Human-Robot Interaction in Health Care Automation

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Abstract. Robot-based assistance systems are widely utilized in industrial production today. In the near future, the numbers of applications in private households as well as in health care are also expected to grow. Such systems need to act and react autonomously, to cooperate and to perform supportive functions. This paper starts with the description of a project of a specially developed humanoid care robot and focusses on the lessons learned from this project. Afterwards, concepts and ideas of industrial human-robot interaction will be presented and discussed with regard to the special requirements in health care automation, such as safety and human factors. Finally, a new full-scope simulation system will be introduced, which should allow experiments on Situation Awareness and usability with experiments with probands under constant environmental conditions.

Keywords: Health care automation · Human-robot interaction · Full-scope simulation · Situation Awareness

1 Introduction

Human-robot interaction (HRI) systems are novel applications in robotics. They were introduced in the last few years in the industrial sector and quickly applied there. In the course of Industry 4.0 campaigns, collaborative robot systems were developed that can be used without protective fences in direct interaction with humans. Suitable robot systems, procedures and new protection concepts are now available. A transfer to the requirements of health care automation seems possible in principle. This paper presents concepts and systems of collaboration between humans and robots and then focuses on the important issue of security in the man-machine interface. The current standards for the permissible operating modes are introduced and the various operating modes are examined for applicability in the field of health care automation. Finally, the concept of a full-scope simulator will be presented, which should allow investigations with probands.

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2 A Humanoid Robotics Approach for Health Care Automation

In the *Rhoni* project, a prototype of a humanoid robot has been developed in our laboratory in recent years [1]. The Rhoni project deals with the conception and the construction of a humanoid robot. The idea is to develop a human-shaped robot that can take over simple tasks in household and health care applications: helping to get up and getting dressed, tidying up or getting a part out off the kitchen shelf. Not the replacement of in-patient care by robots is in the focus, furthermore it is rather about relieving the staff by taking over supporting activities: bring away laundry bags, food or distribute medication, empty trash, transport files or get drinks. A chance for seniors and disabled people to stay longer in their own homes. The construction of a skeletal structure, modeled on man, should increase the acceptance of the machine. In addition, behavior-oriented social characteristics such as intelligence, autonomy and ability to learn should be achieved [2]. Figure 1 shows the prototype humanoid robot which has a size of 1.90 m and weights 80 kg with 54 joints and drives installed.

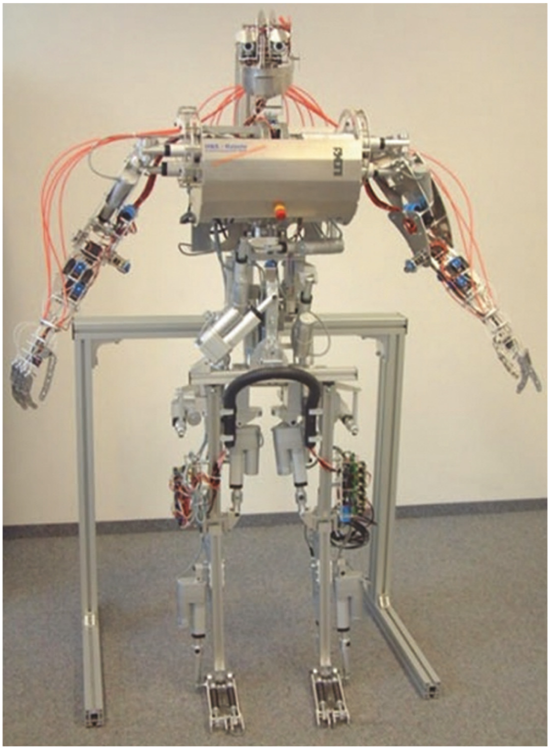

Fig. 1. Prototype Rhoni

Despite intensive work on the project, many goals have not yet been achieved. Lessons learned, however, were formulated as following theses [3]:

- The overall system of a humanoid robot is of enormous complexity, the training of operators and maintenance manpower is very difficult.
- The error rate is extremely high. The amount of maintenance and servicing work is correspondingly high.
- In particular, the user interface is problematic. The operators, already in the laboratory, are often overwhelmed, because checklists and switching sequences must be observed. People in need of health care would be overstrained with the user interface. The problem of man-machine communication is still unsolved for humanoid robots.
- Movements of the humanoid robot are hard-coded and not very sensory supported. There are no variants in the movement or autonomous movements that are not intended by the programmer.
- The humanoid robot can not make autonomous decisions. It is a mechanical engineering project and information technology procedures are therefore only rudimentary. Real autonomy requires powerful artificial intelligence and learning-based procedures.
- Protection mechanisms are not available. In the laboratory operation, security is provided by double occupancy and active control. Certification according to current standards and risk analysis is excluded.
- The dynamic processes of the movement are hardly manageable. A humanoid robot is unable to avoid unknown obstacles when walking.

