ASSISTANCE SYSTEMS IN MANUAL ASSEMBLY

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Abstract
Due to the continuing trend towards more complexity of products with an increasing number of variants and smaller lot sizes, the assembly often takes place - despite relatively high labor costs in Western industrialized nations - manually or partially automated. An outsourcing or relocation of assembly function abroad is not suitable in most cases.
Therefore, it is increasingly important to reduce process variations and waste in manual assembly processes. Assistance systems have the potential, depending on the situation, to assist the worker in his work, to reduce error rate and to increase productivity. In a first part of the paper an overview will be given to different types of assembly assistance systems. Then a morphological chart is developed, which can provide assistance in selecting or comparing assembly assistance systems. With the help of this chart an assembly assistant system is presented. Finally a quick look is taken at further research being done in this area.

Keywords:
Assistance systems, Manual assembly, Morphology

1 INTRODUCTION

More than seven million people in Germany work in manufacturing. In addition to this large number of employees, the industry also has a high export quota of around 45%, which is of significant economic importance to the sector [1]. A number of major manufacturing industries (e.g. electrotechnical industry, mechanical engineering sector, automotive industry) have one thing in common, namely the companies operating in these sectors usually have large assembly areas. Due to the continuing trend towards more complexity of products with an increasing number of variants, smaller lot sizes and shorter life cycles, assembly often takes place - despite relatively high labor costs in Germany - manually or is partially automated. An outsourcing or relocation of assembly function abroad is not suitable in most cases, since the assembly is at the end of the value chain of a company, has a comparatively high logistical and organizational complexity and outsourcing may in consequence have a negative impact on delivery reliability. Due to the large number of employees in manual or hybrid assembly areas and the resulting economic

and occupational concerns, the design of assembly systems becomes more important, both from the employer's and the employees' perspective [2].
Since the mid-1990s, the design of working systems in assembly has also been influenced in Germany by the principles of the Toyota production system [3]. Focusing on adding value, flow and pull principles in combination with a strong standardization of work processes and a strong breakdown of work are some of the main principles of the system. Many companies in Germany have developed production systems based on the Toyota Production System [4] [5], most of which focus especially on the labor-intensive activities in manual or hybrid assembly. Order information with a description of the assembly task is still provided to employees in assembly (varying sections) mostly on paper or is displayed on screens [6]. Based on a survey conducted by Wiesbeck, mostly traditional design elements such as text, tables, or drawings are currently used by companies [7]. Animations or videos are hardly ever used to guide assembly workers. The current way of providing information to assembly employees has several disadvantages:

- When employees have to continuously turn back to look at the display or have to rustle through order papers, it results in additional, adverse body movements.
- Employees cannot fully absorb information due to the unsuitable display of assembly information, so that employees' movements may be delayed or assembly errors may occur as a result of misinterpretation of information.
- Order documents may be damaged or lost. They do not represent an ideal production process that is digitally-supported throughout.

Current requirements for assembly systems contradict the evolution of the technological possibilities for the design of manual and hybrid assembly systems. In particular, this includes innovative assistance systems that give employees situational-based assistance in performing the assembly task. These assembly assistance systems include, for example, cooperative robots, wearables, light and laser-based assistance systems as well as ultrasound-based localization systems. In combination with work design methods and Lean Management (e.g. Low Cost Intelligent Automation), assistance systems can significantly improve the effectiveness and efficiency of the assembly. Effectiveness refers here to the quality of the task processing (e.g. a low error rate) while efficiency refers to the lowest amount of resources being used (e.g. task completed in a low amount of working hours).

2 CONCEPT AND DESIGN OF ASSISTANCE SYSTEMS

An assistance system is a technical system that receives and processes information from its environment in order to support people in carrying out their tasks. The support provided by the system can also include a warning about hazards or automatic intervention in dangerous situations [8]. Employees receive information through a task system, process the information and give the system feedback on input systems. The information output is usually visual, auditory or tactile. The information is processed using human senses and cognitive processes. The subsequent information is entered manually or by foot via actuators, verbally through speech input, using gesture recognition or tracking systems, or through human motion detection (e.g. [9]).

