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IMPORTANT REQUIREMENTS FOR INNOVATIVE ASSISTANCE SYSTEMS IN MANUFACTURING

Master-Thesis

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Kurzfassung

Die effiziente Produktion von hoch qualitativen und kundenspezifischen Produkten wird heutzutage als Grundvoraussetzung moderner Unternehmen gesehen, um wettbewerbsfähig zu bleiben. Damit einher geht ein Anstieg der Produktvarianten und somit eine Zunahme der Komplexität im Produktionsprozess, welche vom Unternehmen beherrscht werden muss. Verbunden mit Entwicklungen wie dem demographischen Wandel oder dem Fachkräftemangel ergibt sich ein enormer Bedarf an Mitarbeiter- und Unternehmensunterstützung im Bereich der Produktion. Im Zuge aktueller Forschungsprojekte im Bereich der Industrie 4.0 werden daher immer wieder innovative Assistenzsysteme als Lösungsansatz für die Produktion der Zukunft gesehen. Dadurch soll ermöglicht werden, die Flexibilität von menschlichen Arbeitern bestmöglich zu nutzen und Arbeiter nicht mehr durch Technologie zu ersetzen, sondern sie durch Assistenzsysteme zu unterstützen.

Ziel dieser Arbeit ist es, das Thema Assistenzsysteme aufzuarbeiten und als ersten Schritt eine Definition dieses breit gefassten Begriffes zu liefern. Dabei sollen sowohl aktuell bereits bestehende Systeme und Technologien betrachtet werden, als auch mögliche zukünftige Entwicklungen im Bereich der Assistenzsysteme. Hierzu werden die Systeme einer Gliederung unterzogen und auf inhärente Eigenschaften und Eignung für unterschiedliche Anwendungen untersucht. Ein spezieller Fokus wird dabei auf Gestensteuerungssysteme gelegt, da in diesem Bereich einerseits eine Kooperation mit dem Unternehmen Xcessity im Rahmen dieser Arbeit durchgeführt wurde, welche sich auf Gestensteuerung für behinderte Menschen spezialisiert hat. Andererseits ist dieser Technologiebereich auch von besonderer Bedeutung für die Industrie auf Grund der Möglichkeit, berührungslos Eingaben in Computersysteme zu tätigen.

Als konkretes Ergebnis dieser Arbeit wurde auch ein System entwickelt, welches in der Lernfabrik des Instituts für Industriebetriebslehre und Innovationsforschung Anwendung finden könnte. Dabei wurden im Speziellen Arbeitsanweisungen digitalisiert und dem Mitarbeiter in der Lernfabrik die Möglichkeit gegeben, über das Gestensteuerungssystem diese Arbeitsanweisungen zu steuern.

Abstract

Nowadays an efficient production with high qualitative and customized products is the prerequisite of state of the art companies to be competitive. This implies an increase in product variants as well as an increase of the complexity of the production process and needs to be addressed by the companies. Furthermore the demographic change and the lack of skilled professionals influence the situation and lead to an increasing demand of innovative assistance systems to support employees as well as the company. Based on current research projects, innovative assistance systems are considered as an initial stage for the future production. The purpose of these assistance systems is to support employees and not to replace them by technologies any more as well as to profit from their flexibility at the best possible rate.

This Master-Thesis pursues the goal to resolve important questions concerning assistance systems, starting with a definition of this broad concept. Therefore it focuses especially on already existing systems and technologies as well as on possible future developments of assistance systems. For this purpose the systems are structured and analysed according to inherent properties and suitability for various applications. Furthermore a special focus is given especially to gesture control systems because the industrial partner of this Master-Thesis, the company Xcessity, has specialised on these systems to support peoples with disabilities. Additionally gesture control has a special significance for industrial applications due to the possibility of contactless data inputs in computer systems.

Moreover an assistance system was developed as a concrete result out of this Master-Thesis that could be applied in the LeanLab of the Institute of Industrial Management and Innovation Research. Thereby especially the work instructions were digitalized and thus the employees in the LeanLab have the possibility to control the instructions due to gesture control.

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1 Introduction

In the last few years, Industry 4.0 has become a very important topic in the area of production research. The primary task is the generation as well as the utilization of information with the objective to improve the productivity of employees and facilities. This can be realized especially with a central orientation of the company towards the peoples. Thereby the task is not to increase the automation and thus to replace humans with machines anymore. The task is to support the peoples in the company with a specific implementation of innovative technologies while also taking the ergonomics into account. The resulting benefit is the utilization of humans' biggest advantage over automated solutions, their flexibility. Especially assembly assistance systems will make a substantive contribution to reach these goals in industry.

The first part of this Master-Thesis deals especially with a literature research to give an overall understanding of assistance systems for industrial applications. Thereby it focuses on the necessity of such systems in the area of Industry 4.0, followed by a definition, main reasons for industrial usage, classification, most important requirements, applications as well as already existing assistance systems. The second part deals with the implementation of a demonstration system in the university intern LeanLab. It deals especially with a short description of the LeanLab, an explanation why the treated use case is that important, how this use case is solved and what the occurring difficulties and benefits are.

1.1 The company Xcessity

Xcessity is a young start-up company located at Graz and developed by Mr Pröll in the year 2012. The core competence of Xcessity is the field of software development. Thereby they design and develop software solutions, create innovations and transfer new technologies to various applications. The vision of Xcessity is to provide unlimited computer accessibility for everyone and to create the next generation of software solutions that is required to make human-computer-interactions more intuitive, efficient or just fun. To realize this, they are working with cutting edge technologies to create new innovative control concepts. Already developed products by Xcessity are the Chrono Clicker, Epoc Simulink EEG importer as well as the Kinesic Mouse.

1.2 Tasks and objectives

This Master-Thesis pursues the goal to resolve questions according the most important requirements for innovative assistance systems in manufacturing. Therefore it is necessary to determine already existing assistance systems that are yet available for industrial applications. Furthermore it is required to analyse the industrial needs of these assistance systems. Based on the result of this research, a detailed requirements specification should be generated to summarize the most important industrial requirements. Last but not least a demonstration system has to be implemented in the university-intern LeanLab to demonstrate the practical benefits of assistance systems.

1.3 Procedure

	Juli			August				September				October					November				December			
Important requirements for innovative assistance systems in manufacturing												first presentation				Magna presentation							final presentation	
KW	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Preparating activities / collection of background information																								
Literature research according Industry 4.0																								
Literature research according the reasons for use of assistance systems																								
Literature research according already existing assistance systems																								
Literature research according requirements concerning assistance systems																								
Documentation of the theoretical part																								
Practical part - preparation																								
Practical part - setup																								
Documentation of the practical part																								

Preparating **Theoretical Part** **Practical Part** **Documentation**

Table 1: Procedure of the Master-Thesis [1]

[1] own representation

2 Industry 4.0

The following subchapters in the theoretical part deal with the theory required for the overall understanding of assistance systems in industrial applications and serve as the basis for the practical part in cooperation with the company Xcessity. Thereby the first part deals with the necessity of assistance systems in the area of Industry 4.0 followed by a literature research concerning the definition, reasons for industrial use, classification, requirements and applications of assistance systems. The last part of the literature research focuses on already existing assistance systems and their associated advantages and disadvantages.

2.1 Fundamentals of Industry 4.0

In the 1980s the idea of computer-integrated-manufacturing *(CIM)* was very popular with the objective to build up fully automated factories without humans. Based on the fact that a complete automation is inflexible, error-prone as well as expensive to keep running, CIM became less important. From that point it was clear that human work never could be entirely replaced by technologies.[2] Nowadays workers take an active role in a human-centred-production and are supported by advanced technologies. On the one hand, the objective of a human-centred-production is to establish and maintain jobs in manufacturing, create satisfactory and motivating work conditions, constantly improve these conditions and let the human in a central role. On the other hand the objective is to tap the full potential of each worker, increase their loyalty, commitment and satisfaction as well as to capitalize unique human qualities. As can be seen in Figure 1, companies as well as employees are nowadays affected by several factors such as globalization, changing customer demands, rapid technological developments, knowledge-based economy and demographic changes. These factors create several threats as well as opportunities.[3]

[2] Cf. Zuehlke (2008)
[3] Cf. Gorecky/Mura (2012), p. 7f.

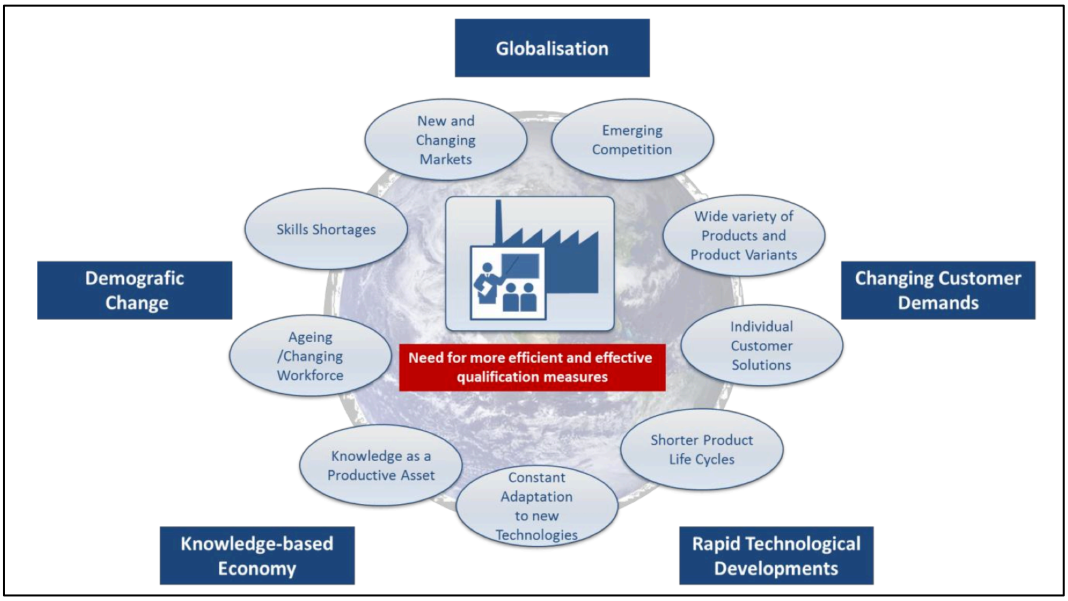

Figure 1: Overview of trends and challenges [4]

In the past two decades the industry in Europe has lost ground, but there is still a possibility that Europe can increase its dwindling industry share from 15% up to 20% of the region's value added. The solution therefore is called Industry 4.0.[5] This term was first used in Germany in the year 2011.[6] An industry-led steering group that includes several committee teams supports Industry 4.0 in Germany.[7] A similar idea to Industry 4.0 is called "Industrial Internet" and was originated by General Electrics in the United States *(US)*.[8] [9] The western civilization has already taken part in three industrial revolutions that resulted especially in higher productivity: [10]

- The **first industrial revolution** used hydropower, steam power and machine tools to improve the efficiency.[11] The productivity was increased because the workers left their private homes and accumulated in central factories.[12]
- The **second industrial revolution** used electricity and the idea of mass production and lead to assembly lines.[13] The production of the Ford Model T in the US can be seen as the peak of this phase.[14]

[4] Gorecky/Mura (2012), p. 12
[5] Cf. Blanchet et al. (2014), p. 3
[6] Cf. Drath/Horch (2014), p. 56
[7] Cf. Drath/Horch (2014), p. 58
[8] Cf. Leber (2012)
[9] Cf. Evans/Annunziata (2012)
[10] Cf. Blanchet et al. (2014), p. 7
[11] Cf. Blanchet et al. (2014), p. 7
[12] Cf. Drath/Horch (2014), p. 56
[13] Cf. Blanchet et al. (2014), p. 7

- The **third** and most recent **industrial revolution** lead to an increased automation based on electronics and information technologies *(IT)*.[15] This was the start of digital programming in automation systems.[16]

In the case of Industry 4.0, the **fourth industrial revolution**, the dominant ideas are consistent digitization and linking of all productive units together.[17] This can be realized by introducing Internet technologies to the industry (see chapter 2.1.5 Internet of Everything *(IoE)*). Most of these usable technologies are already available and often originate from the consumer industry. Furthermore Industry 4.0 is often represented as the application of the generic concept of cyber-physical-systems *(CPS)*. It consists of three main hypotheses:[18]

- **Hypothesis 1:** A significant component in Industry 4.0 will be the communication infrastructure especially in production systems that will be more affordable in future and therefore introduced in all systems.
- **Hypothesis 2:** All used systems such as field devices and machines as well as plants and factories will be connected in a common network.
- **Hypothesis 3:** These systems and even individual products will be able to store information such as documents or knowledge about themselves in the used network.

Cyber-physical-systems require physical objects, data models of the physical objects included in the network as well as services that are based on the available data.[19]

Very important in Industry 4.0 are furthermore cognitive technical systems as well as the cognitive factory:

2.1.1 Cognitive technical systems [20]

Cognitive technical systems are systems with artificial sensors and actuators that are integrated in physical systems and act in the real environment. These systems have cognitive abilities such as perception, conclusion, planning and learning as well as to gain experience. Thus such systems know exactly what they are doing and enable cooperation with humans.

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[14] Cf. Drath/Horch (2014), p. 56
[15] Cf. Blanchet et al. (2014), p. 7
[16] Cf. Drath/Horch (2014), p. 56
[17] Cf. Blanchet et al. (2014), p. 7
[18] Cf. Drath/Horch (2014), p. 57
[19] Cf. Drath/Horch (2014), p. 57
[20] Cf. Zäh et al. (2007), p. 645

2.1.2 Cognitive factories [21]

Cognitive factories have the possibility to monitor themselves, to determine what to do and to intuitively interact with humans. By the use of know-how from previous tasks, a cognitive factory has the possibility to adapt itself relatively fast to new products. As a result they have the possibility to produce small batch sizes and individual products on competitive prices. Thus cognitive factories are able to combine the advantages of automated systems such as low unit costs, high efficiency and short manufacturing times with the advantages of manual production such as flexibility, ability to react and adaptability. Furthermore there is the possibility is to ramp up the production only with rough data and without detailed planning because the production is learning and can adjust itself to the new conditions.

2.1.3 Key characteristic of Industry 4.0

Industry 4.0 can be characterised by the following key factors: [22]

- **Cyber-physical-systems and market place**
  In Industry 4.0, IT-systems will be more and more connected to all sub-systems, processes, internal and external objects, suppliers as well as customer networks. The complexity will increase and these systems will be also connected with machines and storage systems. Furthermore they are controlled in real time. In Industry 4.0 it will be possible to replace machines along the value chain relatively easy and thus will lead to a highly efficient manufacturing.

- **Smart robots and machines**
  In Industry 4.0 robots will become intelligent so that they are able to adapt, communicate and interact with humans. Robots and humans will be able to work hand in hand and communicate together, work on interlinking tasks and use human-machine interfaces that are smart sensored. A plan for the future is also that plants can operate 24 hours a day but workers only take part during the day.

[21] Cf. Zäh et al. (2007), p. 645f.
[22] Cf. Blanchet et al. (2014), p. 8ff.

- **Big data**
  Plants based on Industry 4.0 will generate a huge amount of data. An efficient work with this large amount of data requires an efficient saving, processing as well as an exact analysing of these data.

- **New quality of connectivity**
  In Industry 4.0 the digital and the real world will be connected together and thus machines, work pieces, systems and humans will constantly exchange digital information based on Internet protocols. A further possible function is that products will be able to communicate when they are produced and thus optimize the production capacity.

- **Energy efficiency and decentralization**
  In Industry 4.0 the use of renewable energies will be more financially attractive for companies and furthermore more and more production sites will generate their own power.

- **Virtual industrialization**
  In Industry 4.0 virtual generated plants and products will be used to prepare the production as well as the workers for the physical production. Only those processes that can be successfully simulated and verified virtually are finally uploaded to the physical machines. The interaction between workers and machines as well as the design and visualisation of virtual plants can be done in 3D.

- **Factory 4.0**
  In Industry 4.0 the term Factory 4.0 is used to give an overview of the company as an interconnected global system on a microeconomic level. Furthermore a Supplier Network 4.0 is used outside the factory as well as resources of future customer demands. New production technologies, new materials and new ways of storing, processing and sharing of data are necessary inside these factories.

2.1.4 Results out of Industry 4.0

Industry 4.0 is able to bring more freedom and flexibility, personalization, local production as well as mass customization into the production processes.[23] To be successful in future, companies have to react very quickly and flexible to changing customer demands and to fast-changing customer specifications.[24] Another big advantage is that components, products and other entities in the industrial production will be able to communicate with each other and can be simulated or interconnected. The emerging results will be an efficient testing, optimizations and virtual integrations.[25]

Networked manufacturing and cluster dynamics will also be important so that businesses can operate in dispersed locations. The role of designers, physical product suppliers as well as interfaces with the customer will change due to a fragmentation of the value chain. A further effect will be converging frontiers so that traditional industrial boundaries of industrial and non-industrial applications are becoming blurred. The focus will be set on industrial working methods so that beside products also services can be mass-produced. In Industry 4.0 the dominant technologies will be for certain the IT, electronics and robotics. Furthermore organizations will be set up in much more decentralized and flexible ways. They will be concentrated on selected hotspots instead of a comprehensive global presence and uses open production sites and cluster. Industry 4.0 can be seen as an opportunity for Europe to change the economic rules of the industry and thus to overcome the deindustrialization trends of many European countries.[26]

2.1.5 Internet of Everything *(IoE)*

According to Cisco (see Figure 2), 200 million things were connected to the Internet in the year 2000. Especially due to mobile technologies, this number increased up to 10 billion things today. The connection of peoples, processes, data and things, the so-called Internet of Everything, will lead to the next big wave of the Internet growth and thus up to 50 billion connected things in the year 2020.[27]

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[23] Cf. Blanchet et al. (2014), p. 9
[24] Cf. Blanchet et al. (2014), p. 17
[25] Cf. Drath/Horch (2014), p. 57
[26] Cf. Blanchet et al. (2014), p. 12f.
[27] Cf. Bradley/Barbier/Handler (2013), p. 2

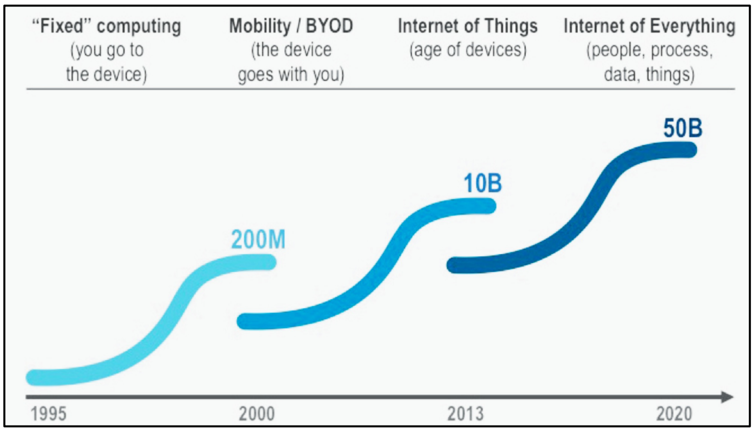

Figure 2: Rapid growth of the number of things connected to the Internet [28]

The benefits of the Internet of Everything will be a Value at Stake for companies and industries of $14.4 trillion worldwide in the next decade. Furthermore the global corporate profit will increase by 21 percent. Value at Stake is defined as the potential bottom-line value (higher revenues and lower costs) created among companies and industries through IoE. Drivers for the $14.4 trillion Value at Stake are asset utilization ($2,5 trillion), employee productivity ($2,5 trillion), supply chain and logistics ($2,7 trillion), customer experience ($3,7 trillion) and innovations through reducing the time to market ($3,0 trillion). Internet of Everything consists of three possible connections based on machine-to-machine *(M2M)*, person-to-machine *(P2M)* and person-to-person *(P2P)* connections. The objective of IoE is to enable peoples to be more productive as well as effective, improve their quality of life and make better decisions.[29]

As can be seen in Figure 3, the four biggest industry sectors manufacturing, retail trade, finance and insurance as well as information services make up more than half of the total Value at Stake. The reason for this high Value at Stake in manufacturing can be traced back to an increase of agility and flexibility as well as optimized applications of the skills of the worker. As a part of manufacturing, smart factories will lead to $1,95 trillion of the total Value at Stake by adding connectivity to manufacturing processes. Thereby applications increase the productivity, real-time inventory reduces inventories and the average production costs as well as supply-chain costs get reduced. Furthermore machines can be programmed relatively easy, will be more adaptable to conditions and allow a greater customization of products necessary to be competitive.[30]

[28] Bradley/Barbier/Handler (2013), p. 2
[29] Cf. Bradley/Barbier/Handler (2013), p. 3ff.
[30] Cf. Bradley/Barbier/Handler (2013), p. 6f.

