Using Anthropomorphism to Improve the Human-Machine Interaction in Industrial Environments (Part I)

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Abstract. The concept of socio-technical systems emphasizes the mutual interrelationship between humans and technical system considering the human operator as an integral part of the system. However, to use the full potential of this idea the technical system has to be perceived and accepted as a team-partner. Anthropomorphism is a promising approach to improve the acceptance of a robotic system as a team-partner. In the first part of this joint contribution we introduce a study focusing on the effect of anthropomorphism in industrial environments. A virtual environment consisting of a robotized assembly cell was utilized to conduct a prediction experiment with 24 participants comparing anthropomorphic movements and trajectories based on linear and angular kinematics of an articulated robot. The task was to predict the target position during movement. The corresponding reaction value and the prediction accuracy were analyzed.

Keywords: Human-robot interaction, anthropomorphism, socio-technical system, prediction, self-optimization.

1 Introduction

Increasing globalization and the resulting cost pressure require a flexible adaptation of manufacturers to market conditions in order to meet the demand for diversity or short product life cycles. The necessary flexibility cannot be achieved by fully automated systems. Therefore, investigating the possibilities for increasing flexibility of production systems is an important issue. The integration of the human operator and the cooperation with robotic systems seems to be a promising approach to enable the optimal combination of different capabilities of humans and robots and thereby results in more flexible and agile.

When considering the coexistence of robotic systems with humans, it is necessary to ensure the occupational safety of people. Besides this aspect, when working with a robotic co-worker, the level of stress, comfort and trust of the human operator during the interaction is also a decisive factor for an effective collaboration [1], [2]. Therefore; the analysis of factors influencing the human acceptance of the robot as a

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partner is a central issue. For this reason, current work in the field of human-robot interaction focuses on the idea of anthropomorphism, i.e. the simulation of human characteristics by non-human agents. By transferring anthropomorphic features such as appearance on robotic systems, a higher level of safety and user acceptance can be achieved [3].

Anthropomorphism is an approach that is already used in the area of social or humanoid robotics because there is almost no physical separation between humans and robots. The simulation of human behavior by an industrial robot is rarely investigated because the focus in manufacturing environments lies more on the design of fully automated systems that should operate robustly and efficiently without human interaction or cooperation. Nonetheless, depending on the market situation, these systems quickly reach their limits in rapidly changing manufacturing environments and the integration of the human operator becomes more and more important. Focusing on scenarios with human-robot interaction or even cooperation, anthropomorphism might be an important design principle in order to achieve a safe, effective, and efficient cooperation between humans and robots in industrial environments. Especially with regard to self-optimizing production systems the ability to plan and execute a process autonomously raises the complexity of these systems so that the system behavior cannot always be anticipated by the human operator. Therefore, within a sub-project of the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" at the RWTH Aachen University the interaction between human and a cognitively automated robotic system is investigated. In order to guarantee an effective teamwork between man and machine within such environments in terms of a socio-technical concept, the system behavior should be understandable and predictable to ensure transparency. In other words, the human has to be able to understand and trust the system as well as associate it with intelligence. For this purpose, Krach et al. [4] proved a positive correlation between the degree of human likeness and the perceived level of intelligence of a non-human entity.

The empirical study that will be presented within this work focuses on the effect of anthropomorphism in assembly environments, in particular in motion behavior of an assembly robot. This idea is mainly based on the scientific evidences concerning the neural activity of the brain when watching someone performing an action. These special brain areas (mirror neurons) in humans and non-human primates are activated both by action generation and observation of other humans' actions [5], [6]. Researchers claim, that mirror neurons may explain a variety of social cognitive functions such as the action and intention recognition of others. Based on these results, Gazzola et al. [7] have investigated human mirror neurons during the observation of simple robotic actions and reported a significant activation of these special brain areas. Hence, the research question focuses on how movement trajectories (anthropomorphic vs. conventional movements) of a gantry robot might affect the predictability of its behavior. The paper is divided into two parts. In the first part the results of the first empirical study on the research question are presented. The second part of the paper concentrates on the deeper analysis and discussion of the findings of the first study and the results of a subsequent study related to this issue [8].