When designing the assistance system, the compatibility principle should be considered. This means that information presentation and actuator technology (for physical assistance systems) should be designed in such a way that they mirror the mental model formed to process the task and human logic as much as possible [10]. Many of the signals in the work process require human interpretation. This interpretation is also known as the decoding of signals and means that the user decodes input data on the necessary actions [11]. With the number of transformation steps necessary for decoding, the time needed and the probability of an operational error both increase, given that the cognitive capacity to maintain intermediate results is limited. Therefore, work design measures aim to reduce the necessary transformation steps [11]. The information necessary to execute the work should first be presented in such a way that pictorial information, rather than abstract, conceptual information, is used as much as possible. Second, the information should be made available - in terms of space and time - so that they comply with the necessary actions [11]. These two requirements thus ensure that the necessary information are made available pictorially at the right time and in the right place, so that the decoding complexity and in turn, the use of mental resources, are kept to a minimum and the task is carried out in an effective and efficient manner. The compatibility principle described corresponds in particular to the individual principles of dialogue design. These include task appropriateness, self-descriptiveness, compliance with expectations, suitability for learning, controllability, error tolerance and customizability. These principles should be considered when developing and evaluating assistance systems (DIN EN ISO 9241-110:2006 [12]).

According to Geiser [8], four interdependent models (task, user, environment and interaction) should be distinguished when designing an assistance system (Fig. 1). A modeling with a description of the interactions between essential model variables can effectively support the process of determining requirements and roughly conceptualizing an assistance system.

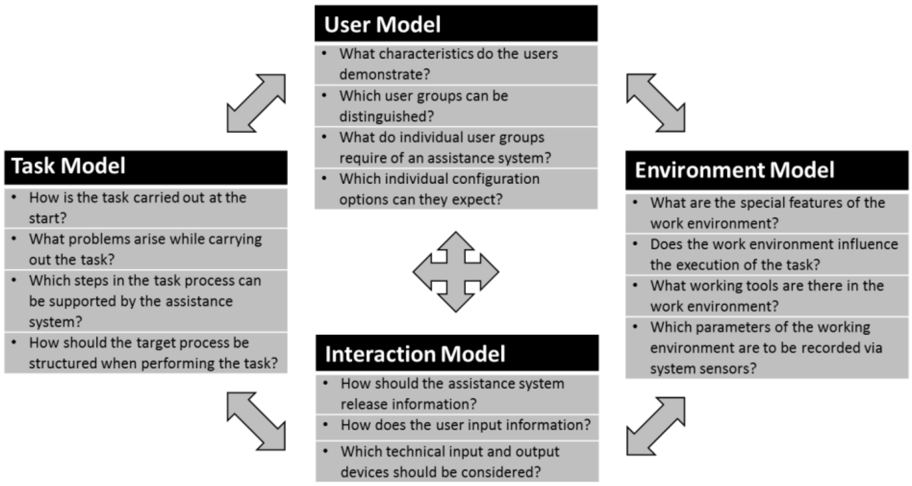

Figure 1: Modeling to support the design process of an assistance system.

At the core of each assistance system is a **task model**. In most cases, the user is guided with step by step instructions through the process. As such, system-guided interaction techniques dominate assistance systems [13]. When designing an assistance system, the task is to break it down into individual activities and present it in a process model. Questioning and observing users, and evaluating existing process indicators (e.g. error rate), can help identify activities and decisions that could be supported by an assistance system. The results produce an initial target process, which provides assistance and support and may be considered appropriate to the task. The purpose of the **user model** is to identify essential characteristics of the user with the goal of determining differences between users to form user groups and, in particular, to become familiar with what users and user groups require of assistance support. The **environment model** includes a description of typical spatial arrangements of users and objects (e.g. products, tools, computers) and of environment variables (e.g. noise, vibrations, light). In addition, the automatic detection of environmental variables via sensors is established in the model. The **interaction model** establishes the terms of the information input and output. Based on these terms, the relevant technical systems are selected for input and output.
The four models influence each other. The conceptualization of an assistance system is an iterative process, in which repeated usability test phases have to be planned according to DIN EN ISO 9241-210:2010 [14]. For example, the user model significantly influences the task and interaction models, in particular the scope and nature of the assistance function, the

choice of input and output units and the dialogue design. The environment model in turn has a large effect on the interaction model since certain environment variables (e.g. noise) can have an adverse effect on certain forms of interaction (e.g. voice input) and the models must be compatible. At the same time task and user models have an effect on the environment model because based on these first two models, one can assume that automatic detection of environmental variables will be required. This often consists of documenting environmental parameters and detecting deviations from the target state.

