 0.001$), suggesting that in part, structure occurs, even in a complex team setting with five participants, when individuals speak and others listen.

4.5 *Total Team Performance*

Sections 4.1–4.4 demonstrated how performance is quantitatively measured at several points in the overall game workflow, however combining these metrics into a single total performance measure warrants careful consideration. Qualitatively, Teams 1 and 2 excelled at communication, triage, and site discovery, but had more false declarations than Teams 3 and 4. Conversely, Teams 3 and 4 did not observe as much information or discover as many sites, but were very accurate in adjudicating what they found. Team 2 ultimately was the winner of the four-team competition and had the best overall performance and game score.

5 Predicting Team Performance

When assessing teams' analytical and decision-making performance, common questions arise regarding how performance in one facet of a decision process affects the performance of either subsequent processes or the aggregate overall process. Section 4 illustrates that the collected measurements enable detailed insight about individual facets of performance; however, we wanted to take this a step further to determine whether behaviors in specific facets of the intra-game workflow were predictive of analytical performance or games outcomes. To approach this, we processed data collected over several years of employment of the game, encompassing 71 different teams comprised of over 350 unique players. For all of the 71 teams, system instrumentation data were recorded. For a subset of 15 of those teams, face-to-face communication data were also collected.

Robust linear regression analyses are used to statistically estimate how predictive various facets of intra-game performance are with respect to workflow processes. For each model, residual analysis, significance testing, and other regression diagnostics are performed, and their results are included in parentheticals with each prediction finding. In undertaking this analysis, we want to address three overarching research propositions, as follows.

5.1 Client Interaction Effectiveness

The first proposition investigated was whether more effective interaction with the game software client led to better game performance. From our analysis, we found that teams (N = 71) who had higher usage across all analytic functions of the game client discovered more total sites ($p < 0.001$, $R^2 = 0.25$) and had a higher probability of correct site discovery ($p < 0.001$, $R^2 = 0.20$). The effect was even more pronounced for the functions of the game client associated with the frequency that players submitted space-time queries for track data and its correlation with increased site discovery ($p < 0.001$, $R^2 = 0.43$). Higher total game client interaction was also associated with more effective observations of scenario site information ($p < 0.001$, $R^2 = 0.21$) and track information ($p = 0.006$, $R^2 = 0.20$). Essentially teams who were more effective at interacting with the functions of the game client observed more relevant scenario information and found more correct sites.

5.2 Information Triage Effectiveness

The second proposition investigated was whether discovery of more scenario information led to better game outcomes. From our analysis, we found that teams (N = 71) who observed more relevant scenario site information ($p = 0.002$, $R^2 = 0.15$) and track information ($p = 0.006$, $R^2 = 0.13$) also scored higher in game outcome. The overall game score is a metric that takes into account several aspects of how well the players perform but it also encapsulates the confidence of their decisions (courses of action strength) and reflects the overall strategy for how they decide to approach the game (aggressive to risk-averse).

5.3 Team Communication Effectiveness

The third proposition investigated was whether teams who communicate more effectively have higher game performance. Our analysis found that teams (N = 15) who communicated more (total time) throughout the exercise also observed more relevant scenario site information ($p = 0.006$, $R^2 = 0.51$) and track information ($p = 0.001$, $R^2 = 0.61$). Additionally, teams who had higher participation (frequency of communication) from all of their members throughout the game also observed more relevant scenario site information ($p = 0.002$, $R^2 = 0.60$) and track information ($p = 0.010$, $R^2 = 0.46$). Lastly, teams who communicated more (total time) throughout the exercise also made better decisions on the most challenging sites to adjudicate ($p = 0.007$, $R^2 = 0.47$). This agrees with qualitative observations of teams during the decision-making process regarding the total engagement and participation of the full team. Team centrality metrics, as shown in Sect. 4.4, did not have a significant association with other aspects of team performance, and warrants further investigation.

6 Conclusion

In this paper we have shown that Humatics can be used to improve the quantitative study and objective assessment of human analytic and decision-oriented processes, and we detailed its application to measuring a team's ability to effectively discover information, collaborate, and make decisions during a serious game. Additionally, we have demonstrated that data collected about intra-game workflow process can be used to predict subsequent game outcomes and other performance attributes. While we described one specific instantiation of Humatics, the framework has broad applicability towards the optimization of a wide range of complex sociotechnical enterprises. Future research will study the combination of multiple sources of heterogeneous instrumentation data and identifying their relationships to other aspects of human behavior and performance.

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Improving Anomaly Detection Through Identification of Physiological Signatures of Unconscious Awareness

Alyssa M. Piasecki, Mary E. Fendley and Rik Warren

Abstract It is well-known and accepted in the field of cognitive psychology that people have no conscious experience of most of what happens in the human mind. Nevertheless, appropriate actions or conclusions are often still made without this conscious effort. This phenomenon has many potential applications, ranging from driving a vehicle to detecting threats in military video feeds. Investigation of these unconscious processes could provide an insight into potential errors that occur. The present study explores missed anomalies in a visual search task and the possibility of unconscious awareness. A total of 24 subjects participated in the task, in which the goal was to locate targets hidden in an image. Eye physiology was recorded with a Tobii T120 eye tracking monitor in order to characterize the eye physiology of detection, non-detection, and possible unconscious detection. Preliminary results indicate outliers in eye-physiology of non-detections, indicating a possible unconscious detection.

Keywords Unconscious detection · Eye-tracking · Anomaly response · Visual search task

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1 Introduction

The occurrence of unconscious processing, and possibly unconscious awareness, during a visual search task is a topic that has been explored by numerous other researchers. It is evident from these studies that relatively little information from the visual world is internally stored; therefore an understanding of how this information is actually processed is needed in order to further examine this possibility of unconscious awareness. Unconscious, as well as conscious, processing can both be connected back to the basic model of information processing developed by Wickens [1]. In this model, sensory information enters a short-term sensory store where the information is transformed into an understandable form by the perceptual processes of the brain. After perception, the information is transferred to working memory which interacts with long-term memory in order to grow and develop the individual's perception of the world and determine a reasonable response to the stimuli.

Working memory temporarily maintains this information as a means for providing an interface between perception, long-term memory, and action. This concept of working memory can be further broken down into separate components using the Baddeley and Hitch Model of Working Memory [2], which includes the central executive, the phonological loop, and the visuospatial sketchpad. The central executive serves as the control system while the phonological loop and visuospatial sketchpad make up the storage systems of the model. With regards to the central executive function, it is arguably the most important of the three components, however, the least understood. The phonological loop exists to facilitate with the acquisition of verbal skills, such as the ability to learn a new language, whereas the visuospatial sketchpad is responsible for the storage of visual cues. Information perceived by an individual is separated into either visual or auditory information, which is then relayed to the corresponding storage system that ultimately is transferred to the central executive for processing in order to determine if action needs to be taken or if the information needs to be stored in long-term memory, for example.

Once information is gathered in the brain, there are several modes for how knowledge and intelligence is further processed and analyzed, such as case-based reasoning, naturalistic decision making, dual-process theory, fuzzy-trace theory, and intuition. For the purposes of this study, intuition will be further examined as a possible pathway for unconscious processing.

There is not one exact definition of intuition that is unanimously agreed upon and, as Betsch states, "There are as many meanings for the term intuition as there are people using it" [3]. However, the term tends to refer to reaching an answer or solution or idea without conscious effort or reasoning. Some consider it a source of knowledge, some a process, and some even a structure of the brain [4, 5]. Nevertheless, the concept that a thought, solution, or idea can be developed without conscious thought is a view that differs to quite an extent from the other previously discussed decision making strategies, although most closely related to naturalistic decision making. The concept of intuition brings several questions to mind, such as "how do these concepts develop in the brain?", "by what mechanism do these thoughts reach consciousness?", and "what neurophysiological biomarkers could exist to track these processes?"

The wide area of research devoted to exploring the causes of missed anomalies provides for numerous ways for characterization and detection, including electroencephalography (EEG), electrocardiography (ECG), and eye-tracking methodologies. For the purposes of this study, eye-tracking methods will be used in the experimental setup and, therefore, will be focused on in the remainder of this paper.

In a study done by Drew et al. [6], naïve observers as well as expert radiologists examined computed tomography (CT) lung cancer screening images for lung nodules, which appeared as small light circles. A picture of a black gorilla, about 48 times the size of the average nodule, was also present in the CT scan. Eye-tracking methodologies were used to investigate the fixation patterns, and the results revealed that twenty out of twenty-four expert radiologists failed to report seeing the gorilla, even though eye tracking confirmed that 12 out of the 20 radiologists that failed to detect the gorilla actually looked directly at the gorilla's location when it was visible in the CT scans. For this group, the mean dwell time on the gorilla was 547 ms. This discovery leads to several questions, such as: (1) what is the cause for this "blindness"?, (2) what are some possible identifiers of the occurrence of this phenomenon?, and (3) how are unconscious processes involved in a visual search task?

Several other studies have produced similar results, showing that changes in a scene receive longer fixation durations even though the changes are not consciously recognized. For example, Droll et al. [7] performed a study to explore how the visual scene or task at hand affects the acquisition of information from that scene. Results from the study revealed that fixation durations on changed objects were longer than other areas of the scene, yet the change still went unnoticed.

It is evident from these studies that relatively little information from the visual world is internally stored. However, this "change blindness", or inability to notice changes in a visual scene, could be due to other reasons even if a mental representation of the pre-change visual scene is stored. One example of this is the failure to compare the pre-change scene to the post-change scene [8, 9]. Taking into consideration the change blindness paradigm, it has been proposed that, even though a participant does not provide an explicit reporting of the change, it does not mean that the change was not detected at all. It only means that an explicit report is not sensitive enough to measure the change [9]. In a study performed by Simons et al. [8], it was shown that participants failed to notice a change initially; however, they were later able to report the exact change when the experimenter provided a clue as to what the change was. This provides an interesting proposition that the participants stored a mental representation of the scene; however it did not reach consciousness until explicitly pointed out to them. This study, therefore, provides evidence that visual information acquisition and mental encoding can occur as unconscious processes. Research by Rensink [10] further supports these findings, in which it is stated that a visual experience (i.e., consciously seeing or noticing) is not required in order to become aware of an object, event, or the surroundings. In the study, images of a scene and a changed scene were presented to the participant, with the change either being related to presence (or non-presence), color, or location of an object. Participants viewed the images and were asked to press a key when they first had a "feeling" that a change was occurring and again when they saw explicitly what the change was. Results from the study suggested that visual changes can be sensed without an explicit visual experience. A follow-up to this study was performed by Galpin et al. [11], in which it was found that sensing did indeed occur in participants without an actual visual experience (as opposed to being random and guess-based) and, furthermore, that sensing and actually visually seeing are two different processes altogether. Other studies have further shown that there is a possibility that visual information processing is distinct and different for perception and for motor action, indicating that eye movements can reflect unconscious visual processing [12, 13].

The goal of the present study is to not only show that unconscious processing exists, but that there are physiological eye-tracking signatures of these phenomena that can be detected and used for acknowledgement and mitigation purposes. There are significantly fewer papers focused specifically on these goals; however, research has been done in an attempt to accomplish these tasks. Rothkirch et al. [14] performed a study in which participants performed a search task in order to locate a Gabor patch that was made supposedly invisible using continuous flash suppression (CFS) techniques [15]. According to Rothkirch et al., "CFS is thought to largely disrupt neural signals from the suppressed eye at early central processing stages, but may leave some subcortical processes and responses in dorsal visual cortical areas relatively preserved" [14]. The participants were asked the location of the Gabor patch, its orientation, and indicated a confidence rating. Results of "very unsure" participants showed that location and orientation identification were at chance level and, therefore, the participants had no subjective or objective awareness of the Gabor patch. However, dwell times of the participants revealed that they were increased by 40 % for the Gabor patch area relative to the control areas. These results indicate that participants' eye movement patterns were affected by the unconscious perception of stimuli.

The present study aims to investigate physiological signatures of unconscious detection in a visual search task and identify events in which unconscious detection may be occurring. Given the previously explained research, it is hypothesized that there will be a difference between the physiological measures of fixation count, fixation duration, and mean saccade length for detections versus non-detections.

2 Methods

A total of 24 participants (16 male, 8 female) completed this study, with ages ranging from 20 to 52 years (mean = 23.75 years). All participants had normal or corrected to normal vision. During the analysis phase, two participants were discarded due to a low quality of eye-tracking data (15 and 17 %), which refers to the percentage of samples collected throughout all trials for that participant. The data quality of the remaining 22 participants ranged from 37 to 80 % (mean = 64.0 %) and were used for the analysis.

2.1 Apparatus and Stimuli

All testing was performed in a controlled testing room in which the lighting, ambient temperature, and ambient noise level were held constant for all participants. Testing was performed using a Tobii T120 Eye Tracker monitor with a data rate of 60 Hz, screen size of 17″, and screen resolution of 1280 × 1024 pixels. Participants were seated approximately 50–70 cm from the Tobii monitor.

The experimental display consisted of a static background RGB (8 bit unsigned integer) image with suits and signals hidden in the image. The suits consisted of one of each of the four standard playing card suits (heart, spade, diamond, club) hidden in the image (Fig. 1).

Fig. 1 Example of stimuli consisting of background imagery and four hidden suits. The *circles* around the suits are for indication purposes only and were not present during the actual experiment

The signals were small flashing circles, of which there were two difficulty levels referred to as “easy” and “difficult”. Two difficulty levels were established in order to account for differences in visual thresholds among different individuals and provide for a stronger chance of unconscious visual awareness among all participants. According to Carmi et al. [16], the primary characteristics of visual images that are noticed by an individual are color contrast, motion, and flicker [17–20]. Therefore, these three characteristics were manipulated in order to provide for a clear difference between the easy and difficult signals. Each easy signal was made up of a small circle approximately 50 pixels in diameter that flashed three times (250 ms flash duration with 50 ms between each flash) while “traveling” in a linear fashion and had an average contrast difference amplitude of 23.2. Each difficult signal was made up of a small circle that flashed three times (250 ms flash duration with 50 ms between each flash) in a stationary position and had an average contrast difference amplitude of 4.9.

The “average contrast difference” values for the easy and difficult signals were calculated using Matlab. The gray index value at the center of each signal was measured, along with the gray index value of the background surrounding the signal at a distance of 25 pixels from the center of the signal (approximately equal to the radius of the signal). The absolute difference of these two values was calculated in order to have a relative difference in contrast for each signal. Since the difficult signals were stationary, each of the three flashes was in the same position which means the same background and, therefore, had the same contrast difference. Therefore, the contrast difference measured was the overall contrast difference of that signal. However, the easy signals travelled in a linear direction; therefore each of the flashes was against a different background as it moved. This means that each of the three flashes that made up each signal had different contrast differences. Therefore, in order to obtain an overall contrast difference for each signal, the three contrast differences from the three “flashes” of each easy signal were averaged in order to have one contrast difference value.

There was the possibility of a combination of 0 or 1 easy signals and 0, 1, or 2 difficult signals in each image. The difficult signals were assumed to be more of a challenge to notice and, therefore, more likely to exhibit unconscious awareness. For this reason, the total number of difficult signals was two times higher than the number of easy signals. The matrix in Table 1 shows the six possible combinations of these two levels of signals. These combinations were tested two times each to give a total of twelve trials in the experiment, with the order of the twelve trials randomized across participants.

Table 1 Possible combinations of easy and difficult signals

	D0	D1	D2
E0	E0D0	E0D1	E0D2
E1	E1D0	E1D1	E1D2

2.2 Procedure

All participants signed a written consent form prior to experimentation and a pre-test questionnaire was administered to obtain basic demographic information. Participants were briefed about the study and told that their main objective was to find the card suits hidden in the image and press the space bar when they found each suit. They were also told that there may or may not be small flashing circles somewhere in the image and that they did not have to take any action if/when they saw these signals. A calibration of the eye tracker was performed, and the participant completed a practice trial with one easy signal in order to ensure understanding of the testing procedure. Participants then viewed each of the twelve images and answered a short post-clip questionnaire after each trial, asking the location and confidence rating of any signals that they detected. After completion of the twelve trials, a post-test questionnaire was administered to the participants, asking about the experiment as a whole. Upon completion of the post-test questionnaire, participants were thanked for their time and released. The total time for the experiment was approximately one hour.

3 Results

During the analysis, 17 trials (1.2 %) were found to have faulty data, possibly due to random error with the eye tracker or the calibration. In order to account for these faulty trials, the data was replaced with the data of the corresponding trial of the same participant. The corresponding trial was the trial with the same number and type of signals. As discussed in Table 1, there were six possible combinations of signals, and each of these combinations was repeated twice to give a total of twelve trials.

Tobii Studio and Matlab software were used to obtain eye-physiological metrics including fixation count, fixation duration, and mean saccade length. The data was analyzed using JMP software in order to perform an ANOVA F-test and a paired difference t-test ($\alpha = 0.05$) for statistical analysis. Preliminary analysis revealed that fixation count of suits was significantly different for detected (mean = 3.16) versus non-detected (mean = 22.61) ($t(21) = -19.45$, $p < 0.0001$). A total of nine scatter plots were then created, comparing the three eye metrics (fixation count, fixation duration, mean saccade length) across the three different AOI types (suits, easy signals, difficult signals). Jitter was applied to the x-dimension of the scatter plots to help differentiate overlapping points. An example for fixation duration of suits is shown in Fig. 2, along with a box plot of the data in Fig. 3. Using these scatter and box plots, outliers from non-detected AOIs were identified as possible unconscious detections. Gaze plots of these outlier points were created in order to analyze gaze patterns (Fig. 4).

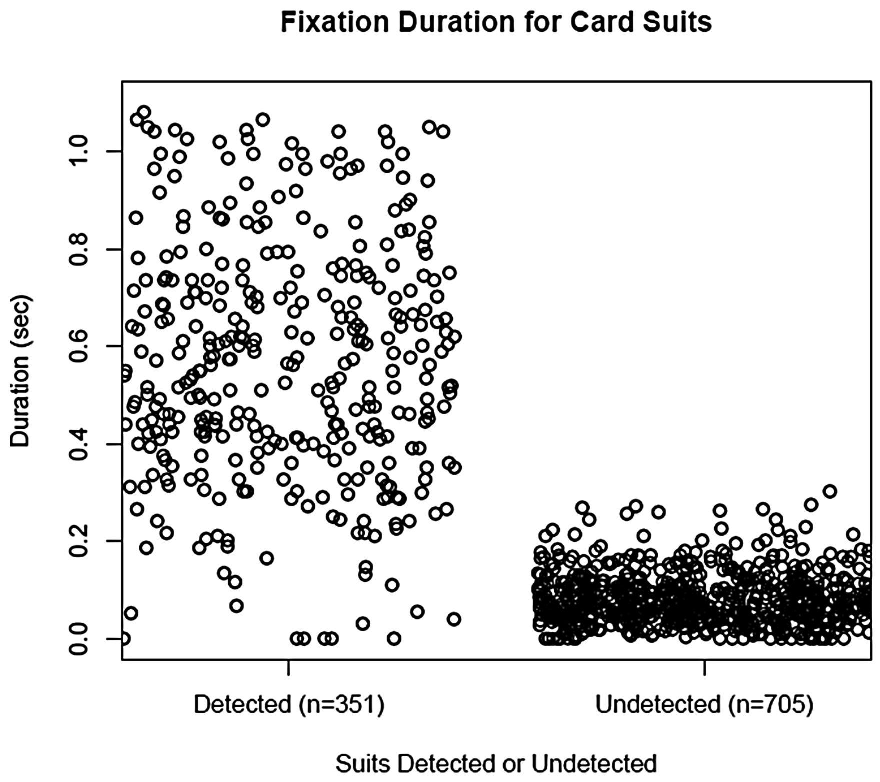

Fig. 2 Scatter plot (with jitter applied) of fixation durations for detected and undetected suits across all participants

4 Discussion

Results from the t-test (α = 0.05) indicate significant differences of detection and non-detection for fixation count of suits. This shows that mean fixation count is higher for non-detections than for detections, indicating that fixation count is a possible correlate of detection versus non-detection. This may be used to identify a model of the differences, in which non-detection outliers could be further analyzed and potentially identified as unconscious detections. Using these results, scatter and box plots were created in order to specifically identify which undetected AOIs could be considered outliers. As shown in Fig. 2, a separation of detection versus non-detection could be made around 0.2 s for suit fixation duration, which can be used for further analysis. A gaze plot was constructed for each of these non-detection outlier data points in order to examine the specific gaze patterns, as shown in Fig. 4. For the specific trial indicated in the figure, the participant consciously detected the heart AOI; however, the spade, diamond, and club were not consciously recognized. The gaze plot indicates several fixation points on the heart

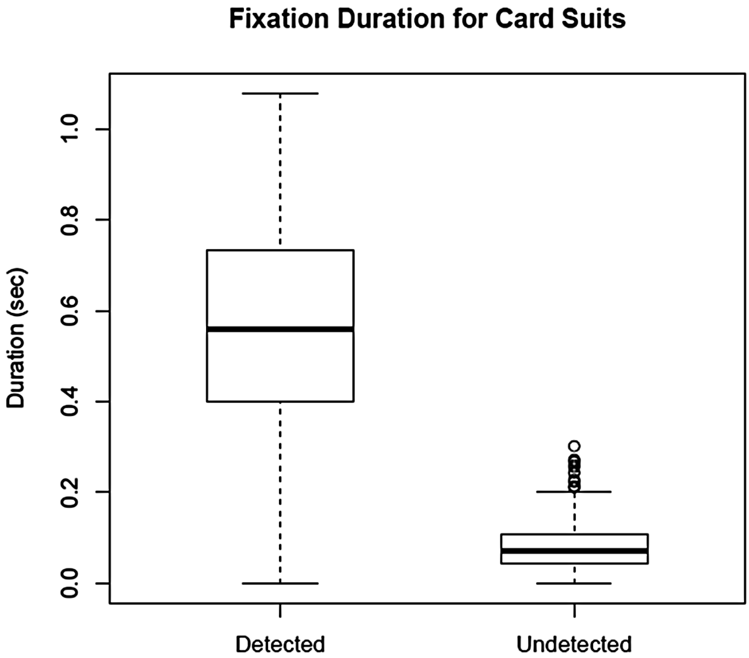

Fig. 3 Box plot of fixation durations for detected and undetected suits across all participants

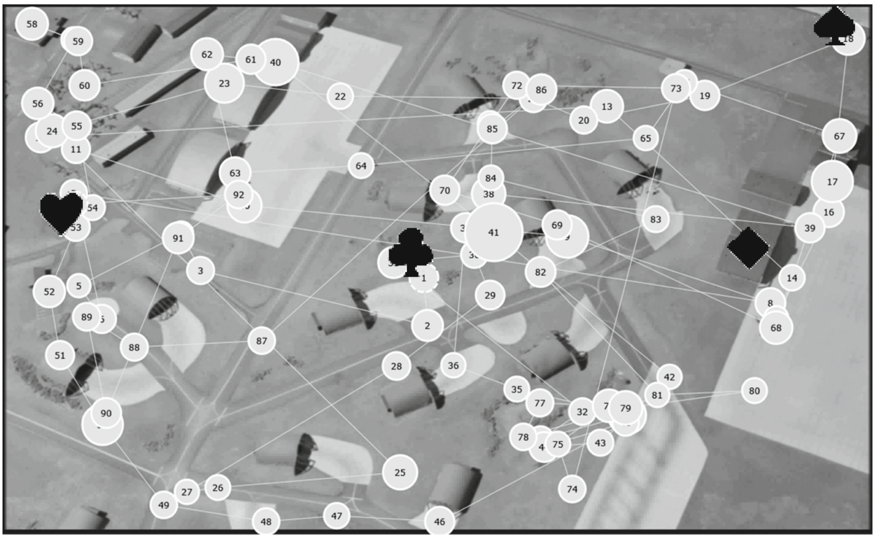

Fig. 4 Sample gaze plot of one trial for one participant. The participant consciously detected the heart and did not detect the spade, diamond, or club. Note that the suits are enlarged for indication purposes only and were smaller and less salient during the actual experiment

AOI, as expected. However, there are also fixation points on the club and spade AOIs, indicating that the participant looked directly at them but did not consciously detect them. The diamond AOI shows no fixations points near it, indicating that this is most likely a true non-detection.

5 Conclusion

The physiological metrics of fixation count and fixation duration were identified as possible correlates of detection versus non-detection in a visual search task. Using scatter plots, non-detection outlier points were identified that have significantly different physiological data than the rest of the non-detection AOIs. Gaze plots of these outlier points further indicate that a possible unconscious detection could be occurring.

6 Future Work

Two areas for future work have been identified in order to further examine the physiological correlates of unconscious detection. Further work should be performed in creating a model of detection versus non-detection using the results of this study. Using that model, future non-detection data points can be applied and categorized as either an unconscious detection or a true non-detection. Additionally, it is desired to use the aforementioned model in order to identify possible ways of channeling focus in the event of a potential unconscious anomaly in an attempt to reduce the occurrence of missed targets in a multitude of applicable domains.

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Human-Machine Interaction in the Cockpit and Applicable Design Changes Towards Better Collaboration

Aysen Taylor

Abstract Current flight deck automation has improved the safety and efficiency of commercial aviation but a broad consensus has developed over the last 20 years that this technology is deficient in some areas. It has been developed in an ad hoc manner and without a human centered approach; leading to problems regarding the human/machine interaction and adversely impacting decision making throughout the flight. Current procedures and design do not give automation liability although it has great authority and autonomy during most phases of flight. Cockpit automation has not been designed in such a way to provide adequate and unambiguous feedback to the human operator as to its current and intended actions. More or different training is the most common response to this problem but has failed to fully compensate for the design flaws in current automated systems. Accidents that cite pilot error do not always acknowledge how difficult it is for human operators to overcome fundamental, system level, flaws in the design of the machines they work with. This paper proposes some changes in cockpit automation design that will improve the vigilance of the pilots and therefore create better decision-making. Numerous accident and incident reports have been cited by regulatory authorities when making changes in automated flight operation regulations. This reflects a "reactive" approach to FAA automated flight safety guidelines and highlights the need for an improved governance system in the cockpit. This paper also provides a literature review for current studies on human-machine interaction related to the cockpit.

Keywords Cockpit automation · Decision making · Governance

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1 Introduction

Early aviation featured aircraft utilizing direct mechanical linkages to the control surfaces which provided pilots with constant feedback through their hands and feet. Pilots manually manipulated the throttle and engine noise provided feedback as to its status. This arrangement proved to be physically demanding and inadequate as aircraft range and service ceilings grew. Longer flight times and flights in poor visual conditions warranted the development of autopilot systems and new flight instruments for the pilot to help them maintain a given heading and altitude. Loss of the visual horizon at night or in poor weather could be compensated for through use of an attitude indicator in the cockpit. The first and second World Wars brought rapid growth in airplane technology and avionics. New guidance systems were developed to improve bombing precision. Advances in autopilot systems were complemented with the development of ground based navigation aids using radio beacons and these were later tied to autopilot systems. Each new iteration of autopilot and navigation aids improved operational precision and efficiency.

