Intelligent Adaptive Assistance Systems in an Industrial Context – Overview of Use Cases and Features

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Abstract

In this paper we give an overview of features and use cases that Intelligent Adaptive Assistance Systems (IAAS) in the literature commonly provide. For this, a literature research has been executed where 29 papers were selected for inspection. In the course of this inspection, most common features are noted, compared and assessed against the definitions we gave for an IAAS. It showed that the development of IAAS can benefit from an intensified research in cooperation with machine learning experts to further develop the intelligence and adaptivity of future IAAS.

1 Introduction

Today's world is characterized by fast changes in the consumer market with customers demanding customizable products in nearly every aspect of their life. Since customization is not yet worth automating in every field, human workers are needed to execute the tasks. Many of them consist of order picking or assembly tasks, which require basic skills and a demonstration or explanation to guide the workers, often provided by an experienced worker, but rarely require a specialized expertise of the field. But since experienced and trained personnel will be rare and expensive due to the upcoming skills shortage [Bundesministerium für Wirtschaft und Technologie, 2013], training of new employees will be costly.

Companies are further required to employ people with disabilities, which often take on simple assembly and order picking tasks, which they are then trained for. In 2015, approximately 7 million workers with impairments were employed in the United States

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[VonSchrader and Lee, 2017]. What's more is the demographic change that leaves countries with an ever growing amount of elder people [*Europe's Demographic Future - Growing Regional Imbalances* 2008; Shrestha, 2011]. This data shows that there are many potentially capable workers when offered the necessary support, but companies can't always afford to do that. Assistance systems can help tackle this problem by supporting workers in their task execution and training by visualizing the task and giving feedback on their execution. As a consequence, this eases the load for companies and workers since training new employees is a challenging task. Different types of assistance systems have been designed to train and support users in their tasks. In this paper we focus on systems interacting directly with the user by displays and feedback.

Since this paper discusses Intelligent Adaptive Assistance Systems (in the remaining paper referred to as assistance systems) a short definition for the three terms will be given here:

Assistance systems *provide users with additional information about tasks and work processes via visual and other sensory channels and is used to instruct, support and/or train users in the work process.*

Intelligent *assistance systems are using acquired information to understand the context and learn the current state of the users actions*

Adaptive *assistance systems are able to adjust to the current context of the task* with the definition of context taken from the work of Schmidt et al., 1999.

2 Method

In order to include works that cover industrial aspects, publications by DHL, Boeing, Airbus and other companies were searched in addition to a search using the Google Scholar engine. As industrial context was the most important criteria for the search, research had to focus on tasks executed in the industry and more preferably have industrial partners for their research. Additionally, works with user studies were preferred, especially when comparing different features (e.g. visualizations, user interfaces etc.). Filtering of the literature happened in two steps, all works were preselected by evaluating the titles, then a finer selection by the abstracts of the selected, in order to choose the papers used for this work. The following search terms were used to search for papers using the Google Scholar search engine, with the additional constraint that results were not older than 2013:

system human machine industry OR industrial OR assembly "adaptive assistance" -automotive -healthcare -education -hospital -driver -robot

industry OR industrial OR assembly OR assemble OR manufacture "adaptive assistance" -web -online -ambient -driver -automotive

decision adaptive support system assistance industry industrial assembly intelligent smart HCI -healthcare -automotive -"e learning" -rehabilitation -web

industrial OR industry "user assistance system" -healthcare -automotive -"e learning" -rehabilitation -web

adaptive intelligent industry OR industrial "assistance system" -healthcare -automotive -"e learning" -rehabilitation -web -vehicle -traffic
The number of papers which will be used for the discussions, selected by using the above search terms, is 29.

3 Use-cases of intelligent adaptive assistance systems

There are numerous ways to use assistance systems in the industry. They can, for example, support employees in assembly tasks or be used in logistics to guide users to the boxes they have to pick or place items, only naming two. The following section describes several use cases and mentions preceding research.

Assembly support is important to the industry, as manual assembly tasks take up to 40% of the costs and 70% of the production time [B. Lotter, 2006; E. Lotter, 2012]. Basically the following ways of visualization are used: Augmented Reality (AR), text guides, videos and images. AR is mostly implemented using Head Mounted Displays (HMD) [Azuma, 1997; Fite-Georgel, 2011]. Projection based systems can use AR, too, which is then mostly known as in-situ projection [Markus Funk, Bächler, et al., 2015; Markus Funk, Kosch, et al., 2016; Müller et al., 2014; Van Krevelen and Poelman, 2010]. Text guides are known in printed formats, but newer systems implement them by separating the steps and displaying them one after another using displays or the working surface. Text guides can also be supported or even replaced by using images and videos for guidance [Markus Funk, Kosch, et al., 2016; Haug et al., 2016; Stork et al., 2008].