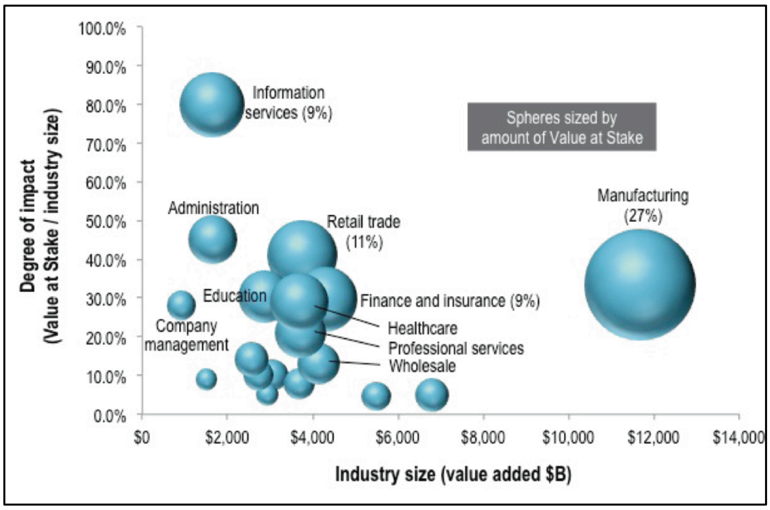

Figure 3: The top four industries make up more than half of the total Value at Stake [31]

As a result out of Internet of Everything, an increase of the employee productivity as well an increase of the customer experience are one of the main drivers for the extremely high Value at Stake in manufacturing. By implementing innovative assistance systems, especially as P2M or P2P connections, can support these mentioned factors relatively easy and thus further improve the economy.

[31] Bradley/Barbier/Handler (2013), p. 6

2.2 Definition of assistance systems

An assistance system can be seen as an additional system that combines the specific and most important capabilities of humans and technologies. Thereby the overall objective is to reach the highest possible quality in industrial applications at simultaneously competitive costs. The task of assistance systems in manufacturing is to link essential information and communication technologies together with state of the art production technologies to reduce non-value adding activities such as training periods, search times and assembly errors as well as to improve the ergonomics of workplaces. Thereby the assistance includes no replacement of humans by technologies, but it emphasizes humans to perform on a higher level due to an appropriate support. Assistance systems can be categorized mainly in stationary as well as in mobile systems. Thus they can be applied to different industrial fields including the assembly, logistics, maintenance and quality control as well as to support workers with restrictions.

2.3 Reasons for the use of assistance systems

This chapter is categorized in three different approaches that demonstrate the necessity of assistance systems in a state of the art enterprise. They can be classified in a quality based, people based as well as in a complexity based approach.

2.3.1 Quality based approach

For a long time fully automatic production systems without humans were seen as the top of the range for future production systems. These systems are especially suitable for the conventional mass production, but do not allow high variability. The human has cognitive abilities that a machine does not has to react on unexpected events, plan further steps, expand knowledge, gain experience as well as to communicate with others.[32] [33] The big advantages of humans against fully automated production systems are based on their cognitive skills especially in the construction of small series, prototypes, complex assemblies as well as adjustments. Negative effects particularly occur in working situations with a high level of concentration as well as precision. In many cases, only a small wrong alignment leads to a high level of failure damage or to defective goods and thus requires cost-intensive rework or reject.[34]

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[32] Cf. Feldmann (2004)
[33] Cf. Zäh/Rimpau/Wiesbeck (2005)
[34] Cf. Berndt/Sauer (2012), p. 46

According to a study conducted by Fraunhofer ISI *(Institut für System- und Innovationsforschung)*, the competitiveness of German companies critically depends on the possibility to manufacture customized products at the highest quality level with technologically leading products as well as on an efficient and flexible production.[35] Thus for manufacturing companies it is very important to fulfil high quality requirements as well as high cost requirements (commercial properties). The quality aspects are influenced from technical properties as well as conditional, operational, social and esthetical properties (local properties). The term quality is defined as the ability to meet all expectations of each individual customers affected by technical and local properties. Thus the quality concept leads to a high variability to meet customer's expectations and results in different product variants and thus in a manufacturing of small series and unique parts. In the past, commercial properties were considered as the most important part and thus automated manufacturing was seen as the ultimate solution, but as mentioned above only suitable for mass production and not for a high variety of products. The big advantages of mass production are a high level of accuracy, absence of errors and low manufacturing costs. A production with a high variety of products requires the involvement of humans but often leads to a high rejection rate and rework and thus to higher costs.[36] Furthermore fluctuating demands, increased complexities and short-term changes of product properties lead to small batch sizes per product variant, to different manufacturing processes and to unexpected changes of the order. Thereby the worker is influenced by all these factors. This results in increasing searching efforts, waiting periods and lacking availability of necessary components as well as to a reduction of efficiency and quality.[37]

Summarised there will be a big challenge in the future to combine the contradiction of high variability and low costs. Human work is ambiguous, because on the one hand they improve the efficiency with their experience, flexibility and practical skills and on the other hand they deteriorate the efficiency with high rejection rate and necessary rework. Thus on the first glance a combination of variability and low costs seems pointless. But technical-organisational systems, the so-called assistance systems, are able to provide solutions based on the support of humans during the order execution to simplify these complex environments and thereby to improve the efficiency and quality.[38]

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[35] Cf. Schirrmeister/Warnke/Dreher (2003)
[36] Cf. Braun (2012)
[37] Cf. Wiesbeck (2013), p. 133
[38] Cf. Braun (2012)

2.3.2 People based approach

Another advocator for assistance systems is the demographic change that influences the social cohesion, the social security systems, the politics as well as the economics by a decline of the birthrate and thus a pushed back age distribution. In the year 2060 the average age will be approximately by more than 50 years, 2003 it was by 41 years. In the next 10 years the generation with the high birth rate – the baby boomer generation – will retire. The main consequence is a shortage of skilled professionals. Out of this situation it is necessary that elderly people still work and be educated. This development influences the economics substantially and leads to unexpected risks as well as opportunities. For companies it will become a big challenge to employ peoples with physical or mental restrictions from the normal ageing process. Furthermore also peoples with disabilities should have the right to be integrated in the working life to perform adapted tasks. One big barrier is that these peoples usually need a direction and supervision from a counsellor that lead to a non economically expenditure. Based on economic and social developments of the last years, there is a special interest to generate a self-determined and motivating work environment for employees with disabilities and employees whose abilities have changed. [39]

Thereby a big potential of assistance systems emerges through a compensation of the lack of skilled professionals. A solution can be a step-by-step guidance of employees with changed abilities. On the other hand also young inexperienced users can benefit from assistance systems and can be introduced to tasks that normally require a higher level of experience. Unfortunately the current legal situation does not promote companies to employ peoples with disabilities because it mostly implies huge disadvantages such as an employment for lifetime.

As explained in the previous chapter, the occurring widespread changes lead to an increasing need of manual operations especially in assembly processes. In order to remain economically competitive, these operations are more and more transferred to sheltered workshops. Innovative assistance systems are required to enable the manufacturing of more complex products in these workshops and to generate a working life for the restricted peoples as autonomously as possible.[40] Furthermore also employees whose abilities have changed through the normal ageing process can benefit very much from these systems. This situation gets more and more important nowadays based on the effects of the demographic change.[41]

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[39] Cf. Martin (2014), p. 11f.
[40] Cf. Korn et al. (2013), p. 1
[41] Cf. Brach/Korn (2012)

2.3.3 Complexity based approach

According to a research conducted by Slama in the year 2004, the fulfilment of information requirements of employees is very important. The reason therefore is that the error rate in rarely occurring variant-specific operations is about five to six times higher than in conventional uniform operations. Most of these occurring errors are caused by inexperience, inadequate qualifications of employees as well as inadequate availability, timeliness and completeness of necessary information.[42] [43] Furthermore the cycle time will increase, if a time consuming search for information is required. The other extreme that occurs quite often are information overloads due to paper-based instructions. Overloads also have negative influences to the working conditions because they often result in actions based on workers' experience as well as on his evaluation of the situation.[44] Thus these decisions often lead to a higher error rate.

A further factor concerning the necessity of assistance systems are computer systems. In the last years, production related information technologies have found their ways into the manufacturing industry. Manufacturing execution systems *(MES)* have simplified the manual data transfer as well as paper-based documents and result in several human-computer-interfaces *(HCI)*. In many cases the heterogeneous system environment leads to awkward inputs by using the classical way of interactions with keyboard and mouse. These manual inputs from the workers are very time consuming and take valuable production time. Intuitive and gesture based interfaces can be used to increase the efficiency of the worker and to simplify existing processes.[45] Thereby these interactions with assistance systems should be easy to learn, intuitive and as natural as possible.[46] Traditional industrial interfaces often use interactions with a mechanical input device such as keyboard, mouse or touchscreen together with a visual output device such as a screen or projector. This information exchange can be simplified by using voice, gesture or mimic.[47] Furthermore smartphones, tablets as well as motion control systems can be integrated to improve these interactions.[48] The handling of multi-touch and voice based operating philosophies result in an increasing freedom of design as well as in an increasing ease of the operation based on an expected handling from the workers.[49] Factors such as robustness and safety often lead to unfavourable

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[42] Cf. Slama (2004)
[43] Cf. Krüger et al. (1998)
[44] Cf. Dreyer (2006)
[45] Cf. Schick/Sauer (2013), p. 731
[46] Cf. Korn et al. (2012)
[47] Cf. Gorecky/Schmitt/Loskyll (2014), p. 530
[48] Cf. Martin (2014), p. 12
[49] Cf. Schmitt et al. (2013)

facts that systems from the consumer market cannot be used one-to-one in industrial applications. One important form of interaction is the well-approved touchscreen, but especially voice and gesture control systems have an enormous potential to be suitable for interactions in industrial applications too. The disadvantage of gesture control is that it requires sensor technologies for position recognition of body parts either image- or device-based. The device-based method is characterised by the use of body carried sensors such as data gloves. The image-based method is characterised by the use of object recognition and image processing systems such as the Microsoft Kinect system.[50]

Requirements from the industrial side on these systems are mainly an improved flexibility for solving different tasks, an easy and fast configuration of the system as well as easy to learn interactions. Requirements that affect the worker's point of view are mainly scalability to his skills, provision of motivating elements and a support based on context-sensitive assistance. Such systems should be able to support and relieve the workers, promote their possibilities, increase the productivity and make work tasks more interesting to improve the economy.[51]

2.3.4 Summary of the reasons

To sum up the reasons for implementing assistance systems in industrial applications, it becomes clear that a cooperation between humans and technologies lead to a flexible automation of process operations (precision versus flexibility) and on the other hand to a big societal benefit. The societal benefit can be attributed to the progressive demographic change, based on the increasing share of elderly people as well as missing of young qualified employees. The arising difficulties can be traced back especially to the increasing complexity of machinery and equipment. Thereby many tasks are physically challenging and a lot of employees currently work on their limit of performance.[52]

[50] Cf. Gorecky/Schmitt/Loskyll (2014), p. 530f.
[51] Cf. Martin (2014), p. 13
[52] Cf. Schenk/Elkmann (2012), p. 109

2.4 Concept of an assistance system

A big competitive advantage based on an increasing productivity can be generated by a faster adaption of the skills of the workers to new and changed situations. According to Figure 4, the conventional curve 1 (connection from A to C) represents a reduction of the costs per piece through the gained experience of the worker. The new curve 2 (connection of A to B) represents an immediate reduction of the costs per piece through additional qualification measures such as assistance, trainings or knowledge sharing to improve the skills of the worker.[53] Information-provision assistance systems have now the possibility to support the worker in his task execution and enable a massive cost redecution, which does not require the developmant of long-term experience. This benefit is available immediately after implementation of the assistance system and visible as Δ in Figure 4. The worker is able to use know-how from the first application in contrast to know-how that has to be developed cumbersome through many repetitions of tasks if no assistance is available (e.g. optimal sequence of handle). The new connection from A to B represents the usage of an innovative assistance system.

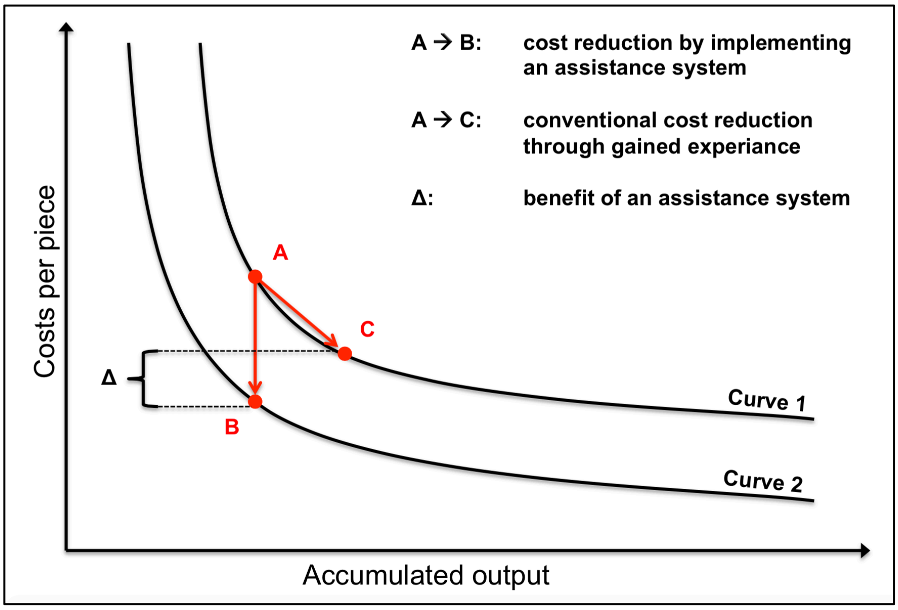

Figure 4: Learning curve in production [54]

The following two chapters deal with the learning process vs. assistance as well as with errors that can be compensated by implementing assistance systems.

[53] Cf. Gorecky/Mura (2012), p. 12f.
[54] own representation based on Gorecky/Mura (2012), p. 13

2.4.1 Learning process vs. assistance

In today's companies different qualifications as well as training approaches are available to support the workers in the manufacturing area with work instructions, training courses, seminars, mentoring systems or learning by experience. Thereby the learning process can be divided into formal and informal learning. The process of formal learning consists of clear didactic and methodological criteria including a precisely specified learning content with an appropriate learning goal. The process of informal learning is a non-institutionally organized process without a specific learning goal and usually takes place unintentionally as well as automatically in daily working situations. The fundamental difference between learning and assistance is that learning follows pedagogical goals to enable an effective retention in the future whereby assistance enables a high initial performance at present to execute tasks from the first time as easy, quick and correct as possible. In industrial applications both approaches are very important based on a high initial performance in unknown tasks as well as a development of the long-term skills of the worker.[55]

As visible in Figure 5, the assistance moves over a time period into learning. To avoid a possible limitation of the performance of the workers through assistance, it is very important that the assistance function of the system has to be taken back step-by-step over the time (red line in the following figure). The reason for this effect is that the worker gains experience through a repetition of individual operations (the process of informal learning). A possible limitation can occur for example if every step in the procedure gets displayed very detailed although the worker already knows these steps. This effect leads to one of the most important requirements for assistance systems, the scalability. More detailed information according requirements for innovative assistance systems are visible in chapter 2.7.2.

[55] Cf. Gorecky/Mura (2012), p. 14ff.

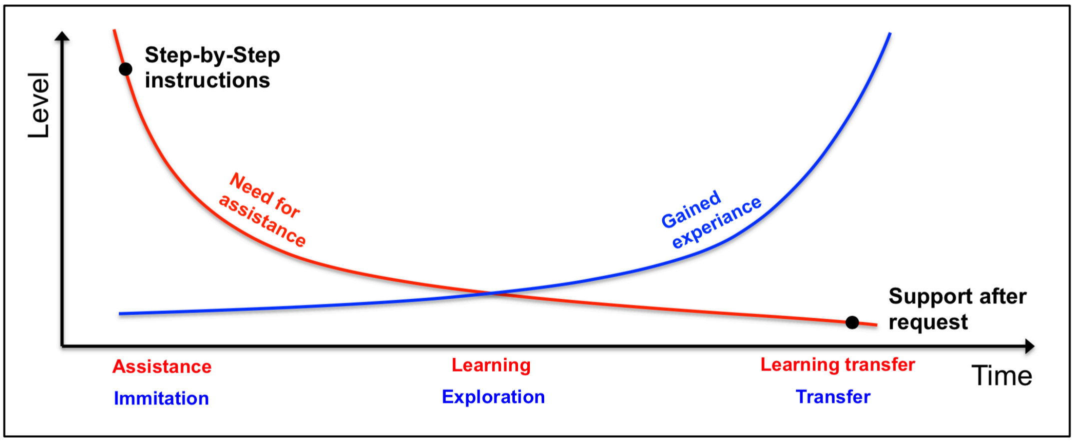

Figure 5: Need for assistance vs. gained experience [56]

2.4.2 Occurring human errors

One of the main tasks of assistance systems is the reduction of non-value adding activities and thus the avoidance of errors especially in complex assembly processes.[57] These occurring errors can be classified into three basic error types: [58]

- **Execution errors** due to an overload of the worker, a lack of concentration as well as slackness
- **Memory errors** due to cognitive demanding tasks
- **Errors in reasoning** due to inadequate qualifications as well as lacking of available, actual or complete information

Execution and memory errors can be avoided relatively easy by an appropriate design of the work process, but errors in reasoning are difficult to avoid and are mostly based on insufficient qualifications.[59] Situation oriented assembly assistance systems are able to reduce errors due to lacking qualifications or information (errors in reasoning). Furthermore the process capability and thus the efficiency in assembly processes can be improved by such systems. These assistance systems provide work instructions, workflows, process knowledge as well as practical knowledge.[60]

[56] own representation based on Gorecky/Mura (2012), p. 16
[57] Cf. Reason (1994)
[58] Cf. Krüger/Schimmelpfeng/Schöfer (1998)
[59] Cf. Krüger/Schimmelpfeng/Schöfer (1998)
[60] Cf. Wiesbeck (2014), p. 56

2.5 Classification of assistance systems

To categorise industrial useable assistance systems, a division into three basic types, the robotic co-worker and tele-supervised as well as augmented reality systems, is necessary. Quite often, available solutions cannot be associated directly to one specific type and thus occur as mixed forms.