As pilots direct control of the aircraft slowly gave way to indirect control, the unrecognized trade off was loss of aircraft state feedback to the pilots as more flight path management duties passed to the autopilot. Edwards raised concerns of potential problems with automated cockpits [1, 2]. Current generation airliners have 80 % of their functionality enabled by software while earlier aircraft from the 1960s had 10 % [3]. These avionic systems were commonly developed in an ad hoc fashion, without consideration of how sub-components interact and with little consideration for the principles of systems engineering. Degani and Wiener [4] studied the airline cockpit as a complex human-machine system and discussed the impact of operational management of the organization on this system. Airline companies developed detailed procedures for pilots to follow as a way to standardize the methods for completing common flight tasks in a logical and efficient manner. Their study found that pilots often vary greatly in some aspects from the standards mandated by their organizations. They blamed this more on the ways procedures were developed than on the pilots. While Standard Operating Procedures (SOP) have a role in aviation, over reliance on them can reduce the role of the human operator and therefore reduce the benefit provided from human operators who can reason when presented with novel situations for which there is no SOP.

Accident and incident reports over the last twenty years cite more problems with the human-machine interaction in these advanced aircraft and use of the term automation surprises [5] became more common. Many advocated for changes to training protocols to overcome shortfalls in airline operations of automated cockpit systems. While this technology was given more autonomy and authority it was not adequately designed to provide sufficient and unambiguous feedback to the human operator as to its current and intended actions. Humans and machines will never be infallible but mishaps from their inability to work collaboratively can best be reduced through improved designs of cockpit automation systems and sound decision governance of pilot-automation interactions.

1.1 History of Automation in Aviation

Early aircraft systems utilized a pilot who moved controls, thus changing the control surface positions and altering airflow, which changed the flight path. Technology was later added to improve accuracy in navigation and reduce physical fatigue on pilots. This improved efficiency while reducing the pilot's direct control of their aircraft. A new hazard was created as the autopilot would happily fly the plane into a mountain without human intervention. The introduction of Flight Management Computers (FMC) required pilots to program waypoints along a planned flight path and enter performance data such as pounds of fuel loaded, runway length, and local barometric pressure readings. The FMC was later tied to the auto throttle controls. With each new layer of automation the pilots lost more direct control of the plane and had more difficulties getting and interpreting feedback from automation [6].

1.2 Regulatory History

The US Army established a flying school near San Diego in 1912 and established the first organized oversight of aviation [7]. The Contract Air Mail Act of 1925 started an innovative postal program that later served as a model for commercial air operations [8]. Various Federal agencies had oversight of airline operations and ultimately culminated in the formation of the National Transportation Safety Board (NTSB) as the investigative arm which suggests rulemaking to improve safety to the Federal Aviation Administration (FAA) [9]. The FAA has sole purview of rulemaking and enforcement relating to civil air operations. They also oversee a certification process for new aircraft models and related subcomponents such as autopilots, to ensure safety. The 1978 Airline Deregulation Act was passed by Congress to promote competitive market forces in the industry [10] and ushered in a host of low cost carriers to compete with legacy carriers such as American, United, and Delta.

1.3 Aeronautical Decision Making and Risk Management

The FAA defines aeronautical decision making (ADM) as the "Systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances" [11]. The FAA places ADM in the broader context of risk management. Noyes, [12] discussed the impact of complex automation on existing models of ADM. She stated "too much automation, and the human operator is not in the loop when failures and malfunctions occur. Making decisions thus becomes problematic as crew are not fully aware of the situation." She further elaborated by saying "the challenge for system design concerns the development of systems, which provide an appropriate level of automation for a particular situation at a given time."

1.4 Two Design Philosophies, Boeing Versus Airbus

Boeing and Airbus dominate manufacturing of large commercial transport aircraft today and their design choices have great influence over other makers and tend to set standards. Boeing introduced the glass cockpit 757 and 767 in the early 1980s and committed the company to using analogue gauges only in a supporting role. They updated the 737 and 747 models with glass cockpits and introduced the fly-by-wire 777 and 787. These advances in technology allowed aircraft to navigate using satellites and on-board equipment. This brought performance-based navigation (PBN), which reduced average flight times, improved fuel efficiency, and is widely credited with reducing accident rates compared to air transports only operating with ground based sensors for navigation guidance [13, 14].

Airbus introduced the first fly-by-wire airliner in 1988 with their A320. This approach provides flight envelope protections which limit the pilot's input when these place potentially damaging G forces on the airframe or lead to an angle of attack that would cause a stall to manifest. This technology also lowered maintenance costs and reduced training times.

Boeing and Airbus each have published automation philosophies; the key difference being that Boeing takes a more pilot centric approach. In both designs, automation will override or resist the pilot at the outer limits of the flight envelope. Airbus has a marginally greater number of these override systems and they activate slightly sooner. Airbus uses a sidestick while Boeing uses a traditional yoke. This yoke uses a stick shaker during a pre-stall event and will push forward automatically if a stall manifests. The sidestick does not do this and they are also not slaved to each other as the yokes are and thus one pilot cannot know what inputs the other pilot is applying. When the aircraft is operating in full automation, the Boeing throttles and yokes move to reflect inputs from the autopilot but the sidestick and throttles in an Airbus do not move while under autopilot control. Airbus recently received a patent for a design featuring a windowless cockpit as seen in Fig. 1.

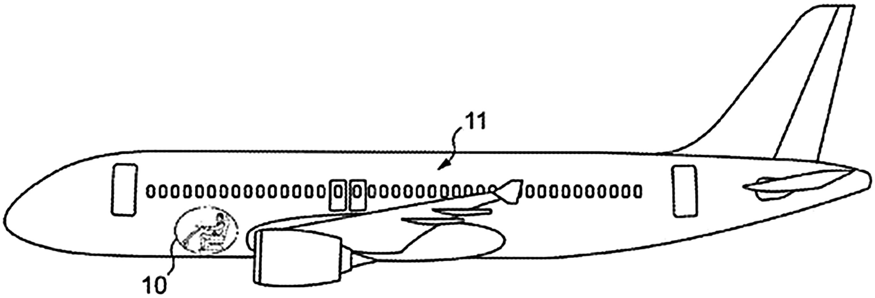

Fig. 1 Airbus' new design to eliminate pilot's natural vision (U.S. Patent No.2014/0180508A1, 2014)

1.5 CRM and Its Implications for Cockpit Automation

Crew Resource Management (CRM) has been a core element of initial and recurrent pilot training for decades. It requires crew members to work together as a team and not show undue deference to a senior pilot and be ready to speak up when one thinks standard operating procedures (SOP) are not being followed [15]. The opaqueness of automation and lack of consistent feedback to the pilots has made it difficult to utilize CRM principles and include cockpit automation as part of the team. Pilots may have trouble recognizing and recovering from automation failures and trying to do so increases workload significantly.

2 Problems with the Current Flight Deck

Previous research on problems with cockpit automation fall into one of several categories. Automation has impacted workload by lowering workload where it was already low and increasing it where it was already high [16]. Various working groups comprising all or most major stakeholders in commercial transport aviation conclude workload is reduced during normal operations but can increase in non-normal circumstances such as a last minute runway change from Air Traffic Control (ATC) as use of the automated systems may increase task complexity and workload on the pilots. Pilots can lose their cognitive model of what the plane is doing while under automated control and this leads to a phenomenon called automation surprises [5, 17]. This situation awareness issue is sometimes more narrowly focused in the literature as mode confusion referring to the many possible mode configurations in the FMS [18].

A common concern in studies over the last 20 years is the degradation of manual flying skills of pilots who operate their aircraft at a high level of automation during most phases of flight [19]. How to improve training to help pilots better utilize automation is a topic of long standing but more recently Geiselman et al.

emphasized [20] that better training is only a partial solution and they call for "a more context-aware automation design philosophy that promotes a more communicative and collaborative human-machine interface." The autopilot systems in use have a myriad of possible configurations, which makes it difficult for the pilot to understand what mode is in force at any given time. A diagram of these modes is shown in Fig. 2.

2.1 Lack of Governance for Automation

Inadequate governance has been identified as an obstacle to improving safety in highly automated commercial transports. Reidemar [21] highlighted the gap between operational policy and practices on the flight deck. She emphasized that the manufacturers' automation philosophy is only about design and says little about operations. Poor guidance is being provided for training, procedures, and the division of labor. She cites problems related to varying policies and cultures among different carriers and calls for a unified policy that "provides general principles for human-automation interaction in the cockpit and all other aspects of operations." The current regulatory model governing cockpit automation/pilot interaction is outdated, ad hoc, fragmented, and may inhibit advances needed to improve safety [22].

3 Need Input from Automation to Improve Pilot's Situational Awareness and Vigilance

When considering broadly how to improve safety and efficiency in commercial aviation, making automation more of a team player should be a primary goal. The process of updating avionics is lengthy and the question arises of how to improve the automation system without making an entire redesign, which would be costly, time consuming, and require much additional training. Some add-on applications should be considered to make improvements until basic design changes can be created and implemented to update current automated systems. Several fatal commercial aviation crashes including Air France 447, Air Asia 8501, Asiana 214, and Colgan Air 3407 have shown that a large obstacle to pilots applying their airmanship skills is automation dependency and overreliance. Once automation had reached its performance limits, it can abruptly disconnect and shift total responsibility to the pilots, often with little or no guidance as to the last state of the aircraft. Sometimes pilots are confused over the course of routine flights as automation can lead to them being out of the control loop. Cockpit voice recordings reveal comments such as "what is it doing now?", "are we descending or ascending?", and "I don't understand why it's pitching up", etc. If a supplemental piece of automation is

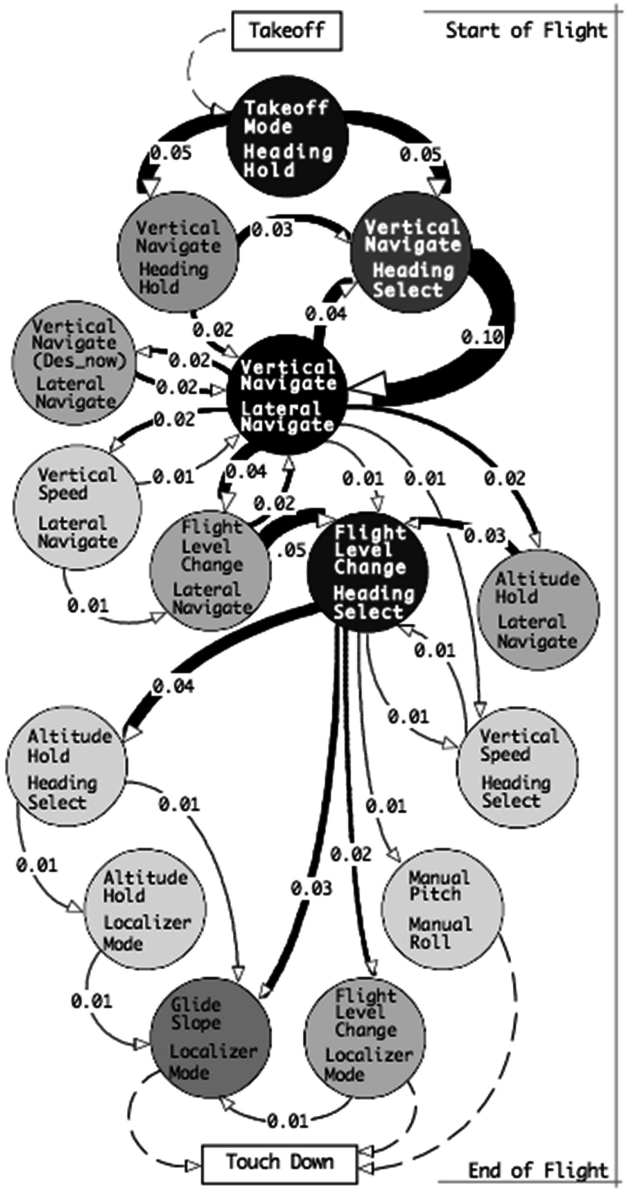

Fig. 2 Diagram of various autopilot mode configurations over the course of a flight. "Modes in automated cockpits: problems, data analysis, and a modeling framework", Degani et al. [18]

provided that helps the pilots maintain awareness of aircraft state, this could help them act correctly and swiftly when they must suddenly take manual control of their aircraft. A survey conducted amongst airline pilots clearly makes us believe that automation has made the pilot's life easier (75 out of 77 survey respondents said this) but the same survey revealed that 37 % of pilots are sometimes surprised by the actions automation takes. We believe if pilots are engaged with their aircraft throughout the flight, it will improve safety and therefore more research is needed in this direction.

4 Conclusions

While automation in the cockpit has reduced accident rates and improved efficiency, there are some prominent accidents in the last decade that point to issues of inadequate feedback between automation and the pilot crew. A new generation of pilots is coming online with far less experience in manual operation of flight controls and the risks associated with sudden autopilot disconnections may increase. The governance process relating to certification of flight path management systems should better account for the recognized hazards identified in the literature about cockpit automation over the last 30 years. Pilots are not less important today, indeed, they are the most critical last line of defense when it comes to aviation safety but they need better interfaces with their plane's computers and automation must be made to conform to the principles of CRM that pilots are expected to adhere to. Boy emphasized that human reliability should be considered from two vantage points; humans have limitations but humans are also uniquely suited to solve novel and unexpected problems [23] and we need to value this crucial component of the system.

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Part V
Human Interaction in Automated and Collaborative Systems

Effect of the Implementation of the Two-Third Power Law in Teleoperation

Yves Rybarczyk and Diogo Carvalho

Abstract This research consists in studying the effect of the implementation of a biological law on the teleoperation of a mobile robot. Two experimental conditions are compared: a Manual one, in which the velocity of the robot is controlled by the human operator, and a Biological one, in which the vehicle's speed is automatically calculated by using the 2/3 Power Law. Results show that the robot is driven faster and safer with the human-like behavior than without. The objective of the study is to propose an innovative method for the development of semi-autonomous vehicles, which is based on an anthropomorphic approach.

Keywords Human-like behaviors · 2/3 power law · Remote control · Robotics

1 Introduction

The remote control of a robot implicates several constraints for the teleoperator. Ones are related to the increase of mental workload caused by the difficulties to acquire new motor schemes adapted to the control interface of the artefact. Another is the low quality of the sensorial feedbacks provided to the operator, which can be a limitation in terms of field of view, delay in the system response, absence of certain sensorial information (e.g., proprioception, audition…), among others. An

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original approach to reduce the gap between the user and the telerobot is to implement human-like behaviors in the robot's way of working [1–3]. For instance, a human behavior that was successfully modelled and implemented on a remote controlled mobile robot was the visuo-motor anticipation over the locomotion, in which the direction of the robot's pan-tilt camera was automatically oriented toward the tangent-point of the inside curve of the path, as walkers/cyclists/drivers do. Recently, [4] have shown that such an implementation enables the teleoperator to steer the machine with a significantly higher trajectory smoothness. In the present paper, we propose to study if the anthropomorphic approach can be generalized to other sensorimotor properties. A fundamental one is the fact that the kinematic of many different human movements seems to follow a same mathematical equation known as the "Two-Third Power Law" [5, 6]. So, whether the action is writing [7] or walking [8], an identical constraint relationship between the velocity and the curvature of the motor trajectory is involved. This law states that the angular velocity of the end effector is proportional to the two-thirds root of its curvature or, equivalently, that the instantaneous tangential velocity (v_t) is proportional to the third root of the radius of curvature (r_t):

$$\mathrm{v}_{(\mathrm{t})} = \mathrm{kr}_{(\mathrm{t})}^{-1/3}. \quad (1)$$

In other words, it means that the velocity of the movement decreases in the highly curved parts of the trajectory and increases when the trajectory becomes straighter. Here, an experiment was designed to compare the remote control of a robot with the "Two-Third Power Law" (Biological condition) versus without this human-like law (Manual condition). In the Biological situation the robot's velocity is automatically servo-controlled by the robot's trajectory according to the Power Law equation, whereas in the Manual situation the individual has to control the direction and velocity manually. The hypothesis is that a semi-autonomous driving in which the velocity is automatically set according to the Power Law principles (Biologic mode) should provide to the user a faster and safer control on the robot than a fully manual remote control of the vehicle (Manual mode).

The first part of the article explains the system developed to carry out the experiment. Then, each of the main experimental condition (Manual vs. Biologic) are described in details. After that, the experimental protocol is presented. The results of the performance for each condition are statistically analyzed. Finally, data are discussed and interpreted in order to draw some conclusions and perspectives of application in the field of the development of semi-autonomous vehicles.

2 Materials and Methods

2.1 Technological Implementation

System's Architecture. The system is composed by three main elements, which are: a remote control based on an Android mobile device, a NXT robot, and an IP camera. A wireless communication between these elements is justified by the fact that the experiment is carried out in teleoperation conditions (visual feedback mediated through a computer screen). The three components are connected in two distinct ways. The Android device communicates with the robot through a Bluetooth technology and is connected to the camera through a Wi-Fi communication. The connection between the robot and the IP camera is carried out through a support library, in order to enables a system integration between the camera and the robot. So, the users interact with the whole system through the Android remote control device, which enables them to steer the robot and receive a visual feedback from the robot's camera. An Android application was developed to allow such an interaction through a tactile user interface. The touchscreen enables the user to control the robot's trajectory, to select the steering mode of the vehicle (Manual vs. Biologic), to calibrate the IP camera, to connect and disconnect the system. Figure 1 exhibits the architecture and the technologies used to interconnect the main components of the system.

Robot's Behavior. The robot is built on four wheels, with two front-wheel-drive (Fig. 2, on the left). Each wheel-drive is controlled by an independent engine. The differential of velocity between the left and right wheel rotation enables the robot to change its direction. The IP camera is set on a mobile support, which is controlled by a third motor. The camera's orientation is automatically calculated according to the direction of the vehicle, in order to point toward the inside of the trajectory. Consequently, the pan camera provides to the user a visual anticipation over the vehicle's locomotion, because any change of direction is synchronized with a camera's rotation proportional to the curvature of the robot's trajectory. This

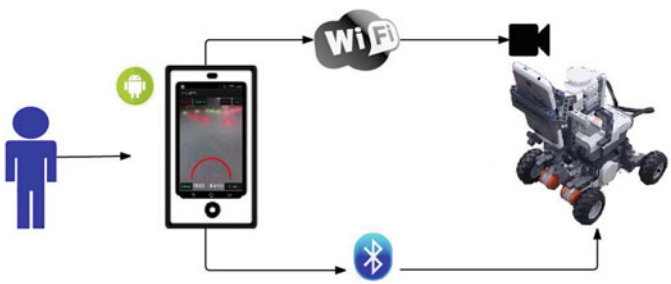

Fig. 1 Diagram of the architecture that represents the main elements of the system (user, remote control, mobile robot and IP camera) and the technologies used to ensure the communication between them (Wi-Fi and Bluetooth)

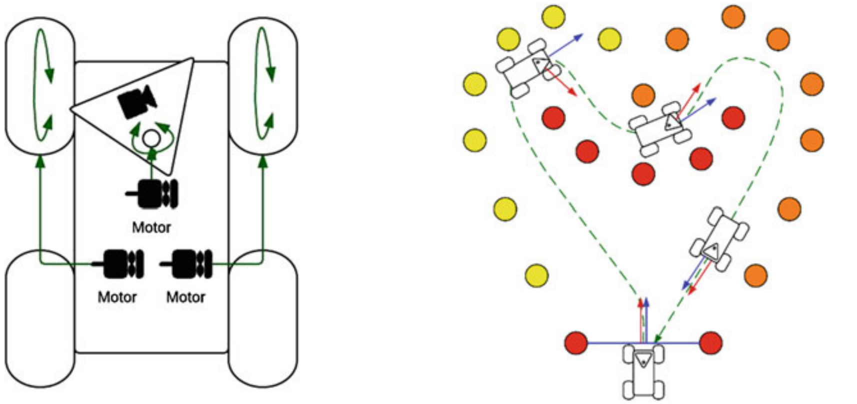

Fig. 2 Figure on the *left* represents a top view of a schematic drawing of the robot used in the experiment. Two motors control the rotation of the front-wheels and a third one drives the pan camera. The mobile vision is implemented to provide a better anticipation over the changes of trajectory. Figure on the *right* illustrates the behavior of the camera according to some examples of different kinds of bend. The *blue arrows* represent the instantaneous robot's direction and the *red arrows* indicate the orientation of the camera at the same instant. To notice that the angle between the two arrows is inversely proportional to the radius of curvature of the vehicle's trajectory

mechanism inspired from the human behavior [9, 10] was implemented by default, because it facilitates the teleoperation [1, 3]. Figure 2 (part right) shows examples of this visuo-locomotor coupling between camera and robot for different curves of the path.

2.2 *Experimental Conditions*

Manual Condition. In this condition the user has to manually control both the direction and the velocity of the robot. On the user interface control panel is represented concentric semicircles, which correspond to different levels of velocity (Fig. 3, on the left). Larger is the radius of the semicircle, higher is the velocity. So, the calculation of the robot's speed is based on the distance between one point on a semicircle and the center of the whole concentric semicircles. The robot's direction is inferred from the angle between the vertical of the remote control device and the fingertip of the user. The amplitude of the angles goes from 0° to 180°, rotating counterclockwise. If the user's fingertip is located between 0° and 90° the vehicle will turn right, with a curvature proportional to the angle between the vertical (90°) and the fingertip's pressure (more the finger's position tends to 0° more the robot turns right). On the other hand, if the fingertip's position is between 90° and 180° the robot will turn left (also, with an amplitude that depends on the angle from the vertical). The controller is constantly waiting for a command input from the touchscreen interface in order to update the velocity and direction of the vehicle.

Fig. 3 On the *left* side is a representation of the GUI for the Manual mode of driving. Each *concentric circle* represents a different speed (larger is the radius of the semicircle, higher is the velocity). On the *right* side is the user interface for the Biological condition. A single semicircle enables the user to directly control the direction of the robot and indirectly set the speed of the vehicle

Biological Condition. In this driving mode the user only controls the direction of the robot through the touchscreen interface. The velocity is automatic and depends on the trajectory of the robot. This velocity is calculated according to the instantaneous radius of curvature of the vehicle's trajectory, following the 2/3 Power Law. If the robot goes straight forward, it will move at a maximal speed of 30 cm/s. However, if its radius of curvature decreases (to the left or to the right), its velocity will reduce by a proportion of one-third. The GUI is represented by a single semicircle, because no manual settings of the speed are necessary (Fig. 3, on the right). This semicircle enables the user to control the direction of the vehicle. From the user's perspective, the way to guide the robot is identical to the Manual condition. The user has to use the right side of the semicircle to turn right and the left side to turn left. More the fingertip is located to the extremities of the semicircle (left or right) more the robot will turn sharply. The only difference between this mode and the Manual one is the fact that when the users pick a determined direction they also indirectly set a velocity to the robot, which will be proportional to the steering angle selected. If the Power Law is adapted to the remote control of an artefact, the matching between speed and steering angle should perfectly fit to the human's skills.

2.3 Experimental Protocol

Twenty people between 22 and 27 years old participated in the experiment. All of them had a normal or corrected-to-normal acuity. They were informed about the purpose of the experiment and they gave us their consent to participate. The experiment consisted in teleoperating a NXT mobile robot through an Android based mobile device. The participants were instructed to steer the vehicle as fast and safe (a minimum of collisions) as possible in an environment delimited by plastic blocks. The total distance of the path was approximately seven meters and was composed by several curves and changes in direction. As shown in Fig. 4, the course initiated with a straight line, then an approximatively 150° bend, then a 90° reverse curve, then again a 150° bend before a last straight line. A blue adhesive strip on the floor marked the start and finish line. The symmetric form of the

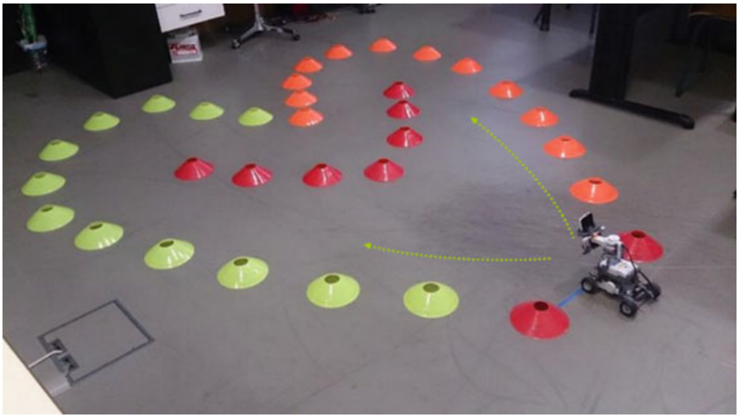

Fig. 4 Picture of the environment used in the experiment. The symmetric form of the path was chosen to easily alternate the course direction of the robot from one trial to the next: once clockwise and once counterclockwise (*green dotted lines*). This alternation was designed to minimize a machine-like way of driving the robot

environment was specifically designed to perform the path in both directions, clockwise and anticlockwise.

After a training session, each participant had to complete the path eight times: four times in the Manual condition and four times in the Biological condition. The order of the conditions were counterbalanced between the participants such as ten people started with the Manual driving and the ten others started with the Biological driving. This counterbalancing was designed to avoid a possible learning effect, which would bias the results of the experiment. For each of the main conditions (Manual vs. Biologic) the path was completed twice clockwise and twice anti-clockwise. Table 1 summarizes the experimental design used for this study. At the end of each trial the completion time and the number of collisions were recorded.

Table 1 Design of the experiment that shows the division of groups based on the order they execute each experimental condition (↻ for clockwise and ↺ for anticlockwise)

	Group 1	Group 2	Group 3	Group 4
List of participants	Participant 1 Participant 5 Participant 9 Participant 13 Participant 17	Participant 2 Participant 6 Participant 10 Participant 14 Participant 18	Participant 3 Participant 7 Participant 11 Participant 15 Participant 19	Participant 4 Participant 8 Participant 12 Participant 16 Participant 20
Sequence of the conditions	Manual ↺ Manual ↻ Manual ↺ Manual ↻ Biologic ↺ Biologic ↻ Biologic ↺ Biologic ↻	Manual ↻ Manual ↺ Manual ↻ Manual ↺ Biologic ↻ Biologic ↺ Biologic ↻ Biologic ↺	Biologic ↺ Biologic ↻ Biologic ↺ Biologic ↻ Manual ↺ Manual ↻ Manual ↺ Manual ↻	Biologic ↻ Biologic ↺ Biologic ↻ Biologic ↺ Manual ↻ Manual ↺ Manual ↻ Manual ↺

3 Results

The experimental data are statistically analyzed through ANOVA tests, for multi-variable, and T-tests, for the pairwise comparisons. The first analysis of the performance is about the completion time to execute the task. Results show a significant effect of the sessions on the completion time [F(3, 17) = 3.25; $p < 0.05$]. The pairwise analysis indicates a significant difference between session 1 and session 4 [$p < 0.03$]. These results show that the necessary time to steer the robot from the start line to the finish line decreases significantly from session 1 to session 4. No interaction effects are observed between the main conditions (Manual vs. Biological) and the sessions (1, 2, 3 and 4) [F(3, 17) = 1.68; N.S].

