Evaluating and Benchmarking the Interactions between a Humanoid Robot and a Virtual Human for a Real-World Social Task

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Abstract. We developed two social agents (a virtual human and a humanoid robot) with various similar functionalities, interaction modalities, intelligence, autonomy etc. and integrated them through a common communication platform based on a novel control algorithm to assist each other in a real-world social task (searching for a hidden object).We also studied human's interactions with those social agents and with some other allied agents for that task to benchmark the interactions. We developed the standards of the performances as well as the performance measurement methods for the agents for the task. We also adopted several hypotheses regarding the attributes and performances of the agents for their interactions for the task.We evaluated the attributes and performances of the robot and the virtual human in their interactions for the task, analyzed them and compared them with the standards. The results showed that both the robot and the virtual human performed satisfactorily in their social interactions though the performances varied slightly.We also found a trade-off between the attributes and the performances of the agents. The results will help develop intelligent social agents of different realities to assist humans in various real-world social tasks, or to get the real-world social tasks done in cooperation between artificial social agents of different realities.

Keywords: Virtual human, humanoid robot, social robot, social task, human-computer interaction, human-robot interaction, benchmarking, system integration.

1 Introduction

1.1 Virtual Humans and Social Robots

The virtual humans are the software generated human-like animated characters. They can be enriched with many social functions and attributes for their interactions with humans such as they can show human-like actions, motions, gestures, emotions, facial expressions, intelligence etc.,communicate and interact with humans, memorize the facts and retrieve them according to the dynamic context, and show reasoning and decision making abilities about what they perceive etc [1]-[2].

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On the other hand, ideally,social robots are human-like robots, they take inspiration from humans, are enriched with human-like communication capabilities, capable of understanding human's affective states, expressions, intentions, actions etc., can interpret them based on contextual information and act based on situations [3]-[4].

1.2 Accomplishing Real-World Tasks by Virtual Humans and Social Robots

The virtual humans (VHs) are presently used to perform many tasks such as serving as the virtual tutor, student or trainee, patient, advertiser etc. They have increasing contributions towards the anatomy education, psychotherapy and biomedical research [5]-[9]. However, the VHs still could not come beyond the virtual environments. Their contributions could be augmented if they could perform real-world social tasks for humans or could cooperate with humans to peform the social tasks. However, such contributions are still not available. On the other hand, the social robots (SRs) are proposed for various social activities and interactions with humans such as therapy for abnormal social development, autism etc [10]-[13]. However, their applications in accomplishing social tasks in cooperation with humans are still limited. In most cases, either they do not look like the human [11], [13], or they look like the human, but cannot act like the human [14]-[15], which reduces their social acceptance.

1.3 Cooperation between Virtual Human and Social Robot in Real-World Tasks

We think that the autonomous SRs and VHs have a lot in common in their objectives and performances though there is a difference that the SRs exist physically while the VHs are software-based visual agents.We also think that the SRs and the VHs may separately cooperate with the humans and also with each other to perform the real-world tasks. However, such cooperation is usually not seen. It is true that a few initiatives have been taken to stage the cooperation between the VHs and the SRs [16]-[17]. However, these attempts are still in the concept design phases, and no real characters and the cooperation methods have been proposed to justify the initiatives.

1.4 Performances Evaluation of the Social Agents

We think that there should have well-defined evaluation methods and standards for evaluating and benchmarking the performances of the social agents in their various social interactions with each other and with the humans, which might help improve their performances as well as their social acceptance and impacts. However, such suitable evaluation techniques are still not available.Of course, a few researchers are addressing the evaluation and bechmarking of the social agents, but their efforts are still limited in scope and applications [18]-[19].

1.5 Objective of the Paper

Hence, the objective of the paper was to present social interactions between a virtual human and a social robot for a real-world social task (searching for a hidden object). Human's interactions with some allied agents were also studied to benchmark the interactions.

