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Uncovering the Potential of Augmented Reality Glasses for Industrial Set-up

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Abstract. Industrial set-up is a critical process in manufacturing contexts, especially from an economic perspective. Therefore, various efforts have been made to optimise it in terms of time and other resources. Based on preliminary findings from an extensive empirical study, we discuss the relevance of experience-based knowledge in such process and explore the potential of Augmented Reality (AR) technology to gather and make this type of knowledge available to machine operators. Furthermore, we explore the relevance of mobile technologies – e.g. head mounted displays (HMD) – in such a context, given that industrial set-up involves a mobility's high degree of the machine operator. The need for situated information at different locations of the production plant should also be noted within the set-up process.

Introduction

Industrial set-up is a core and time-critical process in manufacture, as in many cases without it there is no production. Optimising it is, then, key for maximising efficient production, especially where the challenges are intensified by the trend towards decreasing order or delivery sizes and an increasing range of products and product variants (Burkhard and Meier, 2005). Despite the attempts to achieve an optimal performance in set-up, companies still fail to do so (Miina, 2012). In order to better understand the practices inherent to industrial set-up and how computer technologies can potentially support them, we conducted an ethnographically-informed investigation in four companies, focusing on the set-up process of bending machines. This set-up process contains seven to nine tools and is exemplary for set-up processes on forming machines.

Our findings suggest that industrial set-up is thoroughly knowledge intensive. For instance, as we went on to engage in our fieldwork, we could observe that assembly and disassembly operations involve essential steps requiring special knowledge and skills that machine operators develop over the time. In addition to that, the programming of the machines also require particular knowledge for adjusting the several parameters associated with the production a particular item. Our findings suggest that this knowledge and expertise are strongly linked to individual persons and it is not easily captured and shared. Put it another way, companies are constantly facing the challenge to find effective ways to record and make experience-based knowledge available, as recurrently demonstrated in the literature (Ackerman et al., 2013; Nonaka and Toyama, 2003). Furthermore, our study shows that the set-up task is characterized by a high degree of mobility of the operator and that situated information is needed at different points of the machine. Seeking innovative ways for knowledge and expertise sharing while carrying out set-up operations, we turned our attention to AR technologies combined with a HMD. Therefore, this paper addresses the question of how mobile AR technologies can support knowledge and expertise sharing for industrial set-up.

Related Work

Since as early as the 1980s, manufacturing enterprises have been working on organisational and computer-based technological innovations in an attempt to improve their competitiveness (Randall et al., 1996). One of the philosophies that has been developed as a result of this search for improvement is Lean Thinking (Miina, 2012), whose central tenet is to eliminate waste in production. In his seminal book ‘A Revolution in Manufacturing’ (Shingo, 1985), Shigeo Shingo introduced the ‘single-minute exchange of die’ (SMED) approach, based on Lean Thinking theory and years of practical experimentation in Japanese manufacturing companies such as Toyota. The author suggests that set-up times could be reduced by up to 90% by applying simple generic measures, e.g. using checklists, performing function checks, improving transportation, and preparing operation conditions in advance. It did not take long until companies all over the world started putting the SMED approach into practice, although findings from the literature show that only a limited number of companies succeed in implementing Lean Thinking approaches (Miina, 2012). A reason for that is the neglect of local and experience-based knowledge (Nonaka and Toyama, 2003).

Indeed, already in 1985 Shingo (1985) observed that the skill and knowledge of the workers can be of decisive importance for the improvement of set-up operations. However, studies that illustrate the role of knowledge management and knowledge transfer in industrial set-up are completely absent from the literature. In the Organisational, Process and Industrial Management literature the focus has been recurrently on elaborating models to understand key elements of knowledge sharing among workers (Hau et al., 2013; Nonaka and Toyama, 2003; Schmidt and Wagner, 2003). In CSCW, researchers have been investigating since early 1990s related issues under manifold designations, e.g. Organisational Memory (OM), Organisational Remembering (OR), collective memory, collective intelligence, expertise location, etc. (Ackerman et al., 2013; Nonaka et al., 2000). The Human Computer Interaction (HCI) literature has also touched upon the matter, particularly with regard to the design of digital visualisation technologies for knowledge transfer (see e.g. the contributions in Seppälä and Klemola, 2004). However, once again there is little mention of manufacturing contexts. This calls for further research on the matter, so to find effective solutions for this long-standing organisational problem.

