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IFAC PapersOnLine 52-13 (2019) 1866–1871

POTENTIALS OF IT-SUPPORTED ASSISTIVE SYSTEMS: COMPARISON OF TWO USER STUDIES IN THE MANUFACTURING INDUSTRY

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Abstract: Since the demand for customized products increases steadily and the work tasks become more complex, the employees at the shop floor have to deal with a higher information density. Although it is obvious to use information technology to output the required information, work stations might require different supportive technologies. Besides finding adequate work stations to be supported by information technologies, there is also the need to have criteria on which technology is suitable for supporting a specific work task and how the needed information has to be displayed to the employees. In this paper, two user studies of implementing different supportive technologies in different manufacturing work tasks are presented, the potentials shown and compared to derive adequate recommendations for actions.

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Keywords: Decision-support for human operators; Human-Automation Integration; Industry 4.0;

1. INTRODUCTION

Wearables represent effective assistive systems to support mobile work tasks, and to provide relevant information at the right time. Due to the increasing complexity of production steps in the industrial sectors and thus a higher information density to fulfil linked working processes of workers, the support by wearables as assistive systems has been assessed in several researches and approaches using different types of devices. Most prominent examples include handheld devices, i.e. tablets, smartphones or IT-glasses. In the context of complex machineries, linked robotics, cyber-physical systems and high data densities, the worker can be integrated in the working environment with the help of IT-supported technologies (Büttner, 2017; Funk, 2016a). For example, Audi uses scanner gloves to simplify the work tasks (Volkswagen AG). Fite-Georgel (2011) set up an comprehensive review on wearables regarding the application in the product-life-cycle. The overview shows clearly the large potential of implementing wearables in the manufacturing, commissioning, maintenance and decommissioning areas. Further application potentials in the manufacturing industry include also trainings (Fehling, 2016).

In the field of research, several comparative studies were performed to identify suitable wearable technologies (Funk 2016b; Bade, 2012; Büttner, 2016). They all have in common that the comparisons refer to single work stations, which have been set up specifically for the examinations, and assess predominantly operational capabilities of the applied technologies. The studies at the commissioning area are quite simple pick and place work task, but a worker, who is doing the pick and place for several times don't have to be supported anymore.

However, research lacks valid criteria and methods to determine potentials at already existing work stations in the daily routine of a manufacturing industry. This paper thus focuses on the establishment of specific criteria, which help to determine the potentials and challenges of different work stations and which technology might fit best. Based on a comparison of two performed user studies in the manufacturing industry, the selection criteria are introduced for finding the most suitable assistive system right from the beginning.

2. RELATED WORK

Recent studies in the field of assembly tasks dealt with the implementation of assistive systems in specific use cases. For example (Büttner, 2015) introduced a projection-based augmented reality (*AR)* assembly assistance for pick and assembly information at a physical workplace. An intelligent tutoring system, which assists an assembly training for a computer motherboard, is presented by (Westerfield, 2015). (Mura, 2016) proposed an error alert system with force sensors that warns the worker in case of an incorrect assembly placement. The force sensor is placed under a workbench and monitors the assembly process by collecting force an toque data. (Nishihara, 2015) introduced a guidance system, which recognizes each piece in an assembly sequence and guides the worker with graphic signs to put the right pieces in position. When finishing the sequence, the system informs the worker with a notification. The proposed AR-system has been developed for this experiment to run an embedded software on a tablet with an integrated camera using a video-see-through approach. (Willers, 2003) and (Beu, 2001) addressed the support of technicians with AR-technologies in the assembly of wires and manufacturing of aircrafts in the context of the ARVIKA project developing a software architecture to apply

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10.1016/j.ifacol.2019.11.474

AR systems (Friedrich, 2002). What is common to all these researches is the testing of the systems, the user interfaces and input devices, but they do not focus on a method how to identify a need for the implementation. Therefore, two user studies have been performed to develop a taxonomy for identifying the potential of work stations to be supported by IT-systems and further to determine a suitable IT-system. The evaluations are based on the assessment of key performance indicators and motion analyses using different technologies of handheld devices and IT-glasses. One user study included the assessment of a manual assembly work process in the automobile industry using an iPad, the Google Glass, and a paper work instruction (Kubenke, 2018a). The other study was performed in the sanitary sector at a machine setting work process with the help of the Huawei tablet, the Microsoft HoloLens and a paper work instruction (Kubenke, 2018c).