According to the current state of the art, however, the humanoid concept for care applications can not be used.

3 Robots as Technical Assistance Systems

In many areas of life an increasing connection between people and technology can be observed. Examples include electronic devices for communication technology, such as smartphones, as well as technical support systems in the home and much more. A constant process of change can also be observed here: people and technology are becoming more and more connected, technical systems are becoming increasingly important in the human environment.

Along this development, the following two different types of support systems can be distinguished from each other:

- Technical systems that substitute one person and thus lead to relief. Here, the technique performs the task for humans.
- Technical systems that help people perform their tasks without replacing them. Here, the person retains control over the processes and is supported by the technology.

Robots in HRI systems can not be assigned to one or the other group [4]. These are systems that can and should relieve people of straining jobs or tasks causing negative effects on their health. However, they are not meant to completely substitute human, but to support him. The human being keeps control at all times. HRI is thus arranged exactly between the two described areas.

4 Human-Robot Interaction (HRI)

The human-robot interaction (HRI) was recently introduced in industrial contexts with the goal to keep people with their cognitive abilities as an active link in the production chain. Improving quality and productivity with a high number of variants through automation, while at the same time aging and dwindling specialist personnel, requires creating new conditions for direct collaboration of humans and robots.

4.1 Safety Requirements in HRI Systems

HRI systems have different safety requirements than those used previously for industrial robots. The main principle of the spatial separation of humans and robots is lifted. The safety-related implementation of HRI systems must therefore be fundamentally re-evaluated. The safety fences used very often in the safety technology of previous robot systems can find no further application in HRI systems for reasons of principle of collaboration. In contrast to the classic six-axis industrial robot, most HRI systems are equipped with more than six axes.

4.2 Taxonomies in HRI Systems

According to Fig. 2, three different forms of interactions between humans and robots are distinguished as follows [5]:

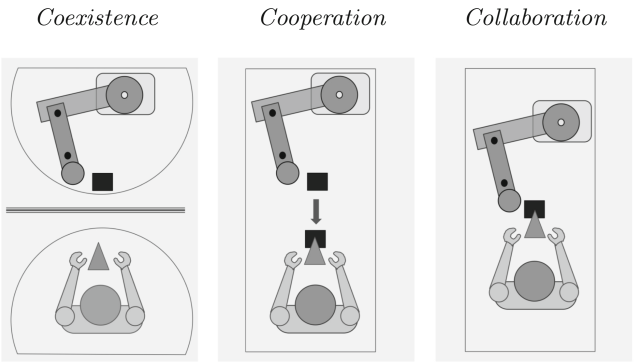

Fig. 2. Taxonomies in HRI systems

- *Coexistence*
  Coexistence in this context means only an episodic encounter of robot and human, whereby the interaction partners do not have the same goal. The interaction is limited in time and space.
- *Cooperation*
  Cooperation works towards a higher common goal. The actions are not directly linked and depend on a clearly defined and programmed division of tasks.
- *Collaboration*
  Collaboration describes the interaction and direct collaboration between human and robot with common goals and sub-goals. The coordination of subtasks is ongoing and situational. Synergies should be used.

4.3 Harm Reduction

The aim of harm reduction is to reduce injury in the event of a collision to the smallest degree. Injuries while collaborating operation can occur for different reasons. Firstly, by direct contact, in a collision, on the other hand by the sharp edges of the tool, which is mounted on the robot. In addition, there is the danger that certain body regions can be pinched by a gripper. In all cases of conflict, it is important to keep the damage to a minimum. In order to minimize the risk of injury, safety-related design measures must be carried out on the robot. According to Table 1, this includes power limitation, compliance and damping at contact points.

Table 1. Injury reducing in HRI applications

Design method	Effect
Power limitation	Reduced power and force effect, Bio-mechanical limit values
Compliance	Plastic deformation of robot components, Installation of predetermined breaking points
Damping at contact points	Padding of pointed, sharp or hard surfaces on robots and gripping system

4.4 Power Limitation

Power limitation is a reduced performance and power effect. This is determined by the bio-mechanical limit values, which must not be exceeded in the case of contact between human and robot. This includes the force and pressure on humans, which is also to keep as low as possible.