In addition, the overall comparison of the completion time between the Manual condition and the Biological condition shows a significant difference [F(1, 19) = 15.16; $p < 0.01$]. Figure 5 demonstrates that the mean completion time in the Biological condition is lower than in the Manual condition. The pairwise analyses confirm the significant difference in session 1 [F(19) = 3.19; $p < 0.01$], session 2 [F (19) = 2.11; $p < 0.05$] and session 3 [F(19) = 2.33; $p < 0.04$]. However, this statistical difference disappear in session 4 [F(19) = 1.40; N.S], although the Biological condition tends to remain faster than the Manual one. This last observation could be explained by the session effect that reduces the completion time in both, Biological and Manual conditions.

To complement the results, an evaluation of the occurrence of collisions was also carried out. The statistical analysis shows that the average number of collisions is significantly different over the sessions [F(3, 17) = 4.09; $p < 0.03$]. A pairwise analysis indicates a significant decrease of the collisions from session 1 to session 4

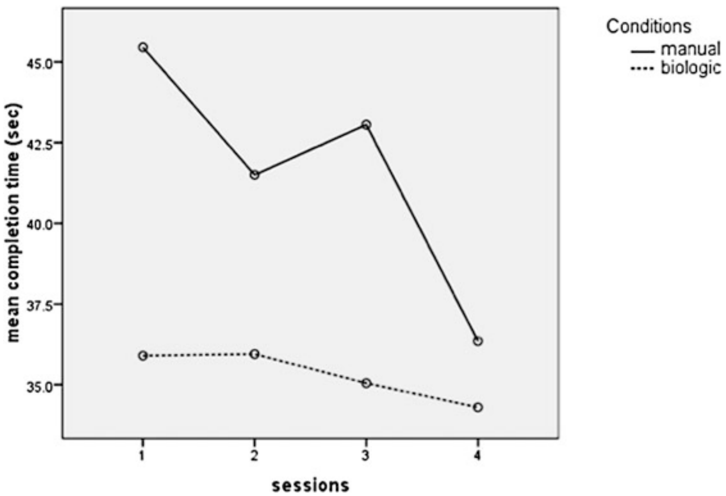

Fig. 5 Representation of the mean completion time (in seconds) for each of the main conditions (Manual vs. Biologic) against the four experimental sessions

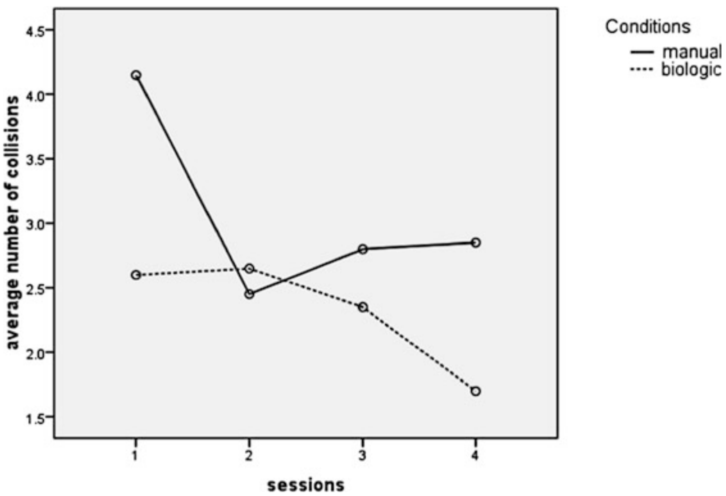

Fig. 6 Representation of the average number of collisions for each of the main conditions (Manual vs. Biologic) against the four experimental sessions

[$p < 0.02$]. These data point out that the participants' skill to drive the robot was improved over the experiment. There is no interaction effect between the two main conditions (Manual and Biological) and the four experimental sessions [$F(3, 17) = 2.08$; N.S].

The main comparison between the Manual vs. the Biological condition, over the whole sessions, indicates a significant difference [$F(1, 19) = 7.75$; $p < 0.02$]. As shown in Fig. 6, less collisions are produced in the Biological condition than in the Manual one. A statistical analysis session by session shows a significant difference in session 1 [$F(19) = 3.59$; $p < 0.01$] and session 4 [$F(19) = 2.50$; $p < 0.03$]. This last observation means that the learning effect do not enables the participants in the Manual condition to get driving skills as good as in the Biological situation.

4 Conclusions and Perspectives

This study consisted in analyzing the effect of the 2/3 Power Law on the control of a mobile robot. Two experimental conditions were compared. A first one in which the user had to manually control both, direction and velocity of the robot and a second one in which the robot's speed was automatically set according to the Power Law equation. The task of the participants was to remotely control the vehicle in order to complete the path as fast and safe as possible. The performance was recorded on four sessions. The statistical analyses shows that the completion time and the number of collisions significantly decrease across the sessions. This result can be explained by a learning effect of the participants, which leads to an improvement of the performance. The main comparison of the study shows that the velocity and precision to execute the task are significantly better in the Biological condition than in the Manual one. The advantage of the Biological mode can be explained by the fact that the automation of the velocity decreases the mental workload and sensorimotor resources of the teleoperators, who can focus their attention only on the way to guide the robot.

In a situation of human machine interaction, this is not always an advantage to automatize some parameters of the artefact. Usability rules that take into account the characteristics of the human being have to be followed. Here, the method proposed is to implement a human-like behavior to automatize the robot's velocity according to its trajectory. In the case of teleoperation, the anthropomorphic approach seems to be successful. Currently, a trend in the automobile industry is to create more autonomic cars [11]. However, the fact that drivers still want to keep the control is a big challenge for the constructors. As suggested by the results of this study, the use of human-like behaviors such as Power Law [12], Fitts' Law [13] … could be a promising process to automatize some key aspects of the vehicle's way of working. The potential success of such an approach is based on the fact that a vehicle that behaves as a human being would be easily understood and appropriated by the driver [14]. Future work will consist in testing the anthropomorphic approach in conditions more real than the laboratory and, also, in exploring other methods to implement human-like behaviors such as machine learning.

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Speed and Accuracy Improvements in Visual Pattern Recognition Tasks by Employing Human Assistance

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Abstract This study investigates methods of enhancing human-computer interaction in applications of visual pattern recognition where higher accuracy is required than is currently achievable by automated systems, but where there is enough time for a limited amount of human interaction. The first author's doctoral dissertation research and experiments are summarized here. Within this study the following questions are explored: How do machine capabilities compare to human capabilities in visual pattern recognition tasks in terms of accuracy and speed? Can we improve machine-only accuracy in visual pattern recognition tasks? Should we employ human assistance in the feature extraction process? Finally, human assistance is explored in color and shape/contour recognition within a machine visual pattern recognition framework.

Keywords Human-machine interaction · Visual pattern recognition · Feature extraction · Machine learning

1 Introduction

Most pattern classification tasks are comprised of the following processes: preprocessing, feature extraction and classification [1]. In visual domains preprocessing can involve the isolation of an object from other objects. Feature extraction usually reduces the data by measuring certain distinct and measurable features. In the case of face recognition, for example, this can involve the distance between eyebrows, length of the nose, etc. The last process is classification, where the feature space is typically divided into decision regions and the object is assigned a

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category. Pattern classification and machine learning are often viewed as two facets of the same field [2].

Each of the pattern classification processes can be performed by humans, by machines, or by a combination of both. Humans have been attributed with high accuracy and low speed, while machines have been attributed with high speed but low accuracy. Investigations on how to combine human and machine capabilities to increase accuracy while maintaining a reasonable time to accomplish the task in visual recognition tasks is the focus here, in particular in the feature extraction process.

Feature extraction in visual recognition can include color, texture, and shape extraction methods. Each of these methods has been researched individually, and the way both humans and machine algorithms perform these tasks has been investigated.

The first author was introduced to the concept of combining humans and machines interactively in visual pattern recognition tasks through a concept named CAVIAR (Computer Assisted Visual InterActive Recognition). The key to effective interaction is the display of the automatically-fitted adjustable model that lets the human retains the initiative throughout the classification process [3]. Using CAVIAR with its human-machine interaction model, the accuracy level of visual pattern recognition achieved is higher than that achieved by human-alone or by machine-alone operations. CAVIAR has been implemented as a flower recognition tool and a facial recognition tool, both named IVS (Interactive Visual System).

The research plan in this study is to investigate different ways of human-machine interaction in the various phases of the pattern recognition process. One exploration was in feature extraction process where the objective was to determine precisely the specific area in which the human-machine combination provides highest accuracy.

2 Initial Research

The details of this experiment have been presented in the poster session of the HCII (Human Computer Interaction International) Conference 2014 [4]. This experiment was conducted in three parts: human-only recognition, machine-only recognition and interactive recognition. We utilized an IVS tool for flower recognition. Three testers were used and an experiment coordinator monitored the activities and recorded the results. We collected a database of 535 images from 131 flower species.

In the manual recognition part, testers were asked to identify the correct flower species by finding them in a flower guidebook. The top three choices and the time to accomplish the tasks were recorded.

The automated recognition was conducted using IVS. Three separate testers loaded the flower images into IVS and performed automated feature extraction and recognition process. This was done without providing any human input in the feature extraction process. For each flower image the application presented the top three selection choices which were recorded by the experiment coordinator.

The interactive portion of the recognition task was divided into three subtasks. The first subtask let the machine perform automated feature extraction, but humans

Table 1 Experiment results

Test type	Percent accuracy (Top 3)			Average accuracy (%)	Average time (s)
	Tester1 (%)	Tester2 (%)	Tester3 (%)		
Manual	40.0	36.7	20.0	32.2	173
Automatic	13.3	13.1	13.3	13.3	56
Interactive A	13.3	16.7	16.7	15.6	44
Interactive B	63.3	60.0	30.0	51.1	41
Interactive C	40.0	36.7	40.0	38.9	44

provided the petal count values. The second interactive subtask let humans provide petal count and color values (primary petal color, secondary petal color and stamen color). The last subtask added image cropping assistance by humans.

The result of the experiment is presented in Table 1. Interestingly only interactive B presents accuracy high enough to look into further. This is when human assistance is employed in providing primary and secondary petal color, stamen color and provides feedback on the number of petals on each flower.

We conducted another experiment, focusing on human interaction in color extraction only. This experiment used 20 flower images from different species and 15 testers. The result of this experiment showed an even higher accuracy, with an average of 74 % accuracy results in finding the right flower within the top three selections, with an average completion time of 53.7 s.

After two experiments, we have noticed that human interaction in the color extraction process does increase accuracy results significantly. Human assistance in shape-related feature extraction activities did not increase accuracy level enough to warrant further investigation. The next questions that came to mind were about our tool/environment: IVS. How much of these results are caused by the tool? How about doing similar experiments on other tools or a different version?

3 Further Literature Research in Image Segmentation

As the first author presented the findings above during the poster session of the Human and Computer Interaction International Conference 2014 in Greece [4], he was fortunate to have a number of discussions with visitors from various countries. A discussion with a visitor revealed that Rochester Institute of Technology has an Imaging Science Center, and that the writer should inquire on their latest findings on color recognition.

After contacting Rochester Institute of Technology Imaging Science Center, and being redirected to Prof Eli Saber, the first author was directed to their latest survey on Color Image Segmentation. This publication contains a comprehensive survey of color image segmentation strategies within the past decade [3]. This survey is not only quantitative, but also qualitative, as they ranked the results of the image segmentation using a segmentation criterion.

In the survey, Rantaram and Saber define color image segmentation as: "the process of partitioning or segregating an image into regions (also called clusters or groups), manifesting homogeneous or nearly homogeneous attributes such as color, texture, and gradient, as well as spatial attributes pertaining to location." Therefore, their survey not only includes color segmentation, but also involves textures, contour, etc.

The survey conducted an evaluation benchmark on the prominent color algorithms using a measuring technique developed at UC of Berkeley for image boundary detection. The top four algorithms indexed based on the survey's quantitative evaluation are: UCM (ultra-metric color map) algorithm [5], GSEG (gradient segmentation) algorithm [6], MAPGSEG (multi-resolution adaptive and progressive gradient segmentation) algorithm and GRF (Gibbs random field) algorithm [7]. It is interesting to note that the highest accuracy for boundary detection for color image and gray image as of today (Mar 10, 2016) are still both held by humans.

Possible areas of research could be measuring the results of combining each algorithm above with human assistance, or the opposite: human image segmentation assisted with some machine capabilities with the hope of finding even better algorithms or knowing how humans perform image segmentations.

4 Tool Upgrade

To uncover and have a better understanding of every algorithm used in IVS, we decided to build an updated version of IVS. The details of this activity were part of the poster session of the HCII Conference 2015 [8].

Currently IVS uses a modified watershed algorithm for segmenting image from its background, a histogram to aggregate color within an area is utilized to detect color, a rose-curve algorithm (using 6 parameters: center, outer radius inner radius, number of petals, and initial phase) for its object identification, then kNN (k-Nearest Neighbor) for final matching [9]. Data is stored locally on the machine.

The initial tool upgrade was done using Appinventor (originally invented by Google, now maintained at appinventor.mit.edu), which allows a very quick and easy method to build android based mobile application. The new mobile application allows taking high resolution pictures (3–4 MB) of flowers and saving it to the cloud (Google drive) [8]. The user can provide color feature extraction inputs for petal primary color, petal secondary color and stamen color. We added location information (automatically retrieved while taking the picture) and kept human input for petal count capability. All feature extraction data is also transmitted to Google cloud into a table, readily available for further analysis.

Human color input in this mobile application is done by touching the screen. The color picture of a flower is displayed after the user takes a new picture or uploads an existing picture. Within this high resolution image, the user can then touch to select petal colors (primary and secondary) and stamen color. The selection is presented

Fig. 1 IVS2 data collector

with a copy of the color image in a palette and the corresponding RGB values. If the user is satisfied, then he/she can submit the value. If not, then he/she can re-input their feedback.

During data collection process, which was conducted by undergraduate and graduate students of a capstone course, we added 70 more flower species. For each flower species, we took around 4–5 pictures from different angles.

The students collecting the data wanted to change the mobile application into a web application to incorporate a more guided process. A web application, using Python with Flask framework, was created. User actions were guided one web screen at a time and final identification using the kNN algorithm was implemented (Fig. 1).

5 Next Experiment

As we now had a high resolution flower data set, we wanted to know the increase of accuracy level in various color spaces and then also compare the results with previous experiments. HSI (Hue, Saturation, and Intensity) color space is considered close to human perception, but device dependent; whereas CIELab is typically considered the most complete color space and is device independent. If the accuracy results were not consistent using CIELab, then we needed to pay more attention to the device being used and potentially the image capture process. We also wanted to have a data model using a statistical tool.

Color selection during the feature extraction process was recorded in RGB values. These values were then converted into HSI, XYZ and CIELab. As all data were already in a table, we just had to find the conversion formulas and automatically converted all existing values into those different color models. RGB can be converted directly to HSI or other variations of it, such as: HSV (Hue, Saturation, and Value), HSL (Hue, Saturation, and Lightness) with a mathematical conversion.

There is no direct conversion from RGB to CIELab. It must first be converted to XYZ, then we can continue converting to CIELab.

Formula for conversion from RGB to XYZ is as follows:

$$X = \mathrm{int}_{\mathrm{red}} \times 0.4124 + \mathrm{int}_{\mathrm{green}} \times 0.3576 + \mathrm{int}_{\mathrm{blue}} \times 0.1805 \tag{1}$$

$$Y = \mathrm{int}_{\mathrm{red}} \times 0.2126 + \mathrm{int}_{\mathrm{green}} \times 0.7152 + \mathrm{int}_{\mathrm{blue}} \times 0.0722 \tag{2}$$

$$Z = \mathrm{int}_{\mathrm{red}} \times 0.0193 + \mathrm{int}_{\mathrm{green}} \times 0.1192 + \mathrm{int}_{\mathrm{blue}} \times 0.9505 \tag{3}$$

After completing all needed data conversions for color spaces, we proceeded to create data models for each of the color space using SPSS Modeler.

In SPSS Modeler, each block of activity was done through node creations. There are four distinct categories of nodes: source, process, output, and modeling nodes. First we created a source node, where we input raw data. A filtering node was then created (which is a process node), where we selected which data fields we wanted to use. This is where we selected the specific color space values to use. We then defined data types for each field that we would use, by creating a data type node (Table 2).

We then created a data preparation node, where we chose to optimize for accuracy. There are other options available, including speed, balance, custom analysis, etc. For large data sets, speed is definitely an option that should be selected. The next step was to build the algorithm node, where we selected kNN with the option for accuracy.

Four separate models were created for each color space. We could then run the model using training data (Table 3).

CIELab accuracy level is the highest accuracy level that was found from all of the data models.

Table 2 Data types defined

Field	Data type	Role
Species name	Nominal	Target
Primary color	Continuous	Input
Secondary color	Continuous	Input
Stamen color	Continuous	Input

Table 3 Training data test results

Color space	Data type
CIELab	89.3
XYZ	78.3
RGB	85.3
HIS	82.0

Table 4 Testing data test results

Color space	Data type
CIELab	78.2
XYZ	60.2
RGB	72.0
HIS	67.5

We then conducted our testing phase, where we used all data available and passed them through the model that we built in SPSS. The results are shown in Table 4.

6 Conclusions and Future Work Recommendation

Through the first and second experiments, it was found that using human assistance in color feature extraction, and the machine for shape recognition yielded higher accuracy than human-only (amateur humans) or machine-only recognition. Even in creating another tool, the result was consistent that human assistance in color feature extraction improved accuracy results significantly, and this human assistance was performed in a reasonable amount of time to accomplish the tasks.

In the first experiment, human assistance in shape recognition did not improve the accuracy results. Automated shape feature extraction also did not improve the accuracy results. Further literature review indicated that humans are better than machines in color image segmentation, which include background and foreground separation.

In the last experiment, it was found that the highest accuracy resulted from using the CIELab color space. Human assistance was also employed in color extraction for this activity. The value of color extraction was initially recorded in RGB and then converted to various color spaces.

Comparing the results in all three experiments, a consistent increase in accuracy was found when applying human assistance in the color extraction task. Human assistance in color feature extraction significantly increased the accuracy level while maintaining a reasonable amount of time to accomplish the tasks.

The kNN procedure was used as the primary method to perform matching/classification. As there are various other machine learning methods that can be used for this purpose, a comparative analysis of various methods could be an interesting area of future research.

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Development and Evaluation of Augmented Object Prototypes for Notifications in Collaborative Writing Environments

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Abstract In Ubiquitous Computing, augmented objects refer to those elements of the real world which have been provided with computational capabilities to meet a specific need. Meanwhile, Collaborative Writing Environments (CWE) allow groups of people to work together and increase the chances of success and share knowledge when they are working on shared documents. An extremely important aspect in CWEs is notification mechanisms as these are essential to provide users awareness about the collaborative work they are doing. In this paper, we describe a set of augmented objects created to support the notification in CWEs; these objects can improve the way in which the notifications are delivered to users, according to the writing strategy defined by the collaboration team.

Keywords Collaborative writing environment · Notification system · Ubiquitous computing · Augmented objects · System interfaces · System interaction

1 Introduction

Throughout the years, many people have been working together on different types of shared documents in a collaborative manner. Recently, the use of the Internet and other technologies to work with people from different geographic regions has caused an increment in the use of online tools for the creation and edition of digital documents. This situation generates a need to coordinate how the editing work will be done [1].

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Collaborative Writing Environment (CWE) was proposed a solution. In a CWE, a group of people combine efforts in the edition of a shared document [2]. In this type of environment, communication and interaction within the group are of utmost importance [3]. In complex CWEs, the communication and interaction between users can become difficult to manage. Therefore, collaborators must be able to find out: *if* they have pending work, *which* documents require their attention, *when* are the deadlines, *who* is available at a given time, and *what* are the latest changes performed. These pieces of information could be delivered to the user through automatic notifications. This is why notifications in CWEs become a very relevant and transcendental topic.

Researchers found that awareness can be provided by applying new technologies and non-traditional interfaces in order to improve interaction between collaborators in a CWE [4].

Furthermore, it is possible to provide additional capabilities and functionalities to common objects (i.e., create Augmented Objects) through the incorporation of computational capabilities, and use them to improve the interaction between humans and the environments in which they operate their daily activities [5–7].

In this paper, we describe a set of prototypes that help improve the notification process to users in a CWE. We evaluated our set of prototypes by assuring that they aid a set of collaboration strategies [2]. Out system can be applied when users are collaborating with other people through online editing tools, such as Google Docs.

2 Notification Mechanisms Used in CWEs

Various examples of notifications and communications systems created to provide awareness in CWE can be found in literature. Many of these systems are based on Graphical User Interfaces (GUIs) to keep users informed. Examples found in literature include:

2.1 Doc2U

Authors propose a presence awareness system that implements document notifications. This system employs instant messages as notifications. Users (only 2 allowed) must register themselves and the shared document. Collaborators are notified when and in what section the document is modified via text message [8].

2.2 Notification Based on Annotations

This system provides a text editor, and a tool to create annotations to the documents [9]. Authors defined an annotation model and developed a version control to keep up with the changes. Replicating real annotations model was their goal. The system also provides the ability to send notifications through email.

2.3 Smartphone Based Notifications

Authors created a system that triggers notifications via users' smartphone [10]. The system uses information about the environment captured by ubiquitous monitoring devices. The collected data allows selecting the best way to generate the notifications, improving the user awareness even when they are performing multiple tasks.

2.4 Notification Guided by Post-It

In this case, the authors have created an augmented object to deliver notifications. With this device, the user can be notified when the platform of collaboration triggers digital notifications, but in this case, the notification is presented to the user as a physical Post-it on his/her desk. This allows the user to know when the document has changed without the need to use a computer [11]. This paper, proposes an extension of this last described system. We use physical objects as means of notification allowing the user to know what is happening with both the documents and in the collaboration environment.

3 Design Issues from the Point of View of Ergonomics

Previously, some examples of notification systems and mechanisms to improve user interaction in a CWE were specified. However, most of these cases are found in literature that correspond to desktop applications or web systems that manage the documents, making notifications and alerts in a digital manner. In other words, the notification system is based on instant messaging, email, or other graphical interfaces. In this context, users have to connect to these systems using a computer or digital device in order to know what is happening in their CWE.

Throughout the day, users tend to complete their activities using computers from time to time, but not actually being in front of them the whole time. Their time is usually distributed in executing different types of tasks that might be more physical than digital (e.g., revising physical documents, attending to meetings). It is during these shifts into these activities that many users might not be able to direct their attention to the different digitally delivered notifications. These notifications might fail, since they are restricted to their digital domains.

In relation to this, Iqbal and Horvitz [12] in their analysis of work environments, concluded that even though desktop (GUI) notifications are valued by user in order to obtain information and awareness, most of these notifications are actually ignored. Moreover, we can indicate that digital notifications are not sufficient for CWEs. Many of these digital notifications and alerts are not reviewed by the users in the moment they are delivered. This means the users might lose important time on the shared documents because they are not aware on time about the changes that happen to these. In general, CWEs are used to not only share work, but also to deal with deadlines that can only be achieved as a group. Having to rely on these types of notifications might mean delaying the work of others, and essentially a delay in the work as a whole.

4 Solutions from the Ideology of Ubiquitous Computing

The existence of the various problems that emerge from implementing the digital notifications to users, implicates the existence of the need to improve the interaction between collaborators, systems and tools they choose to work on their documents.

From the ubiquitous computing perspective, we can base the design of this new notifications system or mechanism, to use everyday objects. These objects can have augmented characteristics to alert the user about the changes in the CWE. Moreover, these new notifications mechanisms can be as intrusive as they are required to be developed more natural according with the user's mental model. The main purpose of these objects is to provide notifications in the users' workplaces, without having to log into a computer or other devices.

Using a notification system developed with augmented objects, users can benefit throughout the interaction within their groups. This is because once a user is alerted s/he will easily recognize what the notification is related to, and can decide whether to immediately take and action or ignore it. Moreover, depending on the availability of various augmented objects, the notification may be improved in the same context. It is then valid to define a notification environment, since this will be able to precisely inform the user about their CWE. In such scenario, a system that manages the augmented objects and that coordinates the notifications is required, in a way that the objects react in the actual moment that the changes are made. This system must also be able to coordinate new augmented objects as they are added.

The coordination system would have the task to manage the registered documents in which the team or group of users are working on, and also to register the available augmented objects, the type of notification that those can execute, basic information about the notification context, and the collaborative editing strategy that is utilized in each document, among other aspects.

Increasing the number of objects as opposed to digital notifications has to be done in a way that is not extremely intrusive and harmful for the daily work of the user. Figure 1 shows the architecture of our notification environment. The Coordination system is in charge of verifying the documents' states and trigger notifications when necessary. These documents are shown inside the third party system that handles the collaborative editing.

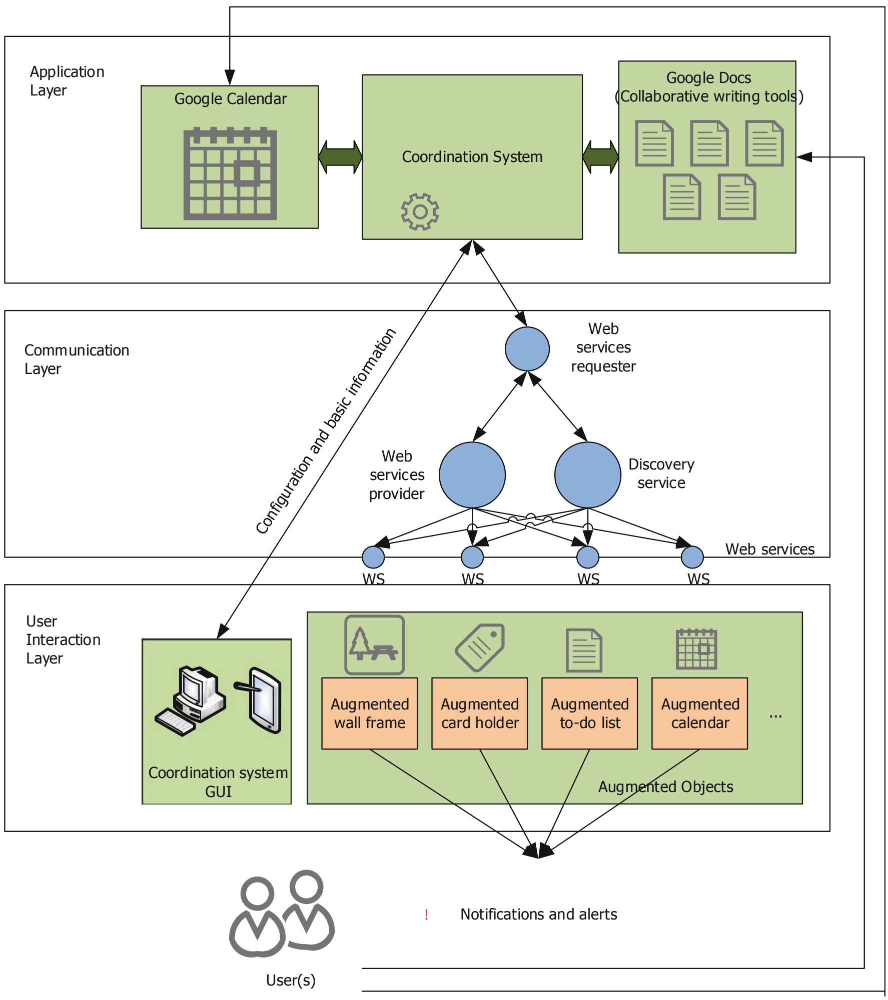

Fig. 1 Notification environment architecture

5 Augmented Objects Proposals and Development Process

In this section, we present the selected objects that could act upon the notifications or alerts. For the creation of the augmented objects prototypes in this project, we followed the Framework for Designing, Developing and Evaluating Augmented Objects [7]. This methodology works on selecting the most natural objects to be augmented, so that it has the adequate capabilities to solve a particular problem. We developed augmented objects to notify about: (a) Deadlines, (b) Currently connected collaborators, (c) List of pending documents, and (d) Changes in the state of the documents.