3. MEASUREMENT SETUP

In the user studies, the repeated measure design was performed with the applied assistive systems as the independent variable and the information processes assessed with the motion analysis, the task completions times, error rates and subjective evaluations as the dependant variables. The applied assistive systems include the usual paper work instructions, representatives of handheld devices, i.e. Huawei tablet, iPad, as well as different representatives of the IT-glass, i.e. Google Glass and Microsoft HoloLens.

In the first user study, a manual assembly work process of the car body construction of a German automobile manufacturer was set up in a laboratory environment. The task included the fitting and fastening of metal sheets on a special appliance. The second user study was integrated into the daily working processes of a sanitary manufacturer. The addressed occupational group of test persons were machine setters at the production plant. The focussed task of the machine setters included the preparation of an ultrasonic welding machine, the installation of a specific set of tools and adjustment of machine program. The applied assistive systems included the usual paper work instruction, the Microsoft HoloLens as the representative technology for IT-glasses and the Huawei for the group of handheld devices.

The two user studies were developed, performed and discussed in previous works in detail (Kubenke, 2018a; Kubenke, 2018c). In this work, the studies set the basis for the focussed potential analysis of assistive systems. Although the considered work tasks have a different context, content and procedure, both are measurable with usual KPIs, i.e. task completions times and error rates, and the extended application of the Methods-Time Measurement method, in the further course called MTM method, presented in (Kubenke, 2018b). The collected data has been processed with the statistical packages of social sciences (SPSS) following the non-parametric Mann-Whitney-U-Test and the Kruskal-Wallis Test.

The following comparison is based on the analysis parameters applied in the user studies and sets up the criteria for implementation: information processing times, correlative relation between the error frequencies, the task completion times, as well as the user feedback, which has been assessed with the NASA-TLX questionnaire and a further subjective assessment questionnaire.

4. COMPARISON OF THE STUDY RESULTS

4.1 Information processing times

In both user studies, the duration of the assessed information processes revealed that the IT-supported assistive systems showed that the users needed less time to process the given information compared to the original paper work instruction. That means, the test persons could achieve, admit and transfer the visualized information faster and fulfilled their work task more efficient with the help of a handheld device or IT-glass.

In detail, in the first user study, the handheld device was found to be the most efficient device. The resulting mean value and variances of the paper work instruction showed a large difference over the complete user group, whereby the usage of the IT-systems resulted in lower mean values and variances. The test persons using the IT-glass demonstrated a similar processing times of the information and showed only a small variance over the complete group. In summary, the IT-glass led to a homologous task performance as well as the handheld device, whereby the mean value of the handheld device resulted in lower processing times and is therefore more efficient.

In the second user study, the IT-glass was assessed as the most efficient device. In summary, the test persons using the IT-glass could achieve, admit and transfer the given information in the most efficient way regarding time. The paper form showed the highest variance over the complete user group. This means that some test persons could process the information quite fast, while the others had problems in processing the data using the paper work instruction.

When comparing the user studies regarding the information processing times, the following can be stated: In general, the handheld devices and IT-glasses performed best. In fulfilling a repetitive assembly task, the handheld device has been found to be more effective in processing the information. While performing a machine setting task with a higher amount of specific information, the IT-glass turned out to be the most efficient assistive system due to the stepwise visualization of the work instruction. The work instructions at each user study contained the same text passages and pictures displayed at the different systems, just the perception of the information has been different throughout the applied systems and group of test persons.