2 Anthropomorphism in Industrial Environments

Recent research has repeatedly shown that anthropomorphism is an interesting concept to improve the human-robot interaction [9]. Concerning industrial environments a subarea of the European research project ROSETTA focuses also on human like design of industrial robot systems in order to increase the acceptance of human when cooperating with such systems. The investigation focused on an anthropomorphic model of the kinematic control of an industrial robot during manipulation tasks. For each position of the end effector the anthropomorphic posture of the elbow joint can be calculated by a human inspired movement pattern algorithm. The study could empirically prove that by applying the kinematic control on a 7-degree-of-freedom (7-DOF) anthropomorphic manipulator, a reduction of the stress level of the humans working side by side with the robot can be achieved [10].

Huber et al. [11] also investigated how human cooperation characteristics can be transferred to human-robot cooperation scenarios. In this case a handover process was used, in which the human-human, human-robot and human-humanoid cooperation were compared to each other. They used a human-inspired trajectory that was modeled after the maxim of a free flow as smoothly as possible and compared it to a trajectory that resulted from a trapezoidal velocity profile. Results of this analysis have shown that reaction times of the humans concerning human-inspired trajectories were lower than the trapezoidal case. Findings concerning anthropomorphic characteristics in appearance could also prove shorter reaction times. Because of the results concerning the appearance, the hypothesis was generated that human trajectories as opposed to trajectories based on simple inverse kinematics could lead to a further improvement of the reaction times.

Moreover, in contrast to traditional approaches in industrial robotics, there are an increasing number of new concepts for automation solutions with human-like characteristics such as two-armed robots [12], [13]. Accordingly based on these findings, augmenting the movements of an industrial robot with anthropomorphic features might be a promising approach to improve safety.

3 Method

To address the aforementioned research question, a first study with a repeated measures design and three within-participants factors (perspective, movement type, and position) was conducted by means of a virtual simulation environment consisting of an assembly robot and its workplace. A C++ simulation program which was already utilized in different empirical studies within the Cluster of Excellence was adapted and employed as testing environment [14]. The simulation scene comprises a six-axis gantry robot that could be regarded as a real human arm in a real "placing" situation. A black and white grid with 20 fields was used to illustrate the working area of the robot. Within the study the focus lies on how movement trajectories (anthropomorphic vs. conventional movements) of an assembly robot might affect the predictability of its behavior. The movement type (anthropomorphic vs. robotic), the field position and the perspective (frontal vs. lateral) were considered as independent variables, whereas the reaction time, the relative reaction way and the prediction accuracy were the dependent variables. The prediction accuracy was analyzed in terms of correct, incorrect and missing predictions. The reaction time describes the elapsed time from the beginning of a movement sequence until the prediction of the participant and the relative reaction way is the percental part of the presented movement trajectory that was tracked from the start of a movement until the subject predicted a target field. Furthermore the sequence of the testing conditions to be passed was permuted to avoid order effects. For the evaluation process the virtual working area of the assembly robot was divided into rows and columns in order to be able to make further analysis regarding the incorrect predictions (see Fig. 2).

3.1 Pre-study: Generation of the Human Motion Data

In order to generate the movement data for the main empirical study, a preliminary experiment was conducted using an infrared optical tracking system. Therefore, human motion trajectories during placing an object were recorded and analyzed. For the execution, the participant was standing in front of a table, where black plastic discs were mounted at regular intervals for placing a cylindrical object (see Fig. 1). As depicted in the figure, the participant always started in the same posture in front of the table and placed the cylinder with markers in the black marked area on the grid without changing the posture of the body. The data recorded by the motion tracking system represent the trajectory of the human wrist during the execution of the placing movements. In addition to the cartesian coordinates, the duration of the complete movement from the start position until placing the object was also computed. Figure 1 represents on the right side the human and the conventional point-to- point robot trajectories for the same starting point and end points in comparison.