5.1 Augmented Wall Picture to Notify User That They Must Work

With the objective to alert the user about the changes on the states of the shared documents, various candidate objects were found to be fitting to be augmented including: a paper weight, a wall frame and a desk organizer. From these objects, after being analyzed, the wall frame was selected.

Using a wall picture with an image representing the metaphor of work (e.g., hammer, cone, or helmet) could be appropriate. Our frame can change images in order to inform the user if s/he has to work on the document (see Fig. 2—left).

5.2 Augmented Calendar to Alert About Document Deadlines

In order to provide a notification about deadlines for the documents that a team is working on, various objects have the capability of outputting these alerts (e.g., post-it notes, telephone, calendar, yearly planner). The selected object was the calendar, since this object can show different deadlines at the same time and users can recognize that dates marked on it are important dates in the collaborative process. Figure 2 (right) shows the prototype, in that image it can be seen the calendar with an event related with the collaborative work marked (the date is filled).

Fig. 2 *Left*: Augmented wall frame prototype. *Right*: Augmented calendar prototype

5.3 Augmented To-Do List to Stay Alert About Pending Work

If the users are interested in the information regarding which tasks are pending, and which ones are finished, it is possible to utilize the following candidate objects: a writing board, a to-do list, and a document organizer. In this case, and after some analysis, the to-do list was selected. Figure 3 (left) shows the prototype, in which the tasks finished are marked in red and pending tasks are marked in green. The colors change automatically depending on the document's state.

In this prototype a discussion was carried to determine if the tasks should also be digital and change automatically or if the tasks should be static and the status dynamic. We found that both approaches are viable and useful; however, we only developed one in which the status of tasks is augmented (i.e., box color changes if the task is complete or incomplete).

5.4 Augmented Card Holder to Inform Who Is Online

If a user needs to know when a collaborator is connected and working on a shared document, various common objects could provide a way to present that information. Objects that seem to satisfy this need are: a telephone, a card holder, a pencil holder, and a paper weight. From this list, the card holder is the object that best fits into the user's cognitive process, without requiring too much cognitive work. In this situation the user would also be able to have other collaborators' contact information at hand. This can be helpful in clearing up ideas, doubts, or to talk about a specific aspect of the collaborative process. Figure 3 (right) shows the prototype.

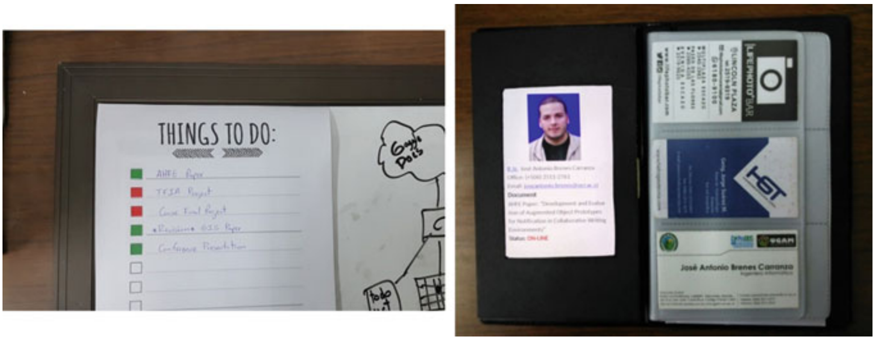

Fig. 3 *Left*: To-Do list prototype. *Right*: Augmented card holder prototype

6 Collaborative Writing Strategies

For the development of this project, the collaborative editing strategies that were defined by Lowry et al. [2] were considered. These strategies refer to the general approach in which the working teams execute their work. The authors propose 5 strategies: group single-author, sequential, horizontal-division, stratified-division and reactive.

Group single-author writing occurs when a single person, that is member of a collaboration team, writes in representation of the whole group. A situation that exemplifies this is when one of the participants summarizes the notes taken during a meeting attended by all the members of the group.

Sequential writing occurs when only one person in the collaboration group writes at a time, in which one of the collaborators writes one section and when finished passes the document to the next person.

Horizontal-division writing is a bit more complex. This strategy is derived from the parallel strategy, in which the work is done without an order or consensus. When this happens, a group divides the work in small parts that can be done in a parallel by the collaborators. Then, these parts are compiled into the final document. An example of this strategy is Storybooks written a story per author, and then compiled into a whole book.

Stratified-division writing is also derived from the parallel strategy. In this case, the collaborators play a predefined role in the group according to their skills. One example of this is when research papers are written by team of authors, reviewers and/or editors.

Finally, *reactive writing* happens when a collaborator creates a document in real time and all of the other collaborators work on this same document in an unordered manner without consensus and coordination.

7 Use of Augmented Object Notification Environment

In this project, we used Google Docs as third party application to support collaborative work. Google Docs is an office suite that includes the primary tools to manage data: a text processor, a spreadsheet management tool, and an application for the creation of digital presentations [13]. Google Docs provides the ability to work with information in real time, and with a great number of collaborators. As mentioned previously, our goal is to augment objects that are naturally available in a business or home office.

This section describes the use of each of the proposed notification mechanism matching the collaboration strategies proposed by Lowry et al. [2] and described in Sect. 6.

The first strategy is *Group single-author writing*. In a scenario, one of the collaborators is in charge of creating the document. Table 1 shows how the

Table 1 Use of augmented objects to provide awareness, to the main author, in group single-author writing

Augmented object	Applicability
Calendar	Shows the document's deadline and meetings arranged
Wall frame	Displays when a meeting is approaching. It does not make sense to keep it notifying this user since he is the only one that must work on the document
To-Do list	Not applicable (it will replicate information provided by other object)
Card holder	Not applicable

Table 2 Use of augmented objects to provide awareness, to other authors (not the creator of the document), in group single-author writing

Augmented object	Applicability
Calendar	Shows the document's deadline and meetings arranged
Wall frame	Displays when a meeting is approaching (the only work of this type of author is attending to meetings)
To-Do list	Not applicable
Card holder	Informs when the main author is connected

Table 3 Use of augmented objects to provide awareness in sequential writing

Augmented object	Applicability
Calendar	Shows the user's deadline to him and the next author. Besides, it notifies about the document's deadline
Wall frame	Notifies when the user must start working (his turn to edit)
To-Do list	Shows the pending tasks (or sections of the document) that the user is supposed to work in (only when is his turn)
Card holder	Only allows knowing which user is currently working on the document. It will only display one name at the time

augmented objects are used to provide awareness to the main author in this strategy, while Table 2 shows how they are used for other authors (i.e., not in charge of creating the document).

The second collaboration strategy is *sequential*. In this strategy the work is conducted progressively (i.e., one author after other). Table 3 shows how the proposed objects could be applied in this context.

The third collaboration strategy is *horizontal-division writing*. At first each author works in a part of the document and when the parts are finished they are sent to one author to combine and edit them. Table 4 shows the application of our prototypes in this strategy.

Table 4 Use of augmented objects to provide awareness in horizontal-division writing

Augmented object	Applicability
Calendar	Indicates the user's deadline, the final user's deadline and the document's deadline
Wall frame	Working image is showed from the beginning of the process and disappears when the author sends his part of the work. It will appear again when the "final" author finishes because the user should revise the document
To-Do list	Informs the author of the sections that he is supposed to work in
Card holder	It will show the collaborators of each section when they are working, during the edition process it will only show the final user

Table 5 Use of augmented objects to provide awareness in stratified-division writing

Augmented object	Applicability
Calendar	It indicates the deadline for each role, and the document's deadline
Wall frame	Indicates to the reviewer when the author finished the draft of the document, then the author is notified when the document has been reviewed. Finally, the editor is notified when the final draft is sent to be edited
To-Do list	Each member is reminded of their role in the document
Card holder	Shows the name of the person currently working depending if the document is being written, reviewed or edited

Table 6 Use of augmented objects to provide awareness in reactive writing

Augmented object	Applicability
Calendar	Displays the document's deadline
Wall frame	Not applicable (it will be always displayed)
To-Do list	Not applicable (it will generate chaos since tasks could change while a user is working on it if others are working on it too)
Card holder	Shows which collaborators are connected at a given time

The fourth collaboration strategy is *stratified-division writing*. In this strategy, three roles are required: author, editor and reviewer. The author is responsible of writing the first draft. The reviewer provides specific feedback about the draft he does not change the document. The editor is the person who has the responsibility and ownership for the overall content of product. Table 5 shows the application of augmented objects in this strategy.

Finally, the fifth strategy is called *reactive*; in this writing strategy there is not a set of rules to follow in order to complete the work on a document. Table 6 describes how our proposed augmented objects apply in this scenario.

8 Discussion

From an ergonomic perspective, the creation of the notification environment complies with the ideas of Wilson [14] since the activity was guided by the analysis of the individual parts of the system and the augmented objects that execute the alerts. Moreover, the notification environment complies with the requirements specified for our CWE. Also, other requirements can be achieved by adding new augmented objects to improve user awareness and interaction.

Even though this paper does not present evaluation of the augmented objects, the developing process followed evaluates them and their application. We decided to focus on the integration of several objects instead of the detailed description of each one. Moreover, we can assure that the proposed notification environment improves collaboration because it provides user awareness (a key factor in collaboration).

In the model that was proposed for the notification environment, it is possible to include a component that can capture external information from the user. This would allow the coordinating system to make better decisions. In Fig. 1, this component could be located in the User Interaction Layer. Said component can be in charge of the obtaining other information from the user such as, for example, user's location, status (busy/available), etc. This information could be used to improve the way in which notifications are administered, possibly allowing the notifications to arrive at other different application contexts like an office at home or when user is inside the car. Our notification environment leaves aside the topics of privacy and security; however, authors agree that policies to assure both security and privacy must be defined by experts in the area.

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Connecting Small Form-Factor Devices to the Internet of Things

Andrea C. Martinez

Abstract The proliferation of inexpensive, small form-factor devices, such as Raspberry Pi, have enthused electronics hobbyists for years. IBM has recognized the opportunity for such devices to sense and control at the very fringes of the Internet. This paper will provide an overview of how to connect devices using IBM Bluemix, the IBM Watson IoT Foundation Platform, and other freely available technologies to bring unique IoT solutions to the enterprise.

Keywords Human factors · Human-systems integration · Systems engineering · Internet of things · ARM · MQTT · IBM Bluemix · IBM Watson IoT platform · IFTTT · Raspberry pi

1 Introduction

We are witnessing a massive explosion of Internet connected things in our workplaces, homes, and communities. Wearable devices, embedded systems, smart appliances, connected cars, and the like, are becoming pervasive in our everyday lives. They are increasingly connected to the Internet to create a stronger digital connection to our physical world; this is the Internet of Things (IoT).

Driving the IoT trend is the convergence of sprawling networks, hardware commoditization of small form factor devices, and proliferation of IoT-oriented standards, software, services, frameworks and protocols. All of these factors contribute to low-barrier entry points for any person, entity, or enterprise to integrate the capabilities of the Internet of Things.

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1.1 On Sprawling Networks

Network connectivity, be it hardwire, Wi-Fi, or cellular are commonplace in the home, retail, or work place setting in most developed countries. The proliferation of high-speed fiber optic and even Bluetooth and Bluetooth Low Energy (BLE) access points are a harbinger of the next generation of advanced network connectivity that will continue to pervade the globe. This march to a ubiquitous network removes barriers to device interconnectedness and opens opportunity for establishing communication with even the most remote locations and "things" (Fig. 1).

Connecting devices to the IoT requires accommodation of persistent and constrained network connected "things".

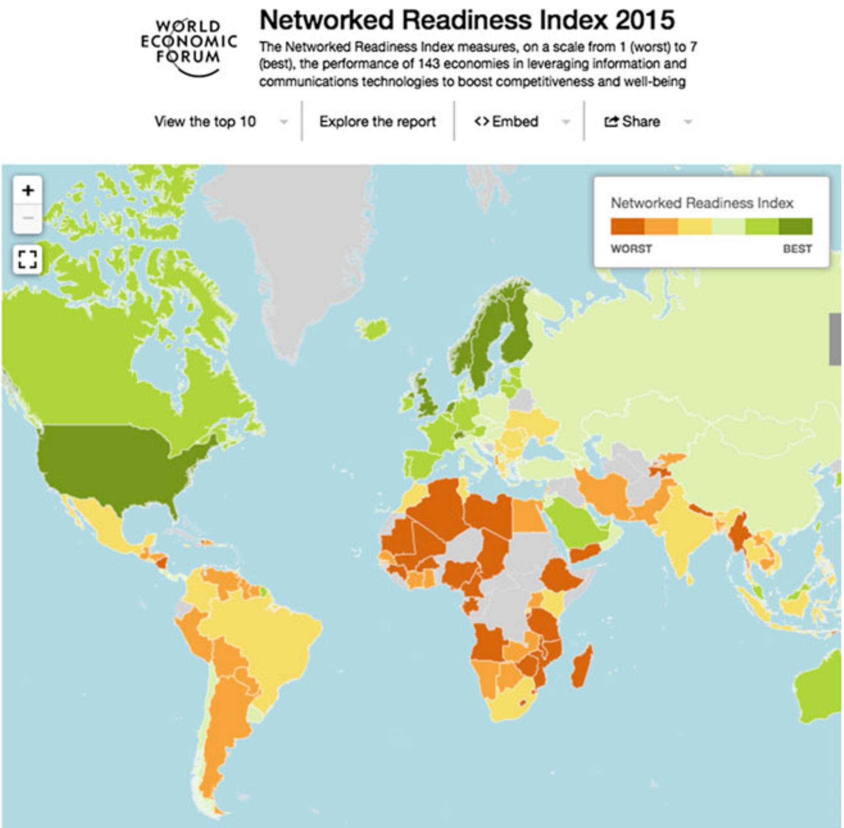

Fig. 1 Although not currently ubiquitous, network sprawl continues with the *network readiness index* (World Economic Forum. "Network Readiness Index 2015". https://widgets.weforum.org/gitr2015/) demonstrating many of the world's advanced economies in at least a neutral or favorable network position to leverage IoT

1.2 On Hardware Commoditization

The commoditization of hardware and components, such as ARM processors, have made small form factor devices, such as Raspberry Pi consumable due to their low price point, ability to connect to networks, and extensibility to patch in electronic sensor components (such as temperature sensors, accelerometers, gyroscopes, and so on). Commoditization of hardware platforms enables increasingly common adoption and experimentation of small form factor device platforms by enterprises, small businesses and even the average hobbyist in developed economies.

A stunning and impressive disruptive innovation from ARM Holdings (a British company) has driven the adoption of ARM-licensed RISC processors to manufacturers around the world who wish to supply the world with low power consumption tablets, smart phones, and small form factor platforms. ARM processors make up 95 % of the tablet and smart phone market.[1] ARM processors are being manufactured as the CPU components for small form factors such as Raspberry Pi, Pine64, Android phones, and iPhones. Devices with ARM Cortex-A microprocessors (MPU) can be found for as low as $15 for the lower end platforms (such as the Pine64). ARM Cortex-M microcontrollers (MCU) lend themselves to so much commoditization that they are manifesting themselves in disposable "things" (Fig. 2).

Connecting devices to the IoT requires small form factors be integrated with everyday "things".

Fig. 2 Commoditization of *small form factor devices* is manifesting itself in common items

[1]Timothy Prickett Morgan, The Register. "ARM Holdings eager for PC and server expansion Record 2010, looking for Intel killer 2020." Feb 2011.

1.3 On IoT Standards and Protocols

Incumbent on any large-scale adoption is that of standards, upon which frameworks, and technology implementations can be based. To date, industry standards for connecting devices to the Internet of Things have consolidated around 2 network access models: *persistent/reliable* and *constrained*. The Internet Engineering Task Force (IETF)[2] has established standards that have been used for IoT-specific protocol implementation (such as CoAP[3]) OASIS (the non-profit consortium of private enterprises) has also contributed to the cause by proposing standards such as MQTT.[4]

Devices with persistent network connections to the IoT tend to be larger devices that have a persistent reliable power source and reliable access to the Internet (often through cellular or LAN connection). Note that these types of devices tend to have long lasting onboard battery power that can be recharged easily or a persistent power supply (or both). The explosion of devices really requires the use of expanded IP addressing schemes, however, the transport, application and security protocols are extremely familiar to most. The MQTT protocol standard was proposed only a few years ago, however it is an application protocol that is optimized for “things” to send and receive device payloads.

Devices with constrained network access, due to lack of generous onboard power or lack of access to the network use a different set of standards to connect to the Internet of Things. Most notable is 6LoWPAN (IPv6 over Low PoWer Personal Area Networks) and CoAP (Constrained Application Protocol). Note that the UDP transport protocol is used to accommodate extremely small device payloads without a lot of overhead, due to constrained connectivity scenarios (Table 1).

Table 1 Summary of IoT-related protocols (B. Curtis, T. Siegfried. “ARM and IBM “Arm” themselves to help others build connected devices with ease”. https://www-950.ibm.com/events/global/interconnect/sessions/preview.html?sessionid=IND-2540)

	Large devices Mains powered Fast networks	Small devices Battery powered Constrained networks
Addressing	IPv6/IPv4	6LoWPAN
Transport	TCP	UDP
Application	HTTP, MQTT	CoAP
Security	TLS	DTLS

[2]Internet Engineering Task Force. https://www.ietf.org/

[3]Internet Engineering Task Force. “The Constrained Access Protocol (CoAP).” https://tools.ietf.org/html/rfc7252

[4]Organization for the Advancement of Information Standards. “OASIS Message Queuing Telemetry Transport (MQTT) TC.” https://www.oasis-open.org/committees/mqtt/

With these IoT standards, frameworks and API's have emerged to help service developers and programmers use these protocols. Examples are Eclipse Paho[5] (a set of client API's for MQTT) and Californium[6] (a Java implementation of a CoAP server).

Connecting devices to the IoT requires "things" communicating with each using standards-based protocols and frameworks.

2 Understanding the IoT System Context

There are many implementations on how to connect devices to the Internet, but all take one general approach. Instrumented "things", must be able to send data payloads to a controller gateway on a local network or straight through to remote, and optionally receive commands in cases where remote control is desired. There are different approaches to achieving the connectivity of "things" to the IoT, among them are platform as a service providers like IBM Bluemix and IBM Watson IoT Platform, application service providers, such as If This Then That (IFTTT, *pronounced* "*ift*"), or others may chose to build out connectivity using their own devices such as Raspberry Pi and a combination of Cloud and traditional hosted infrastructure. The richness and diversity of low barrier entry services and availability of open source frameworks for custom IoT implementation is diverse and there is no one "right way".

This architecture can be extended to many industry scenarios with different technologies, software, hardware and even communication protocols that can be used. Once device connectivity is established and "things" are connected to the Internet, the profound richness of data storage, logic workflow, enrichment, transformation, analytics, decisioning, and dashboard capabilities all apply.

IBM Watson IoT Platform and IFTTT (to greater extent) both abstract the complexities of the connectivity model in Fig. 3 to provide a low cost, low barrier entry to connecting "things" to the Internet. This would result in a "collapse" of the tiers in Fig. 3 to simplify the connection logistics. IBM Watson IoT Platform also provides modular composable cloud-based micro services for infusing data storage, analytics, and other customizable business logic.

[5]Eclipse Paho. http://www.eclipse.org/paho/

[6]Eclipse Californium. http://www.eclipse.org/californium/

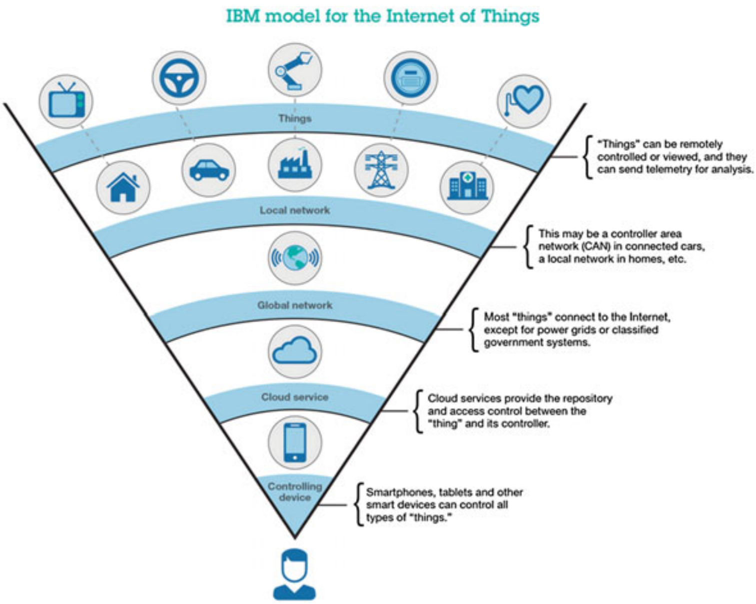

Fig. 3 The IBM model for the Internet of Things (*Source* IBM X-Force Research and Development) is a representation of "*Things*" that access a *local network* (typically through a device gateway), and invoke *cloud services* through a *global network*

3 How to Connect Devices to the Internet of Things

The next section will focus on how to connect "things" to the network, or simply, how to add devices into the "Internet of Things". Device connectivity typically starts with instrumenting an object with some sort of sensor and mechanism to transmit payloads (or receive commands) through a local network connection. There are different service-oriented platforms and self-service approaches to achieve device connectivity. Three approaches to device connectivity will be reviewed.

3.1 Self-Service Open Source

For those that prefer a more hands on approach with a finer grain of control on how a device connects to the IoT, installing open source software to connect to a message broker that supports MQTT or CoAP might be a suitable option.

The example below uses a small form-factor platform (Raspberry Pi) with the standard Raspbian OS (a Debian variant of Linux optimized for the ARM-based device). Raspberry Pi is primarily a hobbyist platform, but it (and any other ARM-based platform) can be used to instrument a home, workplace, or even outdoors with devices that can connect to the Raspberry Pi's general purpose input/output (GPIO). These GPIO pins can be used to wire up sensor components (such as digital thermometers, hygrometers, accelerometers and so on) (Fig. 4).

Using the Raspberry Pi with a standard version of Raspbian "Jessie",[7] the github project below installs the necessary package dependencies including an MQTT client (Paho) to enable custom code to connect to an MQTT broker publically available and hosted in the cloud (iot.eclipse.org).

From a Raspberry Pi, cloning and installing a Python code project to enable a Raspberry Pi to publish and subscribe to an MQTT message broker.

`git clone` https://github.com/acmthinks/connectThingMQTT.git. ~/connectThingMQTT/install.sh

This is a simple example of code that can be forked so that message payloads can be sent and interleaved with business logic. For example, perhaps a temperature sensor could be wired to the Raspberry Pi and temperature data could be included in the message payload that is transmitted to the MQTT message broker in the cloud. What ever is put on the "thing" that connects to the IoT is extremely flexible and connecting to any other MQTT message broker is as easy as replacing "iot.eclipse.org" with any other MQTT message broker hostname.

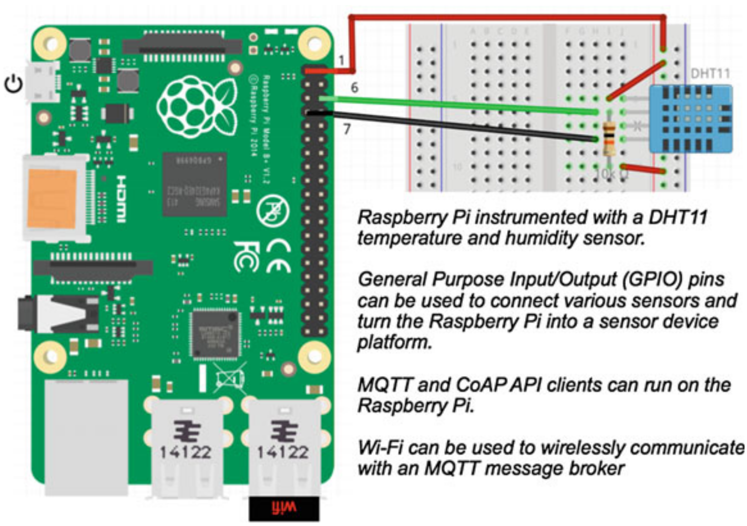

Fig. 4 *Raspberry Pi* can be instrumented to work as a sensor device platform

[7]Latest versions of Raspbian. https://www.raspberrypi.org/downloads/raspbian/

3.2 *IBM Watson Internet of Things Platform*

IBM provides IoT as a service with IBM Bluemix (Bluemix) and IBM Watson Internet of Things Platform (Watson IoT). Watson IoT is a publically available mix of advanced Connect, Information Management, Analytics and Risk Management services to enable device connections to a public cloud. Using Watson IoT also exposes a rich set of composable micro services in Bluemix (IBM's platform as a service) to perform storage of device data, transformation, storage, analytics and insightful decisioning. Watson IoT and Bluemix are subscription-based services that are available on a public platform (Fig. 5).

Bluemix provides an "Internet of Things" Boilerplate application that prepackages and deploys a skeleton application on the public cloud that uses NodeRED workflows. NodeRED is hosted on Bluemix and provides ready to use connectors to the "Connect" services in Watson IoT Platform.

Prescriptive steps and explanation of the exact steps to connect a device (such as a Raspberry Pi) to the IBM Watson Internet of Things Platform are contained in several IBM developerWorks Recipes,[8] please refer to published recipe URL's in the *References* section.

Fig. 5 IBM Watson IoT platform enables devices to connect to a public MQTT message broker using Bluemix micro services

[8]IBM developerWorks Recipes. https://developer.ibm.com/recipes/

3.3 If This Then That (IFTTT)

If This Then That (IFTTT) is a public platform of services that has gained much industry momentum and adoption. Vendors have contributed connector services to their IoT devices so that they maybe controlled by logic that *individuals* specify using IFTT recipes. The appeal with IFTTT lies in it's low barrier entry point of being free, easy to use, and able to connect common household devices for personal scenarios.

IFTTT provides a simple "If Then" or "Do" paradigm for controlling devices. Basic concepts include: Channels, Triggers, Actions, Recipes, and Ingredients. Users can log onto the IFTTT web platform and stitch together these constructs such that an end-to-end workflow would result in a situation where one can "Turn on your WeMo Switch automatically at sunset,[9]" (Fig. 6).

There is a rich set of IFTTT recipes, with vendor channels that contain customizable triggers and actions to define device behavior in a variety of ways. Users can create their own recipes and share them in IFTTT's public marketplace or platform.