4.2 Error frequencies and task completion times

The error frequencies and the task completion times differed between the two user studies out of several reasons. While in the first user study, the test persons could realize an error almost immediately, i.e. the metal sheet was positioned at the wrong place and could therefore not be fastened, this led to higher task completion times due to several tries or repeated information processing times when checking the work instruction twice or more. However, the errors appeared mostly when using the paper work instruction. The test persons lost track on the paper or skipped an assembly step by accident. In total, no serious errors occurred, which would have caused defective products. Since a bimanual handling of the metal sheets was required, the task completion times were higher when using the paper form or the handheld device due to the repeated putting down and picking up of the assistive system. A bivariate correlation analysis revealed a positive relation between the task completion times and error frequencies of all applied supportive technologies. This means, the higher the task completion times were, the more errors occurred; respectively: the higher the error frequencies were, the higher the task completion times.

In reverse, the correlation analysis reveals as well how effective a certain applied assistive system supported the worker in fulfilling the work tasks most effectively, i.e. with less errors and a lower task completion time and therefore a lower effect size *r*. Based on the effect size, the level of impact can be determined. If the effect size has a positive value, the relationship is positive linear. Moreover, the higher the value of the effect size, the stronger is the correlation between the examined criteria. If *r=0.10*, the effect size is weak. If *r=0.30*, the effect size is moderate. If *r=0.50*, the effect size is strong *(Field, 2013)*. In the case presented in the paper, the effect size shows a strong effect regarding the observed variables with *r=0.886*.

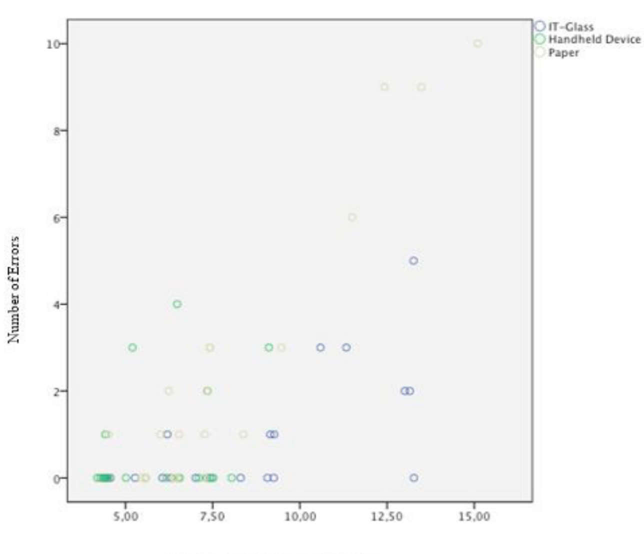

Fig. 1. Scatter diagram of the correlation analysis.

The correlation analysis of the paper work instruction revealed the highest score with an effect size of *r=0.886*, a significance level of *p=0.000* from a sample size of *n=40* participants, compared to the IT-glass (*r=0.664, p=0.001, n=20*) and the handheld devices (*r=0.249, p=0.289, n=20*). The results of the analysis are shown in Fig. 1. The paper analysis with the yellow circles shows a high variance in error frequencies and task completion times. The results of the IT-glass, represented with the blue circles, shows a distribution with low error frequencies, but a higher variance in the task completion times. The distribution of the handheld device displayed with the green circles shows the lowest variance in task completion times, but has the highest amount of errors per time.

