Biological, Biomimetic and Sociological Aspects of Human-Robot Interaction in Work Environments

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Abstract. Human-robot cooperation in work environments is an upcoming, but still crucial topic in the study of human-robot interaction (HRI). Aspects of work safety are substantial. In many areas where industrial robots are used in the production process, they are separated by security spaces from the workers. Nonetheless, there is an upcoming need for robots taking part in collaborative actions with human workers. For this purpose, the interaction with the robot has to be safe, as well as intuitive and unproblematic. The construction of interactive working robots can learn from different disciplines in order to achieve this goal of successful and convenient human-robot interaction. This article presents insights from biology, biomimetic robotics and sociology regarding perceptual, constructional and interactional issues. Biological aspects help understanding how humans work and allow the transfer of these insights to the construction of robots and human-robot interaction. Abstracting biological principles and transferring them to the construction of robots is the part of biomimetic robotics. A biomimetic approach unfolds a huge potential for the safety issue in HRI. Sociological insights may help evaluating human-robot interactions behind the foil of human-human interactions and contribute important social factors.

Keywords: Human-robot interaction · Physiology · Biomimetic · Sociology · Safety

1 Introduction

Before the 19th century, horses were used for heavy work. Horses have been carrying loads, drawn equipment and were indispensable as livestock in people's lives [2]. With the invention of machines everything changed. The machines could undertake the work of humans and horses gradually, resulting in the reduction of production costs and duration. Consequently, demands could be accomplished more quickly, easily, and cost-effective. In the beginning machines took over transport and handling tasks. With time, machines improved and could perform independent filigree work increasingly, the so-called robot [3, 9, 12, 16, 20, 34].

The history of the robot began with a fiction in a film like in many other technological developments. Nowadays they are becoming increasingly important and have become indispensable in many areas of the working environment. The first industrial robot is a product of the 1960s. Together with George Dovel, Joe Engelberger developed the first

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of these robots and produced it with the for this purpose especially established company *Unimation* [3, 9, 34]. A new phase of 'Advanced manufacturing' was introduced (in German also called 'Industrial revolution 4.0 [2, 10]). This process is divided into two phases: First, industrial robots were introduced; they were stationary and separated from humans. Now, there are autonomous mobile robots: stationary and mobile robots are working together with humans [21].

Since the 80s, industrial robots are used routinely in the automobile manufacturing. Robots enter everyday life and the world of work. Up to date already 176,000 robots are in use in Germany [10, 17].

Initially, the machines and robots were delimited by cages or other shelters from the human employees, making an interaction rarely possible. Today, machines and robots should be user-friendly and thus the research focuses on a human-centered interaction [16, 18, 20, 36].

The question arises, how a robot must be designed in order to realize a successful and compatible interaction – and to guarantee work safety at the same time.

In this respect, it is worthwhile to consult different disciplines to understand the biological/physiological, psychological and cognitive abilities of people and to take advantage of this knowledge to apply it to the construction of robots (1). In the second section, we will discuss the potential of biomimetic robotics for the issue of work safety (2). A sociologically informed approach may help to evaluate human-robot interactions in contrast to human-human interaction and focus on important social interactional aspects (3). We close the contributions with different disciplinary focuses with some concluding remarks (4).

2 Physiological Abilities of Humans

The window to our world is assisted and in the same time limited by the physiology of our senses. We need the feedback of our environment to discern and interact with it. Through our senses, information in a magnitude of 10^9 bit/s is received; whereas only 10^1–10^2 bit/s are added and processed consciously. The remaining information will be processed subconsciously or strained to be not used. As a comparison, by speaking and motor information, we produce about 10^7 bit/s [28].

Generally, we perceive our world with 5 senses, but concerning human-robot interaction, vision, touch, and acoustics are especially considered to be important and should therefore be focused in the following. The stimuli of the environment affect the body in various forms of energy, mainly mechanical and electromagnetic waves. There are specific receptors in the sensory organs and each sensory cell has its adequate stimulus which effects a specific sensory impression. The different qualities of a stimulus within one sensory modality (acoustics, vision, touch) can be differenced by quantities like intensity and frequency, e.g. sound or light [11, 24–29].

The optical sense alone contributes about 80 % of the information of the surrounding and thus establishes most of our perception [11].