AR technology, as will be demonstrated in our findings section, can potentially help there. AR technology has been used for a couple of years to enrich reality with additional context-based information in various applications (Mann, 2014; Cakmakci and Karasu, 2007). The potential of such technology to support complex assembly activities in the field of industrial application through advanced possibilities of information visualization has been observed very early (Cakmakci and Karasu, 2007). One possibility of support is the projection of data directly onto the object to be mounted. A second possibility consists in annotating and/or manipulating a scene of the real world in the virtual world (Langlotz et al., 2010; Grant and Baden-Fuller, 2004). Both possibilities would be very useful to address the systems requirements we gathered throughout our study, as clarified further ahead.

Research methods

We draw on Wulf et al.'s Design Case Study methodology (Wulf et al., 2015) to frame our user-centred design approach. According to the authors, Design Case Studies involve three distinct phases: *pre-study*, in which the practices and the design space are understood; *design*, in which the actual design of technologies to support the practices identified in the pre-study happens; and *appropriation,* in which the changes in practice due to the usage of the new designed technology are analysed.

The findings presented in this paper come from the first phase of our study. For this phase we adopted an ethnographically-informed approach based on naturalistic observations, eye-tracking sessions, and in-depth interviews. Overall, 24 workers across the 4 SMEs participated in the study, which resulted in a total of 14 shadowing sessions, 14 eye-tracking sessions, and 24 interviews, which ranged in length from 45 to 120 minutes (see Table 1). Interactions observed before, during and after shadowing and eye-tracking sessions were documented through fieldwork notes and interviews were audio recorded and transcribed for posterior analysis. Table one provides an overview of the participants' background and the data collection activities in which they participated.

Table 1: Participants of the empirical study. I: Interviews, E/S: Eye-Tracking/Shadowing. Education (u/s): Education (unspecialized/specialized)

Participant	I	E/S	Role	Company	Education (u/s)	Job tenure
P1	x		Foreman	A	gratuated (u)	> 10 years
P2	x		Designer	A	Master school (s)	> 10 years
P3	x		Foreman	A	Master school (s)	> 10 years
P4	x		Production Engineer	A	gratuated (u)	> 10 years
P5	x	x	Machine setter	A	Master school (s)	< 10 years
P6	x	x	Machine setter	A	Master school (s)	< 10 years
P7	x	xx	Machine setter	A	Apprenticeship (s)	> 10 years
P8	x	xx	Machine setter	B	Apprenticeship (s)	< 10 years
P9	x	x	Machine setter	B	Apprenticeship (s)	< 10 years
P10	x	x	Machine setter	B	Apprenticeship (u)	< 10 years
P11	x	xx	Machine setter / Foreman	B	Apprenticeship (u)	< 10 years
P12	x		Process Owner	B	Apprenticeship (s)	< 10 years
P13	x		Foreman	B	Master school (s)	> 10 years
P14	x		Technical salesman	B	gratuated (s)	> 10 years
P15	x		Technical salesman	B	Master school (s)	> 10 years
P16	x		Construction Engineer	B	gratuated (s)	> 10 years
P17	x		Technical salesman	B	gratuated (s)	> 10 years
P18	x		Production Engineer	B	gratuated (s)	> 10 years
P19	x		Quality Engineer	B	gratuated (s)	< 10 years
P20	x	x	Foreman	B	Apprenticeship (s)	> 10 years
P21	x	x	Machine setter	C	Apprenticeship (s)	< 10 years
P22	x	x	Foreman	C	Master school (s)	> 10 years
P23	x	x	Machine setter	D	Apprenticeship (s)	< 10 years
P24	x		Production Engineer	D	gratuated (s)	> 10 years

Data analysis has been carried out following a Thematic Analysis approach, which entails a set of well-established steps involving open coding of the media excerpts, the systematic revision of the coded segments, and the identification of code-families and their relationships (Braun and Clarke, 2012).