Regarding the more complex setting task of an ultrasonic-welding machine, the errors were more severe and resulted in most cases in serious machine or product defaults. The errors occurred for example, when the operator did not adjust the exact parameters of the tools and the machine at the right time, or did not follow the specified sequence of the manual program input in the machine controller. Due to this, the machine program was deleted or the wrong program was installed, so that the prescribed parameters displayed on the controller did not match the machine settings. The false input parameters only became evident, when the setting process is finished and the first components were welded. Due to this, the work tasks is highly complex, requires a large information density and every single step of instruction has to be followed in an exact way. In this case, the IT-glass, i.e. the Microsoft HoloLens, was found to be the most effective assistive system due to an average task completion times and only a few errors, which were not critical. The application of the paper instruction resulted in good task completion times, but diverse severe errors, i.e. skipping, missing or repeating relevant process steps. The same errors occurred using the tablet, which would have led to defective products or even a deleted machine program. Again, a bivariate correlation analysis revealed a positive relation between the task completion times and error frequencies of all applied supportive technologies (see Fig. 2).

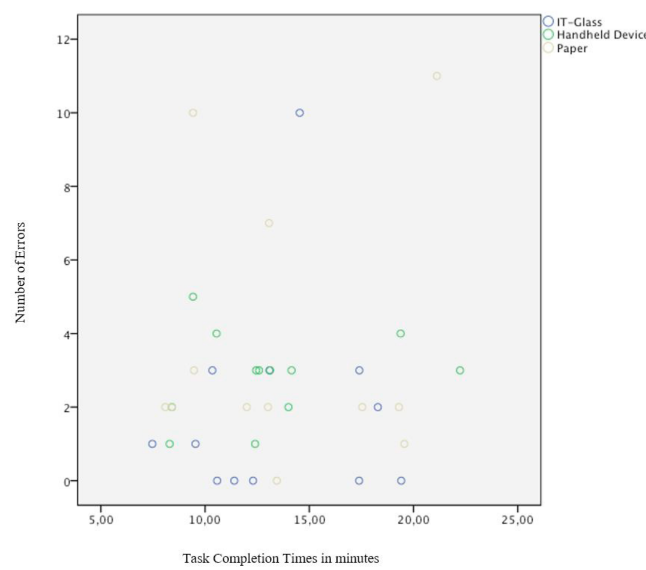

Fig. 2. Scatter diagram of the correlation analysis.

The correlation analysis of the paper revealed the highest factor (*r=0.215, p=0.312, n=24*), compared to the IT-glass (*r=0.094, p=0.770, n=12*) and the handheld devices (*r=0.203, p=0.526, n=12*). The distribution of the paper analysis, represented by the yellow circles, reveals the highest variance in error frequencies and task completion times. The results of the handheld device, i.e. green circles, and IT-glass, i.e. blue circles, show a nearly centralised arrangement of the correlations at the lower value levels.

In summary, the application of the IT-supported assistive systems resulted in lower error frequencies and better task completion times compared to the paper instruction. Whereby the usage of the IT-glasses resulted again in lower error frequency compared to the representatives of the handheld devices. The underlying reason includes the step-by-step displaying of the relevant information and the saving of additional times to drop or pick up a device.

4.3 User feedback

In both user studies, the user feedback was assessed with the NASA-TLX stress and strain questionnaire, which was performed after each trail. The NASA-TLX requested the cognitive load for the dimensions mental, physical and temporal demand as well as the performance, effort and frustration. Further, the assessment of the different applied work instructions focused on the three criteria: ease of use, level of satisfaction, and evaluation of performance. In addition, an open question input was requested from each participant after finishing the trails. This questionnaire was based on the 5-stage Likert-Scale, i.e. “1=does not apply” and “5=fully correct”.

Regarding the assembly work station of the first user study, the subjective evaluation of the cognitive stress and strain levels based on the NASA-TLX questionnaire revealed that the IT-glass has a higher value compared to the handheld device or paper work instruction, i.e. the usage of the IT-glass was more exhausting. Regarding the final assessment of the applied assistive systems, the comparison of the ease of use and satisfaction level revealed no significant difference. When focussing on the individual performance, the test persons preferred the handheld device as the most efficient assistive system. The overall feedback of the participants included the simple operation of the iPad and the stepwise display of the relevant steps. The display window of the Google Glass was rated as being too small and too hard to use, i.e. the user had to look to the upper right corner to see the information, which caused eyestrain during long-term usage. The operation of the Google Glass was described to be easy, but an application in a production environment was doubted due to different light conditions, pollution, etc.