Since the human being is in the immediate vicinity of the robot, the robot has to drive slower to limit the force effect. This can be achieved by permanent monitoring of the power consumption of the drives by the robot controller [6].

4.5 Compliance

Compliance refers to the plastic deformation of certain robot parts in the event of a collision. This can be achieved with special elastic materials used to construct or equip the arm members. In addition, elastic drives are proposed as a protection concept [6]. A robot equipped in this way can react elastically to collisions and injuries can be avoided.

Another approach to compliance is the installation of predetermined breaking points. In addition to the HRI robot itself, the tools attached to the robot can lead to injuries. For example, a gripper mounted on the flange can wound people due to any existing edges. Here, a break at the joint of the gripper would cause it to break off to prevent further injury. In this case, a collision would have to have a force acting on the person which exceeds the stipulated biomechanical limit values. The goal of breaking points is to increase safety and minimize injury risks.

4.6 Damping at Contact Points

Damping at contact points is understood to be the external covering of pointed, sharp or hard surfaces by means of an elastic sleeve. The robot is designed so that as few danger spots as possible can occur during a collision. The elastic sleeve, which is attached to the robot, serves to dissipate the stored kinetic energy in exposed areas of the robot. These locations can be, for example, areas in the vicinity of the axes, since there is a high risk of crushing. Sharp edges are concealed and securely padded.

5 HRI in Health Care

Can systems derived from industrial HRI provide an approach to assistance systems in health care? Are robots generally an option to relieve the nursing staff? What could the future bring and what has already arrived in everyday health care? What is done in other economies?

A look to Japan shows, that robotics can actually be used to relieve the nursing staff in health care. No other industrialized nation is aging so fast, so research on corresponding systems was started early in Japan. There are a number of prototypes in Japanese research institutes and pilot installations. In addition to collection and delivery services, Japanese research focuses on systems for lifting, carrying and supporting those in need of care. In Germany, there are also a number of research projects on the subject of care automation. Pickup and delivery services are also being automated here, but the focus is rather on supporting nursing staff. For example, autonomous care wagons should support the staff of inpatient care facilities by automatically providing care utensils [7].

For the development of assistance systems in health care automation, the use of the HRI robots described above in a care-specific system technology is also suitable. In contrast to previous research approaches, it is possible to use technically available, standardized and therefore also economically interesting automation systems. There is also considerable know-how in HRI, which would then also be available for new developments in other fields of application. The assistance functions that are so far in the focus of health care automation, such as fetching, providing, applying, and delivering, are furthermore familiar to applications in industrial handling technology and have been solved in a variety of forms. The endangerment of humans must be ruled out, the safety has unconditional priority. However, this is not only a dogma of caring automation. Safety is also guaranteed at all times for the HRI in its current areas of application. There are also a number of experiences, methods and last but not least regulations that describe exactly how operational safety is defined and measured. If these insights are extended by methods of human factor engineering and the man-machine interfaces are adapted to the new applications, then e.g. an application of a HRI robot arm on an autonomous trolley could be possible in the near future of health care.

6 HRI Simulation Involving Human Factors

Capturing of human expectations and information processing can be achieved based on human factors methods in HRI contexts by proband experiments, but the results suffer from changing environmental conditions and distractions caused by environmental influences. In our former works we predicted that the results would be more resilient, when measured under constant conditions in the experiment [8]. In addition to constant conditions, a special procedure in the development of appropriate applications is required for the HRI method. For this purpose, we introduced a combination of real test environment and simulator (HRI full-scope simulator) [9].

Of course, a large number of simulation methods already exist in the field of robotics. However, these are limited to the questions of kinematics (e.g. accessibility of gripping positions) or cycle times, depending on the type of simulation and application. At best, humans are included in these simulations as a kinematic model of an ergonomics simulation.

However, there are also a large number of occupational and psychological aspects in the HRI, which should be the subject of planning for the HRI facility. Conceivable investigations are, e.g.:

- How is the operator's attention focused on a particular situation?
- Is there a connection between perception and hazard potential that is relevant in the safety analysis?

Such and similar questions can not or not fully be answered with today's robotic simulation systems.

6.1 Full-Scope Simulation

So far, full-scope simulators have been used exclusively in power plant technology, especially in nuclear technology, where a full-scope simulator is defined as

" ... a simulator incorporating detailed modeling of systems of Unit One with which the operator interfaces with the control room environment. The control room operating consoles are included. Such a simulator demonstrates expected plant response to normal and abnormal conditions [10]."

