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Procedia CIRP 81 (2019) 926–931

www.elsevier.com/locate/procedia

52nd CIRP Conference on Manufacturing Systems

Approach to Increase Worker Acceptance of Cognitive Assistance Systems in Manual Assembly

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Abstract

Assembly workers face cognitive challenges due to the ongoing trend towards high-variant and small-series assembly of products with shorter lifecycles. To decrease cognitive load and to raise efficiency as well as quality, many companies start using cognitive assistance systems. However, several implementations lack of worker acceptance, which decreases the benefits of assistance systems. An early involvement of workers in the decision-making process can increase acceptance. This paper presents an approach for a digital assembly workstation consisting of several hardware and software components. With this demonstrator, assembly workers can experience the diversity of human-machine interaction technologies and potentials of cognitive support.

Keywords: Assembly; Human aspect; Productivity; System

1. Introduction

Fully automated production systems without any human resources have been considered as the compelling vision of future production systems for a long time. However, automation was also accompanied by a strong limitation of product variants. With the increasing demands of customers for product individualisation, fully automated production systems do not represent an appropriate solution [1].

In major areas of today's production, a trend can be recognised that is moving from large series production towards small series production with high product variance [2]. As a result of this development, the efforts involved in set-up and programming are no longer amortised by the large number of manufactured products. In the production of small lot sizes, fully automated systems are unprofitable for the required flexibility and complexity [3]. Consequently, repetitive tasks need to be performed by automated systems and tasks that frequently change by humans [4]. Humans can adapt to an increasingly varied environment easier than machines [5, 6].

Within industrial production, the trend towards small series production effects especially the assembly process. Frequent changes in the assembly process caused by the variety of variants lead to increasing demands on humans in terms of perseverance and concentration [7]. For these reasons, the Fraunhofer IGCV focuses on cognitive assistance systems that will support workers in their activities in industrial assembly. If implemented correctly, they continuously monitor the process- and quality-assured assembly and thus relieve the worker. As a consequence, assistance systems in assembly help the worker to reduce error rates [8] and to increase his productivity [9]. Since the increase of productivity is a key factor for the competitiveness of industrial nations, it is essential to create a positive perception of cognitive assistance systems.

10.1016/j.procir.2019.03.229

2. Assistance systems in manual assembly

A precise definition of the term “assistance system” is problematic because of its different associations and perspectives. In a broader sense, “assistance” means the addition of external capabilities to solve a task [10]. Detailed views explicitly distinguish between hardware and software components. Only the entirety of the components, which is described by their technologies with their own technology readiness level, creates the assistance system [11]. In this context, a breakdown into hardware and software components is unnecessary, since the focus lies exclusively on support for solving manual assembly tasks.

Assistance systems are socio-technical systems founded on the close cooperation between technology and human. The use of these support systems should not be based solely on technological considerations [12]. Therefore, a concept is required which considers **“technology-related”** and **“human-related”** aspects of assistance systems.

For the selection of technologically suitable assistance systems, the Fraunhofer IGCV developed a matrix that structures and clusters available support systems in manual assembly. Since the market for assistance systems is developing very fast, it is a key factor to provide interested parties

- a structured overview regarding the available technologies
- a selection guidance to find the most suitable technology for assembly processes
- an evaluation of different technologies regarding human-machine interactions

The success of the selected cognitive assistance systems strongly depends on the acceptance by workers. The Fraunhofer IGCV concentrates on this human aspect by designing a digital workstation that

- demonstrates the broad variety of cognitive assistance systems
- provides a visual and practical experience which helps to overcome acceptance problems
- offers hands-on testing

Including human-machine interactions already in the technology selection process, this demonstrator shows the advantages of support systems and helps to increase the acceptance of cognitive assistance systems sustainably.

3. Technology-related approach for cognitive assistance systems

The technology-related approach focuses on the classification of assistance systems and their socio-technical characteristics. This approach points out various possibilities of human-machine interactions.