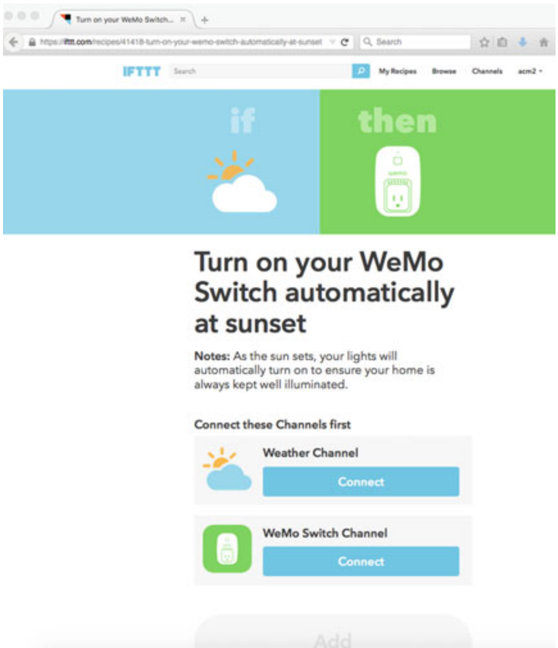

Fig. 6 IFTTT *recipes* are used to integrate *channels*, along with their triggers and actions

[9]"Turn on your WeMo Switch automatically at sunset." IFTTT recipe. https://ifttt.com/recipe_embed_use/41418-turn-on-your-wemo-switch-automatically-at-sunset.

4 Conclusion

The convergence of trends promises the value of pervasive, commoditized, standardized interconnectedness, and the prospect of gaining *insight at the edge of a sprawling network* using analytics-based decisioning *outside* of traditional and cloud data centers. To achieve this integration between physical and digital realms, there are concepts and technologies that can help in *connecting small form-factor devices to the Internet of Things*. Three such approaches have been reviewed here, but by no means encompass the universe of ways to tap into the Internet of Things.

The compelling nature of connecting “things” to the IoT is the richness of *what one could possibly do* with data from devices that are instrumented and deployed in the physical world. Connecting devices to the Internet is the first step to collecting and adding to “Big Data” about our world, so the power of analytics can drive insight at the fringes of our connected world.

GPU-Based Parallel Computation in Real-Time Modeling of Atmospheric Radionuclide Dispersion

André Pinheiro, Filipe Desterro, Marcelo Santos, Claudio Pereira and Roberto Schirru

Abstract Atmospheric radionuclide dispersion systems (ARDS) are important tools to predict the impact of radioactive releases from Nuclear Power Plants and guide people evacuation from affected areas. To predict radioactive material dispersion and its consequences to environment, ARDS process information about source term (nuclear material released), weather conditions and geographical features. ARDS are basically comprised by 4 modules: Source Term, Wind Field, Plume Dispersion and Doses Calculations. Wind Field and Plume Dispersion modules are the most computationally expensive, requiring high performance computing to achieve adequate precision in acceptable time. This work focuses on the development of a GPU-based parallel Wind Field module. The program, based on Extrapolated from Stability and Terrain (WEST) model, is under development using C++ language and CUDA libraries. In comparative case study between some parallel and sequential calculations, a speedup of 40 times could be observed.

Keywords GPU · Parallel computing · Atmospheric radionuclide dispersion

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1 Introduction

During and after a Nuclear Power Plant (NPP) emergency with radioactive material release, an accurate forecast is crucial to successfully guide people protection and their evacuation from the possible affected area.

In order to predict the transport and diffusion of radioactive material and its consequences to environment, atmospheric radionuclide dispersion systems (ARDS) have been used [1]. Such systems need, as inputs, information about the source term (amount of each radioactive material released, activities and release location), weather conditions (wind, precipitation, temperature, etc.) and geographical features (topography, terrain, soil, etc.). All these inputs must be efficiently processed in order to provide accurate directives to support real-time decisions regarding the emergency procedures.

ARDS are basically comprised by 4 main modules: Source Term, Wind Field, Plume Dispersion and Doses Calculations. In special, Wind Field and Plume Dispersion modules are the most computationally expensive.

The quality of the information provided by an ARDS is key to successful decision making during an emergency. Therefore, to achieve adequate accuracy in acceptable time, a high performance computing system is required, specially for running the most time-consuming modules.

This work focus in the Wind Field (WF) module. WF models estimate wind conditions at each geographical point inside the region of interest. Here, the "Winds Extrapolated from Stability and Terrain" (WEST) model [2] is considered as the base for our development. In WEST model, the region of interest is subdivided into many volumes (cells) forming a 3D grid. For each volume, wind parameters, such as velocity, direction and stability are interpolated/extrapolated from several measurements provided by weather stations and available in the NPP data acquisition system.

The precision of this method is influenced by: (i) the geographic positions of the weather stations; (ii) precision of weather stations measurements and (iii) the spatial resolution of the 3D grid. Considering that the positions and instrumentation of the weather stations are unchangeable, the grid resolution is the key to improve precision. However, depending on how much the 3D grid is refined, the computational overhead imposed may make their execution impracticable.

Motivated by the fact that such computational overhead actually occurs in a realistic scenarios, this work aims to develop a high performance parallel computational approach to WF calculations, using WEST model, in order to allow the practical use of a high spatial resolutions.

The parallel computational architecture used here was the Graphic Processing Unity (GPU). The program has been developed using C++ programming language and Compute Unified Device Architecture (CUDA) [3] libraries.

The remaining of this paper is divided as follow. In Sect. 2 the WEST model is described. An overview of the GPU architecture and CUDA programming is provided in Sect. 3. Section 4 describes the parallelization process and most important issues of the parallel program. Results are shown and analyzed in Sect. 5 and concluding remarks appear in Sect. 6.

2 The WEST Model

As already mentioned, the methodology used in this work to generate the wind field is based on the Wind extrapolated from Stability and Terrain (WEST) model [2]. To describe the spatial distribution of the wind in the region of interest, the model use a three-dimensional non-divergent velocity field, i.e., the wind field is made consistent in mass for each volume (cell) of the 3D-grid. Observed wind field (measured values extrapolated and interpolated) represented by their components U^0, V^0 and W^0 in the respective directions X, Y and Z must satisfy the boundary condition on the ground surface.

$$V \cdot \vec{n} = 0. \tag{1}$$

Where, $\vec{n}$ is the unit vector normal to the surface.

The goal is to determine, from the components U^0, V^0 and W^0, a speed wind field U, V and W which satisfies the condition of null divergence, i.e. that check the continuity equation (Eq. 2) in the whole region of interest.

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y}\frac{\partial W}{\partial Z} = 0. \tag{2}$$

Being the solution sought of type:

$$\begin{cases} U = U^0 + \tau_X \frac{\partial \phi}{\partial X} \\ V = V^0 + \tau_Y \frac{\partial \phi}{\partial Y} \\ W = W^0 + \tau_Z \frac{\partial \phi}{\partial Z} \end{cases}. \tag{3}$$

Where ϕ is the perturbation velocity potential and τ_X, τ_Y e τ_W are transmission coefficients based on temperature profiles obtained from upper air soundings.

3 GPU and CUDA Programming

A low cost trend in parallel computing is the use of Graphics Processing Unit (GPU): a powerful co-processor, which is able to perform a great amount of instructions in parallel. Although GPUs has been conceived to improve computer graphics applications performance, their power has been discovered by the scientific computation community and their application has been extended to many other fields out of computer graphics.

Many applications of GPU programming engineering are seen in literature. In Heimlich [4] the GPU program reached a speed up about 125 times when compared to the sequential (CPU) version. Pereira et al. [5] have used a multi-GPU approach for solving a Monte Carlo simulation in reactor physics. In this work a speedup of more than 2000 times was achieved.

3.1 GPU Architecture

The GPU used in this work was the GeForce GTX-480—the third generation of the CUDA enabled NVIDIA GPUs. GTX-480 architecture is based on NVIDIA's Fermi architecture, being comprised by 15 Streaming Multiprocessors (SMs) with 32 CUDA processors each. Each CUDA processor has a fully pipelined integer arithmetic logic unity (ALU) and a floating point unit (FPU). In summary, 480 CUDA processors are available. Figure 4 shows a schematic GTX-480 SM architecture (Fig. 1).

The SM schedules tasks into groups of 32 threads called warps and each SM allows 2 warps to be issued and executed concurrently due to the use of 2 instruction dispatch units.

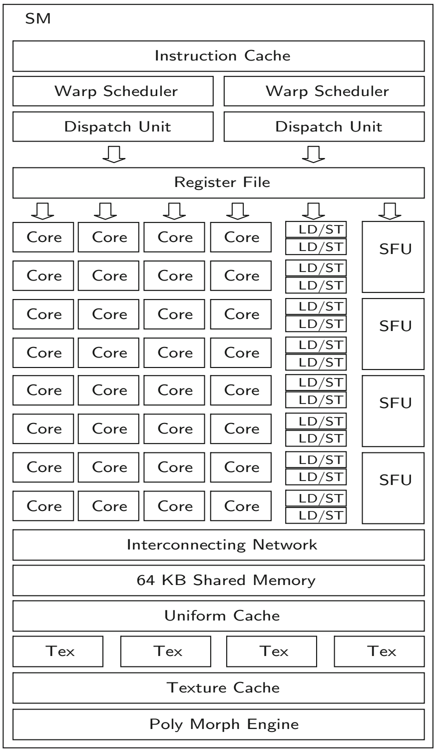

Fig. 1 The NVIDIA GeForce GTX-480 stream multiprocessor architecture

3.2 CUDA Programming

The Compute Unified Device Architecture (CUDA) is a C-language compiler. The GPU global block scheduler manages coarse-grained parallelism at the thread block level across the whole chip. When a CUDA kernel is started, information for a grid is sent from the host CPU to the GPU. The work distribution unit reads this information and issues the constituent thread blocks to SMs with available capacity. The work distribution unit issues thread blocks in a round-robin fashion to SMs, which have sufficient resources to execute it. The goal of the work distributor is to uniformly distribute threads across the SMs to maximize the parallel execution opportunities.

Figures 2 and 3 are used to exemplify the basic structure of a simple CUDA program and its comparison with the sequential version. Figure 2 shows the sequential (CPU) version of a C language function that adds 2 vectors, while Fig. 3 shows its parallel (GPU) CUDA version.

Note that, instead of the *for* loop (Fig. 2) that sequentially adds each element of the vector, the CUDA function (Fig. 3) adds only position *i*. The reason is that this function, called kernel function, is executed by each CUDA core. Each core executes the kernel function for a different position in the vector, at the same time (in parallel).

In C, parameters are transparently passed to the function using the CPU memory. In CUDA, as the functions may run on GPU, the parameters must be copied from the CPU to the GPU memory. At the end of execution, results must be copied back from the GPU to CPU memory. The following peace of program shows memory allocation in GPU, the data transfer between CPU and GPU and the kernel function call (Fig. 4).

It must be keep in mind that the data transfers consume certain time, which is function of the amount of data to be transferred. Therefore, if the processing time is small when compared to transfer time, the speedup in the parallelism may be reduced.

```
void addVectorsCPU(int *c, int *a, int *b, long size) {
        for(unsigned long i=0; i<size; i++) {
                c[i] = a[i] + b[i];
        }
}
```

Fig. 2 A simple C function that adds 2 vectors

```
__global__ void addVectorsGPU(int *c, int *a, int *b) {
        int i = blockIdx.x*blockDim.x + threadIdx.x;
        c[i] = a[i] + b[i];
}
```

Fig. 3 A simple CUDA function that adds 2 vectors

```
...
// CUDA memory alocation in GPU
sta = cudaMalloc((void**)&d_c, size*sizeof(int));
sta = cudaMalloc((void**)&d_a, size*sizeof(int));
sta = cudaMalloc((void**)&d_b, size*sizeof(int));

// Copy input data from host memory to GPU buffers.
sta = cudaMemcpy(d_a, a, size*sizeof(int), cudaMemcpyHostToDevice);
sta = cudaMemcpy(d_b, b, size*sizeof(int), cudaMemcpyHostToDevice);

// Launch a kernel on the GPU
addVectorsGPU<<<blocks, threadsPerBlock>>>(d_c, d_a, d_b);

// Copy output data from GPU buffer to host memory.
sta = cudaMemcpy(c, d_c, size*sizeof(int), cudaMemcpyDeviceToHost);
...
```

Fig. 4 Memory allocation and data transfer in CUDA

4 The Parallelization Process

The main functions that comprise the Wind Field program can be seen on its simplified pseudo code shown in Fig. 5.

The parallelization process has started with the interpolation functions, which are reasonably time-consuming and the parallelism is straightforward. In contrast, although also very time-consuming, due to its strong sequential characteristic, the divergence minimization algorithm is not considered here and will be focused in further work. The transparency calculation, as well, will not be considered due to its reduced execution time. Figures 6 and 7 show the sequential Stability_Interponation and Velocity_Interpolation functions.

Functions in Figs. 6 and 7 interpolate the values of wind stability and wind velocity, respectively for all cells in a tridimensional grid with dimensions of $2144 \times 1376 \times 8$.

Note that both functions present loops for the 3 spatial dimensions (X, Y and Z) and a loop for each weather station (control variable L). The number of iterations in each dimension is NX = 2144, NY = 1376 and NZ = 8. And the number of weather stations NumEwd = 4.

```
program Wind_Field

   WindField_Initialization
   Stability_Interpolation
   Velocity_Interpolation
   Transparency_Calculation
   Divergency_Minimization

end program
```

Fig. 5 Pseudo code of the wind field program

```
void Stability_Interpolation(<parameters>) {

  for (int K = NZ; K >= 1; K--){
    for (int J = 1; J <= NY; J++){
      for (int I = 1; I <= NX; I++){
        Estab[I][J][K] = 0.0;
        if (K <= Iht[I][J]) continue;
        double XNORM = 0.0;
        for (L = 1; L <= NumEsd; L++){
          if (Ess[L][K] <= 0) continue;
          RFOR = (pow(((Ies[L]-I)*DX),2)+pow(((Jes[L]-J)*DY),2));
          if (RFOR <= 0) break;
          Estab[I][J][K] = Estab[I][J][K] + Ess[L][K] / RFOR;
          XNORM = XNORM+1.0/RFOR;
        }
        if (RFOR <= 0){
          Estab[I][J][K] = Ess[L][K];
          continue;
        }
        if (XNORM > 0) Estab[I][J][K] = Estab[I][J][K]/XNORM;
        else Estab[I][J][K] = Estab[I][J][K+1];
      }
    }
  }
}
```

Fig. 6 Sequential implementation of the stability_interpolation function

```
void Velocity_Interpolation(<parameters>) {

  for (int I = 1; I <= NX+1; I++){
    for (int J = 1; J <= NY+1; J++){
      for (int K = 1; K <= NZ; K++){
        XNORMA = 0.0;
        YNORMA = 0.0;
        for (int L = 1; L <= NumEwd; L++){
          RSQDX = pow((Iew[L]-I+0.5),2)*DX2+pow((Jew[L]-J),2)*DY2;
          RSQDY = pow((Iew[L]-I),2)*DX2+pow((Jew[L]-J+0.5),2)*DY2;
          if (J != NY+1)
            Vento.U[I][J][K] = Vento.U[I][J][K]+
                               WU[L][K]*Eww[L][K]/RSQDX;
          if (I != NX+1)
            Vento.V[I][J][K] = Vento.V[I][J][K]+
                               WV[L][K]*Eww[L][K]/RSQDY;
          XNORMA = XNORMA + Eww[L][K] / RSQDX;
          YNORMA = YNORMA + Eww[L][K] / RSQDY;
        }
        if (J != NY+1) Vento.U[I][J][K] = Vento.U[I][J][K]/XNORMA;
        if (I != NX+1) Vento.V[I][J][K] = Vento.V[I][J][K]/YNORMA;
      }
    }
  }
}
```

Fig. 7 Sequential implementation of velocity_interpolation function

The parallel CUDA functions Stability_Interpolation and Velocity_Interpolation use a monolithic kernel approach (for I, J and K loops), meaning that a single large grid of threads processes the entire array in one pass. Hence loops controlled by I, J and K variables were removed.

Another consideration that provided gains in terms of computational time was to convert the 3D matrixes into a big vector, concatenating each dimension. In this case, a correlation between indexes in the 3D matrix and the correspondent index in the vector are calculated.

Figures 8 and 9 show the parallel versions of Stability_Interpolation and Velocity_Interpolation functions. These figures show only the CUDA kernels, i.e., memory allocations and data transfer between CPU and GPU are not exhibit. Therefore, they are considered while computing the execution times on GPU.

```
__global__ void Stability_Interpolation (<parameters>){

  double RFOR = 0;
  int index_Ess = 0;

  int KK = blockIdx.z * blockDim.z + threadIdx.z;
  int K = NZ - KK - 1;
  int I = blockIdx.x * blockDim.x + threadIdx.x;
  int J = blockIdx.y * blockDim.y + threadIdx.y;

  int index_Estab = ((J+1)+(I+1)*(NY+1))*(NZ+1)+(K+1);
  int index_Iht = (J+1)+(I+1)*(NY+1);

  if (K + 1 <= IHT[index_Iht]) return;
  double XNORM = 0.0;

  for (int L = 0; L < NumEsd; L++) {

    index_Ess = (K + 1) + (L + 1)*(NZ + 1);
    if (ESS[index_Ess] <= 0.0) continue;
    double aux_RFOR = (double)((IES[L+1]-(I+1))*DX);
    double aux2_RFOR = (double)((JES[L+1]-(J+1))*DY);
    RFOR = pow(aux_RFOR, 2) + pow(aux2_RFOR, 2);
    if (RFOR <= 0) break;
    ESTAB[index_Estab] = ESTAB[index_Estab]+ESS[index_Ess]/RFOR;
    XNORM = XNORM+1.0/RFOR;
  }

  if (RFOR <= 0.0){
    ESTAB[index_Estab] = ESS[index_Ess];
    return;
  }

  if (XNORM > 0.0){
    ESTAB[index_Estab] = ESTAB[index_Estab] / XNORM;
  }

  else{
    ESTAB[index_Estab]=ESTAB[((J+1)+(I+1)*(NY+1))*(NZ+1)+((K+1)+1)];
  }
}
```

Fig. 8 Parallel implementation of stability_interpolation function

```
__global__ void Velocity_Interpolation (<parameters>){

  int I = blockIdx.x * blockDim.x + threadIdx.x;
  int J = blockIdx.y * blockDim.y + threadIdx.y;
  int K = blockIdx.z * blockDim.z + threadIdx.z;

  int index_VentoU = ((J+1)+(I+1)*(NY+1))*(NZ+1)+(K+1);
  int index_VentoV = ((J+1)+(I+1)*(NYP1+1))*(NZ+1)+(K+1);

  double XNORMA = 0.0;
  double YNORMA = 0.0;

  for (int L = 0; L < NumEwd; L++) {

    int indexW = (K+1)+(L+1)*(NZ+1);
    double aux_RSQDX = (double)(IEW[L+1]-(I+1)+0.5);
    double aux2_RSQDX = (double)(JEW[L+1]-(J+1));
    double RSQDX = pow(aux_RSQDX,2)*DX2+pow(aux2_RSQDX,2)*DY2;
    double aux_RSQDY = (double)(IEW[L+1]-(I+1));
    double aux2_RSQDY = (double)(JEW[L+1]-(J+1)+0.5);
    double RSQDY = pow(aux_RSQDY,2)*DX2+pow(aux2_RSQDY,2)*DY2;

    if ((J + 1) != NYP1)
      VENTOU[index_VentoU] = VENTOU[index_VentoU] +
                            WU[indexW]*EWW[indexW]/RSQDX;
    if ((I + 1) != NXP1)
      VENTOV[index_VentoV] = VENTOV[index_VentoV] +
                            WV[indexW] * EWW[indexW]/RSQDY;

    XNORMA = XNORMA + EWW[indexW] / RSQDX;
    YNORMA = YNORMA + EWW[indexW] / RSQDY;
  }

  if ((J + 1) != NYP1)
    VENTOU[index_VentoU] = VENTOU[index_VentoU] / XNORMA;

  if ((I + 1) != NXP1)
    VENTOV[index_VentoV] = VENTOV[index_VentoV] / YNORMA;
}
```

Fig. 9 Parallel implementation of velocity_interpolation function

5 Results

In order to evaluate the performance of the parallelism proposed in this work, a hypothetical case, considering the vicinities of the Angra dos Reis Brazilian Nuclear Power Plants (NPPs), has been chosen. The NPPs stays at sea level, surrounded by moutains and the sea.

Table 1 shows comparative results between execution times for sequential (CPU) and parallel (GPU) versions of functions Stability_Interpolation and Velocity_Interpolation. Computed times for the GPU versions include the execution of GPU kernels, memory allocation in GPU and data transfer to GPU.

Table 1 Comparative results between execution times for sequential (CPU) and parallel (GPU) versions of the functions

Function name	CPU time (s)	GPU time (s)*	Speedup
Stability_interpolation	2.45	0.24	10,2
Velocity_ interpolation	13.76	0.34	40.5

*Considering: GPU kernel + memory allocation in GPU + data transfer to GPU

Great gains in terms of computational times can be observed for both evaluated functions. Considering the GPU used (which is not the top-of-line), a speedup of 40 times in the velocity interpolation can be considered a very interesting result. On the other hand, 10 times for stability interpolation is good, but it seems to be under optimized.

Actually, it is outstanding the difference between speedups obtained for functions, which in first sight seem to be approximately equivalent in terms of required computational efforts (looping all 3 dimensions interpolating data from each weather station).

Nevertheless, looking at the computer codes more carefully, it can be seen that their complexities are quite different. Note that in the sequential Stability_Interpolation function, the calculations are not made if the cell is inside the terrain (and it does occur many times in the sample case chosen). The following peace of code (see Fig. 6) makes this control:

```
If (K <= Iht[I][J]) continue;
```

Where *K* is the vertical coordinate of the cell and *Iht[I][J]* is the terrain height at position (I, J).

Considering that, many cells (inside terrain) in the 3D-grid are not computed in the sequential code. However, in the parallel approach a CUDA kernel is allocated to each cell, even if the calculations is not to be done. In this case, a pre-processing could increase speedup.

6 Conclusions

In this work, a monolithic CUDA kernel approach was applied in the parallelism of two functions (Stability_Interpolation and Velocity_Interpolation) of the Wind Field program, used in the context of an Atmospheric Radionuclide Dispersion (ARD) system, have been developed.

A sample case, considering the vicinity of the Angra dos Reis Brazilian NPP has been considered and both sequential (CPU) and parallel (GPU) versions of the functions were applied and results compared in terms of computational times.

The GPU version achieved a speedup of 40 times for velocity interpolation and 10 times for the stability interpolation.

This results are quite motivating and point to the feasibility of development of integrated real-time ARD systems for very refined 3D-grids. Future work aims to develop a full parallel version of the Wind Field and the Plume Dispersion modules of the ARD system to be used by the Brazilian NPPs.

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Interfaces for Distributed Remote User Controlled Manufacturing as Collaborative Environment

Vesna Spasojevic Brkic, Goran Putnik, Zorica A. Veljković, Vaibhav Shah and Ahmed Essdai

Abstract Recent advances in information and communication technologies that support the concept of collaborative networks have allowed manufacturing enterprises to use remotely controlled decentralized manufacturing processes. This survey is based on the experiment that involved 34 small collaborative groups at Serbia, that have used the interface for remote collaborative control of manufacturing systems to control of CNC machine located in Portugal. The experiments on collaborative environment are done using two types of "client" user interface, "Wall" and "Window". Measured characteristics included: collaborative effort, involvement, awareness, representational fidelity features and co-presence. Results show that "Wall" interface has higher values of index of interdependence of collaborative virtual environment characteristics. Conclusion is that characteristics of collaborative environment are less interdependent when "Window" is used opposite to the "Wall" interface. Future research ideas are to test similar platforms with more users and to study aspects such as group leader choice and role, possible conflicts etc.

Keywords "Wall" and "Window" interface · Remote collaborative control · Index of interdependence

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Nomenclature

COE	Collaborative effort to complete the task,
INV	Involvement in communication and the experimental task,
ACT	Being active participant in the task,
SAT	Satisfaction with task,
AWP	Awareness of the existence of other participants,
AWO	Awareness of other participants actions,
CPL	Co-presence in laboratory in Portugal,
CPM	Co-presence of nearness of the machine
RDE	Realistic display of the environment,
SDM	Consistency of object motion,
COB	Consistency of object behavior,
URE	User representation,
WA	“Wall” interface,
WI	“Window” interface,
D	Desktop screen,
V	Video beam presentation,
Kolm	Results for Kolmogorov normality test,
p-val.	*P*-value of test.
par. type	Type of parameter Normal of Non-normal distribution i.e. parametric or nonparametric tests,
Cm_i	Individual index of interdependence and
Cm	Overall index of interdependence

1 Introduction

In order to remain competitive in a turbulent and very competitive climate of marketplace, product manufacturers today are forced to search for solutions in terms of new business models and strategies, management principles, organizational models, processes and technological capabilities to satisfy their customers. Recent advances in information and communication technologies that support the concept of collaborative networks have allowed manufacturing enterprises to move to product manufacturing through the resources outsourcing in remotely controlled decentralized manufacturing processes. Collaborative environments today are very successful when used in for multiplayer games and for meetings organizing, which has led us to explore its potential in remotely controlled decentralized manufacturing.

This survey is based on the experiment that involved 34 small collaborative groups including 68 students at the University of Belgrade, Serbia, that have used the interface for remote collaborative control of manufacturing systems to control of CNC machine located at Universidade Minho, in Portugal, since our previous survey [1] has shown that that group work consumes less time than individual work in most working options. The experiments on collaborative environment are done using two types of "client" user interface, when working in small collaborative group consisted of two users. Measured characteristics included collaborative effort, involvement, participants` activity, satisfaction, awareness, representational fidelity and co-presence measures in aim to test which type of interface shows better results, according to previous research recommendations.

1.1 Previous Research

A new competitive environment for manufacturing and service industries has been developing during the last decade, since the fusion of latest technologies enables remote control to answer the acceleration of the globalization, changes in regulations and economic crisis. Today, it is possible to outsource manufacturing process using remote control of decentralized manufacturing process, in way that resources and stakeholders are integrated in a global chain, utilizing ubiquitous computing systems and virtual and networked enterprises concepts for anywhere-anytime control [1].

Collaborative manufacturing networks and manufacturing grids are emphasized by Liu and Shi [2], Murakami and Fujinuma [3] extend it to ubiquitous networking while Camarinha-Matos [4] points out that collaboration is a mechanism to facilitate agility and resilience. Large number of previous surveys pointed out to the importance of immersion and presence, suggesting that they are very important features that distinguish virtual from other types of environment. But, critical soft factors of ubiquitous manufacturing till today are rarely surveyed in literature, although they are very important in usability concept [1, 5, 6].

In that aim Martínez-Carreras et al. [7] introduce Collaboration Usability Analysis, as human-computer interaction technique which offers consciousness about the collaborative actions with significant impact on individual and group performance and details of the interactions with the shared workspace. Hrimech et al. [8] examine user experience in a semi-immersive collaborative virtual environment analyzing collaborative effort, awareness, involvement, and co-presence between other dependent variables that influence egocentric interaction metaphors. Authors in [9, 10] prove that representational fidelity and learner interaction are the most important characteristics of distributed and remote environment.