Accordingly, a full-scope simulator is understood to be a simulator which simulates the behavior of the modeled reference system (here in the technical language of power plant engineering: Unit One) in order to investigate the operator's interactions with the system. The control elements of the reference system are part of the full-scope simulation. Such a simulator is used to train operators in dealing with the regular and irregular operating conditions. In power plant operation, a constant and effective training of the operators is required. The goal is to operate the power plants safely and efficiently. Many important parts of the training programs are carried out by such full-scope simulators. These training programs are designed to increase the operators' decision-making skills and analytical skills and to prepare them for problems that may arise when operating the actual system [11]. Full-scope simulators are recognized as an effective tool for operator training and are used in particular for nuclear power plants.

Through the use of a large number of different human-machine interfaces, people are directly involved in the simulation processes. Furthermore, there is a causal relationship between human actions and the resulting system states. In addition to improving operator performance through training programs, these simulators are also used to improve plant and personnel safety, reliability, and reduce operating costs. Full-scope simulators are also often used to train new employees, staff development and public relations. In addition, occupational science and psychological aspects (human factors) are part of full-scope simulations. These include surveys on perception, attention control and Situation Awareness.

6.2 Human Factors

The scientific discipline of human factors is defined as the understanding of interactions between humans and other system elements. Above all, these are methods, theories and principles that contribute to the optimization of human well-being and overall system performance [12]. The term human factors results from the psychic, cognitive and social factors influencing socio-technical systems. One focus is on the design of human-machine interfaces, especially on security issues and psychological aspects [13].

Due to the increasing degree of automation, human skills in the system have a different role, for example in the form of control activities. The question arises as to which human characteristics, for example in cooperation with robots, can and should be taken into account. Among other things, the topics of environment design, task assignment and responsibilities play an important role.

Perception is a conscious sensory experience (proximal stimulus followed by information processing) caused by a physical, distal stimulus, e.g., Seeing, hearing, tasting and smelling, touch and pain senses. The perception can then be, for example, an auditory or visual process, although other channels of perception may also be considered. For the perception of environmental stimuli they must meet a sense organ. The receptors of the sensory organ convert the stimuli into electrical signals, which are sent to the brain via nerve tracts. The signals generated by the receptors are analyzed and processed on the way to the brain and in the brain itself, until finally a conscious perception experience occurs. Sensitivity-influencing environmental factors that could play a role in full-scope simulation are, e.g., lighting, noise exposure and vibration.

A look at the human perception process shows that at the end of information processing ideally comprehensive mental models emerge, which allow situational perceptions. From the incoming stimuli of the outside world only those are picked up and then action-relevant, to which attention is paid from the abundance of incoming stimuli based on experience, expectation or attitudes [14]. The process of how individuals perceive and mentally represent a great deal of information in order to be able to act effectively in a given situation is called Situation Awareness.

6.3 Situation Awareness

Endsley defines Situation Awareness as " ... perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future [15]". Situation Awareness is a construct consisting of three levels. Level 1 describes the perception of the elements of the environment. Due to inadequate presentation and cognitive abbreviations, this can lead to misperceptions and thus a wrong understanding of the situation. Level 2 describes the understanding of the situation and deals with errors in the correct integration of the information recording. A lack of mental models or blind trust can lead to wrong predictions and thus a wrong decision. Level 3 refers to the prediction of future events. This depends on the expert status of the persons [15].

There are various methods for recording Situation Awareness. A distinction is made between direct and indirect procedures. Direct procedures provide direct access to the product of Situation Awareness, while indirect procedures relate to the process of situational awareness or the outcome of awareness of the situation. To investigate Situation Awareness, various process measures can be used according to Endsley. These include verbal protocols (thinking aloud), psychophysiological measures (ECG, heart rate) or communication analysis. Such process measures, however, are seldom used, for example, in aviation, since these methods permit subjective interpretations or require very complex measurement techniques for detecting psychophysiological measures. In objective processes, the knowledge of the person about the current situation is queried and thus the measure of Situation Awareness is formed.

6.4 Assessment of Situation Awareness by Full-Scope Simulation

The Situation Awareness Global Assessment Technique (SAGAT) method is used to investigate and evaluate Situation Awareness. Prerequisite for such an investigation is a realistic simulation environment. This simulation is frozen at random times, which means that the simulation stops and all information sources are turned off. The probands are questioned by an operator about their actual perception of the situation. This is called freezing [16].