2.5.1 Robotic co-worker systems

Robotic co-worker systems enable the workers to apply the accuracy as well as the power of robots to solve industrial problems and to manufacture products. Thereby the worker guides the robot and makes the necessary decisions. These systems are scalable to different tasks in the production process and combine the accuracy, power and speed of a machine with the flexibility, creativity and decision making ability of humans. The functionality of this system is visible in Figure 6-A.[61]

2.5.2 Tele-supervised robotics

Tele-supervised robotic systems enable the workers to perform their work by the use of a remote control of the robot. Thus the workers do not have to be present directly at the workplace and thus they are protected against hazard conditions as well as environmental influences. Furthermore operations can be carried out directly on risky places where the workers normally do not have access. The functionality of this system is visible in Figure 6-B.[62]

2.5.3 Augmentation systems

Augmentation systems facilitate the tasks of workers in the production area, assembly and quality management by extending the perception of the workers for example through projections directly to the working area. Thereby these systems expand the reality and often provide context-sensitive help as well as offer task specific information by using sensors for object and people recognition.[63] Such systems are able to improve the skills of unrestricted peoples in their day-to-day work but are also able to support

[61] Cf. Brea et al. (2013)
[62] Cf. Brea et al. (2013)
[63] Cf. Brea et al. (2013)

peoples with disabilities and peoples whose abilities have changed.[64] [65] The results are products with a higher quality due to a simplified execution of the work task and an earlier identification of potential failures. Furthermore supporting elements such as progress indicator, levels, point systems as well as acoustical and visual feedbacks are able to improve the quality, the speed and the satisfaction of employees and thus their productivity. The functionality of this system is visible in Figure 6-C.[66] [67]

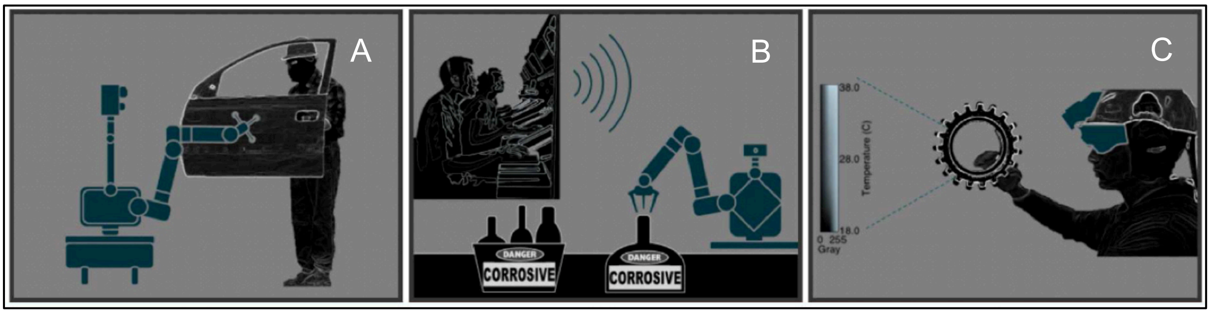

Figure 6: Classification of assistance systems [68]

2.6 Augmented reality systems

Reality-extending systems – called augmented reality – are the most important group of assistance systems. As mentioned in the first chapters, there is a trend towards customized product variants, shorter development cycles, increased product complexities and higher product qualities. These effects lead to an adaption of the organization of workflows and to an integration of information technology tools. The objectives are process times that should be as small as possible, a reduction of potential errors and manageable job steps. The solution therefore is called augmented reality *(AR)*.[69] AR is the enrichment of the human sensual perception, mostly only the visual perception, by the use of an appropriate representation of computer-generated information directly in the field of view of the user. Furthermore it includes possibilities to interact in real-time with this information and thus it represents a kind of human-computer-interfaces.[70]

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[64] Cf. Korn/Schmidt/Hörz (2013)
[65] Cf. Rosenthal et al. (2010)
[66] Cf. Korn et al. (2012)
[67] Cf. Korn/Schmidt/Hörz (2012)
[68] Brea et al. (2013)
[69] Cf. Schenk et al. (2010), p. 33
[70] Cf. Milgram/Kishino (1994)

These provided information originate from different sources: [71]

- **Product creation process:** includes CAD models or process descriptions
- **Technical documentation:** includes data sheets or operating instructions
- **Operative production process:** includes order progress, operational status or process parameters

The computer-generated information used within AR systems can be represented in different ways. Such systems consist of several components. One important technical component that is often used in connection with these systems is the tracking system, which is required for the provision of the position and orientation of the user as well as the objects in the working environment. Another important component is the display unit that may be a projector, stationary monitor, mobile devices such as smartphones or tablets as well as head-mounted optical-see-through displays or other wearables such as Smart Watches.[72] The main fields of application of augmented reality systems are the development, production, assembly and service areas for the automotive and aircraft industry as well as the machinery and plant engineering.[73]

Augmented reality has already achieved its peak of inflated expectations according to Gartner's hype-cycle of innovations. In the next ten years this technology will go further to the valley of disappointments and to the path of enlightenments. Finally the objective is to reach the plateau of productivity.[74]

Up to now augmented reality never really pushed through in industrial applications. The main reasons are the circumstantial use, restrictions of mobility and the occurring high costs. An alternative to expensive data glasses and co are smartphones and tablets that are already in use. Furthermore the handling is well known and these devices are already equipped with cameras to capture the real world and cross-fade this image with additional information directly at the integrated screen. Possible functionalities are geo and navigation data, information according buildings and objects, current process data, technical documentation, maintenance as well as repair instructions. Furthermore the image that is enriched with AR information can be provided to a support team that is able to assist the people on site. Thus applications in maintenance as well as repair are also very important and lead to a cost reduction. The main advantage of a high-tech data glass such as the Google Glass is the hands-free interaction and thus a sufficient

[71] Cf. Gorecky/Schmitt/Loskyll (2014), p. 528
[72] Cf. Schenk et al. (2010), p. 33
[73] Cf. Schenk/Schumann/Schreiber (2009)
[74] Cf. Burkard/Thesmann (2013), p. 52

freedom of movement.[75] Furthermore time-consuming data inputs during the task execution – a non-value adding activity – can be avoided.

AR systems can be divided into mobile as well as stationary systems. Mobile augmented reality systems can be carried along by the user, are freely moveable and the execution of the primary task is not hindered. The opposite are local limited systems with a clearly defined workplace, called stationary AR systems.[76]

2.6.1 Stationary augmented reality assistance systems [77]

Stationary AR systems typically support processes such as complex assemblies in a locally limited workplace. The objective is to avoid mistakes during this complex task execution and to improve the efficiency. One important example is the manual assembly of a clamping system for a CNC machine that consists of a very high number of variants. To ensure secure operations, it is very important that all parts are mounted in the correct location and that the appropriate components are used. A wrong position or orientation can lead to high repair costs as well as to down times. The AR system consists of many different cameras that are adjusted to the workplace to generate a live display of the assembly situation from different perspectives. The system reads the 3D CAD data as well as the sequence of assembly steps and cross-fades this data with the generated live display. Due to the development, the required 3D CAD data is already available for every part. Last but not least, the bill of material is displayed to the user. Upon completion the next job step is displayed automatically.

Benefits of a reference system:

A reference system was built up for the manual assembly of a complex clamping system of a CNC machine. Usually these systems consist of 30-80 components and currently about 6.000 different system configurations are available. Approximately 70 different clamping systems are assembled per day and workplace. The exact positioning of parts is very important, otherwise high repair costs as well as down times are the results. To simplify this situation, an augmented reality system was developed that uses different cameras. The system cross-fades the live video data from these cameras with the available 3D CAD data and the assembly sequences. Finally the overlayed picture is presented to the worker on a flat screen.

[75] Cf. Mayer/Pantförderer (2014), p. 486ff.
[76] Cf. Schenk et al. (2010), p. 33
[77] Cf. Sauer/Tümler (2007)

The result out of this reference system was a **zero error rate** during the assembly processes in a 3-shift operation within four weeks and an **assembly time** that **decreased by 20 %.**

2.6.2 Mobile augmented reality assistance systems

Mobile interactions can be realized relatively easy by implementing smartphones, tablets as well as wearables in the production process. These devices are well known, mobile, lightweight and powerful to execute different applications directly on site. Thereby multi-touch, speech, gesture recognition and other natural interactions have a positive impact and ensure an efficient, satisfactory as well as effective application. Other advantages occur by applying integrated technologies such as GPS, camera, indoor positioning systems or apps that allow an easy extension of the user platform with useful customized applications. Furthermore a simple exchange of knowledge is feasible with these mobile devices.[78]

At present only few applications of mobile AR systems are known. One reason is that the technological development of such systems is often done without consideration of the user. However, the interaction between user and system is crucial for the success. User-oriented aspects have to be considered because they include the ergonomics as well as the acceptance of the overall system, aspects of industrial medicine and perception psychology as well as strain physiology during long-term use. Thus an interdisciplinary cooperation of experts is necessary to gain knowledge of long-term effects to reduce the stresses of workers and to improve the acceptance of these systems.[79] [80]

In a possible use case, the maintenance staffs get informed as quickly as possible by an automated generated maintenance order. This message receives directly at the smartphone / tablet. The error place can be detected relatively easy by using GPS and indoor location systems. The device can be identified due to a photo, taken with the integrated camera. After that the assistance system can provide fully automatic the appropriate technical documentation that consists of a step-by-step instruction to solve the problem without difficulties. The instruction can be displayed either on the smartphone / tablet or on an additional head-mounted display to ensure a hands-free working condition. Furthermore necessary spare parts can be ordered automatically

[78] Cf. Gorecky/Mura (2012), p. 18
[79] Cf. Tang et al. (2004)
[80] Cf. Fritzsche (2006)

and administrative work (e.g. documentation) can be processed directly by the system.[81]

Another possible area of application for mobile AR systems is a picking station. Therefore instructions are displayed directly on the mobile AR system, for example a head-mounted display. This display shows the task as a combination of text and reference elements.[82]

Benefits of a reference system: [83]

A reference system was used for a long-term study of mobile assistance systems in the field of commissioning. Thereby the order related parts have to be taken correct from a stock and put into a shopping cart. The assistance system is based on augmented reality and uses a head-mounted display to provide necessary information directly to the field of view of the worker. The results out of this study were then compared with the results of the classical paper based instructions. Thereby the number of assembly steps per unit of time as well as the number of commissioning errors was determined.

As a result out of this study, **no higher loads** influenced the user of the AR system in comparison to classical paper based instructions. Furthermore the number of **wrong commissioned parts decreased by a third** and in contrast the total number of **commissioned parts increased by 20 %.**

2.6.3 Functionality of an augmented reality assembly assistance system

The input data required for this augmented reality system is generated on the one hand from a video camera that observes the workspace and on the other hand from the data of the CAD system of the to be installed components. Thereby the view perspective of the 3D-CAD model is aligned directly to the camera perspective of the workspace. Then the picture from the camera of the real assembly situation and the CAD-models are cross-fade and the actual work procedure is added virtually to the camera picture. As a result the worker is supported by useful information according the assembly flow, types of required components as well as sequences of assembly steps, based on the data from position and orientation. Additionally used, fixed or movable cameras can be installed for the observation of the assembly situation to allow different perspectives of

[81] Cf. Gorecky/Mura (2012), p. 26f.
[82] Cf. Tümler/Mecke (2006)
[83] Cf. Tümler/Mecke (2006)

view. Especially complex tasks can benefit enormous from such extensions. The process security can be improved by an accompanying check of the situation, which includes a checking of presence, correct position and correct orientation of the installed parts as well as completeness of the work procedure. Usually two to five cameras are installed in one workplace. The visualisation of the assistance function and the inspection results can be realized by using a projector or screen. This allows a continuous visual inspection of the assembly situation. One of the biggest benefits of such an assistance system is the efficient organization as well as execution of complex and multi-variant assembly processes. Thereby the task of the worker is simplified, the assembly rate increased, the error rate decreased and the quality improved. Furthermore expensive and time-consuming test runs as well as rework can be eliminated and machines can operate much more efficient.[84]

2.6.4 Optimizations for augmented reality systems

The following elements, in-situ projection, gamification, natural operations as well as wearables are technologies or techniques that are able to improve the efficiency as well as the acceptance of augmented reality systems.

2.6.4.1 In-situ projection

In-situ projection is a combination of computer visualisation and projection technologies to generate an improved working environment. Thereby the information is projected directly at the place where it is needed such as the working area or the surface of respective components. This enables the worker to execute specific work processes relatively easy. The information that is provided by the system can be a text, image, video, animation or other supporting elements such as arrows or simple symbols.[85]

2.6.4.2 Gamification

Gamification elements are used to improve the motivation as well as the attention of workers and thus to reduce mistakes during the task execution. Researches have shown that recurring and monotonous tasks often lead to boredom and thus to a decrease of the concentration and motivation. Thereby methods such as progress

[84] Cf. Berndt/Sauer (2012), p. 47ff.
[85] Cf. Martin (2014), p. 22f.

indicator, levels, point system and acoustical as well as visual feedback are applied. The results are an increase in motivation, a lower error rate in task execution as well as more attentive and concentrative workers.[86] Thereby elements from video games such as Tetris can be implemented in the working activities to improve the user friendliness.[87] Furthermore gamification is a very helpful method especially in cooperation with disabled employees.

2.6.4.3 Tracking system and natural operations

A consistent workflow with the possibility to adjust the skills of the worker to the difficulty of specific tasks is influenced by several factors including a clear goal and task description, an equilibrium between the task and the own skills, a clear and direct feedback and last but not least the feeling that every activity is worthwhile.[88] A direct feedback is only possible by using a motion tracking system in real time such as the Microsoft Kinect system. The usage of as natural and intuitive operations as possible is required to simplify the mostly very complex user interfaces by applying swipe, tip or touch gestures or simple voice commands. Such natural user interfaces can be realized relatively easy by using the own body as an input device instead of the classical interactions based on mouse and keyboard.[89]

Measured and observed parameters required for cognitive analysis: [90]

- Analysis of the body language by tracking different parts of the body
- Analysis of the attention by measuring the eye movement
- Identification of mimic activities by a detection of the face
- Voice recognition and assessment of noise emissions

Currently this technology is not predominant in industrial applications because crucial factors such as accuracy, robustness and occlusion are often not fulfilled. An improvement of the classical Microsoft Kinect system was done by 3Gear with the “Akimbo Kinect hack” that allows a simultaneous usage of two different Kinect systems to reach a higher precision. Other very natural interactions are based on speech and are able to replace conventional point and click interactions. One of the best available speech recognition systems is “Siri” developed by Apple.[91] The main disadvantages of

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[86] Cf. Korn (2012)
[87] Cf. Korn et al. (2012)
[88] Cf. Korn et al. (2012)
[89] Cf. Korn/Schmidt/Hörz (2012)
[90] Cf. Zäh et al. (2007), p. 647
[91] Cf. Gorecky/Mura (2012), p. 19f.

these speech-based interactions can be traced back to the fact that usually workers in the industry have different countries of origin and thus different pronunciations. The results will be a bad reliability and thus operating errors. Furthermore these systems typically have to operate in noisy environments and thus non-comprehensible commands will be the result. Therefore this technology will not find a huge acceptance for industrial applications.

2.6.4.4 Wearables

Very promising devices for mobile augmented reality solutions are wearables such as Smart Watches, Smart Glasses, Smart Lenses or Hearing Devices. A wearable can be seen as a mobile computing device that the user wears on his wrist, arm, head or other body part with the purpose to be accessible at any time, to get real-time information, be able to enter data as well as to be able to communicate. Wearables have the possibility to support the workers in their daily activities by providing useful information, increase the flexibility and efficiency as well as to monitor the workers' health in real time. To realize health surveillance, the integrated sensors such as heart rate monitor or UV sensors are used. Thus stress, tiredness, lack of concentration or other affecting symptoms can be determined. These devices are currently still in their infancy, but have a high potential for industrial applications based on the low costs and the fact that both hands of the workers are free in contrast to conventional solutions with smartphones or tablets.

The year 2014 was declared from experts all over the world to the year of the wearables. According to ABI Research, the shipped wearables will increase from 50 million devices in 2013 up to 90 million devices in 2014. The potential for 2018 are 485 million shipped devices, presented at the Wearable Technologies Europe conference in Munich. According to ABI Research, the dominating wearables for 2014 are health-, sports- and activity trackers. Furthermore also Smart Watches and Smart Glasses have a high potential in the future, but until now their market acceptance is very low. According to a study conducted by Forrester in 2013, the most favoured locations to wear sensor devices are "clipped onto clothing" (29 %), wrist (28 %), "clipped on shoe" (18 %), "embedded into clothing" (15 %) as well as glasses, ear buds and jewellery (each 12 %). Google X is a further development of wearables and represents a Smart Contact Lens. The objective of this contact lens is the support of diabetics to measure their glucose level in the tears of their eyes. Thereby this lens transmits the collected data to wireless mobile devices. Further ideas are integrated LED lights that are able to act as an early warning system.[92]

Currently a great number of wearables for different commercial applications are available. The main devices in this field of Smart Watches and sports/activity tracker are the Razer Nabu, Bragi, LG LifeBand, Samsung Gear, Samsung GearFit, Sony Smartwatch and Sony Smartband. Smart Glasses are currently still in their infancy, but some devices are already commercial available such as the Google Glass, Epson Moverio, Optinvent ORA, Recon Jet and Vuzix M100. Promising developments in the field of data gloves are performed from the German company ProGlove. Additional information can be found in the Appendix 1.

According to Figure 7, created by ABI research, the trends for further developments in wearable technologies are clearly identifiable. The market of smart watches will rise substantially in contrast to smart glasses and thus illustrates a huge potential for future applications.

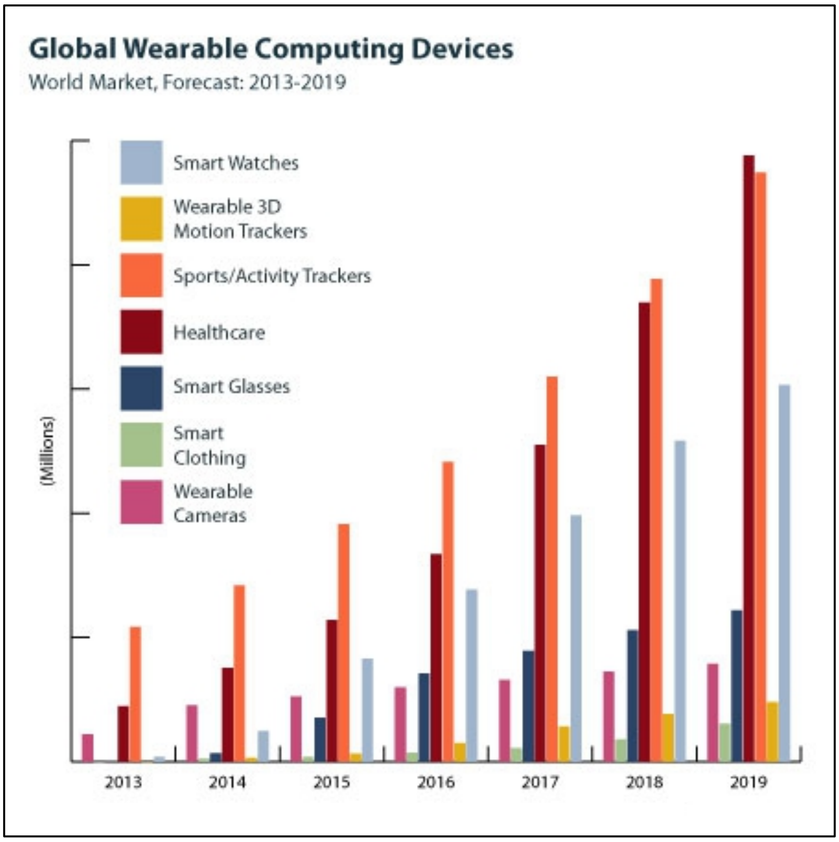

Figure 7: Global wearable computing devices [93]

[92] Cf. Schumacher (2014)
[93] Schumacher (2014)

2.7 Requirements for innovative assistance systems

The following chapter deals with the most important requirements for innovative assistance systems to ensure a successful implementation in manufacturing as well as to generate a sufficient acceptance for the workers. It is very important to note that these mentioned requirements only represent the basic requirements of assistance systems. More meaningful and detailed requirements are very situation specific with regard to the functionality and cannot be generalised. For example robotic co-working systems usually deal with other requirements than stationary augmented reality systems with a projector or mobile systems with data glasses.

