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Function-Based Mapping of Industrial Assistance Systems to User Groups in Production

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Abstract

By looking at the last few decades, industrial production has undergone great changes. Industry 4.0, also called the fourth industrial revolution, describes the change in the entire value chain through the digital networking of systems, machines, and products. In addition, product variety and complexity in assembly increased due to customization. Big Data Analytics, Internet of Things, Horizontal and Vertical Data Integration and Cyber-Physical Production Systems are just some examples of technologies that find their way from research into industrial practice. However, the most important resource is often neglected, when talking about industry: the human. When we look at companies, we find different types of personnel in production, each with different requirements and capabilities. Assistance systems can be used to counteract these new challenges and offer adequate support to each individual worker. In the past, much research has been done to develop new worker assistance systems, while the analysis of specific needs of user groups in production has been ignored. This paper presents a function-based mapping of industrial worker assistance systems to different user groups and proposes a method for selecting the most appropriate assistance system to each user group.

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Keywords: industry 4.0; worker assistance systems; human factors; human-machine interaction; manufacturing; assembly

1. Introduction

When we look at nowadays production, the trend is moving more and more towards so-called mass customization [1]. The days in which only three types of a product rolled off the assembly lines are over. The customer wants a personalized product, the result of the permitted configurations are millions of possible combinations that can no longer be produced with traditional sequential production [2]. In addition to individual characteristics of products, even non-customized products are subject to shorter life cycles increasing the need of flexibility in manufacturing. Few basic products, such as screws, have been available in the same configuration over years and decades. Instead, most of today's consumer goods are being replaced by products at shorter intervals [2]. Furthermore, the customer does not accept long delivery times. Customers want to buy a product today and have it delivered ideally at the same day [3]. Consequently, manufacturing companies must be very punctual due to the demand for high process efficiency and in view of volatile market needs [4].

The human factor is one of the most important elements when implementing Industry 4.0. With its inimitable capabilities and creative skills, it remains a decisive factor in production and smart factories. A clever positioning of the human work force in production must be pursued, which considers and uses their natural skills, intelligence, motoric skills, and creativity. This is a key point and decisive for the success of Industry 4.0 in industrial practice [5].

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Schlund [6] divides people's activities and tasks into three categories:

- Human sensory skills,
- Human decision-making skills (thinking ability),
- Acting and reacting skills.

In addition, Mark et al. [7] differentiate the benefits of worker assistance systems in two main groups:

- Increase worker capabilities (upgrading)
- Support for workers with physical or mental limitations or disabilities (compensation)

Up to now, there is limited literature available on matching the specific requirements of user groups with the capabilities of assistance systems available on the market. In this paper, we want to provide a function-based mapping to close this gap in research and practice. Therefore, the paper is structured as follows: first, we review the state of the art of assistance systems and user group in Section 2. In Section 3, we show the research methodology applied in this paper. Section 4 analyzes the needs of each single user group, while Section 5 presents finally a functional mapping of functional requirements and existing assistance systems. Section 6 explains the methodology based on an exemplary case. In Section 7, we discuss further needs in research before closing with a brief summary and conclusion in Section 8.

2. Theoretical Background

2.1. State of the art of industrial assistance systems

According to Romero et al. [8] assistance systems can be divided into the following three categories: (i) cognitive, (ii) sensorial, and (iii) physical systems. By conducting a profound literature and market research, the currently available systems have been identified by the authors. The following Table 1, based on the previously mentioned three categories, shows the result of this research subdividing the identified assistance systems in the three above mentioned categories. The table assigns to each aid system an index number that will be used later (in Table 4) as reference for each single assistance system.

Table 1: Identified Assistance Systems for Production.