In *Order picking* (or commissioning) tasks, the workers pick items out of boxes or positions and collect them in a target. Typically, order picking tasks are executed using a paper based instruction where the item id and/or name is written. But new systems are developed by different facilities, like the system by Wanzl[1], which implemented a pick-by-light display. Other systems are using approaches like in-situ projection [Bächler et al., 2015] or helmets with an integrated projector [Markus Funk, Mayer, et al., 2016]. Systems that use AR in combination with HMDs are also imaginable, but no solution, with sole focus on order picking, has been found in the literature.

Maintenance, due to wear and tear of machines, is and always will be a costly task. Since components have to be replaced, processes may have to be adjusted and possibly more. This is often executed by workers with either experience or a training specific for the task, but due to the skills shortage, specialized workers are becoming rare and expensive. To counter this, systems can be build that provide users with the knowledge to repair the machines without the need for special training. These systems may use projections directly on the machine [Stanimirovic et al., 2014] or use AR with smart glasses to guide the worker [Kerpen et al., 2016], only showing two possible scenarios.

[1] http://www.wanzl-news.co.uk/17-wanzls-new-order-picking-solutions/

Inclusion of impaired and elderly persons is an important topic, as in the United States alone approximately every 8th person has a reported disability making up 40 million US citizens in 2015 with around 7 million of them employed [VonSchrader and Lee, 2017] in addition to the already mentioned demographic change. Workers with impairments are skilled workers that need support due to cognitive or physical impairments, normally receiving a training in manual assembly to execute the tasks. To support them specially trained instructors should be employed, which may lead to an outsourcing of impaired workers to sheltered work organizations, since they employ these trained instructors. Here, assistance systems can be used to integrate workers in the companies, as training and supervision is mostly done by the system. Several studies were conducted to test the effect of assistance systems on the performance of impaired workers [Markus Funk, Bächler, et al., 2015; Haug et al., 2016; Kölz et al., 2015], which show that the workers' performance increased and that they did not need additional support by an employee. In the work of Haug et al. the effect of gamification was inspected, when applied to systems for impaired workers. They performed a user study which showed that gamification improves the performance of users in the learning process. An additional effect for some workers was a more comfortable feeling while executing their work, which may be due to the missing supervisor watching them, resulting in less pressure. This confirms a hypothesis stated in [Haug et al., 2016].

With learning as an integral component of our life, assistance systems as *Teaching systems* can help by providing users with information about tasks or exams to test their knowledge. These exams can be a simulation using AR where users have to carry out a task virtually. Such tests are commonly used for pilots and, as of late, for drivers in training, to simulate stressful or rare situations without putting anyone in danger. More industry related situations are the teaching of a systems' characteristics or assembly and repair tasks. An approach to teach users/students is by using gamification aspects in tutorials [Blohm and Leimeister, 2013; Haug et al., 2016; Koch et al., n.d.; Korn et al., 2014]. These systems can implement a quiz with constant feedback, a progress bar and a reward for a successful quiz like points or virtual badges.

4 Overview of used features

Here we give a short description of the different features that we noted during the literature research. In this section, first the information presentation is discussed, followed by the use of robots to assist users, then gamification aspects in systems are discussed and finally the implementation of machine learning in current systems is inspected.

Different *devices for information presentation* are one of the main foci in a large portion of the literature where they describe the pros and cons of different ways of visualization, with some works additionally comparing them against each other. We focus on Head Mounted Devices (HMDs) and projection-based visualization for this paper due to their potential. The projection based systems use a projector that is pointing directly on the working surface [Spindler and Dachselt, 2009] or a projector-mirror combination to direct the projected images [Pinhanez, 2001]. In-situ projection, in contrast to the use of a projector simply as a monitor replacement, displays information directly in the working area and more importantly right beside or on top the workpieces. This way of visualization is e.g. used in the work [M. Funk et al., 2015] which show the users, via a highlight, where to place the next component. Bächler et al. built a table combined with a projection based system and a projection based picking cart for commissioning tasks, with an RGB camera and infrared depth sensor to track the users hands, estimating their position on the assembly worktable [Bächler et al., 2015]. Both systems were evaluated in a user study, which showed that the systems provided adequate support for the workers. In their user study for commissioning tasks, they compared their projection based visualization to a pick by light system and a state-of-the-art paper based visualization. Numerous research has been conducted to show the applications of smart glasses in the industry [Servan et al., 2012; Willers, 2006]. Büttner, Markus Funk, et al. conducted a comparison between a projection based assistance system and the use of smart glasses to provide instructions. They state that smart glasses are still in their early developments and that an aspect to improve is the form factor, since the devices are still heavy and big [Büttner, Markus Funk, et al., 2016]. These results are reconfirmed when comparing it to the study in [Stocker et al., 2017], where the participants also stated that the device was uncomfortable to wear and inconvenient to use.