The subjective assessments in the second user study revealed different results. The NASA-TLX showed that the applied Microsoft HoloLens resulted in higher perceived cognitive load based on the mean values, whereby the paper form was rated with the lowest cognitive load in average. The results of the final assessment are almost similar to the first study. The ease of use and satisfaction level showed no significant difference, the performance was rated in favour of the IT-supported assistive systems. Regarding the evaluation of the effort and benefit, the Microsoft HoloLens convinced with the clear structured step-by-step display of the instruction and the intuitive operation. Especially in polluted production environments, the hands-free operation was of advantage. The paper form brings the negative effect of being polluted or become soaked by oil quite fast during the work process.

In general, the positioning of a handheld assistive system, i.e. paper or tablet, turned out to be difficult and required more often special consideration at this specific work process. After picking up again the device, the participants needed some time to get back on track. The subjective assessments revealed the handheld device as the most efficient assistive system for the assembly work tasks and the IT-glass as the most suitable technology to support the machine setting processes based on the performed MTM-analyses. In both cases, the subjective evaluations support the previous assessed objective findings and finally confirmed the IT-supported assistive systems as more suitable to fulfil manual work processes.

5. DISCUSSION

The comparison of the manual and IT-supported assistive systems demonstrates an effective modification of two different manual work places and an enhancement of the support of workers according to the situation. Both considered experiment designs have in common that the working process includes a manual task, the basic operations are assessable with the MTM-method, while the demand for information retrieval is necessary to fulfil the task and can be objectively evaluated. The slight difference stems from the amount, density and granularity of the relevant information. The assembly task includes simple step-by-step instructions without considering further adjustments. The worker just has to take the right metal sheet, position it and fasten it. Errors are directly visible by comparing the target picture on the work instruction and the actual picture on the appliance. The whole process could be illustrated with pictures, so that written text is not required.

In contrast, the machine setting task is more complex due to the specific parameters for the adjustment of the tool inside the machine. If, for example, the tightening torque is way off the required value, the parameters of the machine controller will not match anymore. Then, worker has to perform a complete error analysis, which can occur at any process step. Further, it is necessary to describe the orders of the machine setting task in text form, while pictures can be used additionally.

Besides this, the environment of the work station has to be considered regarding the implementation of IT-supported systems as well. In the case of the handheld devices, the positioning of the device was often difficult and disrupted the information and work processes during the machine setting task. The same problem did not occur at the assembly task, where the device could be dropped on the appliance or the tool table. Thus, the working environment also has to be taken into consideration before implementing an IT-support in order to avoid additional processing times in operating the system. However, based on an MTM analysis of a work station, a potential type of assistive system can be narrowed down in determining the predominantly performed basic motions to retrieve, admit and transfer the information. For example, if the worker has to scan a label with one hand, a handheld device would be adequate. In case of a hands-free premise for fulfilling the task and a great demand for information, an adequate assistive system are IT-glasses. For example, a worker has to move and position heavy objects or has to arrange several objects in a precise way, which requires both hands at all times. Within the flow diagram in Fig. 3, the decision criteria to implement an IT-system and first causal connections regarding the information processing times and restrictions of the considered work station are visualized. The presented diagram shows first steps on how to decide whether an assistive systems is suitable or not. The steps can be further elaborated later after the initial decision.