2 Requirements for the Integration between Social Robot and Virtual Human

The effective integration of the social robot with the virtual human for a specific real-world task needs to satisfy a set of requirements. The robots need to have attributes for social interactions such as interactivity, intelligence, autonomy, perception, bilateral communication and interactions, social functions etc. [3]-[4], [10]-[15].Similarly, the virtual humans should have intelligent decision technologies, autonomy, interaction modalities, personality, natural interactivity etc. [20]-[21]. Kapadia *et al.* identified several key limitations in the existing representation, control, locomotion, multimodal perception and authoring of the autonomous virtual humans that must be addressed to stage successful interactions between the virtual human and the social robot [22]. Other requirements for creating interactive virtual humans for interactions with social robots are presented in [23]. Emotion, memory, remembering, recognition etc. for the social robots and the virtual humans also seem to be important for their integration for multimodal social interactions for many cases [24]-[26].

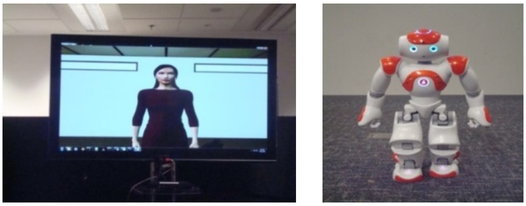
The required interaction modes for the selected task might be vision, audition (speech), demonstration, recognition, gesture, locomotion etc. It means that, the social agents may need to see and recognize each other, the object and the environment, to speak and listen the counterpart for verbal instructions by the agents about the search path for the hidden object, to show gesture and understand/recognize the counterpart's gesture that may be used by the agents to demonstrate/understand the search path for the hidden object. They may also need to show movements to search for the object etc. They need to be enriched with the required technologies, control methods and algorithms, interfaces, sensors, common communication platform etc. They should also be as human-like in appearances and performances as possible.

3 Development of the Social Agents

3.1 The Virtual Human

We developed a realistic autonomous intelligent 3D virtual human (VH) with a western woman face. We used Smartbody (http://smartbody.ict.usc.edu/) for her control and animation. We created the model based on the joints and skeleton requirements of Smartbody and exported it to the software Autodesk Maya 3D (http://www.autodesk.com/). We determined the anthropomorphic data (walking velocity, joint angles, body dimensions etc.) for the VH by being inspired by that for the human. We used Ogre (http://www.ogre3d.org/) for graphical rendering.

The software package included Application Programming Interfaces (APIs) for various functions (actions, emotions, expressions etc.). The VH could be displayed in a screen as in Fig.1 (a). The VH was enriched with many social functionalities and attributes such as speech (from text to speech), locomotion (walk to a position), manipulation, gaze, nonverbal behaviours, facial expressions, emotions, actions, communications with human, turn head, look at a position, point at something etc.



(a) (b)

Fig. 1. The intelligent autonomous social agents, (a) the virtual human, (b) the social robot

3.2 The Social Robot

We used a NAO robot (http://www.aldebaran-robotics.com/en/) as shown in Fig.1 (b) as the social robot (SR). We developed various functions and attributes for the robot to make it intelligent, autonomous and social such as stand up, sit down, walk, shake hand, wave hand, grab and release object, look at a position, point at something, speech (text to speech) etc. Like the VH, it could perceive the environment through sensors such as video, audio etc. It could make decision based on some adaptive rules and stored information and react by moving, talking or showing internal emotions. The software package included the APIs for the functions.

3.3 Development of Common Communication System for the Social Agents

Animation of each function for each character was commanded from a common command script (client), which was networked with the control server through the I2P (Integrated Interaction Platform) Thrift interface. The I2P was our in-house platform, which could be used to animate both the SR and the VH using the same command script (client) through specifying the character. However, each character had its own APIs for the functions called in the client script. The similar functions between the VH and the SR generated similar behaviours. Architecture of the common communication scheme for the social agents through the I2P is illustrated in Fig.2.

