Simulation and participatory design of HRI work systems in the SOPHIA project

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Abstract: Human-robot interaction (HRI) systems have not yet been fully established as industrial applications. Besides technical and economical reasons, the perception of employees who interact with the system is crucial. The SOPHIA project aims at developing new forms of HRI applications and implementing them in concrete industrial use cases in order to increase the productivity and flexibility of existing work systems and to improve their ergonomics. The paper describes the methodical procedure using a 3D process simulation to define the technical and user-specific requirements. The simulation is combined with a systematic evaluation of the expectations of potential users of the HRI system to ensure a human-centred design. First results are presented based on an HRI implementation in a Dutch SME company.

Keywords: Human-robot interaction, ema Work Designer, Digital human modelling, Worker evaluation, Human-centred workplace design

1. Introduction and objectives

After initial euphoria, a wide spread of HRI systems in which humans and lightweight robots work directly with each other is still missing in industrial practice. Besides the technical and economical requirements, a high task-technology fit as well as the early consideration of the user perspective are required in order to ensure an efficient and healthy design. The project "Socio-Physical Interaction Skills for Cooperative Human-Robot Systems in Agile Production" (SOPHIA, www.project-sophia.eu), funded by the European Commission, aims at developing work systems with humans and robotic components in order to increase the productivity and flexibility of manual manufacturing and improving its ergonomics.

For this purpose, the project combines the competences of interdisciplinary professions and institutions: for the development and implementation of technological components (e. g. University of Montpellier; Istituto Italiano di Tecnologia), for virtual work planning and validation of feasibility and ergonomics (imk automotive GmbH) and for the analysis and consideration of the user's perspective (Federal Institute for Occupational Safety and Health; Vrije University of Brussels). In addition, three industrial partners are involved, where concrete applications will be implemented (Hankamp Gears, a Dutch SME; HIDRIA, a Slovenian medium-sized supplier company; Volkswagen Sachsen, an automobile OEM).

2. Methodology for a participatory design process of HRI systems

Within the project SOPHIA a holistic approach for planning and implementation of HRI systems is applied. In the following the single steps are described in detail.

2.1 Initial analysis and digital planning

In order to determine if HRI systems may be implemented in a certain industrial use case, a "Quick Check" methodology is applied to assess the technical and economical potential for improvement of productivity, flexibility and ergonomics. This method was developed in a previous project funded by the German Ministry of Education and Research (BMBF) called "KOMPI", freely available at: https://kompi.org/quickcheck/. The checklist tool enables practitioners in production planning and industrial engineering as well as researchers to efficiently identify potential HRI use cases in a certain industrial setting and compare cost and benefits of different HRI solutions before they are being implemented.

After a specific use case is identified, the technical specification needs to be worked out in detail (e. g. type of robot, gripper, additional sensors, etc.). In parallel, a holistic 3D simulation of the manual (=current system) and the semiautomatic (=future HRI system) work process is prepared (Seckelmann, Barthelmey, Kaiser & Deuse, 2019) using the software "ema Work Designer" (emaWD) provided by imk automotive GmbH (Leidholdt, Fritzsche & Bauer, 2016).This tool is typically used for the digital planning and assessment of manual work tasks in different industry applications (Fritzsche, Ullmann, Bauer & Sylaja, 2019). However, it has been improved and enhanced during in the last couple of years in order to realistically simulate the motion behavior and synchronized task completion of humans and robots in one scene. Beside the regular task-based and parametrized human operations, a set of machine operations and a large library of containing technical specifications and limitations of available heavyweight and lightweight robots has been included . Simulation results include the visualization of the HRI work process, an automatic assessment of productivity based on MTM-standard (e. g., production time, value added content, walk path) and an ergonomic risk assessment based on EAWS-standard (Schaub et al., 2012). In addition to that, more HRI-related features were integrated, such as the security check according to ISO/TC 15066 standard and the event-based sensor control, in order to validate feasibility and safety of the technical HRI-system (Spitzhirn & Kaiser, 2020).

2.2 Worker evaluation: methodology and analysis

Within SOPHIA project, we have identified different concepts for joint evaluation that will help us to describe and better understand the working environment of our use case in order to optimize the interaction quality between workers and obotic systems from a human-centred perspective. The evaluation process is based on the HTO framework: the human (H), the technology (T) and the organisation (O) (Karltun et al., 2017). For the worker characteristics (H), we considered their prior experience with robots respectively working with robots. To do so, we used three items with a response format from 1 "strongly disagree" to 5 "strongly agree" and the option to choose "no idea". For technology characteristics (T), we focused on the expectations regarding the form of interaction using three open questions considering expected changes caused by the use of a robot and the associated benefits and challenges in a short-term as well as long-term perspective. For task-related characteristics (O), we used the concept of job control. Job control or job autonomy (including the concept of decision latitude) is one of the most important factors related to the design and quality of working tasks (Häusser et al., 2010; Rosen & Wischniewski, 2019). For this analysis, we used eight items based on the BIBB/BAuA employment survey (Wittig et al., 2013) addressing different aspects of job control: *Timing control, method control* and *decision latitude*. The answering format allowed respondents to rate the degree of job control form 1 "never" to 4 "often". Additional questions regarding the perception of robots in the media, expected system usability and technology acceptance were also addressed.