3.1. Classification of cognitive assistance systems

The challenge in designing a digital workstation is the great variety of assistance systems and the multitude of providers. A major difficulty has been found in the general validity of socio-technical characteristics of a support system. Modification and design of each assistance system can vary greatly from one supplier to the next. Due to this complexity, this document presents an objective evaluation approach to classify currently available assistance systems. The classification and evaluation are the basis for the selection of preferred assistance systems that are later implemented on the demonstrator. They represent a broad spectrum of interaction options that can be experienced at the digital workstation.

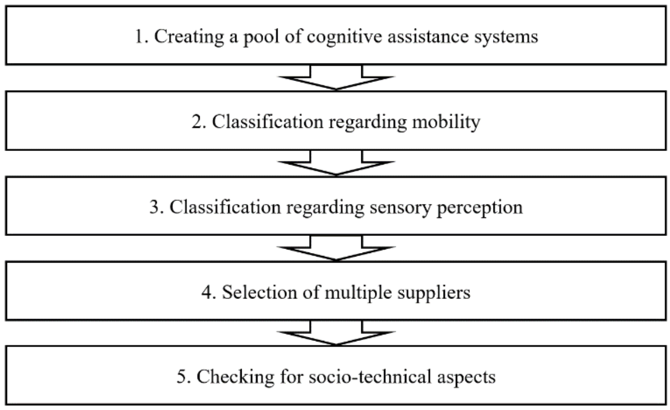

Fig. 1. Objective evaluation approach for the classification of cognitive assistance systems.

1. The first step is to create a pool of assistance systems that can support workers in assembly work. This collection should not explicitly focus on classical forms of support in assembly, but also potentials from other areas. Often new technologies arise from the gaming industry, aerospace or military. The aim of this collection is to discover new support capability that can be applied in assembly. It is also an up-to-date market overview of support possibilities in assembly, which must be continuously updated in order to provide maximum support for workers.

Assistance systems can be classified to physical and cognitive aspects [13]. Physical assistance systems help to reduce physical strain and ensure that the task can be performed. Examples are lifting aids or exoskeletons. Informational assistance systems, which are, in this context, listed exclusively as cognitive assistance systems, provide workers with the information they need to complete tasks.

In the conception of a digital workstation the physical assistance plays only a subordinate role. The focus of the demonstrator is primary to cognitive assistance. Due to an increasing product variety, psychological stress is the main factor. Cognitive assistance systems support workers in performing complex assembly tasks. As a consequence, workers become more productive and produce fewer assembly errors despite increasing cognitive strain [14].

2. Cognitive assistance systems can be categorised by their mobility at the assembly workplace. They can be grouped into stationary, mobile or wearable systems. If the cognitive assistance system is bound to one location, it is a *stationary assistance system*. In contrast, *mobile assistance systems* can easily be moved manually. Examples are smartphones or tablets. *Wearables* are wearable assistance systems that are attached to the worker during the use. Examples include intelligent wristbands or data glasses [15]. This form of near-body support has the advantage that workers are not restricted

in their freedom of movement. The permanent attachment to the body enables hands-free and uninterrupted working [16].

3. In addition, cognitive assistance systems are sub- grouped according to their sensory perception in order to ensure a practical and logical comparison. In the assembly area, the senses of *optics, acoustics* and *haptics* are most common. Each assistance system can be assigned to a human sense, which it uses and supports the most. This differentiation could help to find the optimal tool for a worker, e.g. an individual with high visual perception probably prefers an optical support system.

The combination of cognition, mobility and sensory perception leads to nine categories to which each assistance system is clearly assigned:

- wearable optics
- wearable haptics
- wearable acoustics
- mobile optics
- etc.

In line with this categorisation, for example, a headset is a wearable acoustic cognitive assistance system.

4. In order to avoid preferences for a certain supplier, as well as to provide a general overview of the socio-technical capabilities of assistance systems, a standardised method is applied. Due to different designs or modifications of cognitive assistance systems, multiple suppliers should be represented in order to cover as many socio-technical characteristics as possible. For example, not all data glasses feature gesture control. However, there are data glasses that possess this feature, which is why gesture control is confirmed for this assistance system.