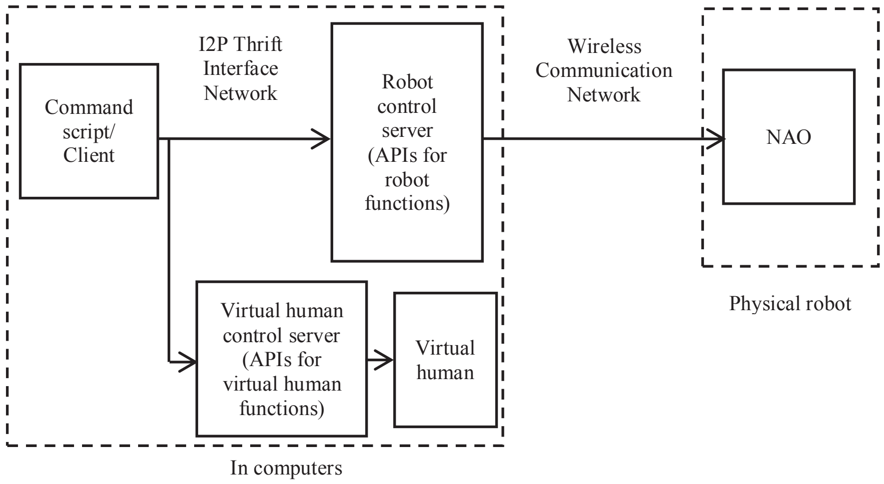


Fig. 2. Architecture of the common communication system for the social agents through I2P

4 Experimental Setup

As shown in Fig.3, we had three rooms. In Room 1, we put the computers to control the SR, the VH and other hardwares. In Room 2, we put 10 rectangular boxes of identical dimensions and appearance (black). Five boxes were put randomly on a table in the left side of the room, while the remaining five boxes were put randomly on sofas in the right side. An object was hidden in any of the 10 boxes by the experimenter. One agent needed assistance (called the assisted agent) from another agent (called the assistant agent) to search for the hidden object. Usually, the assisted agent stood at point P1, and the assistant agent stood at point P2 (the assistant agents who existed physically e.g. social robot) or appeared at the screen (the assistant agents who were physically non-existed e.g. virtual human, assistance through video etc.). There was a sound system near point P2 and the voice of the assistant agent could be played through it. Laptop 2 was used for Skype connection with Laptop 1 if any real human served as the assistant agent but he/she did not appear physically, instead appeared in the screen through Skype. In addition, kinect cameras were put in Room 2, and other devices required for gesture, action and speech recognition were put.