3. Study design and results of the first use case

The SOPHIA methodology including quick check, technical requirements specification, 3D validation, and human factors analysis was firstly applied in an use case at Hankamp Gears, a SME (= small and medium-sized enterprise) supplier of gears for automotive and aviation industry located in Enschede, Netherlands.

3.1 Use case description

Lifting tasks conducted by employees of Hankamp to load machines are repetitive and often performed in poor ergonomic positions which make these tasks physically demanding. A variety of lifting aids such as overhead cranes and forklifts are available at the company, but these aids are rarely used for small payloads since they are regarded as bulky and impractical. The company therefore decided to look for lightweight HRI robots (“cobots”) that are able to support frequent lifting tasks.

After analyzing potential work stations at the shopfloor and evaluating costs and benefits, it was decided to start with a first implementation at a certain CNC-machine that is cutting and deburring raw parts of about 5 kg weight. The cobot would take over pick-and-place activities of this part to and from the CNC-machine, while the human would still be doing more complex and filigree actions like clamping/unclamping, part cleaning and quality control.

Based on the company's requirements and the technical specification analysis, the use of the ROBOTNIK RB-KAIROS 16 manipulator, a mobile platform with a Universal Robot (UR16) arm mounted on top, was proposed. This cobot solution can handle parts up to 16 kg of weight and move omni-directional guided by a set of integrated sensors. Hence, it provided sufficient flexibility both from a technical point of view and with regard to possible other applications adapted to the specific conditions of the Hankamp production system.

3.2 Results of digital planning and 3D validation

After pre-selecting the ROBOTNIK platform, a 3D simulation was created using emaWD software. In order to create realistic simulations we firstly analyzed the current situation based on available documents provided by Hankamp, such as work instructions, videos of the current work process, CAD-data of machines, parts and logistics, etc. This data was used to create a full process simulation of the current work situation (as-is) that was iteratively detailed during discussions with Hankamp.

In the second step, we included a 3D model of the selected cobot in the scenario (see Figure 1). We discussed task distribution between human and cobot with Hankamp in order to assign suitable subtasks to both partners of the HRI work system.

The 3D simulation was now used to validate the desired task distribution in terms of feasibility, safety, synchronization/waiting times, walk/drive paths, etc. This way we detected some issues that needed optimization: to ensure the necessary accessibility, a socket of approx. 30 cm height was added and the speed was set to 0,25 m/s for safety reasons based on ISO/TC 15066.

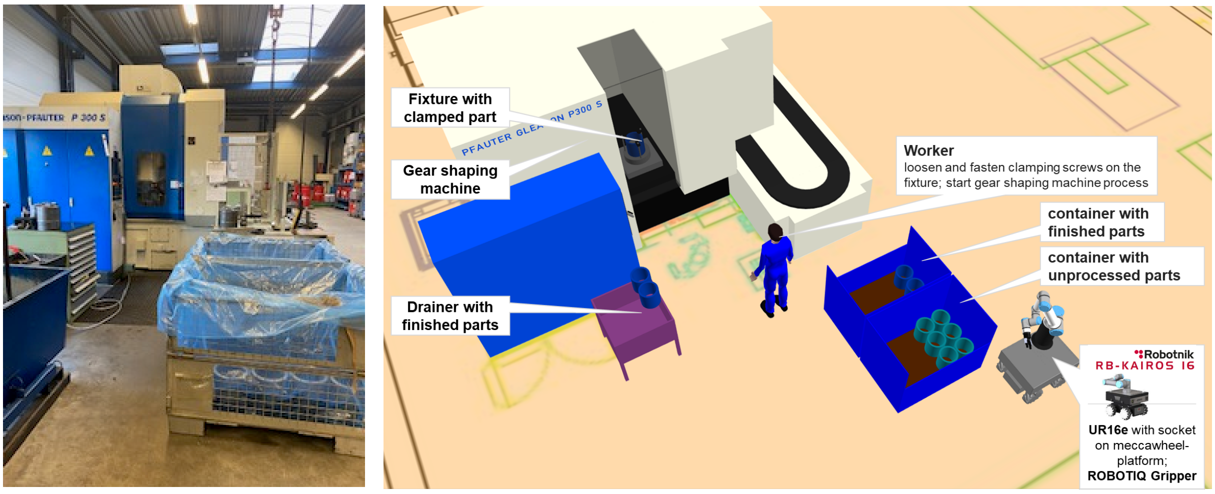

Figure 1. *real workstation at Hankamp (left); 3D simulation with emaWD incl. cobot platform (right).*

After all optimization loops we concluded that the RB-KAIROS platform will be able to perform the tasks as required and that the planned set-up will improve ergonomics and productivity substantially: Firstly, active worker time based on MTM standard is reduced by 32 % and available time for other tasks is increased by 18 %. Secondly, walk ways at that workstation are strongly reduced by 83 %, since the cobot is taking over most of the motions needed for the pick and place tasks. Thirdly, the use of the cobot also reduces the ergonomic risk score at this work station based on EAWS standard by 59 %, transforming a previously critical work station with high ergonomic risk (“red”) to a workstation with low ergonomic risk (“green”).