3 CONCEPT AND MORPHOLOGY OF ASSISTANCE SYSTEMS IN MANUAL ASSEMBLY

Manual assembly assistance systems are technical systems that receive and process information to assist employees in carrying out their assembly tasks. Assembly tasks (assembling) refer to all manual and mechanical operations in place to ensure the creation of a detachable or non-detachable connection of geometrically-defined entities [15]. Assembly operations always consist of joining and handling operations. In addition, assembly operations can also consist of adjusting, controlling and various auxiliary operations (e.g. cleaning, unpacking, printing, oiling) [16] [17].

Manual assembly assistance systems can be classified according to various criteria. The results can be summarized in a morphological box. The purpose of the morphology method is to present a solution space by breaking down the complex situation into individual characteristics and characteristic values [18]. Through morphology, the characteristic values of a specific assistance system can be presented by relating the individual features of the characteristics. A solution idea is generated analytically by changing one or more characteristic values for benchmarking purposes and the individual assistance system can be further developed. An initial morphology of a manual assembly assistance system is shown in Figure 2.
Based on the type of system support, one can distinguish between physical (e.g. cooperative robots lifting a load) and informational (e.g. displaying the content of the next work step) assistance [19] [20]. Physical assistance systems are designed to ensure the feasibility of the task and to reduce the physical strain on employees [19]. Informational assistance systems are designed to avoid uncertainties and mental stress among employees. Both types of assistance systems particularly aim to increase productivity and quality.

Manual assembly assistance systems can be broken down into stationary assistance systems, mobile assistance systems, hand devices and wearables. Data is transferred either through a cable or wireless connection (e.g. ultrasound, Bluetooth, RFID or WiFi).

CHARACTERISTICS	CHARACTERISTIC VALUES					
TYPE OF SYSTEM SUPPORT	Physical	Informational				
TYPE OF THE ASSISTANCE SYSTEMS	Stationary (fixed installation)	Mobile (mobile installation)	Hand device	Wearable - Head - Upper body - Arms/Hands - Legs/Feet		
DATA TRANSFER	Linked by cable	Wireless				
TYPE OF SUPPORTED OPERATIONS	Joining	Handling	Adjusting	Controlling	Auxilliary processes	Setting up the assembly system
SCOPE OF PROCESS SUPPORT	Partial process(es)	Total process				
HUMAN-MACHINE INTERFACE	Unimodal	Multimodal				
TYPE OF INFORMATION OUTPUT	Visual (optical)	Auditory (acoustic)	Tactile-kinesthetic (tactile)			
TYPE OF VISUAL INFORMATION OUTPUT	On-screen display	Representation in the working area (e.g. illuminated display, projection)	Working area display superimposed over the assembly object (e.g. in-situ projection, AR display)			
SCOPE OF THE VISUAL INFORMATION OUTPUT IN THE WORKING AREA	No output	Selective presentation (e.g. illuminated display, marking aids)	Limited display of symbols, images or drawings	Extensive presentation of items such as images, videos and animations (multimedia)		
TYPE OF THE INFORMATION INPUT/ SYSTEM CONTROL	Manual (via actuators)	Verbal (voice control)	Gesturing (tracking system)	Automatic (sensory)		
SCOPE OF USER CONFIGURATION	Set configuration of information input and output	Individual configuration of information output	Individual configuration of information input and output			
USER RECOGNITION	None	Registration and uploading of user profiles	Automatic registration and uploading of user profiles			
SITUATION/ MOTION DETECTION	None	Via measurement sensors	Via optical sensors	Other		
COMPATIBILITY/ INSTALLATION EFFORT	Entire workplace has to be newly configured	Basic adjustments made to the workplace	Minor adjustments made to the workplace	No adjustments made to the workplace		
FLEXIBILITY IN RECONFIGURING THE WORKPLACE	Substantial adjustments to be made to the main hardware	High software reconfiguration effort (done by qualified specialists)	Average software reconfiguration effort (done by specialists on site)	Low software reconfiguration effort (done by user on site)		

Figure 2: Morphology of assistance systems in manual assembly.