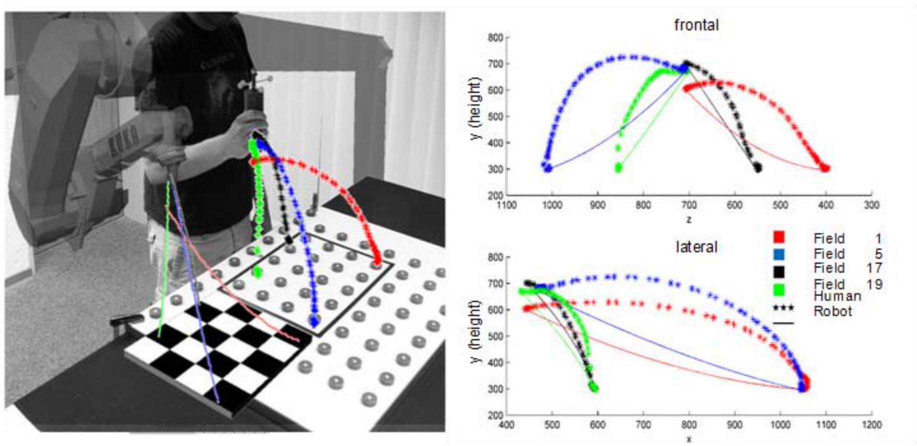

Fig. 1. The experimental setting for motion tracking in comparison to the virtual environment with the corresponding robotic and the human movement trajectories (left) and the acquired trajectories (right)

The trajectory of the robot proceeds on a relatively straight course, whereas the recorded human movements appear more curved. Afterwards, the human motion data were adapted to control the articulated robot in the simulation environment.

3.2 Procedure

The main study can be divided into three different phases. Within the first phase the personal data of the participants were collected, e.g. age, profession, experiences with 3D simulation environments (e.g. computer games) as well as with robotic systems. Afterwards, a visual acuity test, a stereo vision test, and a color vision test were carried out to control intervening variables related to visual perception. After completing these pretests, the participants were seated in front of a TFT LCD 28" monitor, and were asked to observe the virtual articulated robot while performing different pick and place operations on the grid. To avoid order effects, the study started with the frontal perspective for the one half of the participants and with the lateral perspective for the other half (see Fig. 2). During the observation part of the study, the virtual robot placed the cylinder on every field of the grid. Each of these 20 fields was approached by both the human trajectories and the conventional point-to-point robotic movements whereby the order of the motion sequences was permuted before each experiment. The participants should monitor each of these 40 motion sequences per perspective and predict the target field as early as possible within the duration of the presented movement trajectory by using a computer mouse. After all 40 motion sequences have been executed within the first perspective, the view changed and the same motion sequences were again presented from the other perspective. After marking a field the simulation was interrupted and the next motion sequence could be started by the participants. During the experiment the corresponding reaction time, the relative reaction way and the prediction accuracy were collected for later examinations.

Within the last phase the participants were asked to give their opinion about which perspective has improved the predictability best.

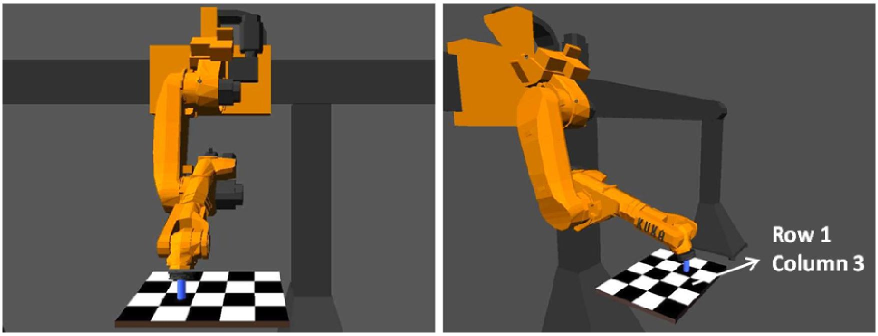

Fig. 2. The virtual scene presented from the frontal (left) and the lateral perspective (right)

3.3 Participants

A total number of 24 male subjects, who are either taking part in an engineering bachelor/master program or have just graduated, participated in the study. The participants were aged between 20 and 33 years (mean 25.21 years, SD 3.799). 83% of the participants had already experience with 3D simulation environments. Almost 38% of the subjects had worked with robotic environments and even 33% of them for several months. All of the participants passed the visual acuity test, the stereo vision test, and the color vision test.