Exploring the potential of AR technologies for knowledge sharing in industrial set-up

Based on the empirical results we introduce a discussion across this section on the potential of AR technology for industrial set-up. Our findings suggest that industrial set-up is a knowledge intensive process and the high proportion of knowledge intensive operations gives knowledge transfer a decisive role here. Our analysis reveals a strong need to initiate an exchange of knowledge among colleagues because expert knowledge lies within a very restricted number of people and is neither easily nor well documented:

> [...], there is just a lack of documentation so this mainly remains 'in the head' knowledge of the individual employees. If today three employees leave the company and tomorrow three new ones are hired, then a massive problem arises. (P4, Interview)

We argue that with the aid of extended information on real objects, as explored by (Feiner et al., 1993), it is possible to create comprehensible documentation. These in turn help to facilitate the required knowledge transfer between people involved in the set-up process. This is particularly relevant to new employees, who often lack experience.

It is worth pointing out that the extension and diversity of the knowledge involved in industrial set-up add a further layer of complexity for knowledge and expertise sharing in this context:

> I was accompanied for several months by my colleagues at work in the production. During this time, everything was shown to me. Even if everything has been shown, you have to make your own experiences. There are many tricks that you do not immediately know. It is incredibly extensive what can happen there. These are many things that cannot be passed on. You can manage a large amount, but everything will never be passed on. (P5, Interview)

Although the visual extension of the real machine and the provision of instructions using AR technology do not replace the required practical experience, they have the potential to easy the learning curve. The technological possibility to make information and instructions absolutely context-specific and situationally correct to the user is an added value. This increases the accuracy of the instructions, which ultimately has a positive effect on users' confidence in the instructions and can lead to rapid learning success (Argote et al., 1990).

Another potential of AR technology combines the advantages of resource-independent access to instructions with the possibility of providing the instructions in a very user-centred manner. In this specific case, this means that the set-up steps can be displayed realistically and in an application-oriented manner. This can potentially motivate users to engage with documentation during set-up. Our findings suggest that the lack of detail of existing documentation, the fact they are outdated and that their paper-based format is not suitable to be easily used as set-up unfolds, prevents operators to use the existing documentation. These requirements of the timeliness of the information, its strict contextual and fine-grained dependence on the product to be manufactured and the fact that the relevant expertise is often found in the people who daily work on the machines, represent a more complex requirement.

Here too the AR technology offers further potential by not only being understood as a pure visualization tool, but also enabling the operator of a company to store knowledge in the form of instructions. This does not always have to be done via elaborately reworked instructions, which are projected using AR technology. But it can also include video instructions that are shown to the user in a context-specific and location-based manner. With the aid of the AR technology, both the context specificity and the location are ensured.

It is worth pointing out that it is of central importance to correctly display the relevant contextual information during the assembly cycles. Therefore, the areas of the physical machine where the new parts should be mounted must be accurately highlighted. In order to accomplish this, assorted options are available for the AR data glasses Microsoft HoloLens. For instance, with the help of the software kit "Vuforia", its integrated camera can allow for the detection of both two-dimensional markers placed in the room and three-dimensional markers using object recognition algorithms. In both cases, the goal is to automatically synchronize the position of the AR glasses with the real object, thus ensuring that instructions are provided correctly in the augmented reality visualisation. The markers' positioning for the specification of the machine is illustrated in Figure 1.