The full-scope simulator performs a freeze according to the SAGAT method automatically. For this purpose, the process stops unexpectedly for the proband. The lighting is changed to darken the workplace, so that the proband loses the workplace out of focus. Rehearsed noise from the audio system is also stopped. Instead, the proband is asked questions to query psychological aspects to Situation Awareness. After the questions are answered, the light switches back, the sound or noise comes back on and the frozen process continues automatically. The experiment is continued. The freeze can be carried out several times automatically, depending on the specification and planning of the experiment.

6.5 HRI Full-Scope Simulator

The HRI full-scope simulator is a modular, expandable small room system, build as a room-in-room concept. The dimensions of the small room system can vary depending on the simulation task. On the one hand, the HRI full-scope simulator is supposed to simulate spatially close cooperation between humans and robots. On the other hand, it makes sense to be able to adapt the available interior in the simulator to the respective HRI situation. The requirement of the changeover flexibility is therefore essential to be ready for changing configurations [9]. Figure 3 shows a sketch of this small room from outside.

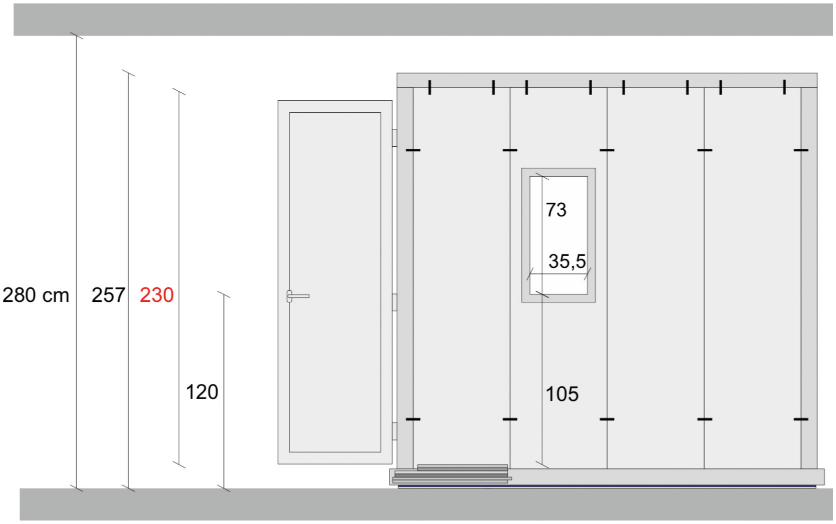

Fig. 3. Modular small room system as full-scope simulator

Inside the room, controllable environmental conditions prevail in order to study influences of light, noise and temperature or to exclude their influence.

The HRI full-scope simulator is used to set up the HRI system to be tested in order to perform proband experiments under specified conditions. The aim is to obtain statistically relevant statements on Situation Awareness, perceived safety and focused attention. Also distraction and error susceptibility can be examined. The basic dimensions are sufficient for a compact HRI workplace. Due to the modular design of the small room system, it is possible to enlarge or modify the space by mounting extension modules. The noise reduction of 44 dB is sufficient to minimize the typical outside noise of the room, such as, e.g., talking or computer ventilation, so that they are barely registerable in the inside, let alone lead to a loss of concentration.

Figure 4 shows the pilot HRI installation of a health care application. The proband is placed in the hospital bed. During the experiment the proband is served by an HRI robot with drinks and medicine.

Fig. 4. Health care application in full-scope simulation

7 Conclusion

In this paper, the question will be examined, whether the concepts of human-robot interaction HRI for industrial applications, can be transferred to new applications of assistance systems, e.g. in health care. This would open the opportunity to use technically available, standardized and economically interesting automation devices and to utilize available know-how.

Assistance functions such as fetching, providing, applying and bringing are solved in a variety of ways in industrial handling technology and could simply be transferred. A hazard to humans must be avoided in any case. In the previous areas of industrial application of the HRI, there are experiences, methods and regulations that determine what constitutes operational safety and how it is measured.

The question of how to obtain statistically relevant statements on human factors, e.g., Situation Awareness is being investigated. This is relevant to hazards, e.g., to avoid by distraction. These statements are to be obtained by means of a simulation method. Based on the concept of the full-scope simulation. well known in the field of energy technology, a simulation with real components and a man-in-the-loop approach is used.

The scientific background is the idea that in experiments with probands, comparable results can only be achieved, if uniform conditions prevail and the experimental procedures do not differ between the probands. The simulation concept for HRI has been specially developed to meet the requirements of ergonomics research and work psychology. With proband experiments under constant environmental conditions, studies on human factors, such as Situation Awareness, and later on, e.g., perceived safety and focused attention can be executed there.

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