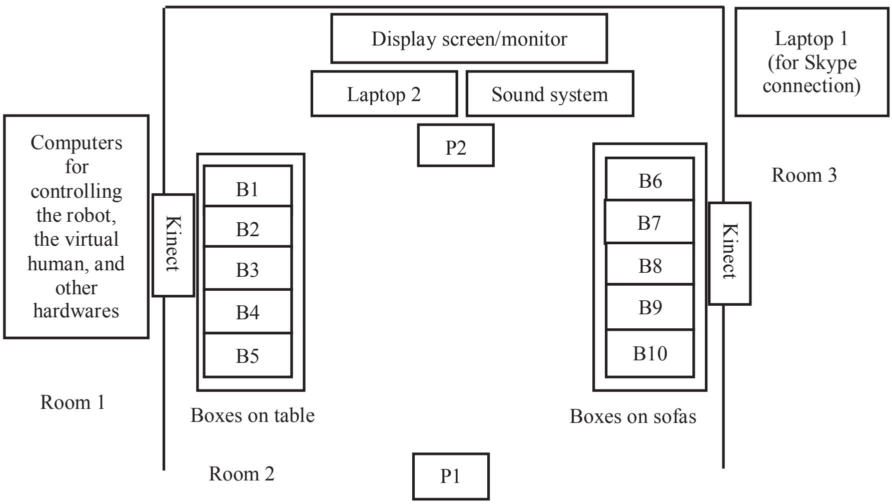


Fig. 3. Layout diagram of the experimental setup

5 Experiment Design

5.1 Experiment Protocols

We considered eight experiment protocols to evaluate the interactions between different social agents for searching for the object (Table 1). In the protocols from 1 to 6, the human was the assisted agent and received assistance from various assistant agents such as another human (protocol #1), voice of another human (protocol #2), video with voice of another human (protocol #3), a human appeared through Skype (protocol #4), the virtual human (protocol #5), the social robot (protocol #6) etc. for searching for the hidden object. In protocols #7 & 8, the VH and the SR assisted each other for searching for the hidden object. We considerd the protocols from 1 to 6 to benchmark the interactions between the VH and the SR.

The VH had human-like functionalities, but it was artificial, screen-based and did not appear physically in front of the assisted agent. Similarly, the telepresented Skyped-human also did not appear physically in front of the assisted agent, it was screen-based, but it was natural. We thought the Skyped-human to be the physically non-appeared real human with the highest intelligence and autonomy. Hence, we considered the Skyped-human as the standard for the VH. On the other hand, the SR was physically embodied and existed like the real human, it had human-like appearance, but it was artificial. The human is the physically embodied and physically existed natural agent with the highest intelligence and autonomy. Hence, we considered the human as the standard for the SR. Human voice was non-embodied. Human video with voice did not physically exist. These two agents were

Table 1. The social agents and their interactions (as acronyms)

Protocol#	Assistant agent	Assisted agent	Interactions
1	Human (H)	Human (H)	H-H
2	Human voice only (Hvoice)	Human (H)	Hvoice-H
3	Human video with voice (Hvideo)	Human (H)	Hvideo-H
4	Skyped human (SkypedH)	Human (H)	SkypedH-H
5	Virtual human (VH)	Human (H)	VH-H
6	Social robot (SR)	Human (H)	SR-H
7	Virtual human (VH)	Social robot (SR)	VH-SR
8	Social robot (SR)	Virtual human (VH)	SR-VH

used to measure the effects of sound, vision and physical existance on the agent performances. The VH and the SR were both artificial, but they differed in physical existance. The two protocols (#7 & 8) were used to understand the social interactions between the VH and the SR, which was our primary goal.

5.2 Subjects

One hundred forty two (142) human subjects were selected to participate in the experiments for different protocols (1 assistant human and 20 assisted humans for protocol 1, 1 assistant human appeared through Skype and 20 assisted humans for protocol 4, 20 assisted humans for each of the protocol 2, 3, 5 and 6, and 20 human subjects to evaluate the VH-SR and SR-VH interactions for protocols 7 & 8). 115 subjects were male, 27 were female and they were aged between 21 and 35 years. All the subjects were right-handed and they reported to be physically and mentally healthy with sound functionalities of their eyes and ears.

5.3 Hypotheses

We adopted few hypotheses (research questions as well) to justify the interactions between the agents. The hypotheses were as the following: (i) whether or not the performances of the assistant agents were satisfactory for the task (for protocols#1-8), (ii) whether or not there were variations in the performances of the assistant agents for the same assisted agent (protocols#1-6), (iii) especially, between the VH and the SR in protocols 5 and 6, whose performances were the better in assisting the human, (iv) whose performances were the better when the VH and the SR assisted each other for searching for the object (protocols#7 & 8), (v) whether or not the agent attributes could affect the agent performances, etc.

6 The Experiments

Protocol#1: The assistant agent (human) stood at P2 as in Fig.3 keeping the face towards point P1.The experimenter kept the object hidden in any of the 10 boxes (say, it was hidden inside box B1) in presence of the assistant agent. Then, the assisted agent stood at P1 keeping his/her face towards P2.Then, the assistant agent instructed (once only) the assisted agent how to find the object.The instructions included-

Speech: the assistant agent told “hello! I will help you find the object. The box containing the object is lying on the table. It is not on top of another box. Closest to the screen”.