Robots are used in the industry for many years now, but in a rather independent and isolated fashion instead of collaborative tasks where they provide support for workers, like holding heavy components while workers can execute welding tasks ergonomically. In assembly tasks, robots can hand over components while the worker is focusing exclusively on the assembly. This can be helpful in assemblies with a lot of parts, which forces the worker to move away from his workplace, when the components can't be placed in his direct surroundings anymore, which would disturb the work flow [Haug et al., 2016]. A system that integrated robots is e.g. [Bannat et al., 2009], where a workbench was equipped with an industrial robot arm that can switch between four different tools. Additionally, the workbench is equipped with cameras to track the workpiece and the users' tools, additionally the user is wearing a head mounted microphone to control the robot with command sequences. Further an eye tracking device is worn by the user to provide additional information according to the point of gaze. Other examples for the integration of robots in IAAS are described in the works of [Lenz and Knoll, 2014] and [Savarimuthu et al., 2017].

The main idea of *gamification* is to increase motivation in solving tasks, by adopting aspects from computer games, causing users to develop an intrinsic motivation to execute tasks as good as possible to be awarded with achievements or points [Blohm and Leimeister, 2013; Deterding et al., 2011; Koch, 2013]. Gamification, as a way to design information presentation and train employees, has been tested and verified to be successful in teaching and supporting users [Haug et al., 2016]. Korn et al. measured the effect of gamification aspects in a study with impaired workers, the results showing that workers, though faster with gamification, made more errors during the assembly. They stated that this could be due to the high variance of cognitive abilities inside the groups and that a study wherein user groups have matching cognitive abilities could give clearer results [Korn et al., 2014].

Machine Learning algorithms provide methods and algorithms to react to unknown situations by comparing it to similar, known situations, or by detecting it as an anomaly and require action by the user, which is a good way to integrate adaptivity in assistance systems. Büttner, Wunderlich, et al. implemented a Max-Min Hill-Climbing algorithm in combination with a maximum likelihood estimation to analyze the root causes of alarm floods. In addition to the analysis, the user is provided an interface that display all current errors of the machine, in addition to the predicted root cause, so the user can use his experience in combination with the prediction to carry out the necessary repairs [Büttner, Wunderlich, et al., 2017]. Bader and Aehnelt integrated a method using Finite State Machines (FSMs) in combination with a Hidden Markov Model (HMM) to create working instructions based on observations of the task execution. The tools and parts are equipped with RFID sensors to track them and then implement the sequence as an FSM. After the model has been created, the system monitors the users actions and compares them with the model and if deviations are detected, the user is informed and provided additional support [Bader and Aehnelt, 2014].

5 Conclusion and Outlook

Over the course of this paper, assistance systems in various fields have been presented, with focus on industrial use cases. The terms adaptive and intelligent, though much used in the related work, are not implemented in the way defined here. The adaptiveness of systems is rarely given at all and the intelligence is often limited to basic Machine Learning (ML) algorithms. The systems are mostly taught a model of the task and only detect deviations from that model, with [Bader and Aehnelt, 2014] being the only work found that allowed a flexible order of steps. As the focus lay on the industrial environment and the systems produced there, other fields that use assistance systems received little attention. Additional work that compares differences in the system concepts of these fields could provide a different perspective on the design decisions and the sensors used. For example, systems that predict the user's actions based on their eye and body movements [Husen et al., 2017], e.g. to prevent injuries in an industry plant. Another research topic of interest is an overview of current state-of-the-art technology available to the consumer market and an assessment of opportunities offered there. An aspect to take into consideration in further research is the evaluation of learning effects by using different ways of visualization and guidance. Additionally, during the design process more focus could be laid on the learning aspect when using assistance systems, thus facilitating the achievement of skills when working with them.

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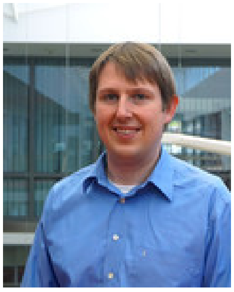

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