3.3 Results of worker evaluation

After creating the initial technical concept, workers were asked for their opinion with regard to implementing a cobot work station at Hankamp. Beforehand an ethics approval was obtained and a data privacy statement was conducted and approved by BAuA’s data privacy officer. In total, seven workers participated in the survey. All of them were directly connected to the identified use case in the pilot area. Because on-site visits were not possible due to the COVID-19 situation, we set up two video calls where workers participated in small groups. To give a better idea of the intended scenario, we showed them pictures of the addressed deburring workstation and the specific robot. Any robot or use case related question that arose was answered by the company’s lead process engineers. Workers were then asked to picture themselves working together with the cobot. They filled in paper pencil versions of the survey which were returned via mail.

For the quantitative data, we focused on a descriptive analysis. The first question refers to the familiarity with robots. In total a high mean of *M*=4.3 (*SD*=0.5) was given (“*How often have you seen robots in real life?*”). The item “*I have a lot of experience in working with a robot*” was rated slightly lower (*M*=3.0; *SD*=0.8). We cumulated these two items to create a value for prior experience with relation to the working context. In result, the overall prior experience with robotic systems of the sample shows a mean of *M*=3.6 (*SD*=0.9), which is above average. In addition, the participants agree that they feel proud that robots would be used in their company (*M*=4.3; *SD*=0.5). For the analysis of job control, we recoded some questions in such a way that a high value represents a high level of job control. Table 1 presents the mean for each subscale and an overall mean for the perceived level of job control.

Table 1. *Means and standard deviations of Job control scales.*

Scale	Mean	S.D.
Timing control	2.9	1.0
Method control	1.4	0.6
Decision latitude	2.7	0.7
Job control	2.4	1.1

In addition, we collected some qualitative data regarding the expected form of collaboration. The material was screened and anaylsed by two independent reviewers. The most frequent aspect regarding task changes caused by the implementation of the robot was the expected improvement in terms of physical ergonomic parameters. Because the robot can perform various tasks, "*repetitive (human) movements are (will be) obsolete*" and the work becomes "*less physical*". This gives "*more time to do other things instead of making production*", i.e. it is assumed that the use of robots will lead to an increase in the variability of tasks. One of the participants also addressed cognitive ergonomic improves in terms of "*less strain*" due to the usage of the robot. Another one stated "*It doesn't change; it just becomes easier and less physical*". Besides, a general improvement of the production process and productivity was brought up by the participants. When assessing the expectation of benefits, a short-term as well as long-term perspective was addressed. The improvement of physical ergonomics and productivity as well as an increase of task variability were again addressed by most participants. For example "*fewer physical complains*", that they feel less tired, "*less suffering joints and muscles*" and the "*preservation of your physical condition*" are expected. But also wellbeing and a relation between physical improvements and age were derived: "*less physical load as a result of which in an older age you have fewer complaints or would never get worse from them*". Besides benefits, potential problems when using a robot (short- and long-term) were also identified. In this regard, mostly technical problems and malfunctions where mentioned. However, "*if all technical problems have been solved*" the participants do not see any problem for their daily routine, nor for physical or cognitive ergonomics. Nevertheless, one employee indicated the "*loss of staff*" as a potential problem caused by the usage of the robotic system.

4. Discussion and limitations

The results of this use-case study show that the general methodological approach in SOPIHA is suitable for designing a strong technical and social implementation concept for HRI systems.

Overall the results for the evaluation of physical ergonomics and productivity are very promising and clearly show that the integration of the cobot is likely to create to a more productive and ergonomic workstation. In order to use personal experiences and opinions in the sense of a human-centred work design, the employees' attitudes and expectations were involved at an early design stage. Overall, based on the quantitative and qualitative analysis, it is expected that the introduction of the robot will result in mainly positive task changes and it is expected that benefits will outweigh problems that may occur.

Because only a limited number of participants were available, the results need to be interpreted with caution when applied to other use cases. This specific sample overall shows a very positive attitude towards robots in the workplace. Other workforces might show opposite results being more hesitant and sceptical towards robots, which would need to be addressed more carefully in the introduction process. The analysis of the target groups' attitude towards robots is therefore highly recommended for each individual use case.

Within the ongoing project period of SOPHIA the final implementation of the robotic system will be evaluated, too. This evaluation will focus on the workers' perception of the overall interaction quality, system usability, and changes regarding the perceived level of job control as well as the emotional experience and strain when actually interacting with the robotic system. Of course, the final evaluation will also prove if the predicted gains in productivity and ergonomics will come true.

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