Application Areas for Human-Centered Assistive Systems

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ABSTRACT
With the advances of technology, intelligent assistive systems that adapt to individual humans will become feasible. However, application areas of such systems are rarely discussed within the *Industry 4.0* community. Most assistive systems that have been presented have been developed for specific task, such as assembly support or warehouse picking, but there might be a huge uncovered design space to be explored. With this work, we want to step back from existing systems and analyze the design opportunities of assistive systems especially for small and medium-size enterprises (SME). To achieve this goal we conducted a study in four SME, consisting of observations and interviews. Here we present our findings about the potential future application areas of human-centered assistive systems.

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Industry 4.0; Assistive Systems; Small and Medium-Sized Enterprises; SME; Human-Centered Design; Human-Computer Interaction for Industry;

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H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
Until recently, the digitalization of the manufacturing sector – referred to as *Industry 4.0* - has mainly been addressed from a technical point of view. But since the paradigm of *Industry 4.0* will significantly disrupt the way humans work in industrial environments it is advisable to take a human-centered standpoint when developing interactive industrial systems. Our current research is concerned with the development and implementation of assistive systems for manufacturing purposes. Theses systems represent one specification of cyber-physical systems, the corner stone of *Industry 4.0*. Current sensor and actuator technologies offer the opportunities to overcome on-sizes-fits-all approaches. Hence, our long-term goal is to design intelligent assistive systems that adapt to the individual human rather than the other way round. As a first step towards this end we undertook user research efforts in relevant industries in order to identify application areas for such human-centered assistive systems. Initial research showed that especially small and medium-sized enterprises (SME) are hesitant to embrace *Industry 4.0* technology due to various reasons. Therefore we selected four SME to perform an in-depth study to reveal design opportunities for assistive systems. These enterprises are intentionally from different domains in order to cover a broad spectrum and later derive universally applicable hypotheses. In a nutshell, our goal is to improve work satisfaction with regard to a workers well-being and thus increase the quality and performance of the entire sociotechnical system.

RELATED WORK
The support of users through new technology and with assistive systems is addressed in a lot of publications. Bringing new interaction technologies and paradigms, such as augmented reality into industry is often discussed within the *Industry 4.0* community, e.g. in [5].

Early works focused particularly on warehouse picking (e.g. [12] and [15]) with the assistance of augmented reality glasses and the systems have been evaluated in empirical studies (e.g. [7] and [16]). In the last years there have been many studies and prototypes for the support of manual assembly work with assistive systems: Billinghurst et al. [2] present assembly support with a mobile device. Grubert et al. [6] and Paelke et al. [11] analyze the use of augmented reality assistive systems with smart glasses to help users with assembly tasks. Lately, the research focus has shifted to projection-based assistive systems for manual assembly, e.g. the systems developed in the MotionEAP-project ([4], [8], [9], and [10]) and the systems presented by Büttner et al. [3] and Rodriguez et al. [14]. Activity recognition in the context of assistive systems has been presented by Aehnelt et al. [1], Korn et al. [8], and Röcker et al. [13].

The presented publications show that assistive systems in the area of assembly and warehouse picking reached a high level of maturity, at least in research labs. However, such systems are rarely used in SME and despite diverse efforts to promote the use of new Industry 4.0 technology in SME, such systems have a very low prevalence in SME [5].

With this work we want to add to the ongoing research with an analysis of potential application areas besides the mentioned warehouse picking and manual assembly. We want to find new design opportunities that are especially relevant for SME and start a discussion, how existing research results can be transferred into practical applications that are relevant for SME.

METHOD

We visited four different SME from the domains of manufacturing, logistics and recycling. For each of the companies, we held a semi-structured interview session with different stakeholders. For one interview session we recruited at least one participant from each of the following groups: CEO / management, engineer / technical expert, employee. The interview sessions were prepared specifically for the related enterprise. Some of the interviews were held in the work context of the employees (contextual inquiry). Additional to the interviews, we did field observations to get an in-depth knowledge of the work context.

APPLICATION AREAS

Based on our four selected SME, we show the following application areas for human-centered assistive systems. We describe the general situation, the identified needs and the resulting design opportunities.

Recycling: 0 to 1 Digitalization

General situation: Although it is widely acknowledged that digitalization is imminent, especially SME are either hesitant or even unwilling to fully commit and take actions towards networking their processes, operations and means of production. Many are heavily entangled in their daily business leaving little room for strategic action.

Our first object of investigation represents the group of *Industry 4.0* novices, i.e. there is a very low degree of digitalization. As an actor in the domain of metal recycling this business is characterized by a high amount manual work processes. It is physically demanding work were there is currently no effective digital counterpart. Humans are disassembling large pieces of machinery or sorting small objects in loud industrial workplaces. Especially the sorting of pieces of metal not bigger than a few centimeters (so called flakes) is an activity, which puts a lot of strain on the worker, physically but also cognitively.

Need: There is a need to quickly and efficiently elevate the enterprise from 0 to 1 in terms of digitalization by implementing assistive system at carefully selected points within the organization.

Design Opportunity: The goal is to draft measures for Industry 4.0 starters, i.e. to digitally model the most important processes and operations and then install basic assistive systems for selected activities. Thus, organizing the work and the workforce shall be facilitated while at the same time reduce the strain on workers.

Approach: In face of literally a blank sheet in terms of digitalization a divide and conquer approach appears to be most suitable. Practically this means that we first establish a basic digital infrastructure to better monitor and manage processes and tasks. Additionally, the most pressing needs in terms of human factors are addressed by implementing an assistive system as a pilot in order to demonstrate the benefits of such systems to all stakeholders.