2.7.1 Basic tasks

Perfect interactions between humans and technologies can be seen as one of the most important factors that influence the economic success of a company. Thereby the basic tasks of future production systems without a comprehensive automation are to: [94]

- Support humans in processes of perception and decision making to improve the quality, reliability as well as efficiency by enhancing the precision, speed and production flexibility.
- Support humans that suffer under a restricted physical performance concerning motor skills or load applications during the order execution by taking over repetitive activities. Such systems have to be user-friendly and error-tolerant.
- Use sensor technologies and information memories to detect the current working processes and to provide a systematic support of the working routines of humans.

2.7.2 Requirements

Assistance systems can be seen as innovative technologies that combine the specific capabilities of humans and technologies with the objective to generate high qualitative industrial applications at simultaneously competitive costs.[95]

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[94] Cf. Braun (2012)
[95] Cf. Braun (2012)

The main requirements therefore are: [96]

- **Flexibility of the system**, which is aiming to the fact that the system should be applicable for the solution of many different tasks.
- **Scalability of the system**, which is aiming to the fact that the system should be adaptable to the skills of many different workers as well as to the gained experience. Thus a rigid guidance of the users is not welcome.
- **Simplified user interfaces**, which are aiming to the fact that the system should be intuitive and thus easy as well as quick to use and to configurate. An additional expenditure to operate with the system is not welcome.
- **Mechanisms for motivation**, which have the task to motivate workers and to improve the workflow by using motivating elements such as progress indicators.
- **Context-sensitive help**, which is necessary to support the workers in all situations and to give a situational support.[97]
- **Increase of the process orientation**, which is aiming to the fact that the system should run in the background to reach a consistent workflow and to support the worker only if necessary.[98] [99] [100]

Beside the requirements to the functionality of the device itself, there are also requirements in relation to the software that is used within the scope of the assistance system: [101]

- **Modifiability**, which is very important to enable a later modification of the software (e.g. adaption to new products, new workplaces, new procedures, etc.).
- **Robustness**, which is very important to ensure a stable and safe process because the possibility of wrong inputs cannot be ruled.
- **Reliability**, which is very important because the software acts as a reliable support of the worker in real industrial processes and thus a breakdown can lead to enormous costs.
- **Usability**, which is very important to simplify the handling of the user interfaces as well as functional possibilities to avoid additional temporal expenditures.

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[96] Cf. Martin (2014), p. 17
[97] Cf. Martin (2014), p. 13
[98] Cf. Korn (2012)
[99] Cf. Korn/Schmidt/Hörz (2012)
[100] Cf. Korn/Schmidt/Hörz (2013)
[101] Cf. Martin (2014), p. 73f.

The most significant difficulties can be derived from the requirements of assistance systems and lead especially to design problems. These design problems can be compensated through answering the following questions: [102]

- In which context should the assistance system be used?
- Which tasks should be solved by the use of these assistance systems?
- What skills and limitations do the workers have who will use the system?

A user-centered design is applied to meet the requirements of assistance systems in which the user always stays in the focus of the design process. Thereby the system should be able to adapt itself automatically to the skills, needs, intensions as well as restrictions of the user.[103] [104] [105]

2.7.3 Extension of the basic tasks / requirements

If the three basic tasks mentioned in the chapter 2.7.1 are extended, new manifold assistance systems can be developed. Fraunhofer IAO *(Institut für Arbeitswirtschaft und Organisation)* calls such a system CamP *(computer assisted manual production)*. CamP is able to detect the current work steps and to compare these work steps with predefined as well as optimized work steps. After that the system supports the workers in decision-making based on the ideal workflow. Additionally the system is able to avoid human errors by applying optical, acoustical or haptic signals. Furthermore the system is able to cancel the current process if necessary. CamP works sensor, didactic and navigation based to realize a real-time tracking of relevant body parts for an actual / target-comparison, guide the operator through the process and support him with know-how to successfully fulfil the tasks. The objective is to avoid power fluctuations and make task-based information available in real-time based on the worker's comprehension, experience and scope of the tasks. These systems are able to support the human either physically to reach higher repetition accuracy as well as informatively to improve the memory capacity. On the one hand this extension leads to a higher quality and on the other hand to lower manufacturing costs (see Figure 8) by producing resource-efficient and avoiding time- and cost-intensive rejection or rework. Furthermore the aspiration level of tasks can be increased, the products can be

[102] Cf. Martin (2014), p. 17
[103] Cf. Korn/Schmidt/Hörz (2012)
[104] Cf. Brach/Korn (2012)
[105] Cf. Korn et al. (2012)

configured more flexible, small and medial series get more economic as well as humans' ability to work can be maintained.[106]

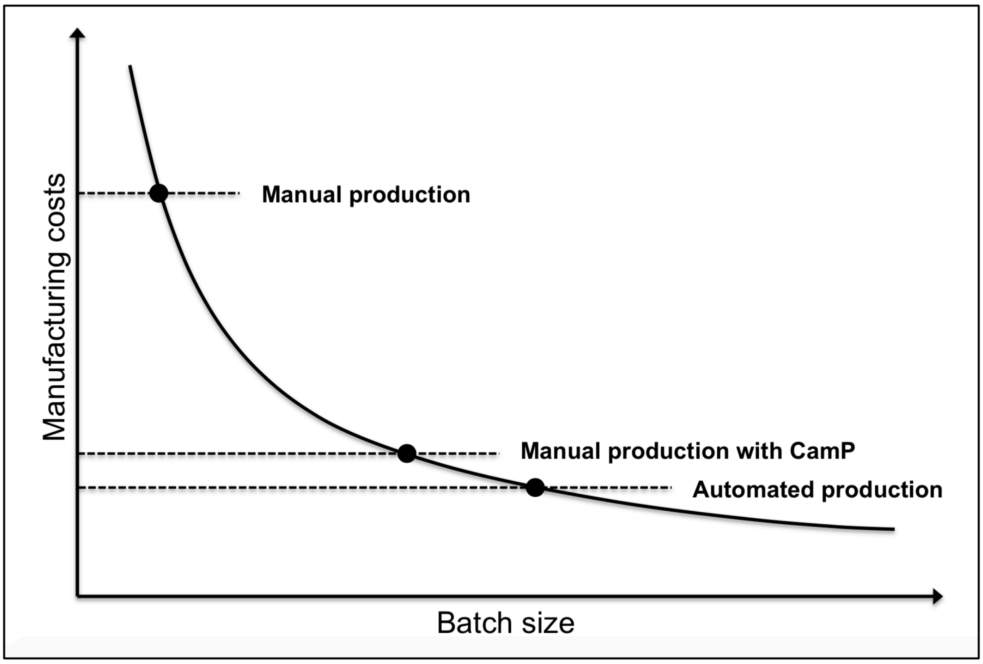

Figure 8: Dependence of manufacturing costs on the batch size [107]

2.7.4 Industrial requirements – DIN EN 60529

According to DIN EN 60529, electrical equipment has to be assigned to a protection class (IP-Codes, Ingress Protection) corresponding to its load through foreign objects and water. The protection class does not take external influences into consideration. Electric shocks are considered in the electrical protection class. Thereby IP00 stands for the smallest protection class and has no protection against foreign elements and water. IPXX stands for a not defined protection class, because no verification has carried out. The electrical equipment is protected against IP20 if no protection class is specified.[108]

[106] Cf. Braun (2012)
[107] own representation based on Braun (2012)
[108] Cf. n.u. Osram (2012), p. 2

First key number:

As visible in Figure 9, the first key number of the protection class describes the protection against contact and penetration of solid bodies and dust.[109]

Schutzgrade nach der ersten Kennziffer			
Erste Kennziffer		Schutzgrad	
		Kurzbeschreibung	Kurze Einzelheiten, welche Fremdkörper nicht in das Gehäuse eindringen dürfen
0		Ungeschützt	Kein besonderer Schutz
1		Geschützt gegen feste Fremdkörper größer als 50 mm	Große Körperoberfläche, z. B. eine Hand (jedoch keine Schutzmaßnahme gegen absichtliches Berühren). Feste Fremdkörper über 50 mm Durchmesser.
2		Geschützt gegen feste Fremdkörper größer als 12 mm	Finger oder Ähnliches bis 80 mm Länge. Feste Fremdkörper über 12 mm Durchmesser.
3		Geschützt gegen feste Fremdkörper größer als 2,5 mm	Werkzeuge, Drähte usw. mit Durchmesser oder Dicke größer als 2,5 mm. Feste Fremdkörper über 2,5 mm Durchmesser.
4		Geschützt gegen feste Fremdkörper größer als 1 mm	Drähte oder Streifen dicker als 1 mm. Feste Fremdkörper über 1 mm Durchmesser.
5		Staubgeschützt	Eindringen von Staub ist nicht völlig verhindert, aber Staub dringt nicht in solchen Mengen ein, dass ein ordnungsgemäßer Betrieb des Betriebsmittels behindert wird.
6		Staubdicht	Kein Eindringen von Staub

Figure 9: First key number [110]

[109] Cf. n.u. Osram (2012), p. 3
[110] N.u. Osram (2012), p. 3

Second key number

According to Figure 10, the second key number describes the damaging ingress of water.[111]

Schutzgrade nach der zweiten Kennziffer			
Zweite Kennziffer		Schutzgrad	
		Kurzbeschreibung	Einzelheiten zur Schutzmaßnahme durch das Gehäuse
0		Ungeschützt	Kein besonderer Schutz
1		Geschützt gegen Tropfwasser	Herabtropfendes Wasser (senkrecht fallende Tropfen) darf keine schädliche Wirkung haben.
2		Geschützt gegen Tropfwasser unter 15°	Senkrecht fallende Tropfen dürfen keine schädliche Wirkung haben, wenn das Gehäuse bis zu 15° aus seiner bestimmungsgemäßen Gebrauchslage geneigt wird.
3		Geschützt gegen Sprühwasser	Sprühendes Wasser darf aus einer Neigung bis zu 60° gegen die Senkrechte keine schädliche Wirkung haben.
4		Geschützt gegen Spritzwasser	Aus beliebiger Richtung gegen das Gehäuse gespritztes Wasser darf keine schädliche Wirkung haben.
5		Geschützt gegen Strahlwasser	Aus beliebiger Richtung gegen das Gehäuse mit einer Düse gespritztes Wasser darf keine schädliche Wirkung haben.
6		Geschützt gegen schwere See	Wasser von schwerer See oder Strahlwasser unter hohem Druck darf nicht in schädlicher Menge in das Gehäuse eindringen.
7		Geschützt gegen die Folgen von Eintauchen	Eindringen von Wasser in schädlicher Menge darf nicht möglich sein, wenn das Gehäuse in Wasser unter vorgegebenen Bedingungen hinsichtlich Druck und Zeit eingetaucht ist.
8		Geschützt gegen Untertauchen	Das Gerät ist für dauerndes Untertauchen in Wasser geeignet. Die Bedingungen sind vom Hersteller anzugeben. ANMERKUNG: Üblicherweise bedeutet dies, dass das Gerät vollständig abgedichtet ist. Jedoch kann dies bei bestimmten Geräten auch bedeuten, dass Wasser zwar eindringt, jedoch keine Schädigung verursacht.

Figure 10: Second key number [112]

[111] Cf. n.u. Osram (2012), p. 4
[112] N.u. Osram (2012), p. 4

Additional and optional letters

After the two compulsory key numbers, an additional letter and an optional letter (see Figure 11) can be added voluntary. The additional letter is used to determine the personnel protection against access to hazardous parts and the optional letter is used to specify additional necessary information.[113]

Zusätzlicher Buchstabe	Schutzgrad	Ergänzender Buchstabe	Bedeutung
A	Geschützt gegen den Zugang mit dem Handrücken	H	Hochspannungs-Betriebsmittel
B	Geschützt gegen den Zugang mit dem Finger	M	Geprüft auf schädliche Wirkungen durch den Eintritt von Wasser, wenn die beweglichen Teile des Betriebsmittels in Betrieb sind
C	Geschützt gegen den Zugang mit Werkzeug	S	Geprüft auf schädliche Wirkungen durch den Eintritt von Wasser, wenn die beweglichen Teile des Betriebsmittels im Stillstand sind
D	Geschützt gegen den Zugang mit Draht	W	Geeignet zur Verwendung unter festgelegten Wetterbedingungen und ausgestattet mit zusätzlichen schützenden Maßnahmen oder Verfahren

Figure 11: Additional / optional letters [114]

External influences

Furthermore also external influences that may occur during the usage of the electrical equipment have to be considered. They can be classified according to the influences originating from the environment, influences through usage, influences through the structure of the building as well as influences through cleaning and maintenance. Examples for external influences are chemical influences, ice formations, corrosions, mechanical impacts, humidity and microorganisms.[115]

Additional requirements concerning assistance systems are visible in chapter 2.8.6.1 and deal with standards for human-system-interactions according DIN EN ISO 9241. Furthermore Appendix 2 shows a requirement specification to summarize the most important requirements of innovative assistance systems. Thereby the theoretical requirements from the literature research as well as the requirements that result from the practical implementation of the demonstration system are considered and summarized in a short list.

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[113] Cf. n.u. Osram (2012), p. 6
[114] N.u. Osram (2012), p. 6
[115] Cf. n.u. Osram (2012), p. 7

2.8 Applications of innovative assistance systems

The applications potential of assistance systems in industrial processes are manifold and thus they are applicable in nearly all areas. Thereby the main areas of application are the assembly, general industrial tasks, maintenance, support of employees with restrictions and human-robot-interactions as well as information provision directly at the workplace.

2.8.1 Applications in assembling tasks

Complex assembling processes are one of the main difficulties in the production of multi-variant and manual products due to their individual work procedures. Furthermore a frequently change between different variants, a cancel of the learning curve and a high complexity of the assembly relevant data is crucial for these resulting difficulties.[116] Without an appropriate guidance it is often not possible to assemble complex modules correct. Furthermore statements on a paper mostly do not facilitate these activities enough. Therefore visual assistance systems can be applied to improve this situation. These systems are able to guide the workers step-by-step and in real-time while simultaneously monitoring the results. This leads to a timesaving as well as to a minimization of losses in the production and thus improves the overall efficiency.[117] The application of assistance systems also includes downstream activities such as finishing operations or loading. The support of the worker has changed over the time from classical drawings, picture cards and photos on a wall to spoken instructions, PDAs and screens up to robot-assisted systems, remote monitoring and augmented reality systems.[118]

As mentioned in the previous chapter 2.6.1 (Stationary augmented reality assistance systems one common application of assistance systems for assembly tasks is the assembly of a clamping system for CNC machines. These systems are classically built up by using screenshots of the final system. After that the worker has to check the system in a test run with a significantly reduced feed rate. The result is a very time consuming process that extends the production time senseless. A remedy can be an AR system to synchronise the real mounting situation with the digital assembly instruction, overlap both situations and then represent the overall picture. The result is a support of the worker to avoid mistakes as well as eliminate non-value adding activities.

[116] Cf. Zäh/Rudolf/Möller (2005)
[117] Cf. Berndt/Sauer (2012), p. 46
[118] Cf. Sauer/Parks/Heyn (2010)

Such systems also provide a very high level of process security in continuous changing mounting variations because the worker always gets displayed the exact position as well as orientation of the respective components.[119]

2.8.2 General applications in production engineering

Nowadays the part supply and the linking of machine tools is mostly realized by qualified staff. This is a necessary measure because classical automation solutions mostly cannot be used in these fields due to the high number of variants of parts and products in combination with the small lot size. Assistance systems can change this non-productive process because they are able to network already existing machine centres very flexible and new machines can be integrated relatively easy. Thus the throughput can be increased, because many typical sequences such as bring and collect services can be executed without the need of a qualified worker. The worker is now able to focus his valuable work time on demanding tasks such as quality control. Elderly workers can be supported by stationary or mobile assistance systems also in lifting and transportation activities of heavy parts.[120] To realize an automated linking of machine tools, a reliable interaction of several sensor systems such as Microsoft Kinect is necessary. A detailed description of this process is available in chapter 3.15 Microsoft Kinect

Other applications in the general field of production engineering are packaging tasks. Packaging plays a very important role in industrial applications, necessary in nearly every company. People usually place the objects manually into their package, which in turn lead to very tedious and non-ergonomic working conditions.[121] To change this dissatisfied situation, a solution is required to support the handling as well as the manual packing of heavy goods to unburden the workers in this exhausting task. Therefore one of the biggest requirements for packaging tasks is flexibility to enable an adjustment to similar goods as well as a scalability to support different workers. The ideal solution combines the skills of humans with the skills of machines to benefit from the big advantage of machines, precision without the need of breaks and fatigue as well as high productivity. In many factories weight compensators are already used to simplify working tasks with heavy or bulky parts such as assembly or packaging with the objective to avoid work related injuries concerning the lower back and spine.[122] A

[119] Cf. Berndt/Sauer (2012), p. 47
[120] Cf. Schenk/Elkmann (2012), p. 116f.
[121] Cf. Rooker et al. (2013a)
[122] Cf. Rooker et al. (2013b), p. 69

study from the Occupational Safety & Health Department *(OSHA)* detected that lower back pains already affect more than 30% of all European workers and thus cause very high costs for companies.[123] An implementation of this system is visible in chapter 3.12.

2.8.3 Applications in maintenance tasks

Nowadays mobile devices can realize knowledge transfer relatively easy. The appearing advantages are short and fast communication channels, but a global knowledge transfer is still limited by language difficulties, understanding problems as well as different time zones. The task for maintenance activities is that the service features at the place of event are performed as fast and qualified as possible. The requirements therefore are demanded from the necessary high level of technical availability of production plants, from regional legislators as well as from rigorous safety and environmental protection requirements. To be effective also in the future, it is very important that the results of realized service features are saved to ensure a quick, worldwide and a clear mediation. An excellent maintenance is very important due to limited personnel resources and it is furthermore also a significant competitive factor. The task for the future is to replace the conventional paper based documentations with more efficient possibilities of knowledge provision. The objective is to realize that knowledge is available very fast, save, clearly understandable as well as cheap at any place worldwide. As a result assembling and disassembling processes can be represented relatively easy by applying virtual animations, because they are self-explanatory as well as worldwide comprehensible. The biggest advantages are that knowledge is available without learning efforts of instructions and that knowledge does not fall into oblivion because it is provided if it is needed. Thereby the use of classical texts should be minimized. The maintenance assistance systems can be classified into stationary or mobile solutions. Stationary assistance systems for maintenance are used especially for the training of qualified employees to impart a specific and technological knowledge. Mobile assistance systems for maintenance typically use voice or gesture based control mechanism to enable intuitive interactions and to provide the knowledge directly at the service location on-site.[124] A detailed possible use case for maintenance activities is visible in chapter 2.6.2 Mobile augmented reality assistance systems. The application of animations has also a huge economic potential in other areas of application, especially in the assembly process of complex systems.