4 Results

A total of 1920 predictions were carried out by the participants. According to the experimental setup, each cell was approached four times (two different profiles combined with two perspectives).

In 216 presented movement trajectories the selection of the target field by the participants was not done within the movement duration. The distinction between the movement types shows a much higher value of 82.41% for the conventional robot movements than for the human trajectories, where participants could not answer in 17.59% of the cases in a timely manner. 51.85% of the missing predictions are within the frontal perspective and about 48.15% are within the lateral one.

The number of correct predictions, i.e. the matches between the approached target position by the robot and the subjects marked field, is only 112 for both perspectives. 78.57% of the correct predictions are within the frontal and 21.43% within the lateral perspective. This small number of correct predictions shows that the experimental task was quite difficult and stressful so that it was in general not easy for the participant to recognize the right target area. This might be caused due to the lack of depth information in the visualization, which was also remarked by the subjects during the study.

Furthermore, we analyzed the absolute row and column distance between the predicted field of the participant and the correct target position. The average column distances were in general very small, and for both perspectives nearly the same. Analyses show that the minimum of the average column distances between the predicted field and the correct target position are close to zero and the maximum is less than 0.6. The average row distances are in contrast to the column distances much higher. Results for the lateral view show that compared to the conventional robot trajectories, human movements lead in the first two rows (the upper section of the work area from the standpoint of the assembly robot) to higher average deviations from the target field (see Fig. 3). This effect is reversed for rows 3 and 4. The row distances concerning the frontal view are similar to the ones for the lateral view so that the same applies here: the row distances in the front areas of the virtual workplace are lower for human motion trajectories than for the robotic ones.

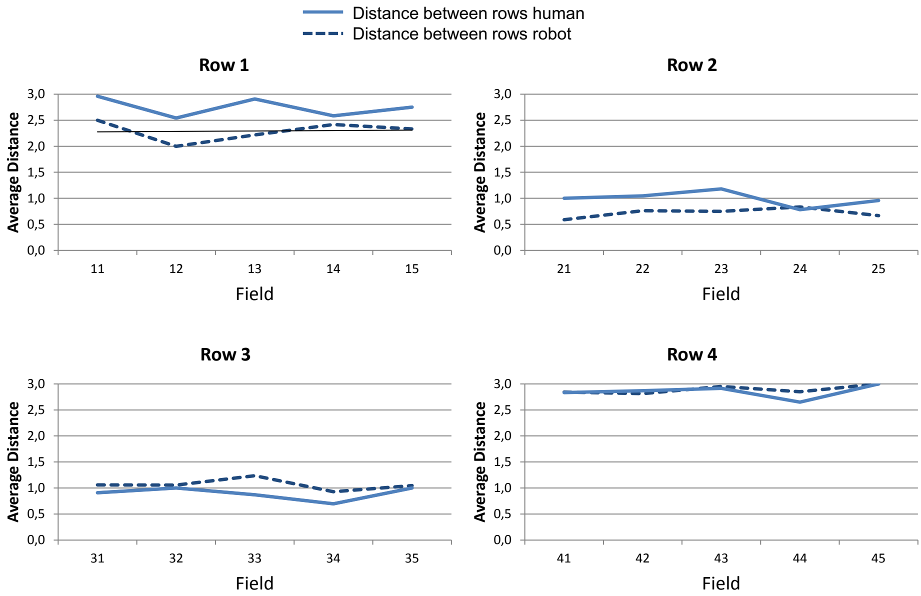

Fig. 3. Average values for row distances between the prediction and the target field (lateral view)

Regarding the reaction time inferential statistics did not show any significant effects neither for the perspective nor for the movement type. Only the field position has a significant effect on the reaction time, which is not examined in detail within this work. Afterwards the different perspectives were analyzed separately, but the analysis of variance did not reveal any significant effects of the movement type on the absolute reaction time.