Fine Assembly: Taking the Next Step

General situation: Having observed the novice we now shift our attention to the other end of the spectrum. The next application area we investigated can be labeled as fine assembly, i.e. the production of sophisticated products such as sensor systems. In contrast to the rugged industrial environment we discussed earlier we now find ourselves on an almost sterile shop floor. Here we are dealing with a variant-rich product portfolio. Hence, the production relies heavily on complex manual assembly activities. This demands a skilled workforce and extensive training, especially because workers are deployed to different assembly stations depending on the production order. Generally, the company is characterized by a fair degree of digitalization. Moreover, workstations are designed according to ergonomic standards and people are working in one-piece-flow contexts, which cater for higher work satisfaction.

However, according to our contextual inquiry there is still room for innovations. We focused on a manual assembly station. Such a workstation consists of many boxes containing the parts that are necessary to assemble the product or sub-assembly groups. The instructions are still paper-based. Since the parts are generally small and often look quite similar it is cognitively demanding to select and assemble the correct parts. Moreover, due to the small size the workers need to possess great motoric skill and the ability to concentrate for longer periods. Combined with the great number of variations this yields a considerable complexity. Hence, the process is potentially exhausting and prone to errors.

Need: There is a need for diminishing cognitive strain and thus reducing the risk for errors without patronizing the skilled worker. Additionally, there exists a need for training tools.

Design Opportunity: The Goal is to offer digital assistance by externalizing memory load. Thus, the worker could concentrate even more on the assembly process and bring his or her motoric skills to even better use, which would ultimately prevent errors.

Approach: Equipping the assembly workstation with means of augmented reality assistance, that is able to guide the worker through the assembly process. This includes correct picking as well as skill-sensitive guidance. An apprentice or a worker who has not performed this particular assembly process certainly needs more guidance than his colleagues who has been working at this station for the last couple of weeks. Using personalization the system would automatically adapt to its user. Moreover, using sensor technology such as fitness trackers the system could automatically adapt to the physiological and emotional state of the user. For example if the worker has been exclusively assembling very delicate parts which demand sharp focus the system could provide different tasks which demand less focus.

Logistics: *Industry 4.0* for Small Enterprises

General situation: Small enterprises face increasing challenges in the wake of the digitalization of their businesses. Customers are more and more demanding customized products and services, which increases the overall complexity.

We investigated a full-service small enterprise that offers solutions for enterprise merchandise. This company designs, builds and maintains online shops while at the same time handling stock keeping and shipping for their customers.

Need: The growing demand for individualization keeps rendering logistic processes more and more complex. Additionally, production-similar tasks like stitching names on clothes become necessary contributing to the overall complexity. The CEO told us about an enterprise competition where winners could choose between 36 different prices which were then personalized making apparent the degree of organization which is necessary to handle such logistic issues.

Design Opportunity: Therefore, the goal is to model the current processes. Based on that model assistive systems can be implemented that address especially the picking processes.

Approach: First a low cost solution for managing the entire process is needed. Especially the current paper based picking process needs to be digitalized. This digital system could then be extended to a AR picking assistance.

Quality Assurance: Better and Safer Work for Special Users

General situation: The concept of extreme users is popular among designers and HCI practitioners. In this context extreme is connoted utterly positive because observing extreme or special users allows gaining insights and deriving unorthodox solutions from which the average user may benefit. Creative and innovative solutions may be found where we are allegedly constrained the most. Having said this, the final application area under investigation dealt with quality testing of products from the domain of traffic engineering. Remarkably, workers with disabilities employed for this task. They are integrated into real production environments and work situations. This is currently done by dividing the work tasks into single sub-tasks, which are appropriate for the respective user.

Need: The task itself is quite demanding because the employees are testing electronic devices. Clearly, the use of electricity always brings about safety issues. An error caused by false handling can irreversibly damage product or in the worst case harm the human worker. In order to test the devices a worker has to connect up to 15 cables and choose from different currents. Hence, many variations are possible variations. Currently, the worker retrieves the necessary information from paper-based instructions. This is not ideal.

Design Opportunity: The goal is to reduce the complexity of the task and to individually assist workers according to their abilities and their physiological and emotional state.

Approach: An assistive system is required, which is fully geared towards reducing complexity. This means that the system itself must be designed in such ways that it does not require extra training. This means for example that one should rather use blinking LEDs instead or smart glasses. The intelligence and complexity needs to be hidden in a black box so that the interface can be as minimalistic as possible.

CONCLUSION

We analyzed the work situation in four different enterprises from different domains employing a combination of observation and interviews. We have seen that design opportunities for intelligent assistive systems exist across all domains. Self-evidently, different domains have somewhat different requirements. We briefly described each use case and derived a first set of requirements and formulated possible approaches for each of these cases. Our intention is to lay the groundwork for a discussion among practitioners on how to apply usability knowledge and human-centered design activity to the field of assistive systems for industrial purposes. In conclusion we would summarizes the possible approaches as follows:

- Use generally accepted HCI research methods to gather user data and evaluate current systems or prototypes regarding their usability and user experience qualities.
- Automate the data acquisition and evaluation process within the assistive system.
- Establish a feedback loop so that the system may automatically adapt to the state of the user.
- Be aware of and design for privacy and security.
- Ultimately and as a consequence of the previous steps, the overall system performance (socio-technical) is increased by designing for human well-being.

In our future work we will explore the design space of assistive systems further by developing and evaluating prototypes for the mentioned approaches in the different domains. By generating those systems we aim on getting a deeper insight in the possibilities of the interaction between humans and assistive systems in future *Industry 4.0* environments.

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