The light enters the eye on the retina, consisting of rods (10^8) and cones (5×10^6). These special cells convert the photons into electrical signals. These are then transferred via different cells in the retina next to the optic nerve (*Nervus Opticus*). The stimuli are transmitted to the thalamus, where the optic nerves of both eyes intersect, via the visual pathway (*Tractus Opticus*) to the primary cortex where they are processed. This is followed by two different ways, the “What-way” or the “Where-way”. The “What-way” leads into the temporal lobe (temporal cortex) via the ventral-temporal brain path. Here, it is processed what the observed object looks like. The dorsal-parietal pathway is the “Where-way” which leads to the parietal lobe. Here is processed where the observed object is in space. The pathway from the eye to the brain requires about 250–350 ms [6, 11, 24–29].

Human have a very small spectrum of vision of 380–780 nm. When exceeding this color range it may result in cognitive impairment or even in an eye injury [11, 29].

In terms of vision, a proper and pleasant color choice is important for an easy interaction, in order to make the worker feel comfortable.

Haptic perception is generally performed via the largest human organ, the skin – and especially via the hands. Here mechanical stimuli are received by 4 different receptors. The receptors are located at different depths in the skin and perceive various types of haptic stimuli. The so-called Merkel cells record details of a touched object, for example a bottle, and the specific pressure, and Meissner’s corpuscles are responsible for grip detection. These two receptor types are sporadically spread on the index and middle fingers, but also on the thumb, and irregularly distributed on the palm of the hand. The slightly deeper Ruffini corpuscles record the stretching of the skin and the penetration depth of objects on the skin. Ruffini’s corpuscles are represented in the center of the hand and at a large area on the index, middle and ring fingers. For the perception of vibrations, the Pacinian corpuscles are responsible, which are the lowest in the skin. They are mainly located on the middle finger and on the outer palm [6, 11, 24–29].

The receptors of the skin pass the information via the spinal cord and the thalamus to the cerebrum. This area is specifically constructed. The various parts of the body are displayed differently in size on the somatosensory area. The higher the density of receptors of a body region, the more accurate and lager the part of the body is mapped in the brain. This is represented by the so-called homunculus [11, 25, 27]. There are two somatosensory gyri. The somatosensory region is mainly responsible for touch, pressure, joint position and reflects, and contains and processes four full maps of the body surface. The second somatosensory area receives bilateral information of the body and is important for the differentiation of size and nature of objects [29]. In addition, the region information transfers from one hand to the other. The reaction time is about 80–150 ms [11].

Haptics are important for human well-being and humans respond to tactile stimuli promptly. Therefore, handles, switches, and pads should be designed so that they, for example, appeal to the relevant hand areas. This should be in accordance with the appropriate receptors and thus give the human the required feedback from the robot.

In acoustic perception, sound waves pitch the ear cups, then are reflected repeatedly and pass through the external auditory canal to the eardrum. This is deflected and transfers the energy through the malleus, anvil and stapes to the inner ear. The sound signal arrives at the water-filled interior of the *Scala vestibuli*. About the oval window, the vibrations of the ossicles are transferred to the atrial transition. The movements of the perilymph are then passed over the Helicotrema to the *Scala tympani* and eventually to the round window. The entirety of these movements leads to deflection of the basilar membrane and the tectorial membrane. This causes the inclination of the stereovilli to the hair cells. This will open ion channels and the membrane voltage changes. The hair cells innervate fibers of the auditory nerve (*Nervus cochlearis*) which enters the CNS and passes to *Nuclei cochleares*. Over the thalamus, the information is transferred to the auditory cortex. The basilar membrane has special areas where it can perform best. Those special areas respond to certain sound frequencies. This structure is also found in the auditory cortex. Thus, certain frequencies are processed there easiest. The reaction time is about 100–150 ms. A human hears between 20 and 20,000 hertz [6, 11, 24–29]. If this threshold is exceeded there is a decrease in the ability to concentrate and also a feeling of uncertainty. Therefore, in order for a human to feel comfortable and sounds to be heard clearly, a suitable frequency and intensity of a tone should be selected.

The use of the comfort zones leads to the best recording and cognitive capabilities in humans and enables a simple and intuitive interaction with robots.

Perception is in principle indirect, meaning the stimulus information is passed to the appropriate areas of the brain via the thalamus as a hub, thus filtering the amount and distributing the information.

The specific regions decode the previously encoded information from the sensory organs, distinguish the information and communicate with each other. The composition and conscious reconstruction of information gives us an overall picture. A human being is confronted with a lot of information that cannot be recorded and processed. The selection of information passed is of utter importance and already begins in the sensory organs. Additionally, filtering processes occur in further certain regions of the brain [24, 25, 27, 29].