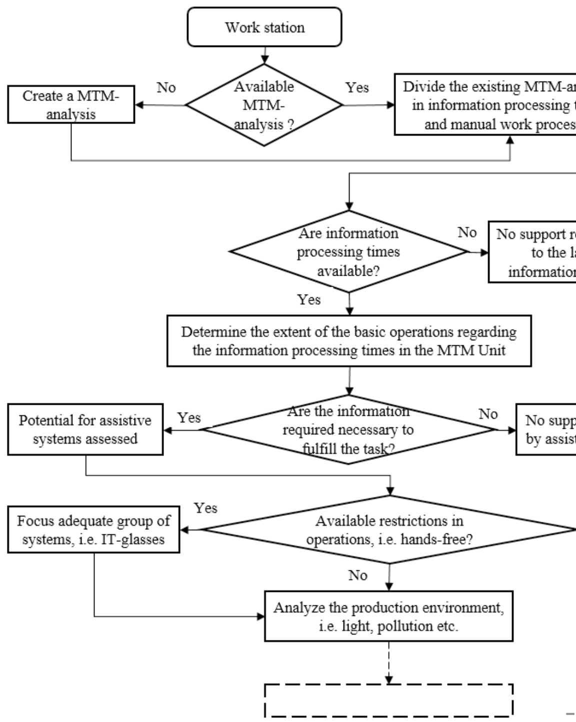

Fig. 3. Flow diagram of the potential taxonomy.

First, the MTM analysis of the working process, if available, has to be narrowed down to the extent of information retrieval and types of performed operations. If a MTM-analysis of the work station does not exist, it should be set up by an MTM practitioner, or at least a rough valuation of the existing information retrieval time should be done. Due to the determination of the information processing times and the underlying basic operations, a pre-screening of a group of assistive systems can be done. A further consideration of the operations of the work process, i.e. the majority of sequences has to be done hands-free, and the production environment is necessary.

In the flow diagram, just the basic decisions are mentioned due to the wide range of different possible production environments and occurring conditions. This has to be narrowed down considering a specific use case. For example, the box at the bottom is left blank, since specific conditions could be written down in there dependant to the focussed work environment The presented taxonomy represents an approach to a guideline, gives ideas for a holistic analysis and recommends causal connections between analysed work processes and assistive systems as collected empirical values.

The criteria considering the production environment have to include the light and pollution conditions, noise levels, the size of the room or work station regarding storage areas of the tools and systems, restricted movements and work surfaces. The temperatures of the work environment have to be measured. Some types of technical systems are not suitable for hot environments due to a high energy consumption of the integrated microprocessors. Regarding the relevant functionalities, the sizes and resolutions of the screens, the screen's form factor, i.e. portrait or landscape, as well as the background lights, colours and user adaption have to be specified. The size of the screen is directly related to the possible extent of information that can be displayed to the operator. Questions like picture or text-based displaying of the information have to be clarified.

6. CONCLUSIONS

In this paper, two user studies performed in the manufacturing industry are compared regarding the application of IT-supported assistive systems and to set up a general and objective taxonomy. The potentials and limitations are assessed and compared regarding the type and content of the specific work task, the information processing times, error frequencies and task completion times as well as the subjective impressions of the test persons. Advantages and disadvantages are elaborated to facilitate further researches in this field and industrial implementations of the same or comparable technologies. The overall findings revealed that the assembly tasks can be supported by handheld devices and the information can be easily displayed via visualisations. More complex work tasks as the setting procedures have to be treated differently. For example, tasks with a high amount of adjustment parameters and specific values should be displayed in the text form and just eventually supported by visualisations. The presented taxonomy, visualized in a flow diagram, underlines the first relevant aspects and findings considering the implementation options of assistive systems from the production environment over the complexity of work processes to the functionalities of the systems, which need to be considered. However, different certain criteria, points of investigations as well as causal connections could occur in different use cases or applications. This might be the content of future work to set up an integrated catalogue or list of criteria based on the described procedure.

REFERENCES

Bade, C. (2012). *Untersuchungen zum Einsatz der Augmented Reality Technologie für Soll/Ist-Vergleiche von Betriebsmitteln in der Fertigungsplanung*, Dissertation.