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[123] Cf. OSHA (2013)
[124] Cf. Scharschmidt (2013), p. 13ff.

2.8.4 Support of employees with disabilities or changed abilities

In this field of application, assistance systems are used to improve the skills of employees with disabilities and employees whose abilities have changed from the demographic change to generate a working life for them as autonomously as possible.[125] Employees whose abilities have changed are workers with physical and mental restrictions arising from the normal aging process. Typically they have a wide working experience, a good strategic thinking, an improved expressiveness, a large commitment and a high motivation.[126] [127] The physical restrictions can be traced back to a decrease of muscle power, slower movements, decrease of reaction time and age farsightedness as well as to a slower recovery phase. The mental restrictions can be traced back to a decrease of the short-term memory, a decrease of the power of concentration and a bad learning ability.[128] These restrictions are manageable relatively easy with assistance systems.

On the other hand, employees with disabilities are workers with a physical and/or mental handicap not from the normal aging process. This group is experiencing similar difficulties as employees whose abilities have changed. Additionally they often have language difficulties, difficulties of comprehension, problem solving deficits, difficulties in adapting changes and difficulties with changes of the environment.[129] Thus an implementation of this group of workers in the normal working life requires a huge effort. Assistance systems are able to simplify this process.

Preliminary studies were performed in which 134 companies were queried about the requirements of assistance systems for the application in production areas. In 17 % of all interviewed companies, more than 6 % of all employees are already faced with disabilities or changed abilities and these companies are sure that the number will increase in future. 87 % of all interviewed companies would use immediately assistance systems to improve the physical and mental conditions of their employees and 63 % will use systems with additional motivating elements. The main resulting requirements concerning this survey are an improvement of the process-orientation, simplification of user interfaces with natural interactions and possibilities to improve the motivation as well as job satisfaction.[130] Already existing assistance systems are mostly only functional designed to represent the necessary information clearly and systematically.

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[125] Cf. Martin (2014), p. 15f.
[126] Cf. Dul et al. (2012)
[127] Cf. Ilmarinen (2005)
[128] Cf. Brach/Korn (2012)
[129] Cf. Korn et al. (2012)
[130] Cf. Korn/Schmidt/Hörz (2012)

This assistance is suitable for "normal" employees, but not for employees with disabilities or employees whose abilities have changed. A remedy can be found by applying additional simplifying and motivating elements (visible in chapter 2.6.4.2 gamification elements).[131] Thereby the worker gets constantly an optical as well as an acoustical feedback, ideally after each process step. For example a display of a virtual face by using emotions and colours dependent on the current processing speed as well as a display of deviations to the previous pass-through in combination with spoken comments such as "excellent" or "snail's pace".[132]

2.8.5 Safe cooperation between humans and robots

Safety is a very big issue in industrial applications especially to ensure a secure cooperation between humans and robots. On the one hand safety is responsible for the robust implementation of the functions of assistance systems and on the other hand it is a fundamental condition for the suitability of daily use. A hazard potential emerges through a physical contact between both members in one common workspace and range of motion.[133] Due to this high risk of injuries, the working areas of humans and robots are mostly separated in time or in space. Thus humans are excluded from the main production line and only program or control the robot from a safe distance.[134] As mentioned in previous chapters, it gets more and more essential that humans and robots are working together in one common working area. Thus a physical contact between both is unavoidable or often desired due to the necessity of increasing flexibility vs. cost efficient production. The robot is and will always remain as a serious risk of injury and can lead to critical trap or squeeze injuries. To minimize these risks, technically advanced and proved sensor systems are required to protect the human in such human-robot-interactions *(HRI)* and thereby not to limit the flexibility in these workplaces.[135] Currently this topic is examined in many research areas with the objective to realize a safe cooperation between humans and robots, especially for applications in the automotive industry. One solution out of this intensive research is the robot Baxter that enables a safe cooperation with humans, supports the worker in manipulation tasks and easy executes repetitive production tasks. However, a limitation is especially the lifting of heavy goods and thus the practical application is restricted.[136]

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[131] Cf. Korn et al. (2013), p. 2
[132] Cf. Korn et al. (2013), p. 5
[133] Cf. Schenk/Elkmann (2012), p. 110
[134] Cf. DIN EN 775 (1993)
[135] Cf. Behrens/Elkmann/Schenk (2012), p. 433
[136] Cf. n.u. Robot Baxter (2013)

On- and off-board sensors are required for workspace monitoring to expand the perception of the robot. Thereby depth sensors can be implemented to generate collision free trajectories and to ensure collision avoidance due to the generation of 3D points of the environment. Therefore they can be placed stationary in the workcell or mobile at the robot.[137] Placing the sensors high in the corners ensures a very good coverage of the monitoring room, but is only possible for stationary robot arms or small mobile robots in a limited workcell. Otherwise the sensors have to be placed directly at the mobile platform. Usually the position of these sensors is selected by expert knowledge and then evaluated in simulations. Humans and other obstacles can be detected as well as tracked, based on the output data of these sensors.[138]

Due to the enormous risk of severe injuries, a lot of standards are available and have to be fulfilled. ISO/TS 15066 is a responsible standard in human-robot-interactions and deals with several specifications such as minimum distances between human and robot, maximum speed, speed supervision, workspace monitoring as well as force limitations in the case of collision. The trade association allows injuries in a human-robot-interaction only with the maximum severity of a hematoma and no open wounds or bone fractures are tolerated. In an associated body-atlas, the maximum force impacts for different body regions are visible.[139]

2.8.5.1 Regulations and standards:

- **Robotic safety [140]**
  Machinery directive 2006/42/EG deals with essential safety requirements for industrial machines. As a mean of compliance of the machinery directive, the standard DIN EN ISO 12100 is used (safety of machines – basic concept, general design principles). The requirements of this standard are substantiate in DIN EN ISO 10218 (industrial robots – safety requirements). Thereby Part 1 of DIN EN ISO 10218 deals with robots that are treated inclusive the construction and building of a safe robot. Part 2 deals with robot systems and their integration inclusive the protection of the workers.

[137] Cf. Fetzner/Frese/Frey (2013)
[138] Cf. Rybski et al. (2012)
[139] Cf. Schenk/Elkmann (2012), p. 110
[140] Cf. Schenk/Elkmann (2012), p. 111f.

- **Safety in collaborating activities** [141]
  It describes the conditions, if the working areas of humans and robots overlap and if a contact between both members cannot be excluded. The standard DIN EN ISO 10218 is supplemented by ISO/TS 15066 (robots and robotic devices – collaborative robots), which deals with risk assessment, risk identification, power and performance limits as well as with speed and distance monitoring. The assessment of a workplace is based on technical, biomechanical and ergonomic aspects.

- **Robot-law** [142]
  The mentioned normative standards are not applicable for non-commercial public environments or private home use and no valid legal certainty is available. A possible solution can be a compulsory insurance with a multistage liability. Thereby the primary liability is attached to the operator and the secondary liability to service companies and to the manufacturer.

2.8.5.2 Realization of a safe human-robot-interaction:

- **Collision analysis** [143]
  The analyses of physical and biomechanical properties of human-robot collisions are the basis to derive the risks and limits of workplaces in human-robot-interactions. A very important question has to be answered concerning the allowable maximum forces during a collision. These investigations lead to new technologies such as tactile sensor systems, safe manipulations and robots with an optimal brake as well as reaction process.

- **Sensorial workspace monitoring**
  These systems allow a complete monitoring of collaborative working areas to protect the worker. The sensorial workplace monitoring can be divided in two systems. The tactile sensor systems that are based on extensive distributed pressure sensors and the optical workplace monitoring systems that are based on projector and camera technologies.[144] Optical workplace monitoring leads to a

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[141] Cf. Schenk/Elkmann (2012), p. 112
[142] Cf. Schenk/Elkmann (2012), p. 114
[143] Cf. Schenk/Elkmann (2012), p. 118
[144] Cf. Schenk/Elkmann (2012), p. 118f.

very high safety as well as flexibility by simultaneously very low costs. Furthermore the scope of protection is visible for the worker.[145]

- **Safe manipulation** [146]
  Robots that implement safe manipulation are only allowed to use robotic arms with a defined, limited danger of injury. State of the art industrial robots mostly use powerful joints, brace links and kinematic chains that increase the risk of injury. In the sense of safe manipulation, they are not suitable for human and robot cooperation.

2.8.6 Information requirements on the workplace

As a result of the introduction of EDV-Systems, everything got recorded. Unfavourable, the resulting complex information was transmitted directly to the production manager. The consequence was a huge effort to evaluate this data that often could not be mastered. To change this circumstantial situation, the objective was to process the data in a way that the respective target group is able to work productive and to respond more quickly. Thus the workers got a collection of pictures with right and wrong outcomes. This method was very effective but unfortunately not ideal because the required organisational expenditures are very time-consuming to keep the data up to date. As a result small changes often do not get updated. A state of the art solution is possible by implementing the latest technology as wearables, tablets or smartphones and an additional individualization dependent on the qualification of the employees can be taken into account.[147] Furthermore with new technologies the production manager will be able to see directly the production status without a necessary time-consuming research. By using data glasses it will be possible to see directly where an order is located without comb through accompanying documents. Modern vehicles often use head up displays in which only the currently necessary information is faded in the real field of view of the driver. This is also the challenge for industrial assistance systems because the tide of information has to be prepared so that the human is able to make the correct decisions without additional expenses.[148] Thereby the worker always has to stay in the focus with his unique creative and associative skills. The objective is a device with clearly prepared and for the task necessary information to further improve

[145] Cf. Behrens/Elkmann/Schenk (2012), p. 434
[146] Cf. Schenk/Elkmann (2012), p. 119
[147] Cf. Schließmann (2014), p. 458f.
[148] Cf. Spath (2013)

the skills of the worker. Finally it is very important that information procurement is not the task of the worker on-site.[149] Otherwise assistance systems will not be able to exhaust their full potential.

2.8.6.1 Survey according information integration

During his doctoral thesis, Wiesbeck performed the survey “adaptive and situational management in the manual assembly”. In many cases, the situations as well as the assembly environment are not or not sufficient considered in the assembly planning. In this study the main question was how companies realize the integration of information of employees, processes and resources. The questionnaire included questions according the actual as well as the possible future situation of the companies. Thereby the survey was conducted with 40 companies at 47 different locations in Germany as well as Finland. The interviewed companies are operating in different industrial sectors and thereby 42,5 % of all interviewed companies are operating in the field of mechanical engineering. Furthermore 72,5 % of all interviewed companies are dealing with production and assembly or only with assembly processes.[150] The survey has shown that 86,4 % of all interviewed companies already had an increase of their product variants during the last five years and in 78 % of these companies the batch size was smaller than 10 pieces. Thereby 29,3 % of all interviewed companies have already dealt with single piece production. Furthermore the survey has shown that many companies are dealing with a large number of product families at a simultaneous large number of product variants. The average lifecycle of the manufactured products is usually more than 6 years. This leads to a high pronounced customized product design. As a result out of this survey it can be seen that a flexible employability of the workers is necessary.[151] As visible in Figure 12, most of the design elements of currently used assembly assistance systems in the interviewed companies are traditionally oriented by using texts (74,5 %), tables / lists (70,2 %) and drawings (74,5 %). Another result was that in future planned assistance systems, the three predominant design elements will be reduced and therefore animations as well as videos will be seen as one of the most important design elements.[152] However, in order to increase the productivity and to

[149] Cf. Schließmann (2014), p. 459f.
[150] Cf. Wiesbeck (2013), p. 57f.
[151] Cf. Wiesbeck (2013), p. 61f.
[152] Cf. Wiesbeck (2013), p. 64

realize responsiveness to unplanned events, it is necessary to implement a fast as well as assembly process committed information provision.[153]

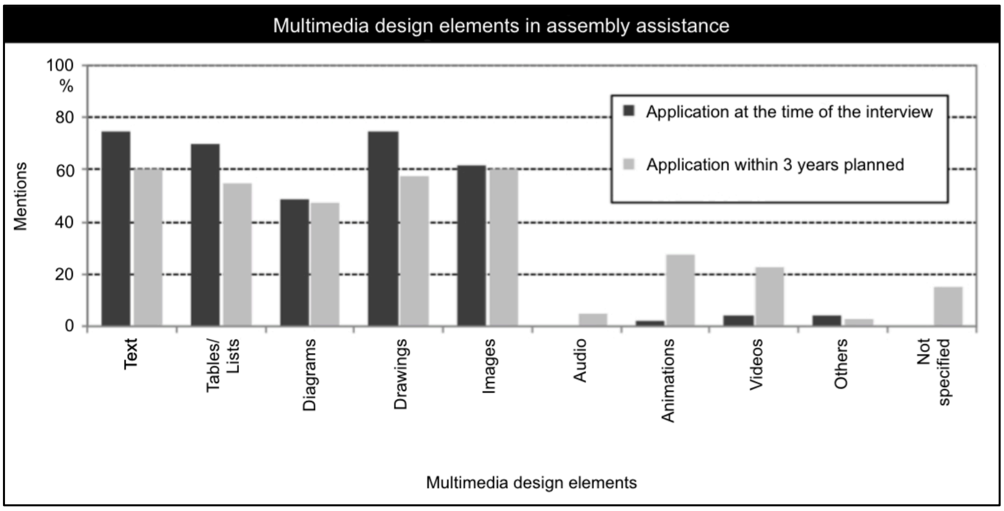

Figure 12: Results of the survey [154]

According to this survey, the overall objectives for the application of assistance systems are a reduction of training periods (>50 %), search times (>80 %) and assembly errors (>80 %) as well as an improvement of the ergonomics at the workplaces (>80 %). The most important functions of assembly assistance systems according to the interviewed companies (more than 80 %) are employee identification, storage and application of employee profiles, workpiece localization, recognition of the progress of assembly, recognition of assembly errors and a reaction to these errors. Additional desired functions (more than 66 %) are automatic adjustments of the output according the availability of components, automatic adjustments according to the tool availability, recognition of the assembly sequence of the worker, automatic adjustment according to this assembly sequence and independence of the representation. Furthermore work scientific aspects are very important in human-system-interactions *(HSI)*.[155]

DIN EN ISO 9241 deals especially with quality guidelines to guarantee the economics in interactive systems. Thereby the term ergonomics deals with the adjustment of working conditions to human capabilities as well as their skills. An inadequate design of the dialogue leads to a dissatisfaction of the users.[156]

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[153] Cf. Wiesbeck (2013), p. 77
[154] own representation based on Wiesbeck (2013), p. 64
[155] Cf. Wiesbeck (2013), p. 65ff.
[156] Cf. Rudolf (2006), p. 10

The related guidelines therefore are visible in **DIN EN ISO 9241-110** and include the following aspects: [157]

- **Task-suitability:** A dialogue is suitable for a specific task, if it is possible to support the user, but not to burden him with properties of the dialogue system.[158] It is important for the design of process-oriented procedures, considers the information requirements of the worker and provides additional information only by the use of an explicit help function. Furthermore the feedback of the system is based on the individual knowledge of the worker.
- **Self-descriptiveness:** A dialogue is self-descriptive, if the purpose and scope of the dialogue system can be explained to the user and if every dialogue step is easy to understand or can be explained.[159] It considers a coordination of the presentation and the expected reaction of the system.
- **Controllability:** A dialogue is controllable, if the user is able to influence the speed as well as the selection and sequence of work equipment or the nature and extent of inputs and outputs.[160] It considers that the type (e.g. choose of input device) and the scale (e.g. alternative approach) of the controllability of the overall system as well as the sequence of assembly operations should be maintained.
- **Expectation-conformity:** A dialogue is expectation conform, if the user's expectations arising from existing workflows or user trainings are fulfilled as well as expectations gained with the use of the dialogue system and the user manual.[161] It considers the equality of the desired expectations of the worker with his real expectations.
- **Error-tolerance:** A dialogue is error tolerant, if the user can achieve the intended outcome either with or without a minimum correction despite recognisable incorrect entries.[162] It considers the natural behaviour of the worker with regard to his activities. The resulting interaction between the worker and the system is also possible in an error containing behaviour.
- **Customizability:** A dialogue is customizable, if the dialogue system allows accommodations to the requirements of the activity, individual preferences of the user and user ability.[163] It allows adjustments of the dialogues and workflows to

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[157] Cf. DIN EN ISO 9241-110 (2008)
[158] Cf. Heim (2009), p. 35
[159] Cf. Heim (2009), p. 37
[160] Cf. Heim (2009), p. 39
[161] Cf. Heim (2009), p. 41
[162] Cf. Heim (2009), p. 43
[163] Cf. Heim (2009), p. 45

an individual worker or to a group of workers. A compromise has to be made between the administrative effort and the personal specialisation.

- **Learning-promotion:** A dialogue supports learning, if it assists and guides the user in learning the dialogue system.[164] It is very important that the realization of the system is done by an appropriate learning strategy to adapt to the production environment.

The appropriate standards for human-system-interactions are visible in **DIN EN ISO 9241-11**. According to DIN EN ISO 9241-11, the term usability is defined as the extent, in which a product can be used from a specific user in a specific usage context to reach specific goals effective, efficient and with satisfaction. Thereby the usage context considers the user, the task and the organisational as well as the operational environment.[165] The effectiveness considers the level, how accurate the worker is able to fulfil his work content in the assembly. The efficiency considers the expenditure of time that is needed to generate work instructions based on assembly sequences. The satisfaction of the worker is one of the most important factors for the acceptance of the system, influenced from the ergonomic design. A complete coverage of the objectives is only possible with a sufficient clarification of all requirements. This can be achieved using a context-related observation of the system as well as the interacting elements. According to DIN EN ISO 9241-11 the production environment, tools and equipment, workers as well as the tasks, objectives, knowledge and skills are included.[166]

2.8.6.2 Conceptual point of view

According to the conceptual requirements, the objective for the representation of assembly sequences in situation orientated worker guidance is to reach flexibility for an individual worker together with a high efficiency of the assembly process. By including the product, the process and the resources, a compensation of actual deficits of existing approaches is possible. The deficits can be attributed to procedure caused deficits from the assembly sequence as well as to attention caused deficits from the information processing of the worker. A reduction of the search effort as well as waiting times in an assembly process can improve the attention of the worker while avoiding distractions from non-value adding activities.[167]

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[164] Cf. Heim (2009), p. 47
[165] Cf. Rudolf (2006), p. 15
[166] Cf. Wiesbeck (2013), p. 67ff.
[167] Cf. Wiesbeck (2013), p. 71

2.8.6.3 Technical point of view

According to the technical requirements, the input information for worker guidance originates from an assembly priority plan including instruction elements. Furthermore a data format is required that maintains the logical structure and sequence of the instruction elements. A conversion of instruction information at the highest level of detail is required to maintain the possibility for a later adaption of the information content. To realize the integration of the production environment in the generation of the assembly instructions, the structure should be based on existing and recognized models as well as on main classes. Parts of the main class are products, processes and resources. Important influential factors from the production environment are the assembly progress, delay of the assembly procedure, realizability of parts of the assembly and the adaption of the assembly sequence. The worker acts as a transceiver of all necessary information of the assembly sequence. He is able to influence the assembly sequence according the readiness, assembly progress and level of detail. Another important factor is the health compatibility including a low cognitive stress for the worker. This can be realized especially by implementing situation-oriented worker guidance, adaptable level of detail of the instruction and adaption of the instructions to available output medias. The performance is an important factor for the realization of the structure of assembly sequences during the assembly planning as well as for the determination of the output assembly instruction.[168]

2.8.6.4 User-oriented point of view

According to the user-oriented requirements, the performance feature of the overall system is influenced from the technical components as well as the perception of the opportunities to interact with the system. The decision parameters can be classified according to flexibility, efficiency, robustness as well as certainty of the system. In the case of flexibility, the goal is an optimized usability for the totality of all workers. The accuracy and completeness of the worker during the assembly is proportional to the effort of the cognitive stress. The efficiency and flexibility have a reverse effect. The robustness is influenced from several cause variables such as the frequency of use and the certainty that assesses the safety of the user.[169]

[168] Cf. Wiesbeck (2013), p. 72f.
[169] Cf. Wiesbeck (2013), p. 74f.