5. Each cognitive assistance system is examined for predefined socio-technical aspects. The aim of this analysis in form of a matrix cluster is to evaluate each assistance system as objectively as possible in order to identify assistance systems that are irrelevant to the demonstrator. Based on the evaluation of cognitive assistance systems, the initial market overview is restricted regarding the similarity and relevance of some assistance systems.

3.2. Matrix cluster for cognitive assistance systems

The "matrix for social and technical components" draws an objective comparison between cognitive assistance systems, whose functionality are demonstratively illustrated at the digital workstation.

The columns of the matrix list the individual cognitive assistance systems that have a support potential for assembly. These are already divided into one of the three matrices depending on the mobility and sensory perception of the assistance system.

In the lines of the matrix, cognitive assistance systems are examined for their socio-technical aspects. The social element refers to the worker who operates the assistance system. On the one hand, the worker can receive instructions from the assistance system or, on the other hand, the assistance system can capture and monitor the worker's assembly processes. The technical element describes the application of hardware and software components.

The chosen socio-technical aspects describe the most relevant points for the demonstrator. While the social elements cover all the worker's assembly activities, the technical elements create the necessary prerequisites.

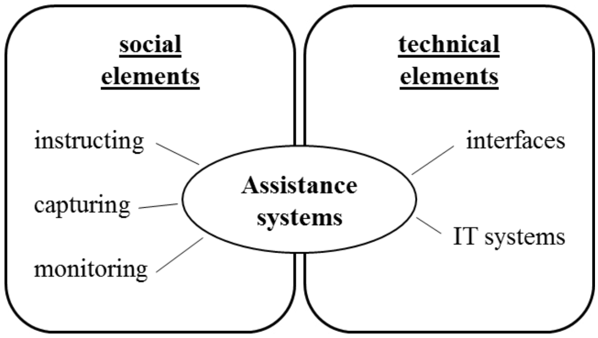

Fig. 2. Social and technical elements of the matrix cluster.

The individual categories of the social and technical elements are further sub-divided in order to assign the cognitive assistance system as unambiguously as possible. The matrix accurately reflects the functionality of the cognitive assistance systems. For this purpose, each socio-technical category is divided into sub-groups for improved comparison. The assistance systems are then checked for their ability and functionality.

- *Instructing* is structured in voice, gesture, display and virtual features. In addition, a further specification level can be created. The voice instructions can be divided into voice input and voice output, since the worker can control the assistance system using voice commands and the assistance system can also instruct the worker on how to assemble the product. The gesture instructions can e.g. be given via finger, hand or arm positions.
- *Capturing* is first divided into the subgroups sensor, lens and scan. The focus here is on the type of capture, which can relate to the capture process of workers or data. For example, sensors listed in detail in the last specification level can track the worker's hand position. The scanning process, on the other hand, is the capturing of data.
- *Monitoring* of the worker or of the workpiece to be assembled is optional. With the worker, the focus is on feedback. With regard to the workpiece, the assistance systems are evaluated whether they have, for example, motion or pattern recognition capabilities.
- *Interfaces* as a technical element in the socio-technical system refer to data transmission, which either can be wireless or wired. Wireless data transmission includes WLAN, Bluetooth or NFC.
- *IT systems* deal with the connection to higher IT systems. The interaction with IT systems, like ERP systems, is not evaluated in this context as they are part of further research.

3.3. Application of the technology-related approach through the example of a projector

This section shows the application of the technology-related approach for the selection of suitable cognitive assistance systems. The theoretical approach is illustrated by the example of a projector chosen from the pool of cognitive assistance systems. All five required steps constitute on each other.

1. Step: A projector supports the worker by projecting textual and visual explanations onto the assembly table of the digital workstation. Since the assembly is carried out by the worker with his head lowered, the projection is always within the field of vision of the worker. There is no need to look at a screen, so efficiency increases and possible assembly errors are detected more quickly. In addition, many different types of information can be projected onto the work environment.

Furthermore, punctual targeted light beams that indicate positioning or contours on the component to be assembled can be used to further limit assembly errors. The current method of assembling components using templates, 2D drawings and rulers is expensive and time-consuming. Projection, on the other hand, reduces quality errors and set-up times.