Remarkably, individual perception fractions can be shifted by brain on the timeline, which in turn collects perception performances and fills gaps in perception. The brain has to manipulate our perception of time in the performance for continuous, gapless perception. Perception is also a memorizing process, storing patterns of perception, and depends on our attention [11].

The question that rises is how can a human being, due to its biological and cognitive abilities, interact intuitively and modestly?

Given the biological role-model, and its failsafe operation, as an outline for biomimetic developments, it is necessary to consider the processes of perception and its application, to exploit the comfort zone of people for optimal interactions. Consequently, robotic developments are driven by the ideal of compatibility of human and robot perception. Robotic perception works with sensors that shall be able to receive the same information and to solve all the different tasks humans are able to perform. The information is then processed via adaptive artificial intelligence. The sensors absorb signals and transfer them to the robot's controller. Sensors are available for a variety of measurements in a variety of forms of changes in the environment [3, 20]. The sensors of the robot can principally detect even a wider range of stimuli than the physiological senses of nature. But they are restricted by the progress of artificial consciousness and processing. The "brain" of the robot would be faced with the task to reconstruct images from the jumble of lines, shadows, and flitting spots of colors that are documented by cameras and microphones [7, 19, 38]. A vast challenge is progressing robotic hands that handle a variety of tasks as human hands do, in terms of the tactile sense. The options for detection are much more complex than in the physiology of a human. In case of humans, millions of years of evolution and adaption led to a filtering process, which would remain to be solved by the engineers and programmers for the development of robot haptic [19, 34, 38].

Therefore, to follow a biomimetic approach, we should consider the following question: How can a robot act accordingly and adapt to a human being to achieve a simple and convenient interaction?

Biological models establish new application possibilities in the field of robotics, especially in the biomimetic robotics.

3 Biomimetic for Security at Work

Biomimetic is defined according to the VDI guidelines as follows:

"Biomimetic combine biology and technology with the goal of solving technical problems through the abstraction, transfer, and application of knowledge gained in interdisciplinary cooperation from biological models" [31 Part 1].

In the course of 3.8 billion years' biological structures have improved. There is a huge pool of ideas from biology that are available for the solution of technical problems [31, 32].

Biomimetic are technological developments inspired by nature. They usually pass through several stages of abstraction and the modification of biological starting points.

The knowledge about the analysis of living systems can be used to create new inventions and innovations and transfer them to technical systems.

The application of research and development approaches is of interest for technical applications [31].

Applying biomimetic aspects to the development of robots is advantageous. Biomimetic robots are "robots that possess an implementation of at least one dominant biological principle and are usually developed based on the biomimetic development process" [32 Part 1].

The source of the benefits gained from the use of biomimetic robots can come from inherent physical properties as well as from a biomimetic-based "behavior".

Biomimetic robot systems are powerful and fast. In the past, the development of robots was always lead by an increase of positioning accuracy and motion speed. To achieve these improvements, it was necessary to use heavy and stiff structures coupled with non-back-drivable transmission mechanisms. These robots were optimized to work fast, accurate and self-sufficient in a well-defined and constrained environment. In addition, all working steps have to be predefined and highly repeatable [30].

For fully automated work and production steps, these kinds of robots might be the best solution. But in fact the industry is now shifting towards automated production of small batch, customized and short-life-cycle products [31]. Therefore, industrial workspaces and tasks can change very fast and a human user becomes more and more important, because only humans are able to understand changing situations and problems correctly. Due to this, a collaboration of human workers and a robot is often the only solution [17, 22].

The upcoming need of a safe and human-friendly coexistence in a shared workspace of a human and a robot leads to a new set of requirements a robot has to fulfill. The robot should have an understanding of the unstructured environments, especially of human demands [1, 22].

However, they can only be used for human-robot interaction when implementing further measures.

In respect to the positive and useful aspects that a robot implicates, humans should still pay attention to the safety when dealing with robots. Above all, this is important because robots are now working increasingly without cages or other shelters, hence directly with the workers at a workstation [3, 17, 20, 34].

The reorganization and changes of properties of the robot would reduce the risk of a human-robot interaction without protective screens. This would come hand in hand with savings in terms of space, time, and investment costs [32]. Humans should have the opportunity to push the robot away in an instance and/or to be able to push a button to escape a dangerous situation.

The robot cannot judge how far his act endangers humans. Therefore, the consequences in case of errors are very high and it is not yet completely clarified who bears the fault on failures or accidents [17].