2.8.7 Technologies to optimize human-machine-interactions

Different methods and technologies are available to optimize existing human-machine-interactions *(HMI)* and thus to improve their efficiency by implementing a 3D visualisation of the process data, a touch interaction and gesture control, social networks and information systems as well as state dependent assembly instructions.

2.8.7.1 3D visualisation of process data [170]

In many applications 3D systems are already state of the art, but they are only seldom used for the visualisation of process data. The big advantage of a 3D visualisation in contrast to the classical 2D representation is that more information can be represented in a smaller space. This is very important especially in complex tasks and simplifies the interaction with this data.[171] Furthermore the error detection can be improved by using a 3D visualisation. The biggest advantages occur, if several process values have to be considered simultaneously.[172] Additionally the use of multi-touch-displays and mobile devices such as smartphones or tablets can simplify the 3D visualisation.

2.8.7.2 Touch interactions and gesture control [173]

Touchscreens are already in use for several machine operations, but in the majority of cases the operating control is only possible with a classical hardware control. The operating concept will be much more innovative by using multi-touch-interactions as well known from entertainment industry. The handling is much different to the already used touch surfaces of process control, because it involves direct manipulations by finger gestures and results in a saving of time. Pioneers in this area are Apple (iPhone, iPad) and Google (Android). The biggest disadvantage of such devices is that the display area is also the input area and thus in the worst case important information are covered. Another disadvantage is the missing haptic feedback if an action takes place or not. The most used touchscreen gestures are tab / double tab, swipe left / right, swipe up / down, pan, rotate, pinch and spread gestures.

The following questions are important for the design of touch interactions: What operating concepts from the communication and entertainment electronic industry are

[170] Cf. Mayer/Pantförder (2014), p. 484
[171] Cf. Mayer/Pantförder (2014), p. 483
[172] Cf. Pantförderer/Vogel-Heuser/Schweizer (2009)
[173] Cf. Mayer/Pantförder (2014), p. 484ff.

also suitable for industrial process controls? Are touch-based operating concepts also suitable for time and security critical controls? How should the touch-based surfaces be designed to ensure an optimal data representation? How can touch-based operating concepts be integrated in the existing system architecture?

Rules for touchscreens are evident in VDI 3850, but the direct manipulation of multi-touch control is not included. The application in the industrial environment is very similar to the communication and entertainment electronic industry, because both areas deal with interactions such as context switching, menu selection, list selection, elements of selectivity, interactive switches or value / text input. For applications in the industrial environment it is very important that the operations are safe and thus invalid entries should be avoided if they lead to dangerous situations for humans and machines.

2.8.7.3 Social networks / information systems [174]

The efficiency can be furthermore improved, if facilities, plant components or single devices are able to post their status, such as error messages or device parameters, automatically on selected platforms. Operating, maintenance and servicing staff will be able to get recommendations for actions and the worldwide community as well as the manufacturer of the devices can participate in the support. The results out of this diagnose could be available on the platform as a recommendation, optimization proposal or software update. Furthermore these functions could also be used for machine-machine-communications.

2.8.7.4 State dependent assembly instructions [175]

The implementation of dynamical generated assembly instructions allows the system to consider additional information concerning the worker as well as the factory environment at any time. The biggest advantage is an increasing flexibility due to the avoidance of rigid worker guidance. The basis of this concept is a graph (see Figure 13) with one initial state (Z_0) and one target state (Z_{Ende}). The corners of the graph (e.g. $A_{0,1}$) represent the work instructions that enable the worker to transfer from Z_0 to Z_1. The virtual states (e.g. $Z_{1\text{-}a1}$) can be reached through a higher level of detail of the work instruction. If a condition has more than one corner $A_{i,j}$, an alternative sequence of assembly is possible. A loop represents a disassembly of the final product. The

[174] Cf. Mayer/Pantförder (2014), p. 488ff.
[175] Cf. Zäh et al. (2007), p. 647

generation of assembly instructions can be done by the use of optimization techniques according to the shortest path. If the actual position is recognized, the shortest path can be determined. The output assembly instruction is represented by $A_{i,i+1}$. If Z_{i+1} is reached, the shortest path is calculated again. An assessment of the corners is done according to process relevant conditions such as costs of realization, availability of parts etc. If a part is not available, the related corner is declared with infinity costs. Furthermore mental and physical conditions of the workers can be considered in the generation of assembly instructions. During the assembly, the maximum step range must not be crossed.

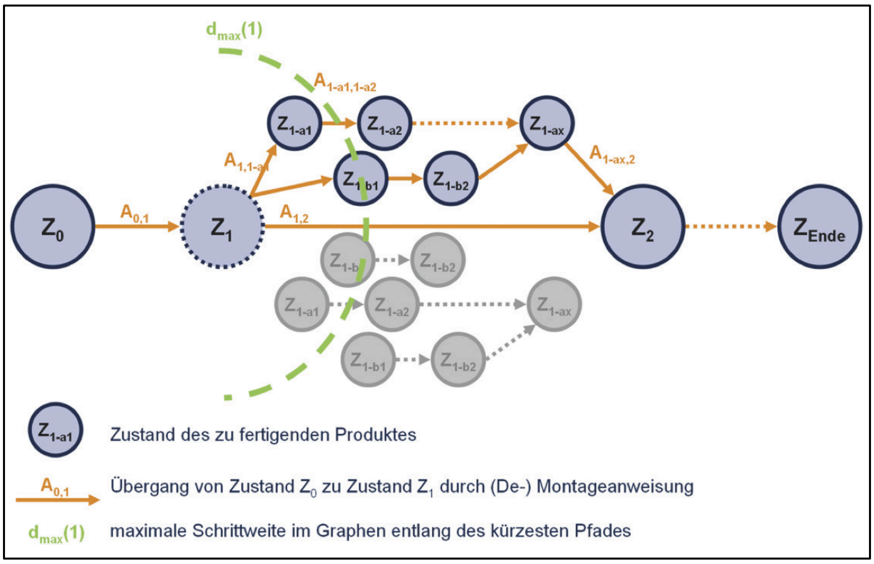

Figure 13: Model for state dependent assembly instructions [176]

[176] Zäh et al. (2007), p. 646

2.9 Results of the literature research

The last chapter of the theoretical part deals with emerging difficulties as well as benefits of implementing innovative assistance systems in industrial applications and finally provides an outlook concerning possible further developments.

2.9.1 Benefits of using assistance systems

Assistance systems, especially information-provision systems using augmented reality, lead to a minimization of non-value adding activities by focusing on data inputs, training periods, search times as well as assembly errors. A reduction of the error rate leads to a saving of valuable production time by avoiding rework and thus to an improvement of the productivity. Furthermore after implementing assistance systems knowledge is available without learning efforts and usually does not feel into oblivion because the worker can be guided step-by-step if required. Workers are also supported in frequently changing conditions because they get the right information at the right time directly at the place of action. Thereby the support takes place only as detailed as necessary to avoid useless information that may limit the performance. The objective is to completely saturate the information requirements on workplaces.

The fields of application are manifold including complex assembly and logistic tasks, general tasks in the production engineering such as packaging and maintenance as well as an assistance to support employees with disabilities or changed abilities due to the demographic change. Thereby the information provision is possible directly on-site by using mobile assistance systems or in a specific defined workspace by using stationary assistance systems. Last but not least intuitive and simple as well as efficient interactions with human-computer-interfaces are possible especially by using gesture recognition.

2.9.2 Difficulties of using assistance systems

The so far available digital representing assistance systems are often not optimal designed and thus can lead to several distractions. On the one hand an application of these systems enables a reduction of mental stresses and an increase in the performance of employees, but on the other hand assistance systems with a procedure caused sequence of actions often do not increase the overall productivity.[177] [178] [179] The reason for that effect can be traced back to the phenomenon of attention tunnelling, which leads to an overstraining of the absorption capacity of the worker and thus to a deflection from important cause variables. This can be attributed especially to a deterministic assembly planning as well as to a generation of work instructions without considering the context of the worker respectively the real production environment. Furthermore the low situation-oriented support and the rigid guidance of the worker negatively influence the phenomenon of attention tunnelling. As a result these systems are often not accepted by the users.[180] [181] An assistance system should optimize the psychological stresses caused by the task, work equipment, work environment, work organization as well as the workplace. Thereby workers should not be unchallenged or overworked. A work under a positive psychological pressure is required to be as efficient as possible.[182]

Other arising problems are unsolved technical, legal, mental and societal problems. The biggest technical problem with augmented reality systems can be traced back to the fact that all calculations have to be done in real time, because an occurring delay will lead to dizziness as well as to sickness. Furthermore the energy supply of mobile systems over a long period of use remains very difficult due to the small dimensions. Another negative fact is that there are no standards for device-independent applications available. A big legal problem occurs concerning data protection, because these systems automatically generate time, motion and interest profiles and thus the potential for misuse increases dramatically. Last but not least a big challenge is triggered due to liability issues in the case of wrong generated instructions.[183]

Currently hardly any industrial application of assistance systems in the daily business is predominant due to the high complexity, unreliability, high costs and the fact that augmented reality is still in its infancy. Thereby the complexity is created especially through additional functions such as the identification of the worker, recognition of the current product status or observation of the production related context. Due to the increasing complexity and emerging unreliability, not all capabilities can be implemented in one single system. The results are customized solutions that strongly depend on the corresponding use case. A possible market entrance barrier is the

[177] Cf. Tang et al. (2003)
[178] Cf. Dopping-Hepenstal (1981)
[179] Cf. Yeh/Wickens (2000)
[180] Cf. Spath/Weule (1993)
[181] Cf. Livingston (2005)
[182] Cf. Martin (2014), p. 15
[183] Cf. Burkard/Thesmann (2013), p. 56ff.

worker acceptance of the new technology due to ergonomics and reliability. Furthermore also the Total Costs of Ownership (TCO) play an important role in the implementation of new assistance systems. To be successful, the gained benefits in production time and quality assurance have to outweigh the TCO within the first year.

2.9.3 Outlook

Cognitive assistance systems will be the future and are intensively investigated nowadays. The special feature of such systems is to support the worker exactly when the assistance is needed, which can be realized by a continuous monitoring of the working situation. Thereby the system analyses the speed and the error rate of the worker fully automatic. With these data and with information from prior analyses, the system is able to adapt the support to the current skills of the worker. Such systems are only possible if an interdisciplinary cooperation takes place.[184]

Furthermore augmented reality systems in combination with wearables have huge potentials in future industrial applications because no interruption of the work process takes place due to hands-free interactions. Similar expectations can be seen in Figure 14 conducted by ABI research. According to this figure, Smart Watches have the highest potential in the next few years in contrast to the other devices.

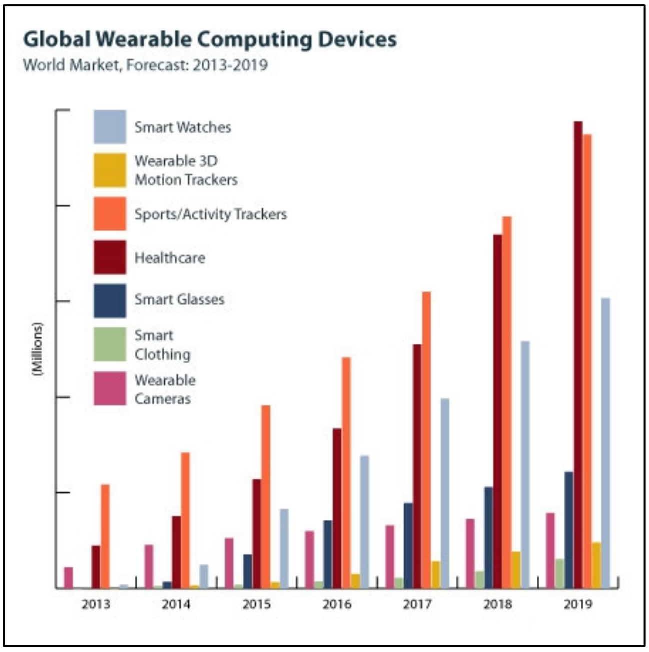

Figure 14: Global wearable computing devices[185]

[184] Cf. Berndt (2014), p. 23
[185] Schumacher (2014)

3 Analysis of existing systems

The today available assistance systems mostly do not completely fulfil all mentioned requirements. Especially in the area of user interfaces as well as human-computer-interactions a lot of potentials for optimization exist. For the sake of completeness, it is pointed out that constantly new developments are made in this topic. This literature research was conducted from early August until mid September 2014 and thus only solutions are considered that are officially presented until this date.

3.1 Overview and classification of treated competitive solutions

COMPANY	ASSISTANCE SYSTEM	TECHNOLOGY
Fraunhofer IFF	Assistance system for Kolbus	**AUGMENTED REALITY**
OPS Solutions	Light-Guide system	**AUGMENTED REALITY**
Schnaithmann	Schnaithmann assembly assistance system	**AUGMENTED REALITY**
Profactor	Show-Me system	**AUGMENTED REALITY**
Korion	Motion-EAP	**AUGMENTED REALITY**
Assistance System for flat module manufacturing		**AUGMENTED REALITY**
Manual assembly in Smart-Factory		**AUGMENTED REALITY**
Evolaris	Data Glasses	**AUGMENTED REALITY**
Universität Bielefeld	PROMIMO	**AUGMENTED REALITY**
FerRobotics et al.	CustomPacker	**AUGMENTED REALITY**
Valentini	Cable harnessing	**AUGMENTED REALITY**
Fraunhofer IOSB	Assistance system for BMW	**GESTURE RECOGNITION**
Myestro	Mobile & embedded solutions, interactive screens	**GESTURE RECOGNITION**
Würth electronic	IBIN	**LEVEL MONITORING**
Fraunhofer IPA	Welding assistance system for SMErobotics	**SIMPLIFIED PROGRAMMING**
Automated information flow on a workplace		**PRODUCT RECOGNITION**

Table 2: Overview and classification of competitive solutions [186]

[186] own representation

3.2 Light-Guide System [187]

The Light-Guide system (see Figure 15) was developed by OPS Solutions and can be used for the simplification of manual assembly processes. Thereby in-situ projection is applied to project instructions, texts, CAD drawings, videos, audio signals, animation as well as graphical elements such as arrows or symbols directly to the workplace by using a projector system. Thereby the projection screen can be enlarged up to 17 square meters and can be any kind of surface. Furthermore the system can be operated either with manual process monitoring solutions such as foot pedals and switches or with automated process monitoring solutions such as light barriers or an automated monitoring of torque values. Light-Guide systems are applicable for manual assembly and quality management processes as well as for teaching and training purposes. External operating components such as mouse and keyboard are necessary to interact with this system.

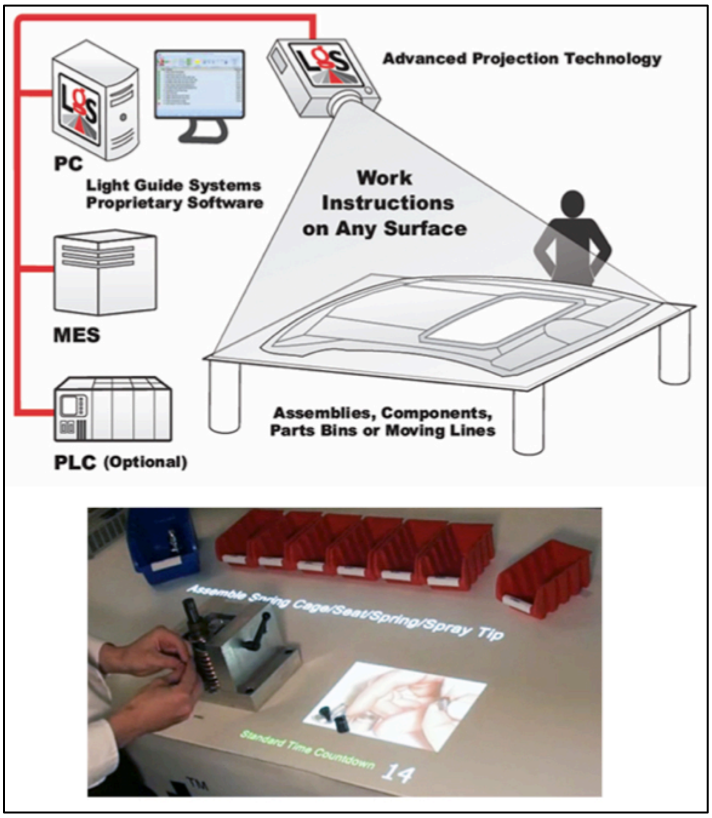

Figure 15: Light-Guide System [188]

[187] Cf. Martin (2014), p. 26ff.
[188] Martin (2014), p. 27

3.3 Schnaithmann assembly assistance system

The Schnaithmann assembly assistance system (see Figure 16) was developed together with the University of Esslingen for applications in manual workplaces. Thereby the task was to simplify complex assembly processes with a high number of variants and to enhance process security with the aim of a zero fault production.[189] In-situ projection and motion detection systems are applied to recognize and avoid errors as well as to guide the worker through the assembly processes.[190] The areas of responsibility are manifold such as teaching, quality improvement and assembly error avoidance in manual assembly processes of modules, complex assembly sequences or quality critical steps. Another field of responsibility is the support of employees with disabilities and employees whose abilities have changed. The benefits of this system are efficient process sequences, improved qualities and process reliable workplaces. Furthermore the training periods and the error rates are reduced and the ability to work as well as the motivation can be maintained. The system can be teached relatively easy to new work procedures by performing a manual demonstration of the ideal process sequences. The functionality of this system is quite simple due to a first in / first out principle. The required parts are taken from a Kanban system and the necessary information such as the assembly sequence is projected directly in the worker's field of view. The removal of components is simplified by a pick-by-light principle and the installation location is displayed by using a put-to-light principle.[191] Simultaneously the position, orientation and type of parts are checked automatically and occurring errors as well as wrong movements result in optical and acoustical signals.[192]

Figure 16: Schnaithmann assembly assistance system [193]

[189] Cf. n.u. Schnaithmann (2014)
[190] Cf. Martin (2014), p. 27
[191] Cf. n.u. Schnaithmann (2014)
[192] Cf. Martin (2014), p. 27
[193] Martin (2014), p. 28

3.4 Show-Me system [194]

The Show-Me System (see Figure 17) was developed from the company Profactor especially for applications in the automotive industry. It acts as an assembly assistance system and uses in-situ projection as well as motion detection. This system can be applied for manual assembly and quality management tasks as well as for teaching and training purposes. Thereby the necessary information can be projected to the workplace or direct on the concerning components. Two cameras are used for motion detection and thus support the early recognition and avoidance of errors. The data is compared in real time with the working data and thus allows an alerting of the worker with optical and acoustical signals, if an error occurs. The system automatically leads the user through the working steps and the user has no possibilities to interact active with the system.