2. Step: After the suitability of the projector as an assistance system for assembly, classification is made as to its mobility. The projector is a stationary assistance system tailored to the workplace. Certain parameters such as distance or surface of the mounting table must remain constant in order to provide adequate assistance.

3. Step: In terms of sensory perception, a projector falls under the category of optics. This allocation is justified by the fact that workers perceive most of the information through their eyes. Although the assistance system projector often also has a voice output, it is not assigned to acoustics because the focus is clearly on optical support.

4. and 5. Step: With the classification of the projector as a stationary optical assistance system, this cognitive support system is checked on the basis of the socio-technical aspects in the matrix cluster. The evaluation is based on the technical data sheets and personal inquiries of three providers.

					stationary assistance systems		
					optical/haptic/acoustic		
					projector	…	…
Assistance systems as socio-technical systems	social elements	instructing	voice	voice input		…	…
				voice output	✓	…	…
			gesture	finger	✓	…	…
				hand		…	…
				…	…	…	…
			display	touchscreen		…	…
				projection	✓	…	…
				…	…	…	…
			virtual	fully		…	…
				mixed		…	…
		capturing	sensor	depth sensor		…	…
				muscle sensor		…	…
				…	…	…	…
			lens	2D-camera		…	…
				3D-camera	✓	…	…
			scan	barcode		…	…
				RFID		…	…
				…	…	…	…
		monitoring	worker	feedback	✓	…	…
				…	…	…	…
			unit	pattern detection		…	…
				…	…	…	…
	technical element	interfaces	wireless	Bluetooth		…	…
				WLAN	✓	…	…
				…	…	…	…
			wired	USB	✓	…	…
				HDMI	✓	…	…
				VGA	✓	…	…
				…	…	…	…

Fig. 3. Matrix cluster of the “projector” assistance system.

4. Human-related approach for cognitive assistance systems

Despite the extensive benefits, cognitive assistance systems are facing an acceptance problem. The introduction of innovative technologies induces both adaptation and behavioural changes for workers compared to a previous habitual mode [17]. The success of cognitive assistance systems in assembly directly depends on the willingness of the workers to use them, which is why a mobile demonstrator is being developed by the Fraunhofer IGCV. It is intended to emphasise the supportive and simplifying character of assistance systems. The acceptance of cognitive support is enhanced by the active involvement of the users based on exemplary and hands-on assembly.

Therefore, the Fraunhofer IGCV builds up a digital workstation where different cognitive assistance systems can be tested, e.g. AR glasses, data gloves, loudspeakers, a headset, a data wristband or a tablet. This list reflects an overview of the assistance systems that can be tried out at the digital workstation so far but should not be considered a limitation. Since the pool of cognitive assistance systems is continuously updated, new potentials for worker support may arise. After reviewing the socio-technical aspects according to the approach presented, new forms of support can be identified that are not yet represented at the demonstrator. This ensures that the complete range of technical and social components will be demonstrated at the digital workstation at any time.

4.1. Fraunhofer demonstrator for cognitive assistance systems

To test the assistance systems, a realistic assembly process was designed to demonstrate the advantages of an assistance-supported assembly in a practical and hands-on manner. During the testing, the worker uses a balanced mix of wearable, mobile and stationary assistance systems which resulted from the evaluation of the designed matrix.

The Fraunhofer IGCV chose the assembly of a gearbox as a demonstration case to show the advantages of cognitive assistance systems. After a short expert briefing regarding the function and use of the assistance systems, the gearbox is assembled assistant-based. The worker can only assemble a gearbox variant correctly with the help of all implemented assistance systems. The worker is thus forced to use and interact with all cognitive assistance systems in order to completely assemble the gearbox. During the assembly process, it was ensured that each assistance system was used for at least two assembly steps in succession. This makes it easier for workers to memorize the way the assistant system is operating and the assembly process at the demonstrator runs more smoothly. A further feature of the demonstrator is that several variants of the gearbox can be mounted. This is intended to draw workers' attention to the trend towards flexible assembly with small lot sizes and rising cognitive strain. The practical testing under real conditions and the production-ready function of the assistance systems shown will increase the acceptance of the worker in the long term.

Fig. 4. Demonstrator at the Fraunhofer IGCV for cognitive assistance systems.