Important topics of today's robot research are features like light weight design and passive (inherent) and active (controlled) compliance [1].

The use of controlled dissipation would cause less injuries and damage during an impact than a comparable rigid system. In the case of bruises and anxiety, certain softness (passive flexibility or elasticity) in the kinematic chain (hand-arm system) would help to facilitate the self-liberation.

With the help of these properties, a biomimetic robot can be designed that is "safer" than a comparable rigid industrial robot [32].

The more biological principles are combined in a biometric robot, the more one can guess that the robot approaches its biological model in its properties and its behavior [32].

This shows that an intuitive use and an adaptive behavior of the robot are of high priority and are beneficial for further human-robot interactions. This could ensure that a human can interact simpler and by reflexes according to situation. Furthermore, the robot could judge a situation and the surroundings due to certain settings of the situation and thus interact and react adequately [17].

All persons involved in the operation, such as the operator, maintenance personnel, and programmers must be familiar with the operating and maintenance instructions of the machines and robots. This can be ensured through training. However, these may not contain all the safety measures in detail which are necessary for the protection of personnel in the workplace. The security can be considered only on a defined machine, a particular process and on an existing environment [17, 34].

The protection of personnel can be subdivided into the following categories [17]:

- Safety during construction and commissioning
- Safety during operation
- Safety during programming
- Safety during the monitoring and maintenance
- Safety in the handling of e.g. student projects

The more intuitive an interaction is performed, the more it will be regarded as successful by humans. Humans should keep their sense of sovereignty over the robot and should not subordinate [8, 17].

Furthermore, it should be noted that the working majority is afraid of losing their jobs by robots. But will robots replace us in all work matters? Absolutely not!

The world of work is changing and deforming as it already has changed the last few centuries. The market is dependent on many factors and all companies must remain economically competitive (worldwide) [3, 17]. Thus, it seems inevitable that humans work together with robots. It could be possible that some work will be completely overtaken by robots. But this re-opens new work fields, for example in the development and research of those robots which need to be re-occupied by humans. With the rapid process of technology, the demand for workers increases [16, 19, 21, 36].

4 Sociological Aspects for Human-Robot Interaction at Work

From a sociological point of view, it is of paramount importance to consider the basic patterns of interaction within human-human interaction (HHI) for the design of a safe human-robot interaction (HRI) in work environments. Several studies in the field of HRI are leading to the assumption that the gaze of the robot is crucial for the assessment of the interaction and has a significant impact on a positive process in performing a cooperative task [23, 37, 38]. Even if a "point of interaction" – embodied as a face with eyes – is completely irrelevant for the function of a robot within work environments, it could be nonetheless vital for a healthy, cognitive exonerative and insofar in total safe HRI design. To understand the key factors, that are defining the HRI as sound and superior to developments focusing on mere functionality, it is insightful to take the HHI as a reference. Even if the implementation of HRI deviates from the standards of HHI, we claim that the orientation towards HHI is the key for the design of a proper and human-centered configuration of HRI. To achieve these goals, we are proposing a conceptual framework based on some basic sociological assumptions in regard to the main factors that are characterizing interaction among humans. The framework should be able to identify the crucial features for a successful interaction and by doing so also increase the acceptance of the workers to willingly engage themselves in HRI.

The main focus of the proposed evaluation framework is to address two key questions related to a successful and pleasant interaction between humans and robots: First, which are the dominant factors that determine whether the interaction is fluid and smooth. Second, to which extent do humans prefer an interaction model with a strong orientation towards conventional interaction experiences among humans – or do they rather prefer an interaction experience similar to typical human-machine interactions? As we already stated in a recent published paper [40], a useful instrument to gain fruitful answers to these questions is the instrument "Breaching Experiments" which was developed by Garfinkel [12] to estimate the strategies that are adopted by humans to achieve a successful interaction between at least two humans. The main categories to describe the HRI at stake in all socially relevant dimensions are taken by a model introduced by

Burghart and Haeussling [5] and further developed by Burghart and Steinfeld [4]. They developed a HRI scheme operating on four levels that is built relying on basic aspects of interaction among humans, although further adapted for the study of HRI. The different levels include the Interaction Context, the Interaction/Co-operation, the Activity of Actors and non-verbal Actions and Emotions. While the scheme is just a systematically ordered pool of elementary criteria (from simple to complex, from mechanistic to cognitive elaborate, from functional to emotional) for analyzing and evaluating HRI, the presented method, which will be further elaborated in the upcoming months within the scope of a FabLab environment, is presenting instruments to empirically measure and determine the relevance of each criteria defined in the model.