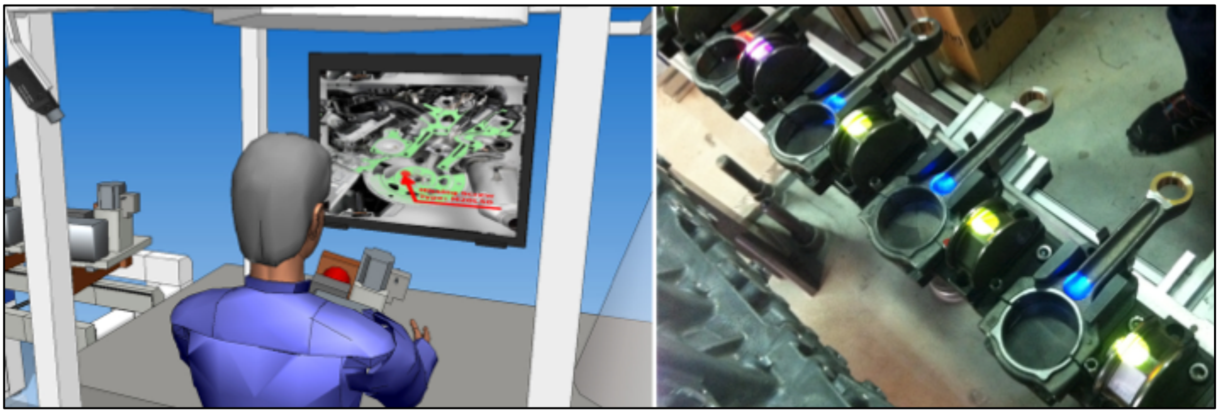

Figure 17: Show-Me system [195]

3.5 Motion-EAP

The Motion-EAP project (see Figure 18) is still a prototype with the objective to improve the efficiency of processes and to assist workers in production processes. Therefore motion detection and projection technologies are applied. The target group of Motion-EAP systems are employees with disabilities and employees whose abilities have changed. Every working step is detected and linked automatically to the appropriate sequence of actions. Furthermore the system is able to give an in-situ feedback for a special working step directly at the workplace.[196] The teaching of the system to new tasks can be done directly on-site by a demonstration through an experienced worker.

[194] Cf. Martin (2014), p. 28
[195] Martin (2014), p. 29
[196] Cf. Martin (2014), p. 41

The system gives a continuous optical and acoustical feedback by taking the current performance of the worker into account. Furthermore the system is able to recognise a possible overload of the worker and to react appropriately to this situation.[197]

Components of the Motion-EAP system are an Acer projector, a Microsoft Kinect camera as well as a Leap-Motion device. Furthermore webcams and additional sensors can be implemented for monitoring. The projector projects the required information directly to the workplace. This information consists of important tips, arrows, boarders and other graphical elements. The Microsoft Kinect camera is applied for position recognition of the hands and determines a contact with the worktable in 2D. The Leap-Motion System is used to recognize 3D hand movements as well as gestures.[198]

Requirements for the Motion-EAP system: [199]

- Increase of the process orientation
- Simplification of the user interface and implementing natural interactions
- Mechanisms to improve the job satisfaction and motivation
- Mechanisms to avoid mistakes and early detect mistakes
- Adaption to the needs of employees with disabilities

Areas of application of the Motion-EAP system: [200]

- **Training and education:** The assistance system can be used for training purposes of the workers as well as for demonstrations of new working steps. Thereby occurring errors can be identified and corrected.
- **Assembling table:** The assembling table is the primary place of action for this assistance system. Thereby an assembly instruction is projected directly to the working area. The worker is informed, if something goes wrong and corrections are proposed. A high flexibility of the system is very important concerning the place of action as well as different assembly variants.
- **Assembly cell:** Assembly cells are used to realize complex assembly procedures by combining different assembly tables and assistance systems. The cameras and sensors of all tables have to interact without difficulties.
- **Commissioning:** The assistance system is used to instruct as well as to monitor pre-packing processes. It replaces the classical pick-by-light or put-to-light systems by highlighting the extraction as well as deposit place with projections. As a result of this measure, the flexibility increases.

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[197] Cf. Funk et al. (2013)
[198] Cf. Martin (2014), p. 42f.
[199] Cf. Funk et al. (2013)
[200] Cf. Funk et al. (2013)

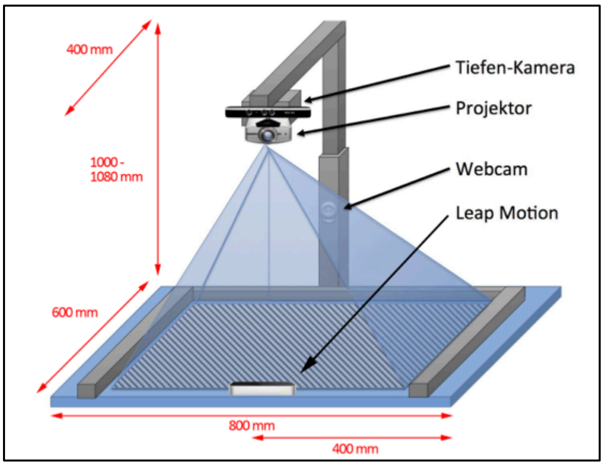

Figure 18: Motion-EAP [201]

3.6 Quality control by finger pointing

Nowadays computers and high-technological systems take an inherent part in industrial processes to improve the efficiency. As a side effect, these systems lead to complex human-computer-interactions especially in quality control. Thereby the result of every to be tested component has to be documented by the worker.[202] Quality management *(QM)* is a very important topic in the process chain of a production plant. The benefits of QM are an early identification of problems and thus a decrease of additional costs. The current situation of quality control is very complex, circumstantial, time consuming and error-prone.[203] Usually the documentation takes place manually by the worker on a PC terminal. Touchscreens have simplified the documentation process, but an interruption of the current work is still required.[204] In the case of an error, the auditor has to memorize all detected errors, walks up to a PC-terminal and uses different input masks to enter the type of error, the exact position and the necessary consequences such as rework or scrap.[205] [206] The solution is an intelligent and sensing environment (smart-room) that perceives the worker as a whole and recognizes on-going activities. This system is able to support the worker by context sensitive information and services. The big advantages of smart-control-room based solutions are that no additional devices, such as augmented reality data glasses, are necessary.[207]

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[201] Martin (2014), p. 42
[202] Cf. Schick/Sauer (2013), p. 731
[203] Cf. Schick (2013)
[204] Cf. Schick/Sauer (2013), p. 731
[205] Cf. Schick (2013)
[206] Cf. Schick/Sauer (2013), p. 731
[207] Cf. Schick/Sauer (2013), p. 731

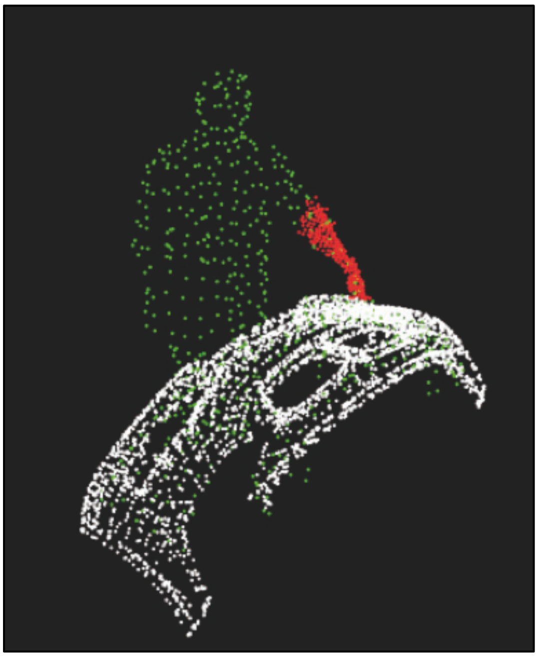

Figure 19: 3D-reconstruction of the quality control system [208]

Fraunhofer IOSB *(Institut für Optronik, Systemtechnik und Bildauswertung)* developed a system for BMW to simplify their quality control processes. Furthermore the task was to support the worker to realize a more efficient as well as a more intuitive kind of documentation. Thereby the system recognizes in real-time the environment and all on-going activities as well as the workpiece that has to be checked. The smart-control-room is based on a 3D reconstruction of the environment through depth images from several calibrated Microsoft Kinect cameras. As can be seen in Figure 19, persons and objects can be distinguished by using segmentation processes. The exact position of the workpiece is identifiable by the CAD data. The documentation is feasible by simple gestures that are detected fully automatic.[209] Necessary information to link the pointing gestures correct with the workpiece can be generated from the following questions: How does the person look like? Where is the person located? How does the person move? What is the person doing? Where is the object located?
In the QM process, the worker has to check the workpiece properly to ensure that the part is flawless. If an error is detected, it can be documented by gesture recognition.[210] Thereby a simple pointing gesture on the exact error position leads to documentation and the system determines the exact coordinates of the error.[211] As can be seen in

[208] Schick/Sauer (2013), p. 732
[209] Cf. Schick/Sauer (2013), p. 731f.
[210] Cf. Schick (2013)
[211] Cf. Schick/Sauer (2013), p. 732

Figure 20, the worker gets a visual feedback on a screen that includes a 3D reconstruction of the treated part as well as the detected locations of the errors. If the component is correct, a simple swipe gesture confirms the correctness of the workpiece.[212]

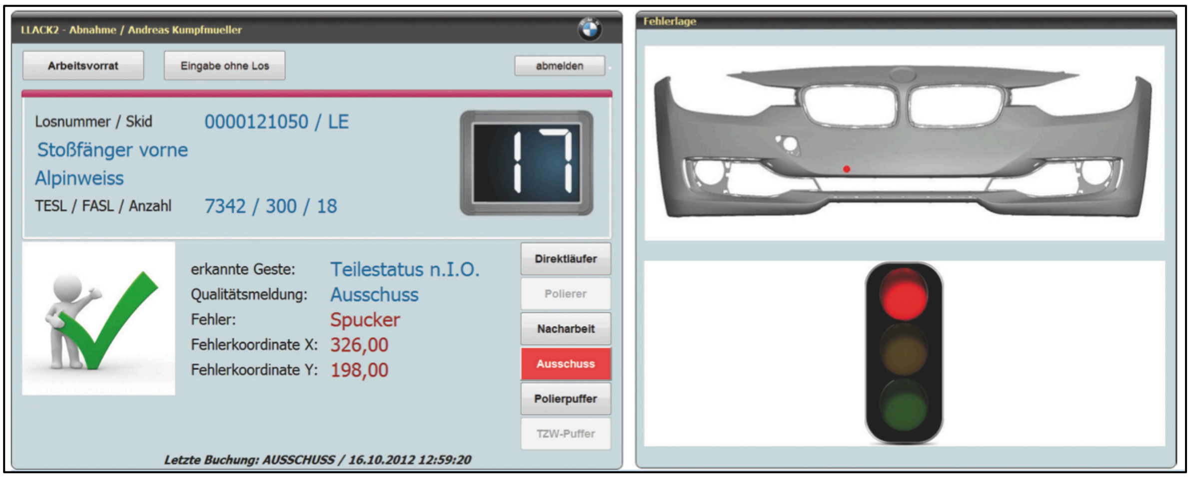

Figure 20: User interface of the quality control system [213]

The requirements to the hardware are very low because only a stock PC and two Microsoft Kinect systems are necessary. To realize the gesture control, the worker is integrated really natural in the smart-control-room. Furthermore also remote displays can be controlled relatively easy by the use of these pointing gestures and thus no auxiliary equipment is necessary. The room automatically recognises the processed action and supports the worker with suitable information and tools.[214] The big advantage is that the documentation takes place directly at the workplace and thus the risk of errors can be minimized as well as time can be saved. One of the most critical point in the implementation phase of such a system is the acceptance of the new technology by the employees. A future, useful extension of this system can be to implement different types of hand gestures to realize a distinction of different error types (e.g. one finger = paint defect, two fingers = something is missing, etc.).[215]

[212] Cf. Schick (2013)
[213] Schick/Sauer (2013), p. 732
[214] Cf. Schick (2013)
[215] Cf. Schick/Sauer (2013), p. 732

3.7 Augmented reality in a flat module manufacturing [216]

By implementing this system, manufacturing plants get a web service based connection to IT systems. The web services are generated automatically by using the EWA communication standard COMESCO *(Connectivity MES Control)*. The arising functions are the identification of products, identification of data, answering of all requests from the client in real time, loading and assignment of NC-programs, collection and transfer of process and quality data as well as communication between control and MES level.

The functionality of this system is to generate a picture from a flat module that gets enriched with additional information from CAD models (see Figure 21). Thereby the black square shows polarity information resulting from the CAD system. The big advantage for the worker is that the actual as well as the target status is visible in one common picture. Other advantages are an automated detection of errors, the recall of all information through touch control as well as the information-technological automation of all positions that have to be checked. The detected errors can be registered in the same dialogue. These augmented reality workplaces are already in use.

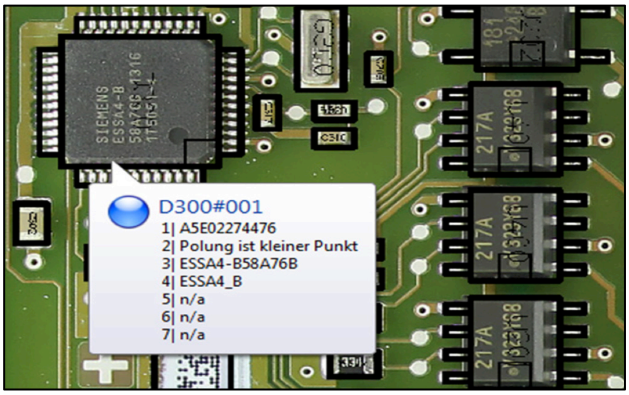

Figure 21: Augmented reality camera picture [217]

[216] Cf. Büttner/Brück (2014), p. 134ff.
[217] Büttner/Brück (2014), p. 137

3.8 Automated information flow on a workplace in production [218]

In many cases, the mechanical automation is done simultaneously to the automation of information technologies. A workplace with automated information technologies but without mechanical automation directly illustrates the benefits of Industry 4.0. Variant related as well as detailed information can be assigned accurate while having a small batch size or batch size 1 and a high variance.

To launch the process, the product is delivered by a work piece carrier and then identified by their barcode. The identification leads to a request at the master computer by using an appropriate web service. After some milliseconds the answer is available, including the checking of the completeness of the product history against the work plan. The product history is always available because of the identification as well as feedbacks of previous workplaces. In the next step, the test plan is selected, appeared automatically, then processed and at the end confirmed. Parallel to this the packing list is displayed on the screen and processed. The implemented light barriers allow a continuous monitoring of the removal of single components. If all process and work steps are passed, the label is printed. Before implementing this automation of the information flow, all job steps have to be processed manually and thus the worker was fully exploited. By using this system (see Figure 22), search as well as assignment activities can be avoided and thus the error potential can be reduced.

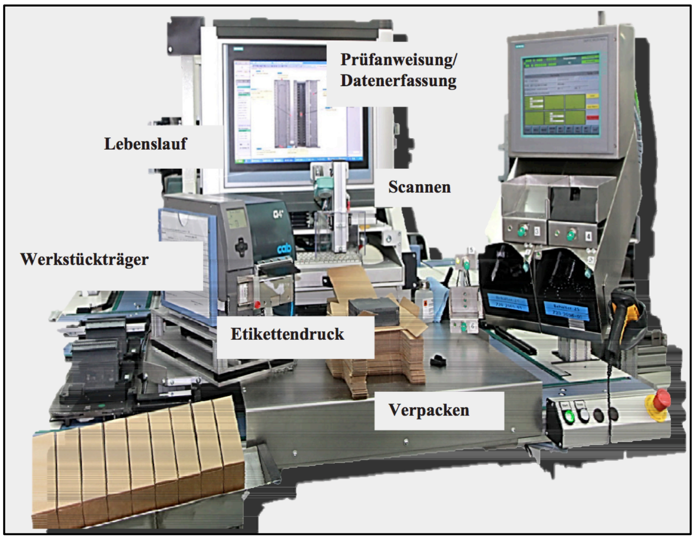

Figure 22: Automated information flow on a workplace [219]

[218] Cf. Büttner/Brück (2014), p. 138f.
[219] Büttner/Brück (2014), p. 139

3.9 IBIN [220]

The IBIN system was developed by Würth Electronics and is applied for inventory taking in individual storage containers. This system allows a continuous and automatic stock registration directly at customer's location and is able to place a new order independent at the right time. Furthermore this system results in a shorter reaction time, lower costs and higher service level. The IBIN system consists of a camera module that is placed in the container, a wireless access point module and a SLM Cloud Server. Thereby the infrared camera module in the container transmits in configurable time intervals these infrared images directly to the smart logistics management server that acts as a cloud server by using the local installed access points (see Figure 23). The smart logistic management server is installed in the Würth Logistic Centre. The software enables the checking of the storage container as well as the placing of orders several times a day.

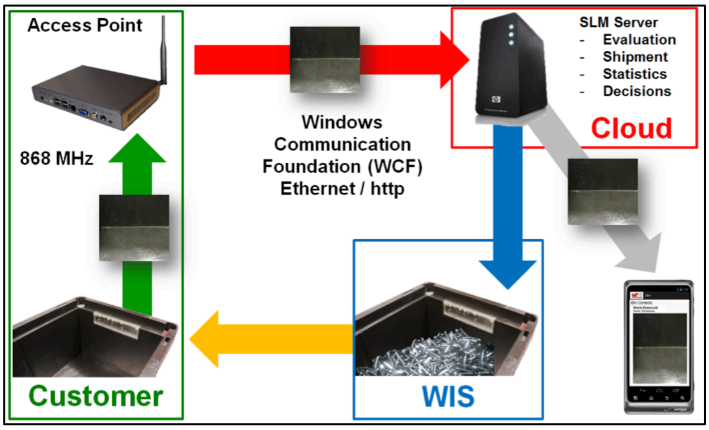

Figure 23: IBIN system [221]

Functions:

- Evaluation of the infrared images regarding to the level
- Representation of the level of the container as a function of time
- Representation of the storage location and the stored goods
- Start of automatic functions if an adjusted level is reached (e.g. place order)
- Manual place of order
- Virtual access to each storage container

[220] Cf. Hoffmann (2014), p. 211ff.
[221] Hoffmann (2014), p. 213

Benefits:

- Avoidance of physical and manual on-site inventory taking by a Würth employee
- Real-time synchronisation of the whole process concerning customer, products, information and human
- Increasing transparency of the whole process
- Increasing speed and quality of decision making
- Decreasing logistic costs

Cloud-computing applications such as smart apps can be implemented to check the storage location, the stock, the usage of parts and how fast these parts are consumed.

3.10 Manual assembly in the Smart-Factory [222]

This system can be used for assembly tasks, quality control processes and rework as well as for initial operations of a product. It consists of a tablet and a Microsoft Kinect system that monitors the work environment. By the use of a RFID reader, the RFID tag can be read and the product status can be checked. In the case that an assembly step cannot be finished in the regular production because of occurring disturbances, the worker gets a virtual instruction to finish the incomplete product manually at this workplace. Thereby the camera image that is generated from the tablet is superimposed with congruent instructions and the overlay is transferred to the screen (see Figure 24). During this process, the assembly steps are monitored by object and hand recognition systems and then compared with the digital model. Thus a real-time support is possible, which leads the worker automatically through the complex working process. If an error occurs, the system is able to give an associated feedback.