Confidence in the accuracy of the information and the performance of the system are fundamental for acceptance and thus for the use of cognitive assistance systems in assembly. The Fraunhofer demonstrator promotes this close cooperation between workers and cognitive assistance systems and tries to overcome barriers in the interaction between humans and machines. The digital workstation makes assistant-supported assembly a tangible experience and provides an overview of the current assistance systems. During the twenty-minute assembly of a gearbox, the worker learns how to use and operate cognitive assistance systems and thus builds confidence in the accuracy and reliability of the technology.

The demonstrator is an answer to the increasing variety and complexity of products, involving workers right from the start. The specifically selected assistance systems prevent acceptance problems and clearly demonstrate the advantages of cognitive assistance systems. Furthermore, the conception and realisation of the demonstrator identifies technical difficulties that may arise during the implementation in companies.

4.2. Exemplary benefits of a projector

By implementing e.g. a projector on the demonstrator, the worker is accompanied, application-oriented, through the individual assembly steps. The features of the projector enable an efficient and quality-assured assembly. The cognitive strain on the worker is reduced by following various information flows. Figure 5 shows the capabilities of a projector in the context of assembly that can be experienced at the demonstrator.

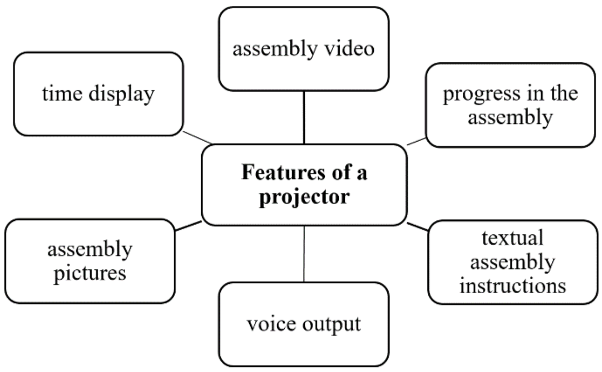

Fig. 5. Features of the projector used at the Fraunhofer IGCV.

The integration of a projector at the digital assembly workstation is one possible support measure for workers to reduce cognitive strain. Regarding the assembly of a gearbox, this assistance system can project textual instructions for the correct mounting on the assembly table. For example, one instruction for the worker is: "Tap the feather key into the keyway of the output shaft with a copper hammer and secure with rubber band". For further ease, images of the actual and target condition are available to the worker so that possible errors can be quickly identified. A technical drawing is also provided. In addition, an assembly video of the assembly step is shown. The worker can access various information flows and is thus able to use his preferred information channel.

As an optical stationary assistance system, the projector is very strongly focused on optical support. In order to test the full range of technical and social components, further assistance systems are required. These were and are also selected according to the approach presented in the document. In this way the most important socio-technical aspects are elaborated which increases the acceptance of cognitive assistance systems in manual assembly.

Fig. 6. Assisted assembly on the demonstrator.

5. Summary

Product variance is increasing significantly due to the trend towards costumer-specific products. In production and assembly, this trend is leading to a growing cognitive strain on workers. For this reason, companies are looking into the use of cognitive assistance systems to reduce the strain on workers. However, it is difficult to find an objective evaluation approach for classifying cognitive assistance systems due to the confusing market and the numerous offers of cognitive assistance systems. This document provides an approach to solving this problem by classifying assistance systems with regard to their mobility and sensory perception as well as by examining socio-technical aspects. The social element in particular is of great importance, since cognitive assistance systems face an acceptance problem among workers. For this reason, a digital assembly workstation is being developed that functions as a visual and practical example for cognitive assistance systems. The aim is to draw workers' attention to the trend towards assistant-based assembly and to demonstrate the advantages of cognitive assistance systems. Through hands-on testing, the readiness for use of cognitive assistance systems is increasing and companies are becoming prepared for complex assembly.

Acknowledgement

This publication is part of the "SynDiQuAss" project for excellence in assembly in the context of Industry 4.0. It is funded by the German Ministry of Education and Research (BMBF) and the European Social Fund (ESF) (grant no. 02L15A281).

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