Type	*Assistance System*	*Index*
Sensorial (extend sensing capabilities)	Eye Tracking	(1)
	Galvanic Skin Response (GSR)	(2)
	Physiological Sensor - Heart Rate (HR)	(3)
	Intelligent Hand Tracking	(4)
	RGB Camera	(5)
	Motion Tracking and Gesture Recognition Device	(6)
	Smart Watch	(7)
	Wearable Tracker	(8)
	Haptic Glove	(9)
	Infrared Camera	(10)
	Portable Vibration Device	(11)
	Position Tracking System	(12)
Physical (extend physical capabilities)	Exoskeleton	(13)
	Arm Support	(14)
	Leg Support	(15)
	Back Support	(16)
	Flexible Assembly Assist Robot	(17)
	Robots/Automats	(18)
	Telemanipulator/ Balancer/ Lifting Aid	(19)
	Wearable Lifting/Holding Aid	(20)
	Ergonomic Manual Workplaces	(21)
	Robot Assistance System with ToF Camera	(22)
	Collaborative Robot	(23)
Cognitive (extend cognitive capabilities like “orient” or “decide”	Augmented Reality (AR)	(24)
	Virtual Reality (VR)	(25)
	Mixed Reality (MR)	(26)
	Tablet	(27)
	Visual Computing System	(28)
	Projection-Based Assistance System	(29)
	Head Mounted Display (HMD)	(30)
	Smart Scan Glove	(31)
	Smart Phone	(32)
	In-situ Projection	(33)
	Laser Projection System	(34)
	Portable computer	(35)
	Computer Assisted Instructions (CAI)	(36)
	Projector	(37)
	Monitor	(38)
	Pictorial Instruction	(39)
	Voice Control	(40)
	AI Based Intelligent Personal Assistant	(41)

2.2. User groups for assistance systems

Looking at scientific literature, it reveals that most of the literature does not treat particular types of users as they refer to a generalized picture of the worker in industrial production. Some authors identify different user groups. Kosch et al. [9] differentiate between experienced workers, freshman workers, and workers with cognitive disabilities. Hallewell et al. [10] assert that the way of providing data depends on primary goals, such as fostering new workers. Renner et al. [11] claim augmented reality guiding techniques to be a useful tool for the “smart worker of the future”. Romero et al. [12] present an Operator 4.0 typology in which the worker of the fourth industrial revolution is categorized in different groups that result by equipping the operator with various aid systems. An example for an employee with physical interaction is the so called “Super-Strength Operator”. A first overview and subdivision of different worker groups in nowadays industrial production, and hence potential user groups for assistance systems, was provided by Mark et al. [13]. These identified user groups can be seen in Table 2.

Table 2: Identified user groups for assistance systems in production (taken from [13]).

Variable	User group	Description
Age	Elder worker	Worker with increasing age, which might have an impact on the task performance
Education	Unskilled worker	Worker, who does not have the required or recommended skills/education
Experience	Unexperienced worker	New or temporary worker in the company, department, or the specific workplace
Variety of work content	Flexible worker	Worker, who switches often between different types of work (or products) within a company (e.g. “Jolly”)
Occupation al Health and Safety (OHS)	Worker with safety risk	Worker with work conditions that might have an impact on the safety
	Worker with health risk	Worker with work-conditions that might have an impact on the health and ergonomics

Handicap presence	Physically handicapped worker	Worker with physical disability that might have impact on the task performance
	Mentally handicapped worker	Worker with mental disability that might have impact on the task performance
Migration	Migrant worker	Worker who usually has a different background in terms of culture and language

2.3. Research question

The literature review showed that actually there is no instrument available to identify the most appropriate assistance system for certain user groups. Most of the papers are discussing assistance systems in general and the related opportunities. What lacks, is the analysis of functional requirements and capabilities of the different user groups in industrial production to match them with existing assistance systems on the market. Thus, the research question of this work can be formulated as follows:

How can assistance systems be selected systematically and based on the functional requirements from the user groups?

3. Research Methodology

Fig. 1 shows the methodology used in this study. In a first step (Section 4), the functional requirements are identified for each of the user groups identified in Table 2. In a second step (Section 5), the available assistance systems are analyzed and examined for their suitability to fulfil the functional requirements identified in step 1 (see also Table 4).