Besides "Breaching Experiments" as the core instrument to study empirically the HRI by taking into consideration the scheme proposed by Burghardt and Häussling to estimate the quality of the interaction, the theoretical background is mainly defined by Erving Goffman's "Frame Analysis" [15] within his work on "Microstudies on Social Interaction" [13, 14]. The baseline is the assumption that every social interaction is depicted by situated (i.e. contextual dependent) expectations and the way how these expectations are held stable over a relatively long lasting period of time (relying on Goffman) and which mechanisms are used – resp. among the interacting entities commonly established as viable – to negotiate an alignment of the expected expectations on both sides (relying on Garfinkel).

In the past decade scholars dedicated to the study of social robots started to analyze the HRI from a holistic point of view, focusing more and more on the interaction experience [e.g. 35]. These insights should be transferred to HRI in work environments insofar as both the interface and the cooperation between worker and machines – resp. robots – are becoming significantly more interactive. Main overall outcomes of HRI focusing on the interaction experience are the insights, that the HRI situation is dominated far more by agency issues than anthropomorphism. Likewise, that the HRI is unique and could not be totally analogized with the interaction situation among humans, however it could be described using similar instruments resp. methods. Another main finding seems to be the relevance of the context and the situated perspectives of the entities involved in the HRI.

The mentioned insights could be in equal measure described and further analyzed adopting the proposed method based on Garfinkel's "Breaching Experiments" (in light of Goffman's "Frame Analysis"). The method is always taking into consideration the specific situatedness related to the successful performance of a social interaction between two entities, due to the fact that it is operating always within the culturally shaped margins of what is seen as a functioning interaction. When adopting the method to deliver fruitful findings related to the main criteria for a proper HRI in work environments – as a very specific socially shaped domain of Human-Machine cooperation – the relevance of the context and the situated perspective of the involved entities is always taken into consideration as an essential component of the basic assumptions the method is relying on. The aim of carrying out HRI experiments within the scope of sociological theories, concepts and methods is to analyze the interaction regardless of the peculiarity as a situation that is taking place within a social environment. The orientation towards the study and understandings of HHI is leading to a holistic assertion of the HRI, especially according to safety issues in work environments. Without considering the factors that are crucial for a successful interaction respectively cooperation among humans, it will turn out impossible to design a safe interaction between humans and robots. Within the scope of very functional cooperation settings, without several interaction sequences, other factors may be of more importance and characteristics of HHI are less important and can be neglected. When developing robots for more intense exchange with humans, that in turn are making more negotiations between them indispensable, the – in part less by functionality characterized – aspects that are defining HHI are becoming more important.

"Breaching Experiments" are highly suitable to determine what humans do expect from the robot while engaged in an interaction sequence with it, and to what extent they are willing to repair the breach – i.e. they are willing to give the robot a second chance even if its action does not fit the expectations. To conclude the remarks related to the relevance of a sociological perspective for the development of safe HRI in work environments – applied for instance to the above stated importance of the gaze of the robot as a socially expected key factor, one may induce breaching experiments to find out if the robot's gaze has a positive impact on the interaction compared to robots without a gaze. One may find out that the robot's gaze is beneficial for the cognitive load, the stress level and the overall assertion of the situation, even if the robot is not always working as expected. In this regard it is important to bear in mind that the more the situation between robots and humans could be described as a social interaction, the more it will be affected by expectation flaws and the execution of repairing strategies e.g. negotiations about how to deal with an unexpected course of the interaction or outcome.

5 Conclusion

To conclude, different disciplinary perspectives can contribute important aspects regarding the safety and intuitiveness of human-robot interaction in work environments. Knowing about the physiological constitution of the human may help designing human-robot interaction in work contexts, taking into account the specific strengths of humans (e.g. complex perception, response capacities, adaption and improvisation) and robots (e.g. strength, speed, consistency) in order to achieve a successful cooperation.

With the knowledge about the physiology and the comfort zones of the human, cognitive abilities can be optimally utilized and in the light of a biomimetic approach, these insights can be abstracted to technological parameters and implemented in the construction of biomimetic robots. For an intuitive interaction, social aspects become crucial. Robots working with humans should be able to adapt to the behaviour of the human and orientate themselves in complex working environments. For the acceptance of robots, understanding and using certain social cues may be of paramount importance. Sociological concepts may help evaluating the interaction of humans and robots in contrast to human-human interaction.

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