Beu, A. et al. (2001). Benutzerzentrierte Gestaltung eines mobilen Service- und Wartungssystems unter Verwendung von AR-Technologie, *In MMI-Interaktiv Journal*.

Büttner, S., Sand, O. and Röcker, C. (2016), "Using head-mounted-display and in-situ projection for assistive systems: A comparison", *In Proceedings of the 9th ACM International Conference on Pervasive Technologies Related to Assistive Environments*, p. 44.

Büttner, S. et al. (2017). The design Space of Augmented and Virtual reality Applications for Assistive Environments in Manufacturing: A Visual Approach, *In Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments*, pp. 433–440.

Büttner, S., Sand, O. and Röcker, C. (2015), "Extending the Design Space in Industrial Manufacturing Through Mobile Projection", *In Proceedings of the 17th International Conference on Human-Computer*

Interaction with Mobile Devices and Services Adjunct. ACM., pp. 1130–1133.

Fehling, C., Mueller, A. and Aehnelt, M. (2016). Enhancing vocational training with augmented reality, *In Proceedings of the 16th International Conference on Knowledge Technologies and Data-driven Business.*

Field, A. (2013). Discovering statistics using IBM SPSS statistics: *And sex and drugs and rock 'n' roll, MobileStudy,* 4th edition, Sage, Los Angeles, London, New Delhi, Singapore, Washington DC.

Fite-Georgel, P. (2011), "Is there a reality in industrial augmented reality?", *In Mixed and Augmented Reality (ISMAR). 2011 10th IEEE International Symposium on IEEE*, pp. 201–210.

Friedrich, W. (2002), "*ARVIKA-augmented reality for development, production and service*", 30 Sept.-1 Oct. 2002, Darmstadt, Germany, available at: https://pdfs.semanticscholar.org/0f9e/15c2413e5f3964d36fff72cb033c07552d20.pdf (accessed 8 December 2018).

Funk, M. (2016a). *Augmented Reality at the Workplace*, Dissertation.

Funk, M., Kosch, T. and Schmidt, A. (2016b), "Interactive worker assistance: Comparing the effects of in-situ projection, head-mounted displays, tablet, and paper instructions.", *In Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pp. 934–939.

Kubenke, J., Kunz, A. (2018a). Efficiency Measurement of IT Support for Information Retrieval at Manual Workplaces, *In IEEE International Conference on Industrial Cyber-Physical Systems*, St. Petersburg, Russian Federation, pp. 567–572.

Kubenke, J., Kunz, A. (2018b). Efficient Motion Analysis of IT Support for Information Retrieval at Manual Workplaces, *In 12th CIRP Conference on Intelligent Computation in Manufacturing Engineering*, pp. 1–5.

Kubenke, J., Kunz, A. and Roh, P. (2018c). Assessing the Efficiency of Information Retrieval from the Digital Shadow at the Shop Floor using IT Assistive Systems, *In Mechatronics 2018*, Glasgow, United Kingdom, pp. 202–209.

Mura, M., Mitrovic, A., and Failli, F. (2016). An Integrated Environment based on Augmented reality and Sensing Device for Manual Assembly Workstations, *In Proceedings of the 48th CIRP Conference on Manufacturing Systems*, Vol. 41, pp. 340–345.

Nishihara, A., Okamoto, J. (2015). Object recognition in assembly assisted by augmented reality system, *In 2015 SAI Intelligent Systems Conference (IntelliSys)*, pp. 400–407.

Volkswagen AG, "*Audi uses wearables in logistics*", available at: https://www.volkswagenag.com/en/news/2016/11/Audi_Wearables.html (accessed 12 November 2018).

Westerfield, G., Mitrovic, A., and Bilinghurst, M. (2015). Intelligent Augmented Reality Training for Motherboard Assembly, *In International Journal of Artificial Intelligence in Education*, Vol. 25 No. 1, pp. 157–172.

Willers, D., Regenbrecht, H. (2003). *ARVIKA Abschlussbericht*, Hamburg.