According to previous research results it is obvious that there is a need to survey collaborative effort, involvement, participants` activity, satisfaction, awareness and co-presence and representational fidelity measures (that are analyzed in paper [10] for individual work) as characteristics of distributed remote user controlled collaborative manufacturing systems.

2 Interfaces for Distributed Remote User Controlled Manufacturing as Collaborative Environment

Effective human communication is extremely important in modern manufacturing system operation [11], that are radically different from those from 20 years ago. Barnum [12] also points out that today the focus must be on the user, not on the product, that means that user must be in the center rather than technology. Accordingly, it should be noted that new communication channels are very important in multiplex (multi-channel) communication systems and special attention should be paid to human operators that control remote cell [13]. Collaboration as the process of multiple people working together interdependently to achieve a greater goal than is possible for any individual to accomplish alone [14] could be very beneficial in remotely controlled manufacturing systems. The success of a collaborative system depends on multiple factors, including the group characteristics and dynamics, the social and organizational context in which it is inserted, and the positive and negative effects of technology on the group's tasks and processes [15].

Accordingly, the examination of distributed remote user controlled manufacturing system herein includes developed "client" user interface for the distributed manufacturing system that belongs to the Ubiquitous Manufacturing System Demonstrator, as described in detail in Spasojević-Brkić et al. [6]. The experiments on collaborative environment are done using two types of "client" user interface, "Wall" and "Window", when working in small collaborative group consisted of two users, as shown in Figs. 1 and 2. "Wall" interface shows the live video feed from the remote cell on wall panel and the human "client" operator is watching the remote cell through on wall while controlling the remote CNC machine, while "Window" interface uses a window panel on the interface and the human "client"

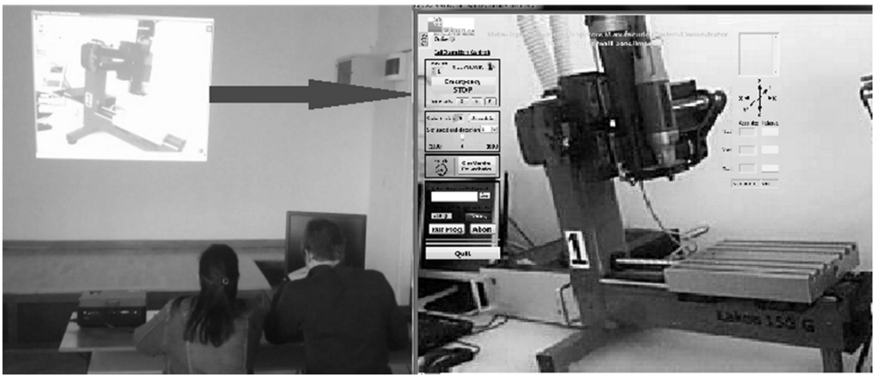

Fig. 1 Group performing task on "Wall" interface

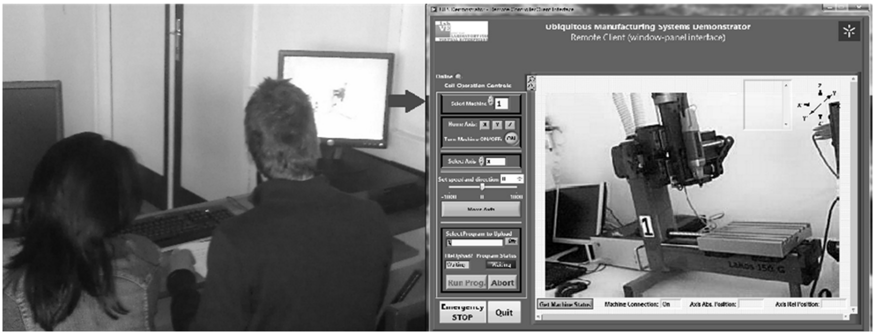

Fig. 2 Group performing task on “Window” interface

operator is watching the remote cell out into a window while controlling the remote CNC machine.

Our previous survey has shown that group work consumes less time than individual work in most working options [1].

3 Methodology and Results

The experimentation involved 34 small collaborative groups including 68 students at the Faculty of Mechanical Engineering, University of Belgrade, Serbia, that have used the interface for remote collaborative control of manufacturing systems to control CNC machine located at Universidade Minho, in Portugal, since our previous survey has shown that that group work consumes less time than individual work in most working options. Each group had task to remotely control the cell as shown in Figs. 1 and 2, using both “Wall” and “Window” interfaces. The task consisted of the following subtasks: to connect to the remote cell, start a CNC machine, upload a CNC program to conduct operations on the machine, remotely use the emergency stop button, move axes, assess the status of the machine and positions of all axes.

Participants in collaborative groups had 23.16 years in average and grade point average 8.27 on the scale from 6 to 10. Their computer literacy was 3.99, capability of knowledge transfer was 3.59 and desirability to learn new software was graded with 4 in average, all on the Likert scale from 1 to 5. Group homogeneity as similarity of individual personality characteristics was also measured. Although there is certain low indication of the statistical significance of the number of homogeneous groups greater than the number of heterogeneous group (p-value = 0.0867), with respect to the size of the sample can be concluded that in this experiment the number of homogeneous and heterogeneous group was the same. The number of male participants in experiments was significantly higher than the number of female participants ($p < 0.001$).

Measured characteristics included: collaborative effort to complete the task, involvement in communication and the experimental task, participants' activity in the task, satisfaction with task, awareness measures (awareness of the existence of other participants and awareness of other participants actions), representational fidelity measures (realistic display of environment, smooth display of view changes and object motion, consistency of object behaviour and estimate of user representation which includes control, maneuver and manipulation of the object) and co-presence measures (co-presence in laboratory in Portugal and co-presence of nearness of the machine).

3.1 Statistical Methodology

Statistical methods used for data analysis include descriptive statistics for observed characteristics, i.e. number of measured groups, mean, median, standard deviation, coefficient of variation, Kolmogorov test for normality and it's p-value of test. Based on the coefficient of variation and on results of Kolmogorov test, type of measured characteristics was determined, i.e. it is decided if the characteristic needs parametric or nonparametric testing. It was also decision criteria for determination of statistical analysis type that was used if parametric testing needed z—tests will be used and coefficient of correlation will be used for simple linear regression while for nonparametric tests methods U* Mann Whitney tests and Spearman correlation coefficients where used [16].

Assessment criteria for the impact of parameters were based on p-value, according to the following criteria:

$$\begin{aligned}
&p > 0.05 \text{ non significance, marked as n.s. and with} =\\
&p < 0.05 \text{ some significance exists, marked with} *, \text{ and with} >\\
&p < 0.01 \text{ strong significance exists, marked with} ** \text{ and with} > >\\
&p < 0.001 \text{ absolute significance exists, marked with} *** \text{ and with} > > >
\end{aligned} \tag{1}$$

In simple linear regression analysis the following criteria for correlations were used:

$$\begin{aligned}
&|r| \in [0.5; 0.7) \text{ no correlation, marked as (n.s.)}\\
&|r| \in [0.5; 0.7) \text{ weak correlation, marked as } (*)\\
&|r| \in [0.7; 0.9) \text{ strong correlation, marked as } (**)\\
&|r| \in [0.9; 1] \text{ absolute correlation, marked as } (***).
\end{aligned} \tag{2}$$

Index of interdependence is calculated to compare the results of correlation relationships for measured characteristics in "Wall" and "Window" surrounding. It measures the number and strength of correlations for observed measures, regardless of the type of correlation, based on p-values for nonparametric testing or values of criteria for correlation strength for parametric testing.

Individual index of interdependence is calculated according to the following formula:

$$C_{m_i} = w_i / w_{m_i} \cdot 100, \quad i = 1, \ldots, m_i \tag{3}$$

where w_i are overall weights for individual parameters corresponding criteria described above, with individual values 0, 1, 2 or 3, w_m is maximum possible weight for parameter, m_i observed parameter of parameters in presented research.

Overall index of interdependence is calculated according to the following formula:

$$C_m = \sum_{i=1}^{m} C_{m_i}, \quad i = 1, \ldots, m \tag{4}$$

where m is number of all correlated observed characteristics.

3.2 Interpretation of Results

Descriptive statistics results for measured characteristics are shown in Table 1. through twelve nonparametric and twelve parametric characteristics.

Since type of display is not subject of this paper, realistic display of the environment, consistency of object motion, consistency of object behavior and user representation are obtained from their combined data from correlation estimates for both desktop and video beam displays.

Using mathematical expressions (1), (2) and (3), correlation results on individual index of interdependence data are obtained when using “Wall” interface and presented in Table 2, while results for “Window” interface are given in Table 3.

Correlations of measured characteristics, shown in Table 2, lead to certain conclusions for “Wall” environment. For large part of relations correlation does not exist. Collaborative effort to complete the task is in direct weak correlation with co-presence both in laboratory in Portugal and of nearness of the machine and vice versa. Awareness of the existence of other participants is strongly correlated to awareness of other participants’ actions and vice versa. Those measures are also weakly correlated to user representation and vice versa. All representational fidelity measures are in certain correlation, but user representation that is correlated only to consistency of object behavior. The highest value of individual index of interdependence has consistency of object behavior, followed by user representation, realistic display of the environment, consistency of object motion and then by realistic display of the environment. There is no interdependence between involvement in communication and the experimental task, participants’ activity in the task and satisfaction with task and other measures.

Table 1 Descriptive statistics for measured characteristics

Characteristic	N	Mean	Med	SD	cv (%)	Kolm	*p*-value	par. type
COE	34	4.368	5.00	1.110	25.41	0.312	$p < 0.01$	Nonparametric
INV	34	2.353	2.50	1.152	48.94			Nonparametric
ACT	34	4.897	5.00	0.239	4.89	0.49	$p < 0.01$	Nonparametric
SAT	34	4.368	4.50	0.568	13.01	0.298	$p < 0.01$	Nonparametric
AWP	34	4.515	4.50	0.691	15.30	0.285	$p < 0.01$	Nonparametric
AWO	34	4.368	4.50	0.752	17.21	0.305	$p < 0.01$	Nonparametric
CPL	34	2.500	2.50	1.115	44.59			Nonparametric
CPM	34	2.838	3.00	0.975	34.35			Nonparametric
RDE WA D	34	3.956	4.00	0.762	19.27			Parametric
RDE WA V	34	4.088	4.00	0.691	16.89			Parametric
RDE WI D	34	3.882	4.00	0.749	19.3	0.239	$p < 0.05$	Nonparametric
RDE WI V	34	3.897	4.00	0.705	18.08			Parametric
SDM WA D	34	4.074	4.50	0.863	21.18			Parametric
SDM WA V	34	4.074	4.50	0.889	21.82			Parametric
SDM WI D	34	4.059	4.00	0.911	22.44			Parametric
SDM WI V	34	4.029	4.30	0.825	20.48			Parametric
COB WA D	34	4.221	4.50	0.676	16.02	0.248	$p < 0.05$	Nonparametric
COB WA V	34	4.25	4.50	0.643	15.12			Parametric
COB WI D	34	4.147	4.30	0.702	16.93			Parametric
COB WI V	34	4.279	4.50	0.63	14.72			Parametric
URE WA D	34	4.265	4.50	0.688	16.13			Parametric
URE WA V	34	4.309	4.50	0.551	12.78	0.312	$p < 0.01$	Nonparametric
URE WI D	34	4.176	4.50	0.777	18.61			Parametric
URE WI V	34	4.235	4.50	0.666	15.71	0.243	$p < 0.05$	Nonparametric

Correlations presented in Table 3, lead to similar conclusions for "Window" interface, but with lower values of individual index of interdependence. Comparison of individual index of interdependence for measured characteristics given in Tables 2 and 3 derives following conclusions.

Collaborative effort to complete the task, awareness of the existence of other participants and awareness of other participants actions have higher values for "Wall" interface while measures of being active participant in the task, satisfaction with task and involvement in communication and the experimental task are not interdependent at all. All representational fidelity measures have higher values for "Wall" then for "Window" interface, except of consistency of object behavior that has equal values for both types of interfaces.

Based on results presented at Tables 2 and 3 overall index of interdependence is obtained using formula (4).

Data given in Table 4, for overall index of independence, show that "Wall" interface has higher values. All indexes of independence are also shown in Fig. 3.

Table 2 Correlations of measured characteristics and individual index of interdependence for "Wall" interface

Wall	COE	INV	ACT	SAT	AWP	AWO	CPL	CPM	RDE WA	SDM WA	COB WA	URE WA	Cm_i
COE	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	6.67
INV	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0
ACT	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0
SAT	*n.s.*	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0
AWP	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	**	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	8.89
AWO	*n.s.*	*n.s.*	*n.s.*	*n.s.*	**	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	11.1
CPL	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	2.22
CPM	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	2.22
RDE WA	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	**	*	*n.s.*	13.3
SDM WA	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	**	X	*	*n.s.*	16.7
COB WA	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*	X	***	23.3
URE WA	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	***	X	18.3

Table 3 Correlations of measured characteristics and individual index of interdependence for "Window" interface

Window	COE	INV	ACT	SAT	AWP	AWO	CPL	CPM	RDE WI	SDM WI	COB WI	URE WI	Cm_i
COE	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	4.44
INV	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0
ACT	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0
SAT	*n.s.*	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0
AWP	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	**	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	4.44
AWO	*n.s.*	*n.s.*	*n.s.*	*n.s.*	**	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	4.44
CPL	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	2.22
CPM	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	*n.s.*	*n.s.*	*n.s.*	*n.s.*	2.22
RDE WI	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	X	**	*	*n.s.*	11.7
SDM WI	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	**	X	*	*n.s.*	13.3
COB WI	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*	X	***	23.3
URE WI	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	***	X	11.7

Table 4 Overall index of interdependence for "Wall" and "Window" interface characteristics

Characteristic		COE	INV	ACT	SAT	AWP	AWO	CPL	CPM	RDE	SDM	COB	URE	Cm
Cm_i	Wall	6.67	0	0	0	8.89	11.1	2.22	2.22	13.3	16.7	23.3	18.3	103
	Window	2.22	0	0	0	4.44	4.44	2.22	2.22	11.7	13.3	23.3	11.7	77.8

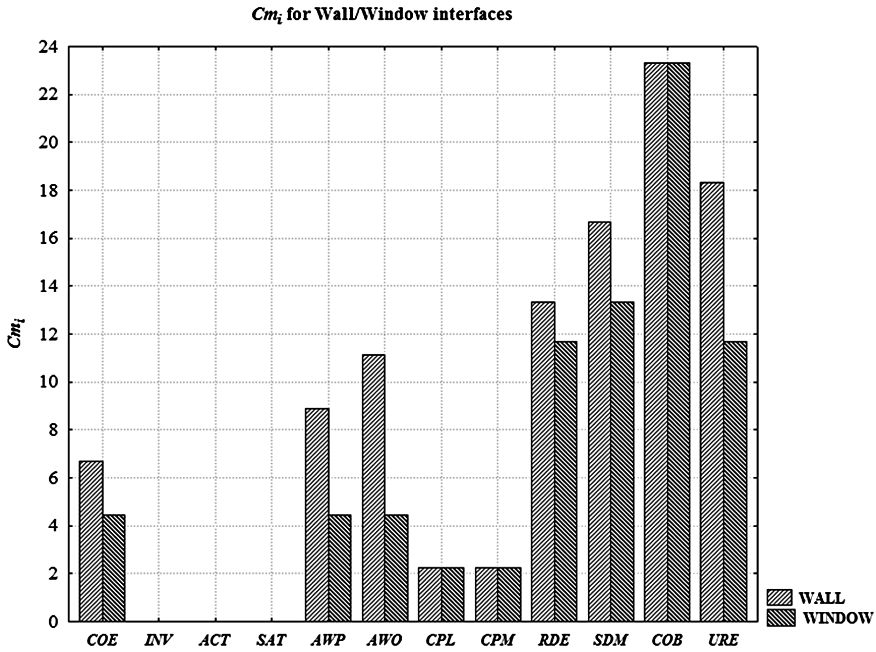

Fig. 3 Comparisons of indexes of interdependence between "Wall" and "Window" interfaces

4 Conclusions

In order to remain competitive product manufacturers should apply new ways of control of human-computer interfaces such as remote control of complex distributed manufacturing systems. The examination of collaborative work on distributed remote user controlled manufacturing system developed in Portugal is tested by Serbian students, as future users of new production paradigm.

Conclusion is that characteristics of collaborative environment are less interdependent when "Window" interface is used opposite to the "Wall" interface.

Comparing values of index of interdependence for both types of interfaces shows that average index of interdependence is higher when using "Wall" then "Window" interfaces.

Our previous research [10] also gives advantage to "Wall" Interface, in the field of representational fidelity measures, when interface is individually used. Accordingly, for further usage and development "Wall" interface as collaborative environment is recommended, since it shows far better results than the "Window" interface. Solution presented in this paper can also be used as 'Distributed and Remote Lab' that enables laboratories usage through both cooperation and collaboration, e.g. universities that do not possess certain labs can use borrowed one through proposed innovation.

Proposal for future research, since the size of group in our experiments was limited to two users, is to test similar collaborative platforms with more than two users and to study various aspects such as the management of turn taking, group leader choice and role, possible conflicts and similar. Also, in future interface improvement characteristic involvement in communication and the experimental task of the proposed solution should be improved.

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Novel Helicopter Flight Director and Display

Edward Bachelder

Abstract A helicopter's final approach and landing are critical phases of flight that are highly susceptible to spatial disorientation when external visual cues are degraded or absent. Current visual landing aid systems display tracking error which the pilot attempts to null in a compensatory fashion. This paper presents theoretical and preliminary empirical support for performance enhancement when providing pilots guidance preview and prediction of states, rather than just a compensatory display of the tracking error. A novel space-time format is proposed for displaying: (1) Previewed 4D guidance information; (2) Projected (predicted) state relative to the guidance preview; and (3) Current state relative to current guidance and terminal objectives. A key objective of the display is to allow the pilot to perceive and control each axis of translation as part of an integrated pattern, thus distributing attention equitably.

Keywords Flight display · Flight director · Human operator control · Motion perception · Predictor

1 Introduction

Humans naturally navigate through their physical environment using the native display provided by their eye-point. Highly-skilled self-motion tasks such as gymnastics and car racing require precision both in timing and amplitude of execution, motion that appears to be governed by time-to-collision (tau theory) [1], or a combination of time-to-collision and precognitive (open-loop) behavior. These demanding tasks tend to be very repetitive and are supported by refined sensing and motor skills. If one or more of these three conditions is absent (i.e. the task setting becomes unfamiliar, visibility is reduced, fatigue impairs response), the risk of

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improper execution increases. But the cornerstone is perception, whether of states at the start of an open-loop maneuver, or continuous perception of time-to-collision intuited from state derivative comparison.

A complicating aspect of human visual perception is that transverse motion cues (left/right, up/down relative to the line-of-sight) are lamellar and fundamentally different from the radial cues produced by motion in the depth axis (fore/aft). In Ref. [2] Bachelder constructed a helicopter simulation experiment that employed a number of unique techniques designed to create an environment where differences in performance between axes would be due primarily to visual perception and control strategy differences. In the experiment depth cues were artificially magnified so that the angular sensitivity of motion cues were equal in all three axes of translation. It should be noted that without artificial magnification, sensitivity to depth motion is approximately 20 times less than transverse motion sensitivity [2] (when the cues are observed within foveal vision, approximately $\pm 3°$). Each axis of vehicle translation was governed by the same dynamics, and the controls were all spring-centering. During single-axis control (where one axis was active and the other two disabled), stability margins and tracking performance were roughly the same for all three axes. However, simultaneous tracking in all three axes yielded significant interaction effects and differences between axes. By varying motion cue sensitivity in one axis and observing performance change in the others, it was concluded that the depth axis receives more attentional resources than the others, i.e. motion in depth is more compelling. Performance during multi-axis tracking was best in the lateral axis.

There are numerous displays used for spatial aiding in aviation, examples include: vertical situation and navigation (Fig. 1a), Instrument Landing System, moving map, electronic approach plate, and optical landing systems. The Head-up-Display (HUD, Fig. 1b) allows the flight path vector and other world-conformal symbology to be overlaid on the actual out-the-window (OTW) scene. More recently, synthetic vision (SV) provides pilots with a computer-generated representation of the OTW scene. Tunnel-in-the-sky [3] symbology can be used with SV to provide pilots current and future guidance cueing (Fig. 2).

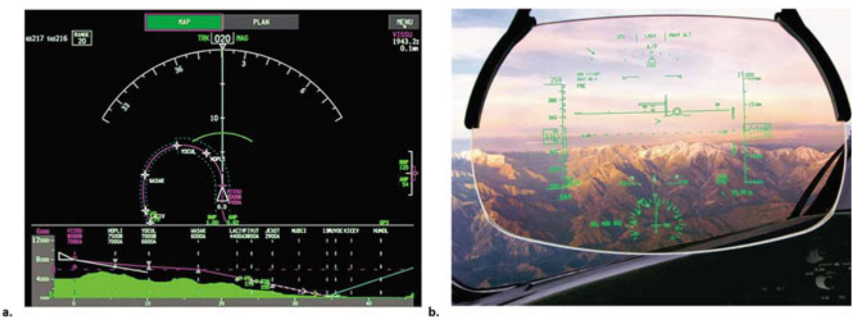

Fig. 1 Boeing 787 displays: **a** Navigation and vertical situation display; **b** HUD [4]

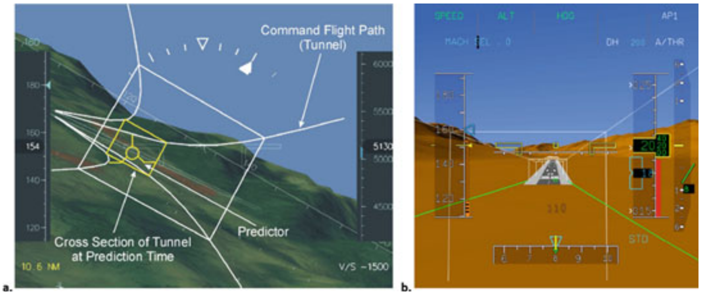

Fig. 2 Tunnel-in-sky cueing: **a** Curved approach [5]; **b** Landing guidance [6]

Specific to helicopters, displays such as the Apache Integrated Helmet and Display Sighting System (IHADSS) depict the landing area relative to current position, as well as guidance for acquiring the landing pad position.

Visual aids that employ multiple planes to represent space (such as horizontal and vertical planes shown in Fig. 1a) generally require the user to devote attention to one plane at the expense of the other. When decision/action events between planes are sufficiently separated in time, this segmented approach can support acceptable system performance and pilot workload. However, when events in both planes coalesce, division of attention can produce high workload and increase the risk for error.

3D displays allow guidance to be embedded in the scene that the pilot captures by maneuvering through that scene, but there are challenges with this approach. Guidance cues closest to ownship's position will appear larger than distal cues, and near and far cues often overlap. When they do, cascading cues (boxes, for instance) can obscure prospective guidance and diminish the advantage of preview, while interfering with perception of the proximal guidance cues. Furthermore, clutter due to cue coalescence along the line-of-flight can reduce visibility of, and create competition with, physical goals such as the runway during approach-to-land. Commanded speed changes in 3D guidance can be implied via cue density, where closer spacing denotes a slower speed, but this only imparts a general sense of future speed.

Figure 3 presents the same trajectory using distance and time as the independent variables, respectively. In Fig. 3a time progression is denoted by dots shown at three second intervals. Much of the trajectory is a constant flight path angle, and the sense for how altitude changes in time is difficult to perceive, especially near the maneuver's termination. However, when viewing altitude as a function of time in Fig. 3b, the temporal nuances of the trajectory are evident.

A workload-intensive maneuver such as landing requires precise, subtle control of both speed and altitude, and employing temporal inference via spatial cueing may not offer significant assistance. Reference [6] reports that while 3D predictive guidance during landings improved the timing of flare initiation, actual execution of the flare was not enhanced by the predictive guidance. It is an unfortunate irony that augmenting a synthetic scene in the direction that one must look—along the line-of-motion—is such a difficult challenge.

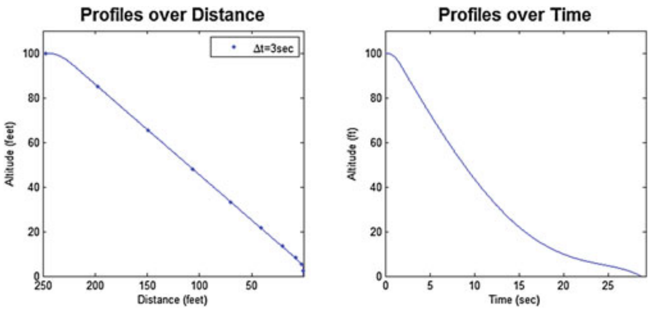

Fig. 3 Comparison of the same trajectory using **a** distance; and **b** time as the independent variable

During day (unrestricted visibility) flight, skilled helicopter pilots can perform aggressive and intricate approach-to-land maneuvers with relative ease. When flying in degraded or zero-visibility conditions, the complexity of a trajectory is often dictated by the workload and performance associated with a particular display. Key metrics for evaluating a landing display should include: performance repeatability, robustness to external disturbance, graceful degradation as task difficulty increases, and robustness to lapses of attention, in addition to pilot workload and opinion.

2 Display Design

Initially conceived at the U.S. Army Aviation Development Directorate as a 4D (time + 3D space) tool to evaluate candidate landing trajectories, the Aircraft Guidance Visualization Application (AGVA) was subsequently recognized as a potential platform for testing concepts which could be integrated with current and future landing displays. Developed in MATLAB, AGVA incorporates a Simulink model that receives inputs from a USB joystick/throttle gaming device plugged into a PC, providing the option for either automatic or pilot guidance-following. A powerful feature of the simulation is that the graphics are driven and rendered in real time thus allowing pilot-in-loop operation, a capability made possible through code optimization. AGVA also establishes the feasibility for portable rapid prototyping and testing of guidance-related flight symbology using a PC, laptop, or tablet.

2.1 Prediction and Preview

AGVA incorporates two complementary mechanisms that can improve performance and reduce pilot workload: guidance preview and state prediction. In his watershed work on human pilot behavior [7], McRuer proposed the Dual Channel model to represent how an operator blends (a) previewed information of the reference signal being tracked with (b) error between the reference and the system output. Figure 4 shows the McRuer Dual Channel model modified to include prediction feedback and external disturbance. A time advance element operates on the guidance to generate the time projection T_{PR} which is used by the predictor H_{PR}, and the projected reference is then compared with the predicted system output. Y_r is the element representing the pilot's transfer function (TF) that operates on the previewed reference signal, and Y_e is the pilot compensatory element that operates on the error e. A disturbance d is added to the aircraft (G_c) output, with the predictor H_{PR} operating on the result.