Stationary assistance systems are installed at a particular workstation (e.g. mounted projection device). Mobile assistance systems, however, are mobile solutions that can be moved to mount an object. Such solutions can be used, for example, in the context of injection molding, stamping and forming die assembly [21]. Hand devices (e.g. tablet PCs) or wearables (e.g. smartwatches) can display the information required for the assembly process in an appropriate form at the assembly site (e.g. AR display, illustrated assembly instructions) or record information of all kinds from the environment (measurement of entity values, gesture recognition, etc.).

In turn, wearables can be classified according to the part of the body where they are worn. Typical body parts are the head (smart glasses), hands (smart gloves) and wrists (smartwatches). For example, the company ProGlove developed a glove that is equipped with various sensors and is suitable for the following uses: "Hands-free scanning of goods, monitoring and training of workflow sequences, identification of tools and parts to avoid incorrect usage, 100% documentation of goods and processes" [22].

Depending on the type of supported operations, the support may be taken from joining, handling, adjusting, controlling and/or auxiliary operations. In addition, the configuration of an assembly system using assistance functions can be supported. The scope of the process support will be distinguished by whether the assistance system supports all operations or one/multiple sub-processes (e.g. pick-to-light function supports the "targeted flow to container" sub-process).

Moreover, it can be distinguished whether the man-machine interface is unimodal or multimodal in design. Unimodal means that a specific channel is available for receiving information, mostly visual, and another for entering information, mostly manual. Multimodal interfaces, however, take account of various input and output modalities [9].

Another classification can be made according to the type of information output. Of the human sensory organs, only visual, auditory and tactile-kinesthetic sensory modalities are addressed through optical, acoustic and tactile display [8]. If different forms of coding are used, such as text, voice and image, it is multimedia [8].

A simple way of displaying information is a touchscreen display that shows the assembly instructions. Other types of information display that can help guide employees include illuminated displays (e.g. pick-to-light) or projections directly in the workplace, or even images superimposed on the assembly object, which can be implemented using an in situ projection or AR display. Furthermore, the scope of the information output is described to indicate whether it is a selective display or a limited display of symbols, images or drawings - as it is the case with laser projectors for example - or whether multimedia presentations are possible in the form of images, videos and animations.

Analogically, one can differentiate between the types of information input. The information is entered manually using the actuators (e.g. buttons, switches), verbally through voice input, using gesture recognition, through tracking systems that detect human movements (e.g. [9]) or automatically by sensors, where the state of the working object respectively the status of the work process is monitored.

Assistance systems can also be differentiated based on the extent to which the user is given the opportunity to configure input and display systems, as well as the level of support provided by the assistance system according to the user's requirements. In this context, one can also determine whether users can log in to the assistance system or are automatically logged in, so that the preferred system configuration of a user is automatically established.

Situation recognition is another possible feature of an assistance system. Sensors record environmental data. The system controller processes these data and informs the user, for example, in case of deviations from the target state. In addition, sensors are used to determine the state of task processing (task model) and to automatically display for the user - once he/she has successfully completed the task (e.g. removal of the correct component from shelf) - the next step to perform (e.g. assemble the component). In this case the morphology between measurement sensors (e.g. resistive, capacitive, inductive, piezoelectric or mechanical sensors) and optical sensors (e.g. CCD sensor, CMOS APS sensors) is determined.

The compatibility of assistance systems can be described in terms of the respective complexity of implementing existing work systems. As such, the degree to which adjustments to the current working system are required plays a role.

To evaluate the flexibility of an assistance system, one can consider the effort involved in reconfiguring a work system that may be necessary to change variants. One decisive factor is whether a substantial hardware conversion is required and how much effort it takes to reconfigure the respective software. The highest possible suitability for use can be achieved with a simple and intuitive configuration option that enables the user to make configuration adjustments on site (excellent usability).

4 CLASSIFICATION OF A MANUAL ASSEMBLY ASSISTANCE SYSTEM IN THE MORPHOLOGY

The stationary version of the projection-based assembly assistance system developed by the Industrial Engineering Lab and the company Assembly Solutions [23] includes an informational assistance function. It is distinguished by the fact that it supports various operations and generates self-descriptive and multimedia assembly instructions. These are displayed in direct view of the user and also superimposed over the assembly object as shown in Figure 3. The display includes text and image content as well as animations and video sequences for an appropriate representation of the assembly instructions, a pick-to-light function for selecting the correct components in the right quantity as well as markings or positioning representations directly on the place of assembly (in situ projection).