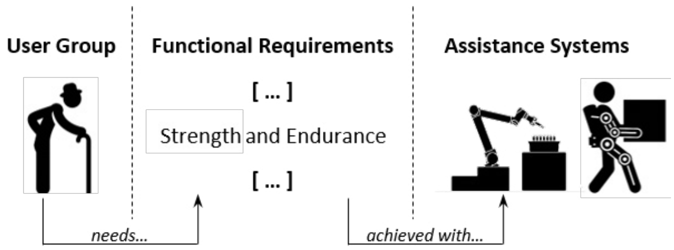

Figure 1: Research methodology.

4. Functional Requirements of User Groups

The approach in this Section is to define the different functional requirements of the aforementioned user groups that have been identified through interviews with stakeholder associations (3), companies (5), and employees (20). The interviews were organized as semi-structured interviews with 11 questions. Table 3 summarizes the outcome of this investigation showing the functional requirements. In this first approach, the user groups "worker with safety risk" and "worker with health risk" (from Table 2) were summarized in one single user group.

Functional requirements describe the missing capabilities of single user groups where assistance systems should be identified to compensate such limitations. As example, elder employees often see themselves faced with problems other working groups do not have in this extend or at all. They might have problems with their strength and endurance, dexterity, ability to hear, ability to see, learning ability, retentiveness, and power of concentration just to mention a few. Consequently, possible assistance systems need to be able to give lifting support, overcome movement constraints, support hearing and visual senses, give concentration support, etc. depending on the work task to be performed. Instead, a worker with migration background might have totally different limitations such as difficulties in language and a different cultural background.

Table 3: User groups with dedicated potential missing capabilities as potential requirements of assistance systems.

	Elder Worker	*Unskilled Worker*	*New/Unexperienced Worker*	*Flexible Worker*	*Worker at Workplaces with Health or Safety Risk*	*Physically Handicapped Worker*	*Mentally Handicapped Worker*	*Worker with Migration Background*
Strength and endurance	•					•	•	
Dexterity		•				•		
Ability to hear	•				•	•	•	
Movability/Ergonomics	•					•		
Ability to see	•				•	•		
Sense of smell		•				•	•	
Learning ability	•	•					•	•
Retentiveness	•						•	
Spatial imagination		•	•				•	
Responsiveness	•	•	•	•	•	•	•	•
Power of concentration	•	•	•				•	
Independence		•	•			•	•	•
Communication skills		•					•	•
Logical thinking		•					•	
Technical understanding		•	•				•	
Technical knowledge		•	•				•	
Mathematical skills		•			•		•	
Attention (simultaneous, selective, concentrate, quick)	•	•	•	•		•	•	
Flexibility	•	•	•		•	•	•	•
Creativity					•		•	
Correctness (Quality control necessary)		•	•				•	•
Physical safe working					•	•	•	
Physical capacity					•	•		
Working velocity	•	•	•			•	•	
Physical health (control)	•				•	•	•	

5. Mapping of Functional Requirements and Industrial Worker Assistance Systems

In a second step, the functional requirements from Table 3 are mapped with the list of assistance systems from Table 1. Assistance systems were checked to define, whether they can meet and satisfy the specific required function or not. The index numbers of the assistance systems in the rows of Table 4 refer to the index in Table 1. The functional requirements build the columns in Table 4.

Eye tracking (index number 1), for instance, is part of the category “extended sensing capability” in Table 1. In the fourth industrial revolution, the digitalization of the production, supply, and distribution chains is aspired. In the course of this, an optimization of the production processes should take place. The role of the employee himself, for whom the working environment should be made more ergonomic and pleasant, is becoming increasingly important. The technological possibilities include eye tracking as biometric measurement method. The system consists of wearable glasses, a recording unit, and the associated software. Cameras that are directed inwards as well as outwards can track the exact viewpoints that later overlap with the recorded video and are thus visible to the user afterwards [14]. Hence, the operator’s correctness, ability to see, and visual perception, etc. can be controlled and improved.