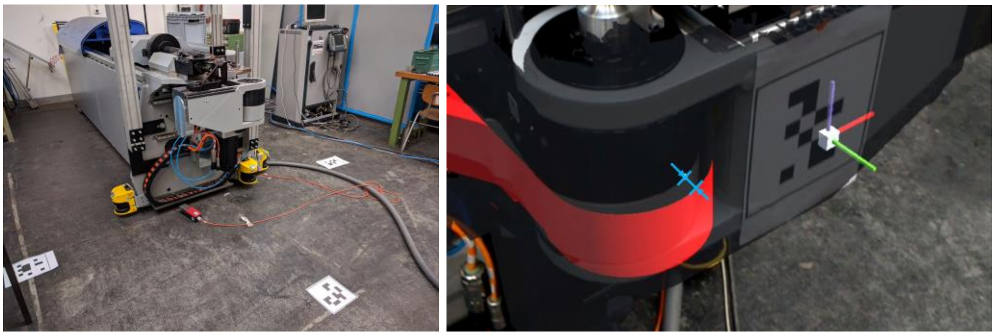

Figure 1: Positioning of three markers for the determination of the machine position (left); deviation between the real machine and the augmented machine representation by using only one marker (right)

Preliminary tests demonstrate that position deviations of more than four centimeters can happen when only two-dimensional markers are used (see Figure 1). This level of accuracy is not acceptable for industrial set-up, in which variations of as little as three centimeters can result in faulty products. By extending the number of two-dimensional markers to elaborate a 3D spatial plane for the representation of the machine elements, it is possible to reduce such deviations to one centimeter. In this case, a triangular plane is drawn from the markers and, at the centre of gravity of the triangle, a perpendicular line is displayed. The machine is then aligned with this plane by referencing this perpendicular line. There are, however, still limitations that must be overcome. For instance, prior to the use of the AR application, fixed mounting positions of the individual machine axes must be specified so that the positions can be referenced correctly by the holographic representations. Our observations show that, overall, the mounting positions can be fixed before the set-up and the machine axes can also be moved into these positions. Nonetheless, there are still exceptions that can potentially prevent the exact positions to be recognized by the

HoloLens, thus resulting in an incorrect contextual reference for the set-up information. Possible solutions exist for the objective recognition of the individual axes. However, the lack of reliability makes their use unfeasible. Another possibility would be to read the current positions of the machine axes with the aid of an OPC Unified Architecture (OPC-UA) interface and translate them into an adaptable kinematic 3D model. The model in turn would be adjusted according to the transmitted position data coming from the machines and the HoloLens, in turn, displays the manipulated model. Thus, a correct contextual reference can be established again and the machine setter can carry out the set-up process with correct data and visualisations.

Last but not least, the set-up process is a mobile work process in which the operator always has to change the assembly locations on the machine. There are also distinctive logistical processes that accompany the set-up process, which also have a strong mobile character. Mobile AR technologies in the form of HMD are suitable in the described setting as a visualization aid, since they take into account the mobility requirements and are nevertheless able to present the situational and context-specific information referred to in the previous sections.

Conclusions and Future work

In this paper we introduced findings demonstrating the relevance of knowledge and expertise sharing during industrial set-up and raised issues concerning the potential of using AR-based systems to support it. We are currently working on a solution based on the Microsoft HoloLens technology to support workers to record, make available and access relevant information for the set-up process as they go on to perform their tasks. As future work we plan to assess the extent to what such a system can respond to the user needs identified during our pre-study. Furthermore, we will investigate how the deployment of such a system in the work environment can shape the workers' practices – also considering ergonomic aspects – and how their practices can shape the use of such technology. In this way, we seek advance the state of the art concerning the use of innovative technologies such as AR systems within industrial context and the understanding of how these technologies can have methodological implications in how knowledge and expertise sharing can happen in this context.

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