The system also has an auditory output that can provide information acoustically (e.g. by means of a headset). Work instructions are displayed intuitively and relative to the situation, and consider ergonomic aspects.

Figure 3: Projection-based assembly assistance system.

The assistance system provides a multimodal operating concept, which includes manual, verbal and gesture-based information input. Thus, the user can navigate through the system via push button or touch pad, voice input or optical gesture recognition. The user can load his/her configured user profile in which information input and output can be configured individually.
The goal of the assistance system is, among other things, to shorten learning time and increase process capability (efficiency). Procedures can be described and visualized in a short amount of time (efficiency) [23].
Currently, the system still has no situational recognition feature. However, it is flexible and can be quickly adapted to company-specific circumstances. Compatibility and flexibility can both be considered high, as only minor adjustments are required to the workplace and when performing reconfigurations on site.
The classification of the manual assembly assistance system in the morphology is shown in Figure 4.

CHARACTERISTICS	CHARACTERISTIC VALUES					
TYPE OF SYSTEM SUPPORT	Physical			Informational		
TYPE OF THE ASSISTANCE SYSTEMS	Stationary (fixed installation)	Mobile (mobile installation)		Hand device	Wearable - Head - Upper body - Arms/Hands - Legs/Feet	
DATA TRANSFER	Linked by cable			Wireless		
TYPE OF SUPPORTED OPERATIONS	Joining	Handling	Adjusting	Controlling	Auxilliary processes	Setting up the assembly system
SCOPE OF PROCESS SUPPORT	Partial process(es)			Total process		
HUMAN-MACHINE INTERFACE	Unimodal			Multimodal		
TYPE OF INFORMATION OUTPUT	Visual (optical)	Auditory (acoustic)	Tactile-kinesthetic (tactile)			
TYPE OF VISUAL INFORMATION OUTPUT	On-screen display	Representation in the working area (e.g. illuminated display, projection)	Working area display superimposed over the assembly object (e.g. in-situ projection, AR display)			
SCOPE OF THE VISUAL INFORMATION OUTPUT IN THE WORKING AREA	No output	Selective presentation (e.g. illuminated display, marking aids)	Limited display of symbols, images or drawings	Extensive presentation of items such as images, videos and animations (multimedia)		
TYPE OF THE INFORMATION INPUT/ SYSTEM CONTROL	Manual (via actuators)	Verbal (voice control)	Gesturing (tracking system)	Automatic (sensory)		
SCOPE OF USER CONFIGURATION	Set configuration of information input and output	Individual configuration of information output	Individual configuration of information input and output			
USER RECOGNITION	None	Registration and uploading of user profiles	Automatic registration and uploading of user profiles			
SITUATION/ MOTION DETECTION	None	Via measurement sensors	Via optical sensors	Other		
COMPATIBILITY/ INSTALLATION EFFORT	Entire workplace has to be newly configured	Basic adjustments made to the workplace	Minor adjustments made to the workplace	No adjustments made to the workplace		
FLEXIBILITY IN RECONFIGURING THE WORKPLACE	Substantial adjustments to be made to the main hardware	High software reconfiguration effort (done by qualified specialists)	Average software reconfiguration effort (done by specialists on site)	Low software reconfiguration effort (done by user on site)		

Figure 4: Classification of the described manual assembly assistance system in the morphology.

5 OUTLOOK

Modeling with a description of the interactions between essential model variables can effectively support the process of determining requirements and roughly conceptualizing an assistance system. Beyond that, the

morphology of the aforementioned features and characteristic values provide assistance in selecting or comparing assembly assistance systems. In addition, a morphology can help to show the potential of an assistance system for further development. To make detailed comparisons, the morphology should be made more concrete.
The market for assistance systems in an industrial context is developing very rapidly. There are various approaches and technologies to support assembly operations - however, their respective application possibilities and limits are still mainly unexplored. In addition to technological developments, it is necessary to develop guidelines to accompany the process of selecting and configuring assistance systems from a user perspective. Moreover, when implementing assembly assistance systems, it should be taken into account that before a system can be implemented, the potentials of work structuring should first be implemented. Employees should also be included in the change process to a great extent, so that the system meets their needs and is accepted well.

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