6. Morphological Box and Exemplary Application

A clear example of application of this research may be embodied by the user group labeled as “elderly workers” and can be seen in the morphological box in Fig. 2. By following the approach presented in this paper, Table 3 suggests which are the requirements of each identified category.

For a clear and concise example, only one requirement of the “elderly workers” user group will be taken into consideration: the need to improve strength and endurance. In fact, it is clear that an elderly person will face body aging, which will affect the efficiency and efficacy on the working place. Therefore, with the help of the mapping in Table 4, one will understand which technologies and which instruments are suitable to overcome that particular need. In the case of a deficiency of strength and endurance possible assistance systems that can improve this aspect are the ones indexed from 13 to 20, plus the one with index 23 (see index number in Table 1). By observing Table 1, it is evident that the assistance systems aiming for an improvement of strength and endurance have been identified as “physical assistance systems” extending physical capabilities. Collaborative robots and exoskeletons together with arm, leg and back support are among the possible solution to counteract the lack of strength and endurance of an elderly worker. Fig. 2 reassumes the steps necessary to move from the identification of the problem (namely the user group and the related requirements) to the identification of suitable solutions (i.e. the assistance systems more adequate to that specific situation).

7. Discussion

In this paper, a first function-based mapping approach of currently available worker assistance systems and requirements of user groups in industrial production is given. Therefore, 25 different functional requirements have been identified and assigned to user groups. The presented method allows to find the right assistance systems for certain user groups.

Nevertheless, (our) research in this area is still in its early stages. This paper aimed to present the developed function-based approach and to motivate other researchers to conduct research in this direction. The presented approach and method is not yet complete and has several points that need to be further developed in future research.

First of all, further analysis and discussions with stakeholders and user groups are needed to complete the list of functional requirements in Table 3. A further need for action is the quantification of the functional requirements. It is important to understand which of the functional requirements should be addressed and solved by assistance systems and which ones can be neglected. Similarly, it is important to map the suitability of assistance systems to meet the functional requirements. At present, it is simply recorded whether an assistance system can make a positive contribution, without quantifying to what extent a requirement can only be fulfilled to a small extent or perhaps completely. This is of great importance, when assistance systems finally have to be selected and the costs of the systems have to be compared with the resulting benefit for the employee and the company.

8. Conclusion and Outlook

The topic discussed in this paper can be seen as a good contribution to the conference on “flexible mass customisation”, as it is a topical issue that will be even more needed in the coming years due to the increased number of assistance systems and also the lack of workers together with the increased complexity of the machines.

Having faced the fact of different user groups in production, in this approach different functional requirements are defined to characterize and describe the different needs. The goal here is to match industrial worker assistance systems and the human operator in the most efficient way and therefore also to improve the effective and efficient use of the work force in production. Based on this, we proposed a function-based methodology for the selection of appropriate worker assistance systems. We further discussed that a next step in the further improvement and development of the selection methodology is to quantify the functional needs as well as the satisfaction of such needs by assistance systems available on the market.

Acknowledgements

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Table 4: Mapping of functional requirements and industrial assistance systems (index numbers for assistance systems from Table 1).