Gesture, facial expressions, emotions and actions: the assistant agent also turned towards the box where the object was hidden, looked at the box, pointed at it with the hand, made some facial expressions matching the gesture and actions etc.

Then, the assisted agent identified the correct box based on the instructions he/she received from the assistant agent. He/she moved to the box, pointed it, touched it, grabbed it, told “the object is here” and released it. The experimenter then opened the box and checked whether or not the object was inside the box. Then, the assisted agent subjectively evaluated the attributes and performances of the assistant agent in his/her assistance for the assisted agent in searching for the object. The evaluation was administered by the experimenter, and was done using a rating scale following a set of predefined criteria. The evaluation criteria for the agent attributes were (i) anthropomorphism- how human-like the assistant agent was in appearance and performances, (ii) embodiments-how embodied or physically existed the assistant agent was, (iii) gesture and action-match between gesture and action of the assistant agent, (iv) stability-how competent the assistant agent was in avoiding any disturbance, noise etc. The performance criteria for the assistant agents were (i) cooperation- how cooperative the assistant agent was in assisting the assisted agent, (ii) clarity of instructions-how clearly the assisted agent could understand the instructions of the assistant agent, (iii) effectiveness-how effective the instructions of the assistant agent were for the assisted agent in finding the object, (iv) cognitive load- how much cognitive load the assisted agent felt for finding the hidden object, the least cognitive load was to be the best, and (v) companionship- whether or not the assisted agent desired to establish a social companionship with the assistant agent based on the assistance. In the rating scale, (+1) was for the worst and (+5) was for the best evaluation for the assistant agent.The experimenter also objectively evaluated the peformances of the assistant agent based on two criteria: (i) time-time taken by the assisted agent to find the correct box. The performance of the assistant agent would be the best if the assisted agent could find the correct box within the least possible time, (ii) accuracy-whether or not the assisted agent could find the correct box.

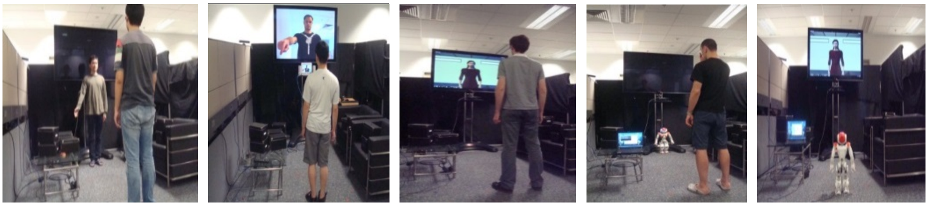
Then, the assisted agent was replaced by another subject, (but, the assistant agent was unchanged) and the whole procedures as described above were repeated for the second subject (assisted agent). In this way, 20 subjects separately acted as the assisted agent. The subjects, who participated in this protocol, did not participate in any other protocols. Figure 4 (a) illustrates the procedures for this protocol.

Protocol#2: the recorded instructions of the assistant agent of protocol#1 were played for audio only in the sound system. The recorded voice of the previous assistant agent served as the assistant agent for this protocol. Then, the same procedures as employed for protocol#1 were employed.

Protocol#3: The recorded video with sound of the assistant agent of protocol#1 was displayed in the screen. The video with sound served as the assistant agent for this protocol. Then, the same procedures as employed for protocol#1 were employed.

Protocol#4: A real human standing at Room 3 appeared at the screen of Room 2 through the Skype. The Skyped-human served as the assistant agent. Then, the same procedures as employed for protocol#1 were employed as in Fig 4 (b).

Protocol#5: The VH appeared at the screen and served as the assistant agent. Then, the same procedures as employed for protocol#1 were employed as in Fig. 4 (c).



(a) (b) (c) (d) (e)

Fig. 4. The human receiving assistance from (a) another human, (b) the Skyped-human, (c) the VH, and (d) the SR for searching for the object. In (e), the SR and the VH are assisting each other for searching for the object. The object is hidden inside any of the 10 black boxes as seen.