Equation 1 gives the error-to-reference TF. If the disturbance d is zero, Eq. 2 shows that the error e is driven to zero when Y_r becomes the inverse of the aircraft-predictor suite.

$$\frac{e(s)}{r(s)} = \frac{e^{sT_{PR}}(1 - Y_r H_{PR} G_c)}{(1 + Y_e H_{PR} G_c)} + \frac{[d(s)/r(s)]H_{PR}}{(1 + Y_e H_{PR} G_c)}. \quad (1)$$

$$\text{if } Y_r \approx (H_{PR} G_c)^{-1} \text{ and } d(s) \approx 0 \Rightarrow e(s) \approx 0. \quad (2)$$

However, since the pilot's actual TF corresponding to Y_r will vary over time and deviate from $(H_{PR} G_c)^{-1}$, and as disturbances (i.e. from wind) will impinge on the aircraft, the resulting error e must also be controlled by Y_e as shown in Fig. 4.

To examine system response to disturbance, the reference signal in Fig. 4 has been set to zero so that tracking becomes a regulation task as shown in Fig. 5. In this task the objective is to negate the disturbance d, hence the negative sign on d.

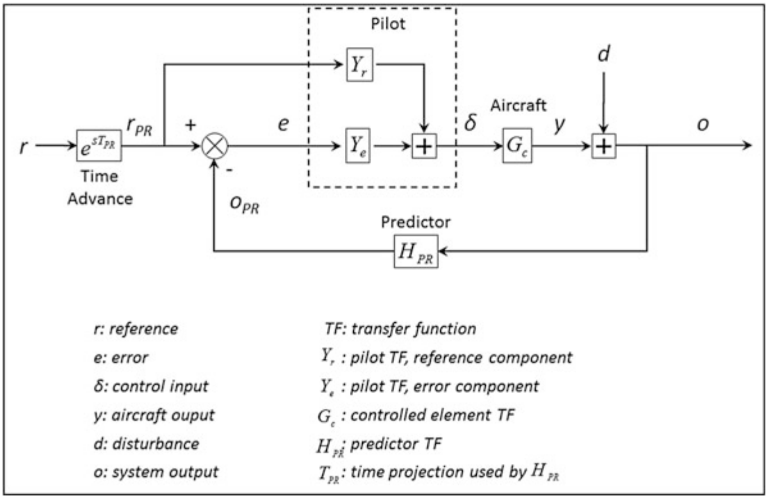

Fig. 4 Dual Channel model [6] modified to include prediction feedback and external disturbance

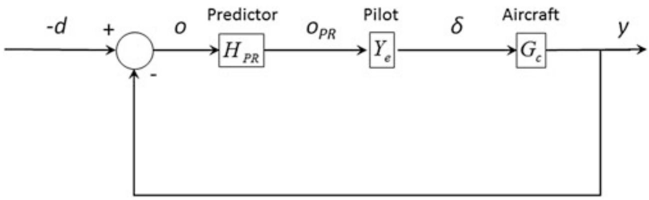

Fig. 5 Dual-Channel model from Fig. 4 reduced to compensatory control for regulation task (reference signal = 0)

McRuer established that compensatory control is easiest for a pilot when he/she can operate as a pure gain, which occurs when the controlled element G_c behaves approximately as a pure integrator K/s in the region of the gain crossover frequency ω_c. Later research showed this rule also applied to the display-vehicle suite. Since the predictor H_{PR} generates the display dynamics that the pilot responds to, the appropriate design for H_{PR} in the region of ω_c would be (Eq. 3):

$$H_{PR}(j\omega_c)G_c(j\omega_c) \approx \frac{K}{s} \;\Rightarrow\; Y_{\mathrm{e}} \approx const \tag{3}$$

Equation 4 follows from Eq. 2,

$$Y_r \approx (H_{PR}G_c)^{-1} \approx \frac{s}{K} \tag{4}$$

Generating pure lead of Eq. 2 in response to the previewed guidance is relatively easy for a skilled pilot. One challenge associated with this approach can be preserving the temporal meaning of H_{PR}'s output so that it can be used with the time-referenced guidance. Of course, if the task is station-keeping, the guidance trajectory is zero over all time so that H_{PR}'s output does not need to correlate with time. But this is a special case, and the objective of AGVA is to address time-varying guidance in general.

The above analysis establishes that H_{PR} has the potential to optimize pilot performance when a previewed reference signal is being tracked in the presence of disturbance. A more detailed discussion of H_{PR} design considerations will be given later.

While most guidance displays are spatially-referenced, the motivations for making AGVA time-referenced were: (1) Preview of near-future guidance is interpreted with more ease when the pilot does not have to infer time by mentally integrating current and future speed; (2) Prediction cueing is projected along the guidance a consistent distance out (speed-invariant), allowing precise trajectory anticipation; (3) Since vehicle dynamics are significantly different for the three axes of translation, optimal prediction times for each axis will likely be different as well. A unique prediction time can be assigned to an axis of translation when there is a unique time axis dedicated to it. This is not possible in a spatially-referenced display; (4) Cueing curvature provides explicit and valuable information about the guidance and prediction derivatives (velocity, acceleration, even jerk); (5) Spatial resolution for each axis of translation is independent of the other, allowing state resolution to be a function of its rate of change, thus enhancing the utility of preview.

2.2 Display Description

AGVA displays key states associated with each axis of translation (position relative to landing zone, error from guidance, and rate of motion), as well as position, rate, and acceleration of future guidance. The vertical guidance appears on the left (controlled by the left hand with the collective), and the lateral and longitudinal guidance are shown in the center and right, respectively (controlled by the right hand with the cyclic). Thus the spatial motion of the three axes is aligned with the reference frames that Army pilots are accustomed to flying (top-down view for cyclic control, profile view for collective control). As earlier noted, human sensitivity to transverse motion is greater than to depth motion, thus by representing 3D space on the transverse plane AGVA maximizes motion sensitivity and spatial resolution. Figure 6a annotates most of the graphical features of AGVA. Three prediction segments, one for each axis of translation (altitude, distance-to-land, and cross-distance), are colored magenta, originating at ownship's current position and terminating at the predicted position. The three guidance trajectories originate from the center of the display, and ownship's current error from the guidance is the distance from the display center to the base of a magenta prediction segment. The time scale assigned to altitude is shown on the lower left of the display (horizontally aligned), the time axis assigned to distance on the lower right (horizontally aligned), and the time axis assigned to cross-distance is on the upper right (vertically

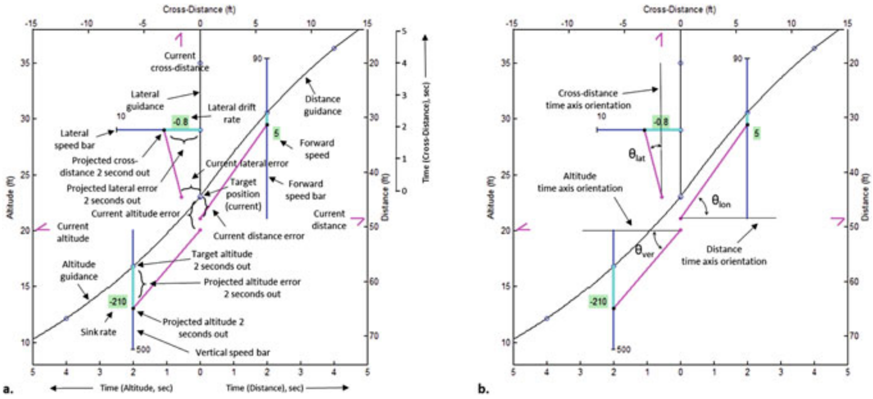

Fig. 6 Annotated AGVA display

aligned). Since the cross-distance time axis also overlaps with the distance (and altitude) axis, it is suppressed from view.

For ease of exposition, the prediction method employed in Fig. 6 simply integrates the instantaneous velocity over a fixed projection time (2 s in this example). The angle formed by the predictor's time axis and the prediction segment controls the segment's slope, which is the instantaneous velocity. Figure 6b shows the velocity angles associated with each translation axis. A speed reference bar is placed at the end of a prediction segment—the point of intersection represents the current speed, at which location the value of the current speed is displayed. The base of the speed bar is placed flush with current position (i.e. the origin of the prediction segment), so that when speed approaches zero the prediction segment will lie parallel to its time axis. The end of the speed bar displays an upper reference value (which can be a not-to-exceed operating limit). The speed scale is nonlinear in order to maintain the reference bar in view. The distance axis scale is a function of forward speed, so that preview of the distance guidance will be visible over most of the time scale. The scales of altitude and cross-distance axes were fixed for the examples presented, since their speeds did not vary as much as the forward speed. However, if a trajectory required sufficiently large speed variation for any given axis, the resolution could be speed-dependent. Although providing less resolution at higher rates, this method is consistent with human perception (Weber's Law): the faster the rate, the less precise the sense of distance traversed.

The tracking strategy when operating AGVA is to place the endpoint of each magenta prediction segment onto its axis' future guidance, which will result in closure of ownship's positional error along that axis. The distance between the future guidance and predicted position is highlighted cyan, so that when the predictor overlays the guidance cyan is no longer visible. A zero-velocity end-state for any axis will result in the prediction segment lying flush with that axis at touchdown. If the terminal speed guidance is 0/0/0 for all axes, the pattern at the maneuver's finish would be an inverted 'T'. An axis' speed bar is only shown when ownship's absolute speed along that axis is above a specified breakout speed. This declutters the display for near-zero speeds, and serves to sensitize the pilot to non-zero speeds. The digital readout of each axis' speed has a colored background that changes from green to red when the speed approaches an operating limit. Magenta pointers lying along the peripheral Altitude, Distance, and Cross-Distance axes indicate the separation remaining between ownship and the landing zone. If the approach was curved in the horizontal plane, Distance would represent distance along the curved trajectory, and Cross-Distance the horizontal separation normal to the trajectory's tangent.

Figure 7 shows a progression sequence from maneuver entry through touchdown. An autopilot was used to track the guidance to provide an illustration of perfect tracking. In this example, predicted position was projected in time using both instantaneous velocity and acceleration, (hence the magenta prediction segments exhibit curvature). Descent commences after clearing a 100 foot high obstacle, at which point the helicopter speed is 10 knots and the distance to landing 290 feet. Since the approach is a straight-in, the lateral guidance is a vertical line

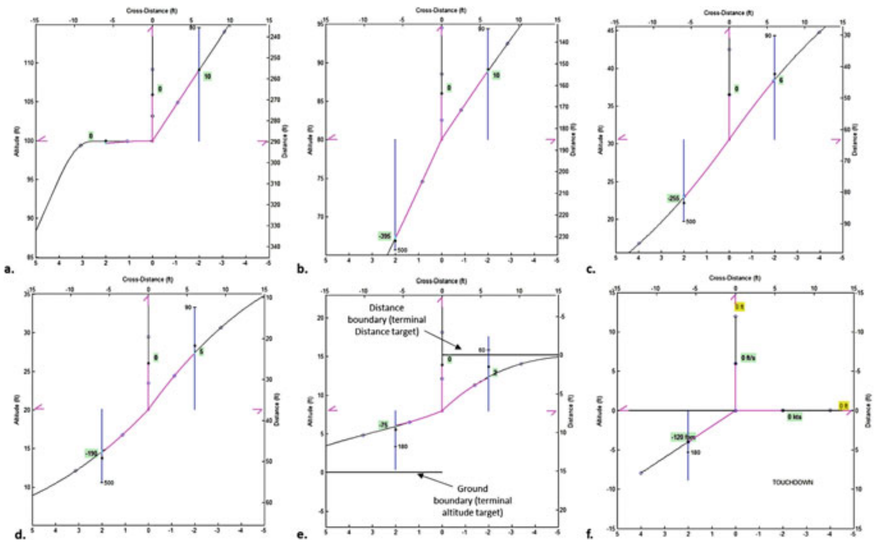

Fig. 7 Obstacle-clearance landing sequence

originating from the display's center. After clearing the obstacle, Fig. 7b shows a sink rate of 395 ft/min and a forward speed of 10 knots. In Fig. 7e a horizontal line on the right representing the landing target has come into view from above, and a horizontal line on the left representing the ground plane has come into view from below. At touchdown in Fig. 7f the target sink rate was 120 ft/min, and the target forward speed was zero knots.

Figure 8a gives an example of imprecise guidance tracking, with the cyan segments indicating error between the prospective guidance and projected position (predicted position was projected in time using instantaneous velocity). The digital values appearing at the end of each magenta prediction segment are the current speeds along each axis. Figure 8b shows an example of near-perfect guidance tracking.

Figure 9 shows pilot tracking performance using AGVA with a rapid-deceleration landing maneuver, where the forward speed must decelerate from 40 knots to 0 in less than 30 s. The helicopter dynamics are representative of the H-60 Black Hawk, and the profile was flown by a pilot using a gamepad for control manipulation. AGVA employs electronic trim, allowing the pilot to use proprioceptive feedback in a manner similar to that encountered during actual flight. This becomes key when the pilot's attention is divided, as an untrimmed control tends to migrate in the direction of the stick's force when that control is temporarily unattended.

Figure 10 compares pilot tracking performance using two kinematic prediction methods: (a) velocity only, and (b) velocity and acceleration. The task is the same deceleration maneuver flown in Fig. 9. Tracking is worse and corrections are more irregular when only velocity is used to project future altitude.

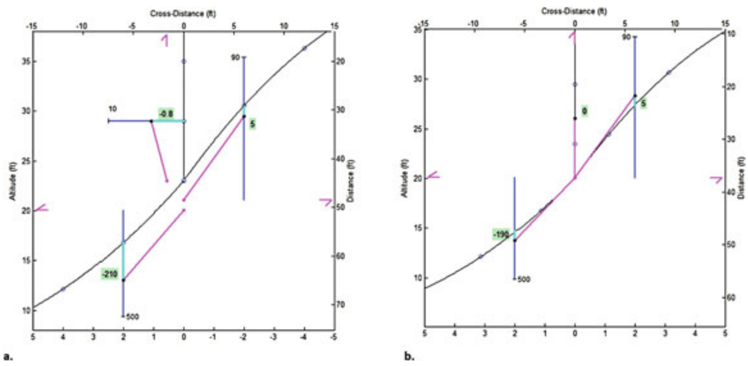

Fig. 8 Guidance tracking: **a** Imprecise control; **b** Precise control

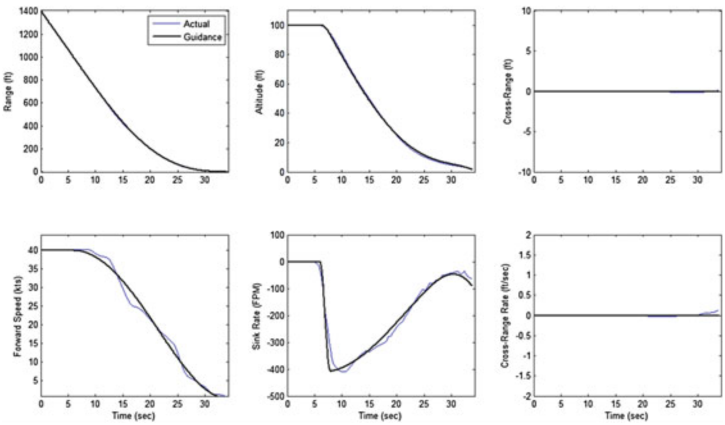

Fig. 9 Tracking performance using AGVA, rapid-deceleration approach

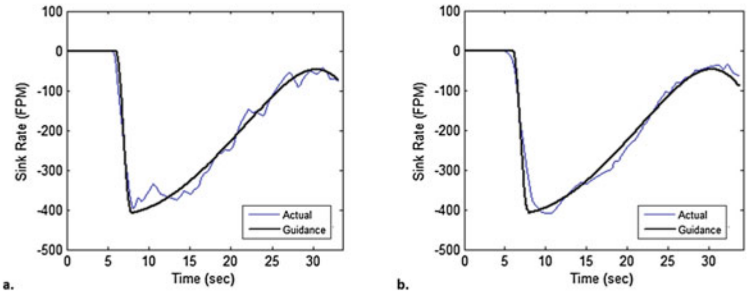

Fig. 10 Altitude tracking using two kinematic prediction methods: **a** Velocity; **b** Velocity and acceleration

3 Predictor Design Considerations

A predictor can introduce large magnitude and/or high frequency response to disturbance, depending on the predictor design and the disturbance spectrum. Significantly, much of the research with 3D predictive displays has focused on disturbance-free performance. A notable exception is [8], which investigated the effect of turbulence while using a flight path vector (FPV) for tunnel-in-the-sky flight. The FPV is used by the pilot as a predictor of aircraft motion. Reference [8] summarized that "a pilot's use of the FPV is significantly harmed when the bandwidth of the turbulence acting on the vehicle increases. In the high bandwidth conditions, the pilot could have performed even better *without* the FPV."

Another potential challenge with predictors is that vehicle modes which degrade handling qualities (such as lightly-damped modes during helicopter sling-load operation) can be excited by disturbances when employing prediction. Other troublesome vehicle dynamics, such as non-minimum phase zeros, can also make prediction compensation in the vicinity of crossover (via inverting vehicle dynamics and inserting an integrator) challenging. Furthermore, cancellation of lightly-damped modes is a poor design approach since the exact composition of a mode is unknown and can change over time. The predictor-vehicle suite ($H_{PR}G_c$) that the pilot must invert for feedforward control may thus be far more complex than the ideal K/s integrator, significantly diminishing the information value of preview and placing a greater burden on pilot compensatory control G_c. In other words, the further ($H_{PR}G_c$) departs from K/s, the more difficult for the pilot to generate the equalization that satisfies the Crossover Model [7] paradigm.

However, if properly designed, the predictor H_{PR} can substantially improve the effective dynamics that the pilot sees, ameliorating the effects of unfavorable vehicle characteristics such as non-minimum phase zeros, pure time delays, lightly-damped modes, and even unstable poles—so that the advantages of preview and prediction remain strong in the presence of disturbance. An additional requirement is that the temporal meaning of the predictor's output is preserved. This paper's author has developed a nonlinear predictor that appears to offer such characteristics, and an example application employing it is given below. The design and an analysis of this predictor will be presented in a future paper.

The vehicle system used in the following example is a triple integrator (i.e. a jerk system), shown in Fig. 11a. The unaugmented (i.e. $H_{PR} = 1$) system is too difficult to be controlled by a human operator, and the standard method of making $H_{PR}G_c$ resemble K/s in the vicinity of crossover fails to yield satisfactory control and tracking. However, using the aforementioned nonlinear predictor, the pilot was able to conduct station-keeping with relative ease in the presence of a sum-of-sines disturbance. Figure 12 shows the frequency response of each element of Fig. 11a, computed using cross-spectral density ratios at the disturbance frequencies. Note that the pilot frequency response is approximately a constant gain, which along with low root-mean-square stick rate corroborates the ease with which the pilot could

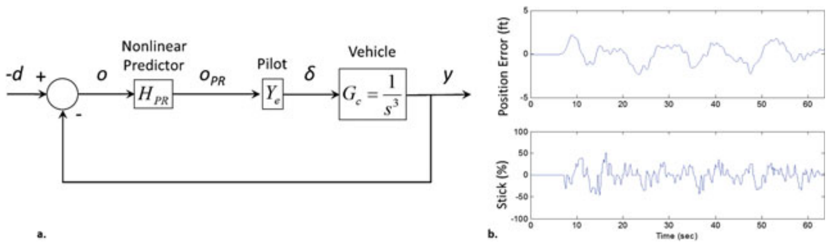

Fig. 11 Station-keeping performance using non-linear predictor with *triple-integrator* plant

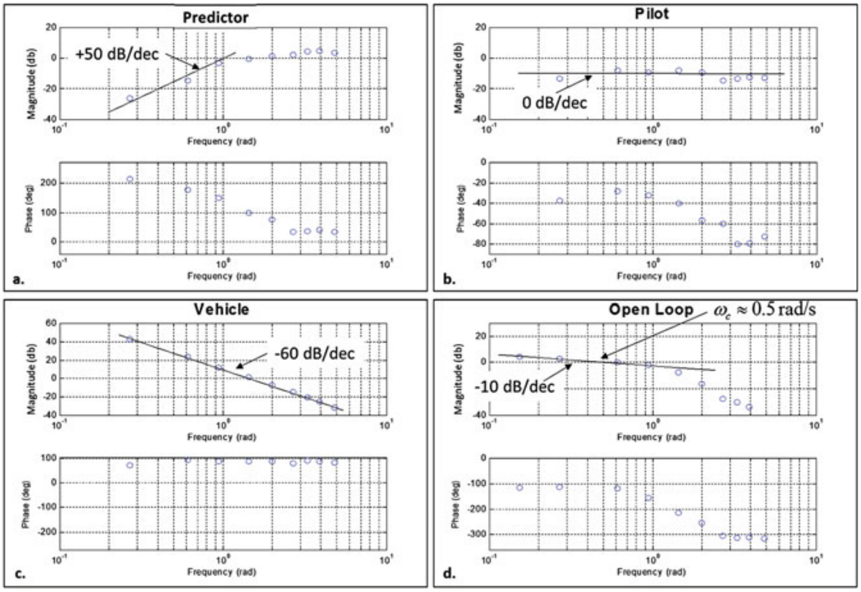

Fig. 12 Frequency response of identified elements of Fig. 11a

control the system. The open-loop bode in Fig. 12 indicates there is favorable phase margin at crossover using the nonlinear predictor despite such challenging vehicle dynamics.

4 Conclusions

A novel space-time format was proposed for displaying: (1) Previewed 4D guidance information; (2) Projected (predicted) state relative to the guidance preview; and (3) Current state relative to current guidance and terminal objectives. A key objective of the display is to allow the pilot to perceive and control each axis of translation as part of an integrated pattern, thus distributing attention equitably. Presented was theoretical and preliminary empirical support for performance enhancement when providing pilots guidance preview and state prediction. Challenges associated with predictor design were discussed, and preliminary results using an innovative nonlinear predictor were given. An illustrative example demonstrated that the nonlinear predictor enabled manual control of a highly challenging system, offering promise for reducing workload and risk normally associated with tasks that currently demand considerable initial and refresher training. Further testing of the display will be conducted in the future, comparing performance with different prediction methods and vehicle dynamics in the presence of disturbance.

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Trust Transfer Mechanism and Intention on Accepting NFC Mobile Payment: An Empirical Research

Hongyu Shen, Pan Liu and Shuping Yi

Abstract The purpose of this research is to investigate whether individuals' trust in remote mobile payment (m-payment) had an effect on the individuals' initial trust in Near Field Communication (NFC) m-payment, and the mechanism of trust transfer also was explored. To implement this research, a questionnaire was carried out on the internet based on sampling survey method, in order to test the developed trust transfer model towards NFC m-payment. Through SEM analysis we got four findings: (1) trust in remote m-payment had an active influence on trust in NFC m-payment, (2) in addition, initial trust influenced individuals' NFC m-payment adoption intention directly and indirectly, (3) further, use context was a vital factor and had an active influence on individuals' NFC m-payment adoption intention, (4) finally, we extended the construct of compatibility and confirmed its effects on NFC m-payment adoption intention. This paper is a van research on the adoption of NFC m-payment, analyzing trust transfer mechanism and its effects on NFC m-payment.

Keywords NFC M-payment · Trust transfer · Adoption intention · Use context

1 Introduction

In 2015, strategy of "Internet +" was drafted in the Chinese government's Annual Work Report. Therefore, it speeds up the combination of the Internet and traditional industries, and this combination will promote more traditional industries to choose

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internet and mobile internet as their transaction platform. Therefore, NFC m-payment will become an important application [1].

Following consideration of the related studies, we found that various factors influencing user's adoption intention on m-payment had been studied [2, 3]. However, in China, few studies had pay attention to NFC mobile payment, especially the effects of compatibility (devices compatibility, lifestyle compatibility, and service compatibility) and use context on individuals' adoption intention was a gap. In addition, based on trust transfer theory, individuals' cumulative trust in remote m-payment may influence their initial trust on NFC m-payment. Therefore, understanding trust transfer mechanism is urgent for NFC m-payment to be adopted and used extensively.

This study chose the NFC m-payment of Alipay (the famous third-party payment mechanism in China) as the object, and it examined the effects of perceived relative advantage, use context, compatibility (devices compatibility, lifestyle compatibility, and service compatibility) and trust transfer on individuals' NFC m-payment adoption intention. The results of this study will help the stakeholders to understand individuals' behavior well, and facilitate the diffusion of NFC m-payment in China.

2 Literature Review

2.1 IDT

Based on innovation diffusion theory (IDT), we knew that an innovation contained five traits, such as, compatibility, relative advantage, observability, complexity and trialability [4]. In some papers, relative advantage was thought to be similar to perceived usefulness, and complexity was semblable to perceived ease of use, and compatibility was "the level in which innovation was believed to be agreement with the present values, past experiences and the needs of prospective users" [5]. In this paper, compatibility contained devices compatibility, life compatibility and service compatibility. Devices compatibility was defined as whether NFC m-payment service could apply to individuals' current mobile devices, while the life compatibility defined as the uniformity of an innovation with individuals' current lifestyles and experiences, and service compatibility denoted that the system of NFC m-payment could be suitable to user' financial account system [6].

2.2 NFC Mobile Payment

In the era of internet, the main accepted definition of m-payment was proposed by Dahlberg, he thought that m-payment was intend to implement business transaction and capital transfer through communication network or other communication technology, and could be divided into two modes (remote payment and near field communication payment) according to the differences of transmission distance.

Previous researches indicated that unified theory of acceptance and use of technology (UTAUT) [7], innovation diffusion theory (IDT) [4] and technology adoption model (TAM) [8] were used widely by the investigators [2, 5, 9] for exploring the elements influencing adoption intention on m-payment. In addition, researches also focused on enjoyment as a main factor to reflect the individuals' adoption intention on m-payment [10], and perceived risk also was introduced as a negative element to response user's concerns on security during the process of financial transactions [3, 11], What's more, in the area of NFC m-payment, Pham et al. had proved its effects on NFC m-payment adoption intention [12]. Although many previous researches interpreted compatibility as lifestyle compatibility and service compatibility, limited paid attention to devices compatibility, and in this paper, three styles compatibility was included. Further, use context is also a determined factor on technology adoption.

3 Hypothesis

3.1 Perceived Relative Advantage

Relative advantage had been confirmed to be a crucial factor of technology adoption [8]. Such as, Dearing and Meyer proposed that innovations' saving money characteristics had been found to spread more rapidly than existing methods due to their perceived economic advantage. Further, Eastin found that perceived convenience forecast adoption decision on e-commerce activities [13]. In addition, Besides Chakravorti argued that the importance of providing a convenient payment way for consumers [14], and Teoh et al. also explained that the advantages actively influenced individuals' perception on e-payment [15]. Similarly, the effects of relative advantage on remote m-payment had been examined [16]. NFC m-payment services provided vital attributions (can be used in no Internet condition) to the relative advantage. As NFC m-payment service could furnish any financial transactions in an online environment, and it also cloud be used in the condition of no internet connection, therefore, we assume:

H1. Individuals' perceived relative advantage will actively influence their intention to adopt NFC m-payment.

3.2 Compatibility

In this paper, our compatibility contained three parts. Firstly, the mobile devices compatibility, and it was described as the degree that individuals' current mobile facilities could fit the new mobile payment technology. According to previous studies, one of the barriers in the intention to adopt MCC was the cost of acquiring a mobile phone [17, 18]. Therefore, compatibility of mobile equipment is important for individuals to use NFC mobile payment.