ASSISTANCE SYSTEM	*Strength and endurance*	*Dexterity*	*Ability to hear*	*Movability/Ergonomics*	*Ability to see*	*Sense of smell*	*Learning ability*	*Retentiveness*	*Spatial imagination*	*Responsiveness*	*Power of concentration*	*Independence*	*Communication skills*	*Logical thinking*	*Technical understanding*	*Technical knowledge*	*Mathematical skills*	*Attention*	*Flexibility*	*Creativity*	*Correctness*	*Physical safe working*	*Physical capacity*	*Working velocity*	*Physical health (control)*
1					•		•				•	•						•		•	•	•		•	
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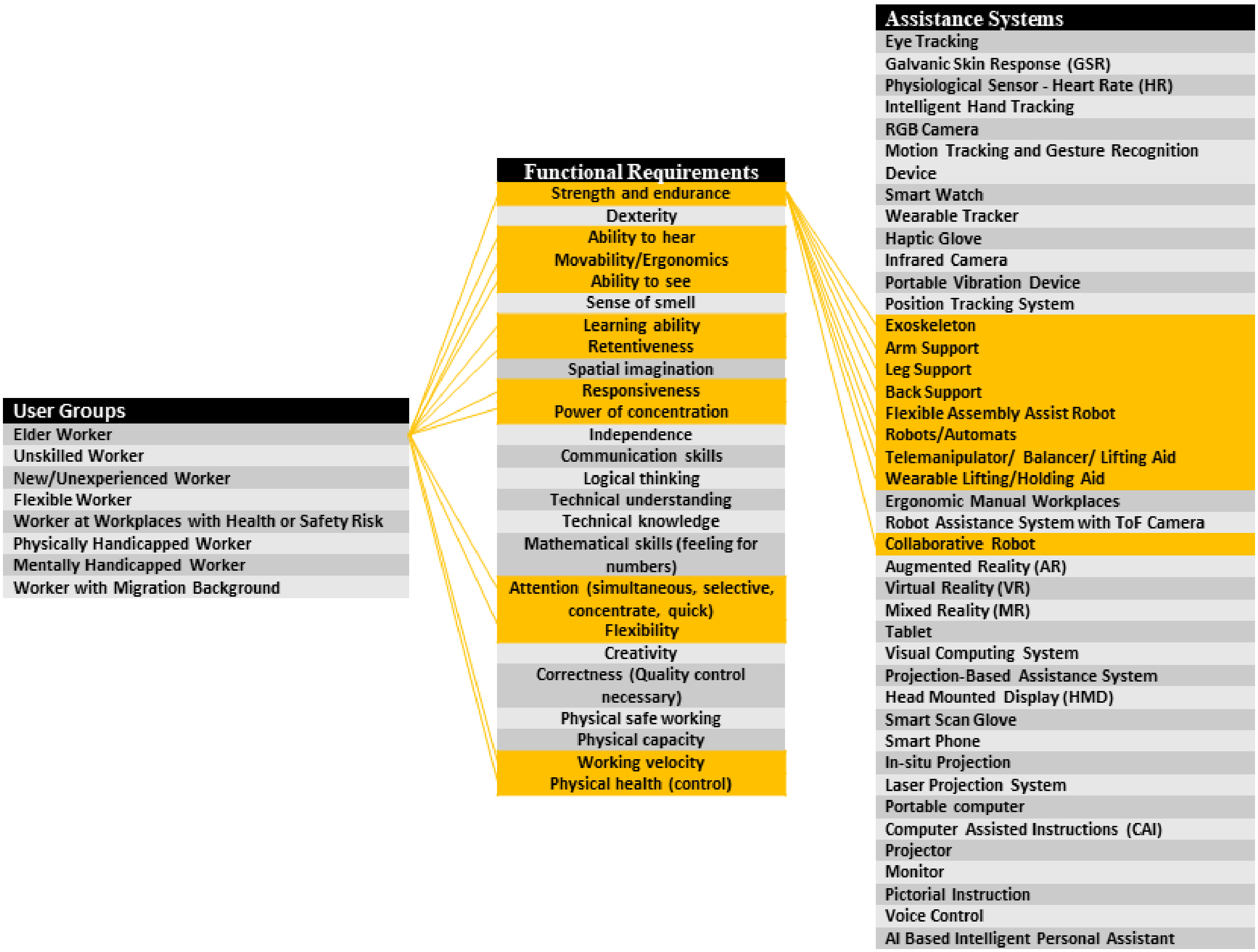

Figure 2: Morphological Box showing an example for the identification of suitable assistance systems (user group: elder worker; functional requirement: strength and endurance).

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