Protocol#6: The SR stood at P2 and served as the assistant agent. Then, the same procedures as employed for protocol#1 were employed as shown in Fig. 4 (d).

Protocol#7: In this case, 10 relevant instruction methods for 10 locations of the 10 boxes were set (called) for the VH in the programming script (client). The VH could instruct the SR about the correct location of the box where the object was hidden if the object was hidden in any of the 10 boxes of 10 locations. However, the VH was needed to be taught the correct location of the box through the programming script. For example, in an experiment trial, the object was hidden in a box closest to the screen (B1). The program was run and the VH instructed the SR to find the object based on the instruction methods set for that location. The instruction methods for B1 location included-

Speech: same as used in protocol#1

Gesture, emotions, expressions and actions: the VH also showed emotions, facial expressions, gesture and actions matching her speech. For example, the VH turned towards the box where the object was hidden, smiled, looked at the box, moved towards the box (within the screen), pointed at it with the hand, told “the object is there”, then stopped and expressed happiness.

In the same programming script (client) as used for the VH, the required functions, gestures, expressions, emotions, speech, actions etc. for 10 different destinations (locations for 10 boxes) were set (called) for the SR. The SR could recognize the gesture, actions and speech of the VH and immediately determine the correct location of the box where the object was hidden, then turned towards the location, moved to that location, looked at the box, pointed at the box, took an attempt to grab the box (but, it could not grab due to its small fingers), then released the grab, then told “the object is inside this box” and then stopped working.Then, the experimenter opened the box and checked whether or not the hidden object was found there. This trial was repeated for 20 times and each of the 20 subjects evaluated the attributes and performances of the assistant agent based on the same criteria and methods employed for protocol#1. The experimenter also recorded the time and accuracy data for each trial. Figure 4 (e) illustrates the procedures for this protocol.

Protocol#8: the opposite of protocol#7 happened when the SR assisted the VH in searching for the object. The SR was taught the correct location of the hidden object through the programming script. The instruction methods for the SR were same as that for the VH. The VH could recognize the gesture, actions and speech of the SR and immediately determine the correct location of the box where the object was hidden, then turned towards the box, moved towards that location (up to screen limit), looked at and pointed at the box, then told “the object is inside that box”. Then, the experimenter opened the pointed box and checked whether or not the hidden object was found there. This trial was repeated for 20 times and the same evaluation procedure as employed in protocol#7 was conducted.

7 Experiment Results and Analyses

Figure 5 shows the mean evaluation scores for the performances of the assistant agents for interactions between different assistant and assisted agents. The figure shows that the human, Skyped-human, human-video, SR, VH, and the human-voice secured the 1st, 2nd, 3rd, 4th, 5th and 6th position respectively for their performances when serving as the assistant agents for the assisted agents (human).The performances of the assistant agents (except human voice) were satisfactory for the task, which justifies the hypothesis (i) of section 5.3. However, there are variations in the performances of the assistant agents for the same assisted agent, which justifies the hypothesis (ii). The Skyped-human performed better than the human-video because the assisted agent (human) could communicate with the Skyped-human, which was not possible for the human-video. However, both the human-video and the Skyped-human performed better than the VH. The reason may be that the VH was artificial, but the Skyped-human and the human-video were the agents with natural origin. The results also show that the SR performed better than the VH probably due to the reason that the SR had physical existence, but the VH lacked it. This finding justifies the hypothesis (iii). Analyses of Variances (ANOVAs) showed, for each criterion in each interaction, variations in the evaluation scores due to variation in assisted agents (evaluators) were not significant (p>0.05 at each case). The figure also shows that for VH-SR and SR-VH interactions where the VH and the SR assisted each other, the SR performed better than the VH, which justifies the hypothesis (iv). This might happen probably due to the reason that the SR had physical existence, but the VH lacked it. Again, the performances of the SR and the VH as the assistant agents were evaluated for two conditions (protocols 5 & 7 for the VH, and protocols 6 & 8 for the SR). ANOVAs showed that the variations in performances for each of the two agents between these two conditions were not statistically significant (p>0.05 at each case). It indicates that the VH and the SR exhibit similar performances in their assistance for natural (human) and artificial (VH or SR) assisted agents. It proves that the VH and the SR may be employed to assist each other in a remote or unmanned environment or in any social environment where human is not the performer but the beneficiary.