Secondly, lifestyle compatibility, one of the innovation characteristics, proposed by Rogers [4], was defined as the uniformity of an innovation with individuals' current lifestyles and experiences. Based on Rogers's studies, Moore and Benbasat put forward a measurement scale for the innovation characteristics [19].

Thirdly, If NFC m-payment service could be compatible with their accounts, it would accelerate customers' adoption intention. In this paper, we defined this compatibility as service compatibility, and the effects of service compatibility had been studied in the remote m-payment context [16].

The influence of an innovation's compatibility on individuals' adoption intention had been studied in many areas, such as, the effects on mobile ticketing service [20], m-payment on public transportation [21], internet payment, etc. In addition, Tornatzky and Klein found compatibility to be a crucial innovation characteristic driving consumer acceptance. The NFC m-payment's better compatibility with their lifestyle and mobile devices, could make it easier for individuals to experience the NFC m-payment in special context, thus increased their perceived relative advantage and use context. Therefore, we assume:

H2a. Individuals' perceived compatibility has an active influence on the intention to accept NFC mobile payments.
H2b. Individuals' perceived compatibility has an active influence on the perception of relative advantage.
H2c. Individuals' perceived compatibility has an active influence on the perception of use context.

3.3 *Perceived Risk*

Perceived risk was defined as the consequences' uncertainty that individuals felt while using m-payment for purchase. A lot of researches showed that perceived risk was thought to be a main factor baring users from accepting an innovation [21, 22]. In addition, Lu et al. also explained that many users today were fearful of transaction risk [23]. Moreover, in NFC mobile payment area, Pham et al. had explained that perceived risk had an influence on the adoption intention of NFC mobile payment [12]. Hence, we assume:

H3. Perceived risk will impact the adoption intention on NFC mobile payment.

3.4 Use Context

Use context was a situation that "users meet when they use mobile services in different places and times" [20]. Current studies about e-commerce had proposed that use context would influence consumers' choice of purchase channel [24]. In addition, Mallat also had examined that use context influenced individuals' adoption intention on m-payment [20]. Therefore, in the area of NFC m-payment, we assume:

H4. Use context has active effects on individuals' adoption intention on NFC m-payment.

3.5 Trust

Trust is a kind of subjective belief that individuals believe that an organization can implement their commitment and the ability of the organization on solving customer requirement. Previous studies found that trust could reduce perceived risk on financial transactions, making active intentions to e-payment acceptance [25]. In addition, in the area of m-payment, Mallat had proposed the effects of trust in reducing perceived risk [20]. Besides, in China, Lu et al. had confirmed trust in remote m-payment inactive influence individuals' perceived risk [23]. Therefore, we assume:

H5a. Individuals' initial trust in NFC m-payment inactive influences individuals' perceived risk.

The relationship of trust and the relative advantage had been researched in many studies, such as Kim et al. found that individuals' trust active influence individuals' perceived relative advantage [26], in addition, Lu et al. also discovered that customers' trust in remote m-payment had positive influence on customers' perceived relative advantage [23]. Therefore, we assume:

H5b. Individuals' initial trust on NFC m-payment active influences individuals' perceived relative advantage.

Previous researches had detected that trust was an important element affecting individuals' intention to adopt e-commerce [27, 28]. In addition, in the area of e-payment; trust was thought to be an essential factor for understanding individuals' behavior on e-payment adoption intention [29]. However, they did not examine the effects of trust on use context and perceived compatibility, we believed that if individuals trusted NFC m-payment, which would promote them to use NFC m-payment in a special context and increased the perception of compatibility. Therefore, we assume:

H5c. Individuals' initial trust in NFC m-payment active influences their adoption intention.

H5d. Individuals' initial trust in NFC m-payment active influences their perceived compatibility.

H5e. Individuals' initial trust in NFC m-payment active influences their use context.

3.6 Trust Transfer

Trust transfer presented that ones' trust in one area had an effect on perspectives and attitudes in another area. Based on the trust transfer theory, there are two ways of trust transfer: (1) trust in a channel may affect the products or services in the uniform channel, (2) and trust in a channel may influence the products or services in another channel.

In many areas, trust transfer had been studied, such as, migrating from offline banks to online banks [30]. In addition, Lu et al. had verified that the trust in e-payment had influence to remote m-payment [23]. Therefore, we assume that a well-established remote m-payment has an effect on the perception of NFC m-payment.

In our study, NFC m-payment was regarded as an innovation, as it adopted different communication technology and transport mode compared with remote m-payment. Therefore, we assume:

H6. Trust in remote m-payment will have an effect on initial trust in NFC m-payment provided by the uniform corporation.

Based on the trust transfer theory, IDT theory and hypothesis, the research model was developed. As shown in Fig. 1. Extended Perceived compatibility,

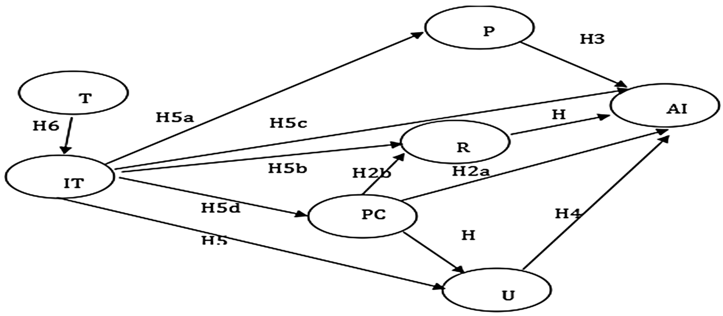

Fig. 1 Research model. *T* Trust in remote m-payment; *IT* Initial trust *PC* Perceived compatibility; *RA* Relative advantage; *UC* Use contexts *PR* Perceived risk; *AI* Adoption intention

relative advantage, use context, perceived risk, trust in remote m-payment and initial trust were proposed to affect usage intention.

4 Method

4.1 Instrument

Seven constructs were incorporated into the research model. All constructs were measured with multiple items and used five-point Likert-type scales ranging from (1) extremely disagree to (5) extremely agree, and most of the items were come from preceding studies but amended to suit our environment of NFC m-payment services. However, items of devices compatibility were made by the study team.

We invited 6 participants who came from ChongQing University and had utilized the AlipayPortal to finish the questionnaire. According to their feedback, we modified the questionnaire to keep simple and clear. Finally, 36 participants were requested to complete the preliminary investigation through WenQuanXing (a website of questionnaire test in China), and then we examined the validity and reliability of this questionnaire. The final questionnaire as listed in Appendix.

4.2 Sample

The formal testing was implemented among young people aged 17–48, as they were generally the early adopters of a new technology. The questionnaires were gathered through WenQuanXing. The total of 207 questionnaires was issued about one week, and the valid response rate is 91.8 % (190 of 207 are returned). The average age of the respondents was 26.8 years, 60.7 % of the respondents were male and 39.3 % were female. The statistical results were presented in Table 1.

4.3 Reliability and Validity Analysis

In order to test whether the scale was suitable to do factor analysis or not, the KMO and Bartlett's test of sphericity were implemented. The results indicated that the value of KMO was 0.919 and greater than 0.5, and the spherical test chi-square values was 6125.834 and the degree of freedom was 325 (p = 0.001), therefore, the results manifested that the scale was fit for factor analysis. As shown in Table 2.

Using the principal component analysis method by SPSS21.0, based on the eigenvalue (more than 1) extracted factors, adopting varimax method to make the factor matrix rotate, and a total of seven factors were rotated, and the total rate of

Table 1 Demographic background of respondents

Variables	Classification variables	n	(%)
Gender	Male	119	60.7
	Female	77	39.3
Age	17–48	196	100
Education level	Primary school or below	3	1.5
	Junior high school	18	9.2
	Senior high school	26	13.3
	Bachelor degree	78	39.8
	Master degree or above	71	36.2
Income per month	<1000 RMB	34	17.3
	1000–2000 RMB	18	9.2
	2000–4000 RMB	70	35.5
	>4000 RMB	74	37.8
Occupation	Students	30	15.3
	Teacher	10	5.1
	Enterprise staffs	101	51.5
	Government workers	10	5.1
	Others	45	33
Use of NFC m-payment	Yes	51	26
	No	145	74
Hear of NFC m-payment	Yes	117	59.7
	No	79	40.3
Use of AlipayPortal	Yes	196	100
	No	0	0
Time of keeping AlipayPortal	<0.5 years	36	18.4
	0.5–1 years	32	16.3
	1–2 years	41	20.9
	2–4 years	50	25.5
	>4 years	37	18.9

variance explained reached to 88.910 %. In addition, all the indexes were greater than 0.5 and had a big load on the corresponding factors, and the factors of the crossed variable had a low load (lower 0.5), which indicated that the convergent validity and differential validity were suitable.

Testing the research model through Smart PLS 2.0, and the results demonstrated that the standard load of all measure dimensions were exceeded 0.7 and the AVE of factors surpassed 0.5, which showed that the convergent validity was appropriate. In addition, the value of CR and Cronbach's Alpha exceeded 0.8 and 0.7 respectively, which indicated that the reliability was well.

Table 2 The value of validity and reliability for the independent and dependent variables

Measure	Item	Factors loadings	KMO	Eigenvalue	Variance explained (%)	AVE	CR	Cronbach's a
Initial trust	5	0.851–0.680	0.919	15.288	52.717	0.645	0.887	0.950
Perceived compatibility	4	0.856–0.722		3.422	11.800	0.600	0.892	0.913
Perceived risk	3	0.950–0.895		2.341	8.074	0.763	0.821	0.945
Use context	3	0.693–0.612		1.718	3.866	0.578	0.857	0.922
trust	2	0.692–0.661		1.405	3.342	0.738	0.833	0.833
Relative advantage	3	0.785–0.670		1.121	2.709	0.723		0.854
Adoption intention	3	0.775–0.766		2.970	87.243	0.679	0.880	0.917

5 Results and Discussion

5.1 Structural Model Test

Testing the research model adopting the Smart PLS 2.0, and the results indicated that H1 got support, which demonstrated that perceived relative advantage had positive effects on NFC m-payment adoption intention; H2a, H2b, and H2c were accepted as well, and it manifested that perceived compatibility influenced the adoption intention, relative advantage and use context actively; however, H3 was not sustained, that is to say, perceived risk had not significant effects on NFC m-payment adoption intention; in addition, H4 also was supported, thus use context had an active influence on adoption intention; moreover, H5a, H5c, H5d and H5e were accepted, and it showed that initial trust had active effects on use context, perceived compatibility and adoption intention, while it had inactive effects on perceived risk. However, H6b was not accepted, which demonstrated that initial trust had not significant effects to the perception of relative advantage. Finally, H6 acquired support, which indicated that the trust to remote m-payment would transfer to the NFC m-payment. As shown in Fig. 2.

Fit index of the research model as shown in Table 3, which declared that the value of $\lambda 2/df$ (2.1) less than 3, and other indexes also were within acceptable limits, such as, NFI (0.92), NNFI (0.93), CFI (0.96), GFI (0.96), AGFI (0.88), and RMSEA (0.04), it indicates that the research model had better fit index.

5.2 Discussion

Through analysis, individuals' perceptions of relative advantage, use context, initial trust and compatibility add the NFC m-payment adoption intention strongly. One

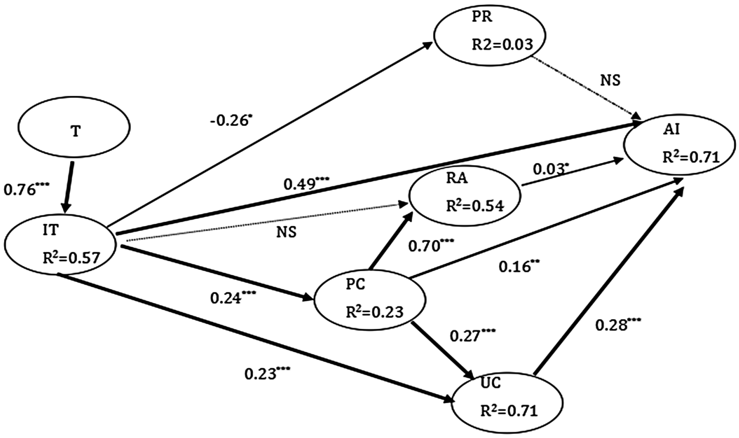

Fig. 2 The results of the research model (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$). *T* Trust in remote m-payment; *IT* Initial trust in NFC m-payment; *PC* Perceived compatibility; *RA* Relative advantage; *UC* Use context; *PR* Perceived risk; *AI* Adoption intention; *NS* No significant influence

Table 3 Fit index of the research model

Index	Chi-square (p)	Degree of freedom	λ^2/df	NFI	NNFI	CFI	GFI	AGFI	RMSEA
Reference range	–	–	<3	>0.9	>0.9	>0.9	>0.9	>0.8	<0.08
Results	17.05 (p = 0.009)	6	2.1	0.92	0.93	0.96	0.96	0.88	0.04

extraordinary vital finding of this research was that use context was confirmed to be an important factor on individuals' adoption intention. It was consistent with prior researches in remote m-payment, that is to say: use context had active influence on a user's m-remote m-payment adoption intention.

Secondly, the initial trust immediate and roundabout influences individuals' intention to adopt NFC m-payment services and their perceived relative advantage. However, individuals' perceived risk had not significant effects on their intention to adopt NFC m-payment, which was not consistent with pervious study on remote m-payment, 23 maybe because their initial trust in NFC m-payment services inactively affects the perceived risk, or most of the participants thought NFC m-payment could use under no internet, and trust this payment would not suffer attacks of crackers or virus.

Finally, individuals' initial trust had active influence on consumers' perceived compatibility and use context. In addition, perceived compatibility would actively affected individuals' perception of relative advantage and use context.

6 Conclusion

6.1 Implications

In the first place, unlike other relevant studies paid attention to extend the impact factors or models to test individuals' adoption intention on NFC m-payment, our study based on trust transfer theory and developed a model to explain trust transfers mechanism. The results indicated that positive factors (e.g., relative advantage, compatibility, use context) were the main factors during making decision to adopt NFC m-payment. In the second place, we explored the trust transfer mechanism in the NFC m-payment context. The results indicated that individuals' trust in remote m-payment had an active effect on individuals' trust in NFC m-payment. Finally, we confirmed the relationship between trust in remote m-payment and the adoption intention in NFC m-payment. Our model provided a new and relatively complete view in the NFC m-payment decision process and laid a good theoretical foundation for researching the decision process of NFC m-payment. Maybe our model can extend other areas, such as, mobile ticketing and internet ticketing.

The results of our study had some practical implications as well. Firstly, our research showed that NFC m-payment providers should focus on four factors (trust, relative advantage, compatibility, and use context) to increase their consumers' trust and individuals' adoption rates. Secondly, providers should consider the trust in remote m-payment and NFC m-payment to build trust relationship with consumers.

6.2 Limitations

This paper had some limitations. Firstly, this research did not contain older individuals and users who did not use the remote m-payment, in the following study, older adults should be covered. Secondly, before participants starting their questionnaire, the introduction about NFC m-payment maybe influence the results, however, it increased the veracity of the questionnaire and decreased the difficulty of the questionnaire. Thirdly, perceived cost may have influence on NFC m-payment adoption intention, at the following study, perceived cost should be included.

Appendix: Scale and Items

Construction (abbr)	Items	Source
Relative advantage (RA)	NFC m-payment had advantages compared with remote m-payment, because NFC m-payment can be used under no internet context	[23, 26]
	is more convenient	

(continued)

(continued)

Construction (abbr)	Items	Source
	is more effective	
Perceived compatibility (PC)	NFC m-payment should be suitable to your mobile phone	Self-compiled
	One of your mobile devices	
	Your lifestyle	[16, 19]
	The way you purchasing products or services	
	Your bank card	
	You fund account	
	The current account	
Perceived risk (PR)	Using NFC m-payment doing transaction will have potential risk	[2, 21]
	Using NFC m-payment doing transaction will lead your fund account to be in danger	
	If you use NFC m-payment, the generated transaction information will be tampered	
Use context (UC)	You will use NFC m-payment, if your bus card has no money or lose efficacy exactly	[20]
	you no charge or cash exactly	
	you are standing in a long queue	
	you time is limited and need quick payment	
Trust in remote m-payment (T)	The remote m-payment always provides accurate financial services	[23, 26]
	Reliable financial services	
	Safe financial services	
Initial trust (IT)	The NFC m-payment always provides accurate financial services	[23, 26]
	Reliable financial services	
	Safe financial services	
Adoption intention (AI)	In the future, you intend to use NFC m-payment	[8, 31]
	You will be like to use NFC m-payment	
	if necessary, you will use NFC m-payment	

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From User Scenario to Design Strategy: Practice Research on Product Innovation

Jun Hu and Kun Zhou

Abstract In the mobile internet era, the meaning of a product depends much more on "scenario", emphasizing better thinking about the future from the present. The competition on the mobile internet is essentially the vying between scenarios. Based on the analysis of user scenarios and the professional insights, designers can adopt efficient and rational design strategies. Through case studies on user scenarios, designers can evaluate the effects and changes a new design and a new product cause on different customers' psychology and behavior. Then they can employ targeted measures in design, so as to realize the design goals, promote customers' understanding and acceptance, and even create both commercial and customer values by product innovation.

Keywords User scenario · Design strategy · Product innovation · Goals

1 Introduction

"The future has arrived—it's just not evenly distributed," William Ford Gibson, a great speculative fiction novelist, once said [1]. Currently, designers are transforming the physical logic focused on "what" into the behavioral logical stressing "system". The development of "internet +" business ecosystem platform, such as, Taobao, Alipay and WeChat, makes a big difference to the industry environment which designers work in, the product attributes that their work focuses on, the design process and the evaluation criteria. All of them will greatly vary from those in traditional design services. Design strategy is to probe into the new visions which has come into being or is becoming more and more obvious. It aims to gain the competitive advantages through product design and can be realized by three means.

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The first is to design new products and explore new markets. The second is to have more insight into the needs of the existing market. The last is to be aware of customers' changing needs [2, 67–70].

Scenario is an ongoing story about human and their behavior [3, 23–46]. The concept of scenario was first proposed by Herman Kahn and has been widely applied to the planning in human-machine interaction, organization management, etc. [4, 1045]. If designers want to create products with a long lifecycle and provide unique services and experiences for customers, they must devote themselves to the study of scenarios. The sense of empathy and reality that scenarios bring about will become one of the important factors in innovative product design. Designers should identify the scenario, know customers well, discover interactive information, and find the balance between customers' needs and commercial purposes. However, there are still a large number of designers who cannot identify and use scenarios, lack design strategies and have no clear idea of where to start. Because of the situation, this essay will be contributed to the breakthrough in product innovation by probing into scenarios. (Figure 1 Scenario analysis).

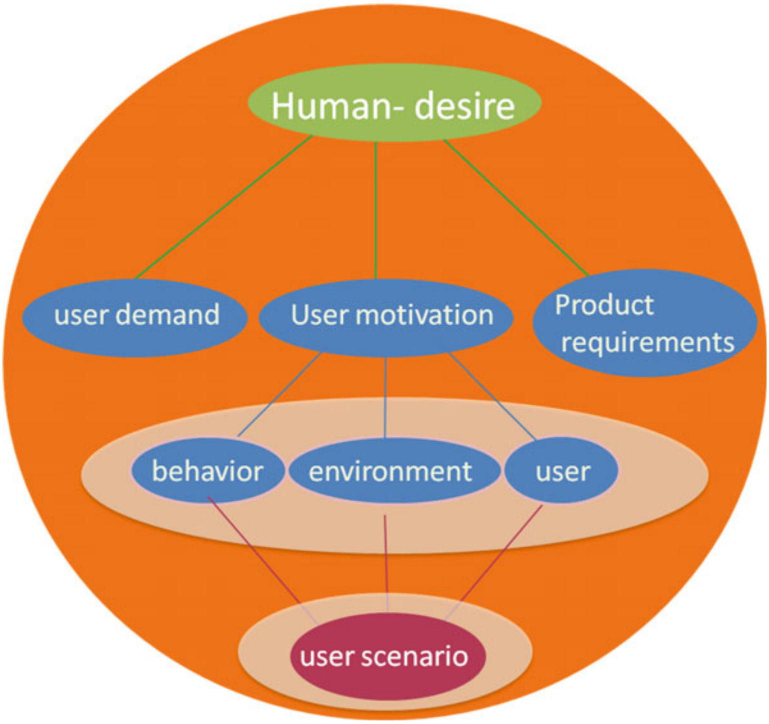

Fig. 1 Scenario analysis. Analyze user scenarios to identify workflow patterns. Identify any specific user requirements

2 Hierarchical Analysis on User Scenario

The essence of user scenario analysis is realizing the customer-focused design by scenario description and applying it to the whole systematic development process. In the early design stage, use the concept of scenario to describe a customer's present situation and get to know his needs. Next, bearing the idea of customer focus in mind, observe the scenarios and detect the necessary and key interactive information which customers use to deal with problems. Then build scenarios based on the previous analysis and provide stimulated scenarios. Test and evaluate it. At last, make revisions and modifications. All should be conducted out step by step and careful consideration should be given to factors like human (user/customer), object (product), thing (behavior), etc.

3 Scenarios-Based Design Strategies

In 1998 when people have been tired of grey desktops, iMac made its first debut. It was mainly enclosed by a colored, translucent plastic case, which was refreshed early on with a sleeker design notable for its slot-loaded optical drive. It has been amazing for the whole world. This is Jobs' differentiation strategy. It is critical to settle on strategy in the product design process before designers rethink about the innate attributes of a design object (what), change the design process (how) and reset the evaluation standards (why) [5, 63]. In the first beginning, define a design strategy which reveals the core values of a product. For example, WeChat Zeng has stated his design strategy as "putting privacy over convenience". Therefore, the local chat log is not been kept, for privacy cannot be sacrificed for convenience.

Scenario-based designing is a creative way to seize every opportunity and realize product innovation based on the scenario analysis. The scenario-based innovative design process mainly has four key phrases—identifying scenarios, producing scenarios, analyzing scenarios and making innovations. The first two phrases stress that a designer should observe scenarios carefully and gain full insights into it, which can help him find the aching points and the possibilities to improve and innovate. While analyzing scenarios, a designer should consider objects in it including people and objects, and have a clear idea about a customer's needs. For innovation, he should deal with scenarios, in an effort to transforming users' needs into a new chance of product design.

3.1 Identifying Scenarios

In order to make innovations based on scenarios, the first and foremost step is to recognize and list user scenarios, which means finding the contact between users and a product. The product can be a competing good or an alternative. For example, if a designer wants to discover the scenarios of Alipay, he should first find the contact between users and money, bank cards or other payment methods. A systematic and complete thinking will be necessary for finding a contact. User Life Cycles, A Day in the Life, User Journey Maps and Cultural Probes are all crucial factors to think about.

After listing all user scenarios, decide on and sort out the strong scenarios based on the priority attribute. While doing this, the following factors should be taken into account: the user type in scenarios (targeted user or not), the hierarchy of needs and the frequency of needs. Functions should be evaluated from the perspective of depth, width and frequency [6]. Once a designer figures out the strong scenarios, he can be concentrated on deal with the urgent issues.

3.2 Producing Scenarios

Producing scenarios refers to presenting the imagined situations which users will be in by observation; role-play and so on, so as to experience the same as they will do. A designer can do this step by step, paying attention to factors like human (user/customer), object (product), thing (behavior). Besides these factors, a designer should be concerned with the environment and users. The former includes time, place (such as, outdoors, office or supermarket), sound (quiet or noisy), light (bright or dim), and crowd density (scarce or dense). The latter is related to users' purposes, habits, behaviors, etc. The POEMS (people, object, environment, message, service) study model can be adopted, which can show the connection between humans, objects and things and thus help to discover users' new motives and needs [7, 50–57].

3.3 Analyze Scenarios

After producing scenarios, designers should start to analyze them, so as to detect the users' needs which have not been met—the aching points. Only if such points are dealt with, they can gain users' acceptance. Usually, it can be done by observing user's behavior and thinking critically. For example, if we go to dinner or karaoke with friends or colleagues, one of us will pay first, calculate how much each should pay, and then collect the money. In this scenario, the aching points are finding a calculator and some change. Do we have to follow the procedure for payment? Of course not, if designers observe users' behavior and do critical thinking. They should start from the disadvantages in a scenario. For instance, we need to hold tightly when on a shaky running bus, so we cannot operate our mobile phone with both hands. The environment is too noisy or not so private, so we cannot receive a voice message by the speaker. The key is to think about users' needs on the basis of scenarios.

3.4 Making Innovations

With the aching points discovered, a designer's job is half done. The other half is to transform these points into feasible design strategies. It means to provide an innovation plan and relevant proposals. In order to complete this successfully, designers should have comprehensive and systematic knowledge, gain insights into users' psychology, discover their needs, and know about a product and the necessary equipment. The transformation can be realized by brainstorming, story-telling, participatory design, empathy design, etc. [8].

4 Principles of Adopting Design Strategies

According to researches, two principles should be stuck to. The first principle is finding the balance between users' interests and commercial profits. For users' interests, designers should use a product created based on scenarios in their ways. To gain commercial profits, the plan should be corresponding to the commercial goals. For instance, bill-splitting in Alipay Wallet fulfills well the online payment in our daily life. Users just need to scan a QR code and then pay their share via smart phones in one easy click. Inputting the total and the number of people involved, etc. are well fit for the scenario and eliminate such aching points as finding change and a calculator. Meanwhile, it fulfills the commercial goals by adding the socializing elements and promoting users' interaction.

The second principle is thinking from goals to measures to deal with problems. A scientific design can determine the target system and reorganize the solutions, which mean proceeding from goals to measures [9, 51]. Goal means what to be dealt with, namely, aching points. Measures are the ways to achieve the goals. For example, we can do divergent thinking based on the idea that users desire a more convenient payment method. Can we replace card numbers with telephone numbers? Can we connect Union pay accounts with different merchants? Can we…? It is similar to that a cup is not necessarily required when we want to drink water. Designers can propose any solutions without taking feasibility into consideration. At present, brainstorming and mind map are often adopted to fulfill this task. After finding a solution by divergent thinking, designers should select the most practical, feasible and effective one with the least risk while restrained by the overall design of a specific product. And they should also consider commercial goals, degree of difficulty, procedures, etc. to determine the most suitable strategies.

5 Conclusion

The manufacturing economy has transformed from production-dominant to consumption-dominant, entering the customization model [10]. Users play the dominant role in design innovation and become an important source of design inspiration. Through observing and analyzing user scenarios, designers can fix the directivity of their study. They can find aching points and decide on design strategies by identifying, producing, analyzing scenarios and making innovations, so as to meet users' needs and achieve production goals. It is a goal-to-measure system. In the mobile internet era, scenarios can reflect the connection between users and products. The change in scenarios can lead to the change of users' needs, which produces a new bond between users and products. Such new bond can be materialized and offer a chance for innovation. For enterprises and R&D staff, it is critical to promote their knowledge and understanding of users and hereby gain precious resources for next design innovation.

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