Concerning the relative reaction way the analysis of variance again could not reveal any significant effects neither for the movement type nor for the perspective. However, the statistical analysis of the different perspectives showed significant results regarding the lateral perspective. The analysis shows that both the type of movement ($F(1, 23) = 6.647$, $p = 0.017$) as well as the position ($F(19, 437) = 7.449$, $p < 0.001$) have a significant effect on this variable. There is also a disordinal interaction effect between the movement type and the position ($F(19, 209.683) = 7.036$, $p < 0.001$), whereby the main effects could not be interpreted separately. Nevertheless, on closer examination of the means of the relative reaction way for the different rows on the grid, the already mentioned tendencies are confirmed. The comparison shows that the reaction way for fields that are closer to the virtual robot (row 3 and 4) are shorter for anthropomorphic movements than for robotic ones (see Fig. 4).

At the end of the experiment the participants were asked to indicate which perspective they would prefer concerning the prediction and about 70% stated that they would intuitively favor the lateral view.

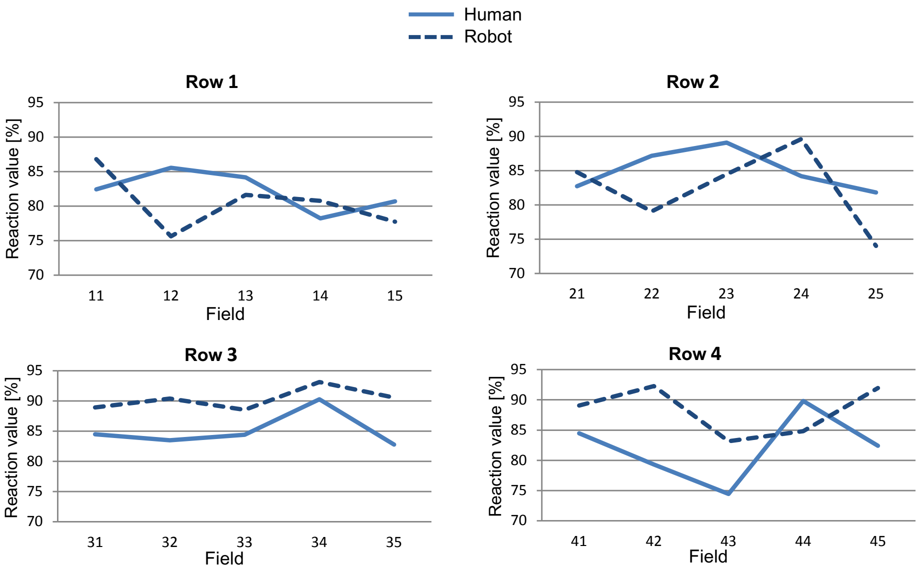

Fig. 4. The relative reaction ways [%] in comparison for different rows on the virtual work area (lateral view)

5 Summary and Outlook

The goal of this paper was to present the results of the first experimental study in which the impact of human-like motion patterns of an industrial robot on human prediction of target positions of placing movements were examined. A laboratory study was conducted, where anthropomorphic movements were compared to conventional robotic trajectories by means of a simulation environment. Therefore, pick and place movements of the human were tracked by an optical motion capture system. The captured data were analyzed and adapted to control the articulated robot in the simulation software. The prediction accuracy, the reaction time and the relative reaction way were analyzed as dependent variables during the evaluation process.

The prediction accuracy was divided into the missing, the correct and the incorrect predictions. Results concerning the missing predictions show that within both the frontal and the lateral perspective the participants more often failed to mark a target field concerning the conventional robot trajectories than the human movements. The number of correct predictions was very small. The probable reason for this might be the lack of depth information of the visualization of the simulation environment. The incorrect predictions were investigated by means of the absolute row and column distances between the prediction field of the participant and the correct target position. Results concerning the average row distances show in both perspectives that compared to the human movements the conventional robot trajectories lead in rows 3 and 4 to higher average distances from the target field. For rows 1 and 2 the average row distances were higher for the anthropomorphic trajectories.