Figure 6 shows the mean evaluation scores for the attributes of the agents. The human voice lacked most of the attributes except the stability. The stability for the assistant agents (except in protocol#1) was also low. The reasons may be that these agents were slightly vulnerable to the external disturbances such as sound and noise. The SR was also affected by floor properties and obstacles (if any). As Fig.6 shows, the assistant agents i.e. the human, Skyped-human, human-video, SR, VH, and the human-voice secured the 1st, 2nd, 3rd, 4th, 5th and 6th position respectively in terms of their attributes. The order for the agent attributes exactly matches that for the agent performancs in Fig.5. In addition, the relationships for the attributes among (i) human-video, Skyped-human, and VH, and (ii) VH and SR for different conditions were exactly same as that for the agent performances (Fig.5). These findings indicate that agent attributes affect agent performances [27], which justifies the hypothesis (v).

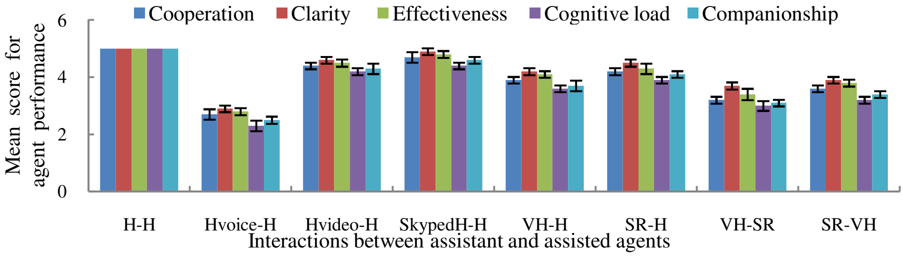


Fig. 5. Mean (n=20) evaluation scores for the performances of the assistant agents for interactions between different assistant and assisted agents

Figure 7(a) shows the mean times required by the assisted agents to find the box for interactions between various assistant and assisted agents. As Fig.7(a) shows, the assistant agents in the interactions H-H, SR-VH, SkypedH-H, Hvideo-H, SR-H, VH-H, VH-SR and Hvoice-H secured the 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th position respectively for their performance for this criterion. This order (excluding SR-VH) matches the orders of the performances and the attributes of the assistant agents in figures 5 and 6 respectively. In SR-VH, the VH found the box based on the assistance of the SR. However, this interaction was software-controlled for the fixed speed of the VH (same speed as the assisted human of protocol#1 as we were inspired by the human while developing the VH). This is why, the time required by the VH was almost same as that required by the assisted human in protocol#1. Again, we see that there is no error bars for the SR-VH interaction, because there was no variation in the time required by the VH as it was controlled by the software for fixed speed. In VH-SR interaction, the input speed of the SR was the same as that of the assisted human of protocol#1(as we were also inspired by the human while developing the SR) and the interaction was software-controlled. Hence, the time required by the SR was also supposed to be the same as that required by the assisted human in protocol#1. However, the SR took the time which was longer than that the assisted human took in protocol#1, and its time-based performance was ranked as the 7th. We also see that there are some small error bars for the VH-SR interaction. The reason may be that eventhough the SR was controlled for the fixed speed, it was affected by the disturbance (e.g. floor properties) in the physical environment. This also reflects in the lower stability of the SR (Fig.6). The Hvoice-H took the longest time due to its low attributes (Fig.6). In general, the required time was related to the agent attributes, which justifies the hypothesis (v). ANOVAs show that the variations in time between the assisted agents were not significant (p>0.05 at each case).

Accuracy of the assisted agents is shown in Fig.7(b). The results show that all the assisted agents in all interactions (except in Hvoice-H) could accurately find the box. This relationship also matches the relationships between the interactions in terms of performances, attributes and time in Figures 5, 6 and 7(a) respectively. The failure of Hvoice-H is due to the lack of attributes of the assistant agent (Fig.6).

The VH in VH-H and VH-SR interactions was very close to the Skyped-human in SkypedH-H interaction, and the SR in the SR-H and SR-VH interactions was close to the human (assistant agent) in the H-H interaction in terms of attributes. Similarly, in terms of peformances, the VH was able to achieve about 80% and 77% performances of the Skyped-human (standard for the VH) in the VH-H and VH-SR interactions respectively, and the SR was able to achieve about 76% and 74% performances of the human (standard for the SR) in the SR-H and SR-VH interactions respectively. However, the human's performance was better than the Skyped-human's performance as the assistant agent. Hence, the SR performed better than the VH.

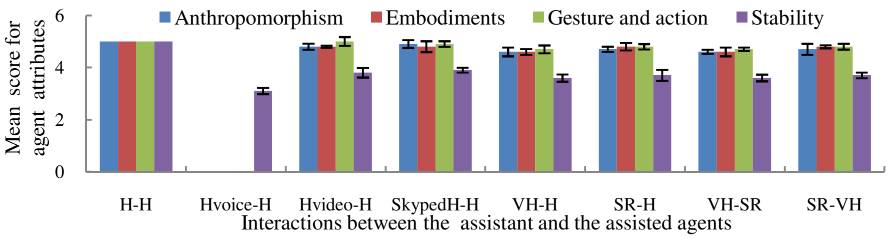
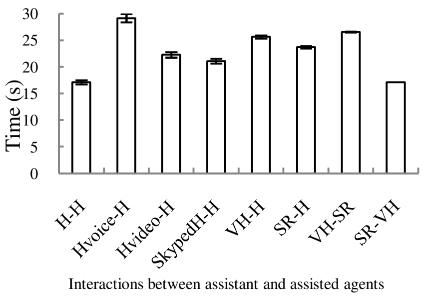
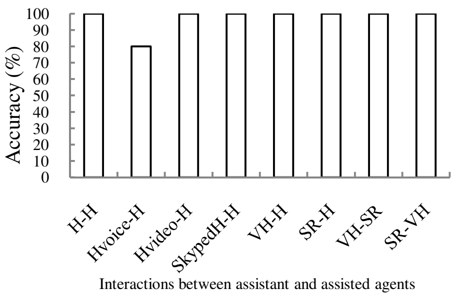


Fig. 6. Mean (n=20) evaluation scores for the attributes of the assistant agents for interactions between different assistant and assisted agents



(a)



(b)

Fig. 7. (a) Mean (n=20) times (with standard deviations) required by the assisted agents to find the box, (b) Accuracy (%) in finding the box by the assisted agents for interactions between the assistant and the assisted agents

8 Conclusions and Future Works

We developed a social robot and a virtual human to assist each other in a real-world social task based on a control algorithm through a common communication platform.We evaluated the interactions between them and also benchmarked the interactions with some other allied interactions. The results showed that the performances of the interactions between the robot and the virtual human were satisfactory, which indicates that the integration betweeen the agents were successful. Again, their performances varied from each other and were affected by their attributes. The integration between social robot and virtual human for real-world task, evaluation and benchmarking of social agents of different realities, communication for social agents of different realities through a common platform etc. that we proposed here are the most novel and have excellent prospects and applications. Thus, the findings will help develop social robots and virtual humans to assist the humans in real-world tasks, and also to assist each other in the social environment. In future, we will improve the attributes, functionalities and capabilities of the social agents, and employ them in the tasks with more complex social interactions.

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