Concerning the relative reaction way, findings showed that both the movement and the position have a significant effect on this variable. Due to the disordinal significant interaction effects, the interpretation of the two main effects was not possible. Nevertheless, the comparison of mean values for the different rows on the grid, the same effect as for the incorrect predictions is evident for the average values of the reaction way. In general this value was better at short distances (rows 3 and 4) for the anthropomorphic movement trajectories and at longer distances for robotic ones. Regarding the absolute reaction time inferential statistics did not show any significant effects.

A clear limitation of this study was that it was conducted by means of a virtual testing environment; hence an interesting avenue for future work is the investigation of the impact of anthropomorphic movement trajectories on human prediction under real conditions.

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References

1. Oleson, K.E., Billings, B.R., Kocsis, V., Chen, J.Y.C., Hancock, P.A.: Antescendents of Trust in Human-Robot Collaboration (2011)
2. Billings, D.R., Schaefer, K.E., Chen, J.Y.C., Hancock, P.A.: Human-robot interaction: developing trust in robots. In: Proceedings of the 7th ACM/IEEE International Conference on Human-Robot Interaction, Boston, Massachusetts, USA, pp. 109–110 (2012)
3. Duffy, B.: Anthropomorphism and The Social Robot. Special Issue on Socially Interactive Robots. Robotics and Autonomous Systems 42(3-4) (2003)
4. Krach, S., Hegel, F., Wrede, B., Sagerer, G., Binkofski, F., Kircher, T.: Can machines think? Interaction and perspective taking with robots investigated via fMRI. PLoS ONE 3(7), e2597 (2008)
5. Rizzolatti, G., Fadiga, L., Gallese, V., Fogassi, L.: Premotor cortex and the recognition of motor actions. Cognitive Brain Research 3, 131–141 (1996)
6. Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Paulesu, E., Perani, D., Fazio, F.: Localization of grasp representations in humans by PET: 1. Observation versus execution Experimental Brain Research 111, 246–252 (1996)
7. Gazzola, V., Rizzolatti, G., Wicker, B., Keysers, C.: The anthropomorphic brain: The mirror neuron system responds to human and robotic actions. Journal of Neuroimage 35(4), 1674–1684 (2007)
8. Kuz, S., Mayer, M.P., Müller, S., Schlick, C.M.: Using Anthropomorphism to Improve the Human-Machine Interaction in Industrial Environments-Part I. In: The Proceedings of the 4th International Conference on Digital Human Modeling and applications in Health, Safety, Ergonomics and Risk Management, Las Vegas, NV, USA (2013)
9. Eyssel, F., Kuchenbrandt, D., Bobinger, S., De Ruiter, L., Hegel, F.: If You Sound Like Me, You Must Be More Human’:On the Interplay of Robot and User Features on Human-Robot Acceptance and Anthropomorphism. In: Proceedings of the Seventh Annual ACM/IEEE International Conference on Human-Robot Interaction, pp. 125–126 (2012)

10. Zanchettin, A.M.: Human-centric behavior of redundant manipulators under kinematic control, PhD Thesis, Politecnico di Milano (2012)
11. Huber, M., Rickert, M., Knoll, A., Brandt, T., Glausauer, S.: Robot and Human Interactive Communication. In: The 17th IEEE International Symposium on RO-MAN 2008, Munich, Germany, pp. 107–112 (2008)
12. Baxter's Capabilities: A unique robot with unique features, `http://www.rethinkrobotics.com/index.php/products/baxter/`
13. ABB concept robot for small parts assembly applications (FRIDA), `http://www.abb.de/cawp/abbzh254/8657f5e05ede6ac5c1257861002c8ed2.aspx`
14. Odenthal, B., Mayer, M., Ph., K.W., Kausch, B., Schlick, C.M.: Investigation of Error Detection in Assembled Workpieces Using an Augmented Vision System. In: Proceedings of the IEA 17th World Congress on Ergonomics (CD-ROM), Beijing, China, pp. 1–9 (2009)