Figure 24: Manual assembly in the Smart-Factory [223]

[222] Cf. Gorecky/Schmitt/Loskyll (2014), p. 536f.
[223] Gorecky/Schmitt/Loskyll (2014), p. 536

3.11 Cognitive and collaborative welding robot – CoWeldRob [224]

Nowadays an intensive research in the field of welding robots takes place due to the challenging requirements of high-qualitative welded parts. To realize a high quality in welding activities, solid knowledge and many years of experience are necessary to precisely guide the welding torch and to maintain the correct welding sequences. Furthermore the working conditions and thus the results are often negatively influenced by air pollution, hotness and non-ergonomic posture. Nowadays many companies have an increasing lack of high-qualified workers to perform their welding operations. Many small and medium-sized enterprises are producing small batches with a high number of variants and thus a fully automation with robotic systems are not realizable due to the high programming effort. The ideal solutions are robotic systems that generate independent proposals for the tasks and for program execution. Furthermore the system should be able to learn from the worker and to apply the acquired knowledge independently in similar situations.

Fraunhofer IPA *(Institut für Produktionstechnik und Automatisierung)* developed a cognitive and collaborative welding robot *(CoWeldRob)* for the company SMErobotics to reduce the programming effort in the automated production. Thereby the weld expert is able to program the welding robot in a very simple and intuitive manner. This leads to an automation of welding tasks and to a higher economy also for small quantities. The welding robot is then possible to transfer the welding programs to similar parts without reprogramming. Furthermore the system is able to localise components, automatically generate the welding path and the welding program, handle uncertainties and learn from the worker as well as work together with him. The following functions are provided:

- **Localisation of components:** The exact position of the part and thus the exact welding path can be determined by comparing the data from sensors with the appropriate CAD data. Thus the path of the robot can be determined without the need of a rigid orientation of the parts.
- **Automated generation of the welding path and programs:** The programs are generated automatically based on different part models, welding processes and used robot system. Changes from the weld expert can be realized very easy and quick by using an intuitive interaction with touchscreen. After that the user inputs and the sensor data are associated logically and are also available for following processes such as grinding or quality control.

[224] Cf. Kuss/Dietz (2014), p. 16f.

- **Robust handling with uncertainties:** CoWeldRob is able to handle occurring tolerances of parts such as air gaps or preparation of the weld as well as occurring tolerances of processes such as different orientations of the welding torch.
- **Learning:** The expandable experience is one big advantage of human workers against welding robots. The worker is able to make several settings to reach the optimum quality of the weld. CoWeldRob is able to absorb this knowledge and thus to continuously improve its own performance. Thereby the worker assesses the suggested sequences of weld seams given by the robot.

One application of this system is the path welding of stitched weld modules. The workpiece can be positioned arbitrary at the workplace, the position is determined automatically by optical 3D sensors as well as associated software and the robot motion is adjusted. Now no knowledge of robot programming is required anymore to create robot programs because the workpiece is virtually visible on a tablet and the worker can select the respective edges for the welding seams easy and intuitive with his fingers. Thereby the programming takes place fully automatic. The system considers the compliance of the necessary welding angle and welding speed as well as the prevention of collisions. The big advantage of CoWeldRob is that the necessary time for reprogramming can be minimized by a simultaneously high and constant weld quality.

3.12 CustomPacker Project

CustomPacker is a research project conducted by FerRobotics, Loewe AG, Profactor GmbH as well as some other companies. The task of this project was the development of a flexible and customizable packaging cell. Thereby the objective was to combine the skills of robots with the skills of humans to realize the packaging of large and heavy consumer goods. To enable this, both sides have to work together interactively, efficiently as well as safe as possible. A universal, robot-assisted packaging cell will allow the packaging of different product variants at simultaneously low reconfiguration costs as well as a reduction of the total numbers of packaging cells.[225]

The basic idea of the CustomPacker Project was to avoid stressful, repetitive and dangerous situations for workers and to increase the throughput of the packaging process. Thereby a Microsoft Kinect camera system and a capacitive sensor mat are

[225] Cf. n.u. CustomPacker (2013)

implemented to monitor the worker permanently during task execution and to determine the exact position to enable a save cooperation between humans and robots. By using the capacitive sensor mat, the position of the human can be identified at any time with an accuracy of 250mm. The Kinect system generates a wireframe model of the human body and calculates the exact position with a depth image of 10-40mm that results in a pose estimation accuracy of approximately 100mm. Errors in the detection of workers can occur especially due to reflections, infrared light as well as occlusions.[226]

The combination of the position data of humans and the workflow information of the packaging process enables an estimation of the future activities of the worker. The support of the worker is realized by visual as well as acoustical technologies to fulfil the dedicated tasks especially for new product variants. Light patterns are projected directly to the working area to guide the worker intuitive. Thereby relevant regions for the following steps are highlighted to enable a symbolic action sequence. To ensure a complete understanding of the task, the worker can activate additional acoustic instructions. The system determines the product automatically by scanning its product-ID and then provides the appropriate packaging instructions from the database. Furthermore it is able to recognize if a task is finished or not by monitoring the hand location of the worker. To avoid an overflow of information and to consider the experience level of the worker, it is possible to adjust the level of assistance or to turn it off completely. Furthermore a flexible gripping system was developed to reach a higher flexibility to enables the packaging of various electronic consumer goods. Therefore an object pose recognition system is required and realized by a 3D surface scan.[227] Based on the depth image from a depth camera (Microsoft Kinect or Asus Xtion), the software ReconstructMe is used to generate the 3D surface model. Thereby the user films the object from different viewpoints by using a portable depth camera.[228] The system allows a gripping of different sizes of parts relatively easy through three independent linear stages. The supported dimensions are from 100mm up to 1000mm. A gripping is possible in four directions, either by the outer or the inner side of the parts, to be flexible for different part designs.[229]

A performance evaluation has shown that the capacitive sensing mat has recognized more than 95 % of all events correct. Also the Kinect system did not show any restriction in clothing, but direct sunlight should be avoided because it may disturb the depth tracking. A performance evaluation of the assistance systems was conducted by

[226] Cf. Rooker et al. (2013b), p. 71ff.
[227] Cf. Rooker et al. (2013b), p. 71ff.
[228] Cf. n.u. ReconstructMe (2013)
[229] Cf. Rooker et al. (2013b), p. 73

comparing paper-based instructions with instructions from the assistance system. The result was an up to 40 % slower cycle time by using the assistance system because the highest level of assistance was adjusted. Due to this high assistance level, all instructions were additionally represented by a spoken output. Moreover the task was very short and simple and thus the paper-based instructions were very short and much faster. It is safe to say that a more complex situation will demonstrate the benefits of this assistance system. The result of the evaluation concerning accuracy of the gripper was also very satisfying.[230]

3.13 Augmented Reality based cable harnessing

In the design process of electromechanical products, cable harnessing is a necessary activity to connect all parts together. Thereby the main task is to find the ideal route for cables and to manage an optimum compromise between cable length, free space, sufficient safety distance, electromagnetic interferences and simplified maintenance. Until now these activities are often addressed at the end of the design process and are mostly performed manually by the worker. This process is very time-consuming as well as cost-intensive. A solution to simplify this task and to improve the overall efficiency is possible by the implementation of an augmented reality assistance system.[231]

The AR system developed by Valentini is able to virtually lay cables in real housings while considering real parts under real physical conditions to find out an optimal solution. On the one hand the worker is able to use AR to operate directly with the real product and on the other hand to use virtual cables for harnessing that are superimposed with real components. To realize this process with augmented reality, the exact position of the worker’s hand has to be tracked and the intentions have to be interpreted. The design of the installed cable is influenced from the geometry of all used components, from the location of the connectors and from the required safe space for the cable path. The used augmented reality system consists of three main parts including an input device to generate video streams, a processing device to manage inputs, store/arrange data flows and render video streams as well as an output device to generate projections. Therefore a Microsoft LifeCam is applied to generate the video stream. It is located on a head mounted display.[232]

[230] Cf. Rooker et al. (2013b), p. 73
[231] Cf. Valentini (2011), p. 45f.
[232] Cf. Valentini (2011), p. 46f.

At the beginning the worker defines the position of the two connectors and thus sets the starting as well as the ending points of the cable connection. Then he sets several points inside the box to define the location and the direction vectors for the system to model the cable. In the next step the worker sets the location and the attitude for each clip. The interaction between human and system takes place with a special stick pointer to track the exact position optically. The worker is able to change the patch of the cables in consideration of physical and mechanical properties. The result is a realistic as well as reliable simulation. Finally the system supports the worker in the upcoming documentation by providing necessary information such as the used cable length, exact location of the cable, attitude of each clip, forces and torques on each clip as well as the exact cable route.[233]

3.14 PROMIMO

Nowadays the product lifetime of many products decreases at a simultaneously increase of the product variants as well as the required high quality. Furthermore the import of cheap products from emerging markets as well as the demand for just in time deliveries leads to enormous challenges in the manufacturing process. To fulfil all requirements satisfactory, an ultra-flexible assembly technology is necessary. In most of these cases a manual assembly is necessary, because automation and rationalisation strategies are limited. A remedy can be offered by implementing assistance systems that support the worker in complex assembly processes.[234]

In response to the necessity of assistance systems, the University of Bielefeld has developed an assistance system called PROMIMO *(Prozessintegrierte Mitarbeiter-unterstützung in der Montage)*. The objective of this system is to support workers in complex assembly processes by projecting the necessary information such as assembly instructions or error massages directly to the workplace (see Figure 25). The worker is able to enter notes as well as errors by his own such as complaints and instructions to avoid errors in the future. The result is an increased product and process quality. Furthermore new products can be added without reprogramming because cameras are able to record each step in a demonstration process. After recording, these steps are reworked and then released by the product manager.[235]

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[233] Cf. Valentini (2011), p. 51f.
[234] Cf. Beste (2014)
[235] Cf. n.u. Universität Bielefeld (2014)

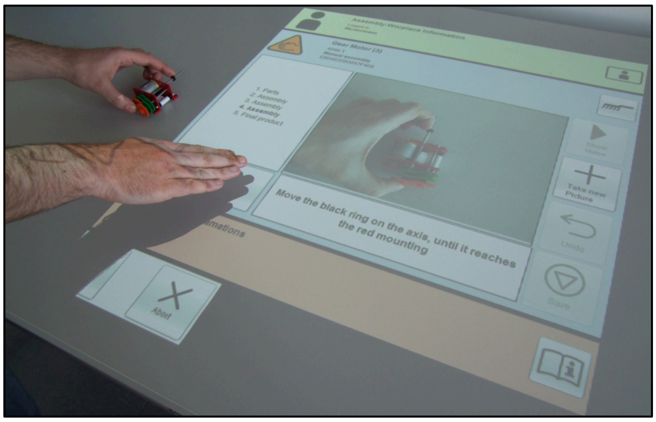

Figure 25: PROMIMO [236]

3.15 Microsoft Kinect [237]

The Microsoft Kinect system was developed from Microsoft together with Primesene. It is a hardware device suitable for the detection of gestures as well as motions. Thereby the inputs can be converted into control commands. The game console Xbox360 was the original field of application. As can be seen in Figure 26, the device consists of a 3D-sensor, a colour camera and four microphones. For distance measurement, a structured light in an infrared range is used. The big advantage of Microsoft Kinect is the extremely low price in contrast to conventional 3D-cameras (Xbox Kinect € 99,99 / Kinect for Windows € 244,72, Amazon August 2014). Since this product was presented, the interest for applications in industrial fields, especially in the production engineering, was very high, mainly caused by the possibility of a cost-effective implementation.

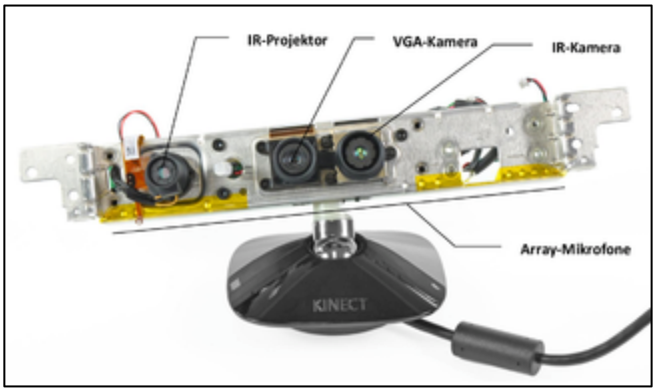

Figure 26: Microsoft Kinect without housing [238]

[236] Beste (2014)
[237] Cf. Steffen (2013)
[238] Steffen (2013)

However, few limitations for industrial applications exist, especially due to the fact that the Microsoft Kinect system was originally developed only for the consumer market:

- **Integration:** The housing has no possibility to screw the device for industrial applications, because factory-made there is only a rubber bumper available. Additional housings are often difficult to implement, because an additional power supply is necessary for the slope motor and the microphones are located on the front-side, which require an obstacle clearance.
- **Accessibility:** A clear view for all sensors is required to ensure an optimum functionality. This can lead to problems in the case of an additional housing. Furthermore the system is switched off automatically, if the temperature reaches 90°. Thus a cooling system has to be installed for the housing.
- **Distance of the depth-camera:** During the gaming operation, the distance is limited between 1,2 and 3,5m. The measurable range is between 0,8 and 4m. By the use of an additional driver, distances from 0,6m upwards are possible. The biggest depth detection of raw depth data is about 2mm at a distance of 800mm.
- **Resolution of the depth-camera:** The resolution of 320x240 is limited usually by the USB bandwidth of the Xbox360 games console. By the utilization of the official Microsoft SDK-driver, three possible resolutions (640x480, 320x240 and 80x60) can be selected at a frequency of 30 Hz. At a distance of 800mm, a horizontal angle of vision of 57° and a vertical angle of vision of 43°, a field of vision of 870x630mm is possible.
- **Environmental influences:** The usage of the camera system in closed rooms is recommendable, because the camera works in an IR-area. To ensure a faultless operation, strong IR-sources (e.g. sunlight) should be avoided as well as strong vibrations. The operating temperature should always be between 5° and 35°C.

General / theoretical applications:

- **Video games:** Kinect replaces the conventional controller (gamepad). The software is able to detect more than one player, which allows a multi-player gaming. Furthermore voice commands are recognized and photos can be made directly on the spot.
- **Object recognition:** Objects can be detected with the camera system from different viewing directions as well as tracked through the room.
- **Robot control:** By the use of the Microsoft Kinect system, robots will be able to move through the room independently.

- **Surgeries:** Surgeons will be able to change radiographs or CT-scans during the operation or to rotate the views without being bacterial contaminated.
- **Gesture detection:** Humans’ body parts such as arms, legs or fingers can be used to control different systems very intuitive and in a natural way.
- **Room mapping:** A room can be virtually recreated by moving the camera through the room. These functions can be applied for navigation purposes.
- **Therapy:** Microsoft Kinect can be used for therapeutic exercises for patients.

Applications in the field of production engineering - object recognition: These functions are possible based on the recognisability of 3D rooms:

- **Attendance check:** The checking of the attendance by the use of 3D data is useful to check the completeness of the loading of blister-trays or the equipping of printed circuit boards. A scanning with conventional light barriers or 2D vision systems is often not possible. The 3D data can be compared with deposited objects, which lead to a higher detection rate. The use of Microsoft Kinect is limited by the size of the objects and it gets inaccurate if it is applied for complex geometries. An ideal application can be the completeness check of egg cartons.
- **Orientation:** Microsoft Kinect can be used for the orientation detection of parts, for example on a conveyer. A 2D camera so far often realizes this function and the data can be processed in conventional vision-systems. The depth camera of the Microsoft Kinect system can be used for the strategic alignment provision of 3D objects in the room. If the object is detected, an own axis system is assigned and the object can be determined by its rotation. The main applications are large volume products.
- **Pick guide:** After object recognition, the parts often get manipulated. Necessary information is the room data of the objects as well as the room data of possible obstacles. These data can be provided by Kinect and thus expensive collisions as well as down times can be avoided. The cycle time can be reduced, because only detected parts are taken and thus empty processes can be avoided.

Applications in the field of production engineering – person recognition / tracking: This function was the original idea especially for gaming applications:

- **Driverless transportation systems:** These systems are useable in assembly shops and are based on light- as well as ultrasonic sensors to drive along preprogramed ways as safe as possible. Thereby operator units and handheld devices realize the interaction with humans. By the use of Kinect, persons and directions of motions are discoverable. A big advantage of using the Microsoft Kinect system for transportation is the detection of gestures. For example a beckon implies “follow me” or an extended arm implies “stop”. Furthermore this system can be used to approve and accept processes relatively easy.

- **Provision of work instructions:** In many cases manual working stations have to provide information to the worker such as assembly drawings or specific model information. This information is typically presented on a screen. A Kinect camera can be applied to recognize the person and to turn the screen for an optimal angle of vision. Furthermore wisp gestures and voice commands can be used to change passive into active interactions. The worker can continue with his work and remains at the workplace while thumb through the drawings without any additional device. Furthermore the worker will be able to rotate 3D models intuitive with his hands and move through the virtual 3D room. The results are lower assembly errors and a better understanding of the task. This system will be a big achievement especially in dusty and oily environments that do not allow the usage of conventional computers or if protective clothing is required.
- **Robot control:** Kinect could be applied to capture the movements of a human arm and to transmit this information directly into control commands for the robot. A big need for this is required, especially for the teaching of multi joint robot arms. The data from Kinect is not very accurate, but sufficient to map rough motions. With this system, robots can be taught very easy and the whole joint kinematics can be followed much easier and faster. A real-time detection is currently not possible.

Not suitable areas of the Microsoft Kinect System:

One big weak point of the Kinect camera system is the low resolution of 640x480. Thus a reliable detection of depth differences smaller than 2mm are not possible. This is a big problem especially for flat objects such as blanks. Another weak point is the maximum frequency of 30Hz that limits the detection of high velocities. Additionally the Kinect System cannot be used in areas concerning personnel safety, because consumer hardware has no sufficient security level. Furthermore no safety-related performance level according EN ISO 12849-1 is available. Last but not least, law forbids the application as an emergency switch.

Since quite a short time, a new version of the Microsoft Kinect camera system is available for purchase, called Microsoft Kinect V2. This device has been improved in several areas. Detailed information is visible Appendix 1.

3.16 Data glasses for general industrial applications [239]

The fields of industrial applications for data glasses are very extensive. Thereby functions such as audio and video support, production support, maintenance support as well as picking solutions can be realized to simplify and optimize existing industrial processes. The Austrian company Evolaris focuses on such areas of application.

3.16.1 Bi-directional audio-/video support

By using mobile devices such as data glasses or tablets, experts are able to give situational assistance to the workers on-site from back office by the use of bi-directional live-audio/video support (see Figure 27). Thereby the main objective is to support the workers on site, perform an on-the-job training as well as specific trainings due to the collected information and documentation.

Functions:

- Mobile live audio-/video streaming by the use of data glasses, smartphones or tablets
- Common view of the task between the worker on site and the experts in the back office
- Transmission of necessary information such as manuals or videos from the back office
- Highlighting of parts of the facility directly on the screen from the worker in the back office
- Storing of audio-/video streams for a later usage

The main resulting advantage is an improvement of the efficiency due to a reduction of downtimes because the workers can be supported earlier. Furthermore a reduction of the time-to-fix is possible because of a specific assistance. Additionally the created documentation can be used as a future video-manual for similar tasks and will lead to a reduction of the education effort. Last but not least both hands are available for work tasks, if data glasses are applied.

[239] Cf. Kittl (2014), p. 10ff.

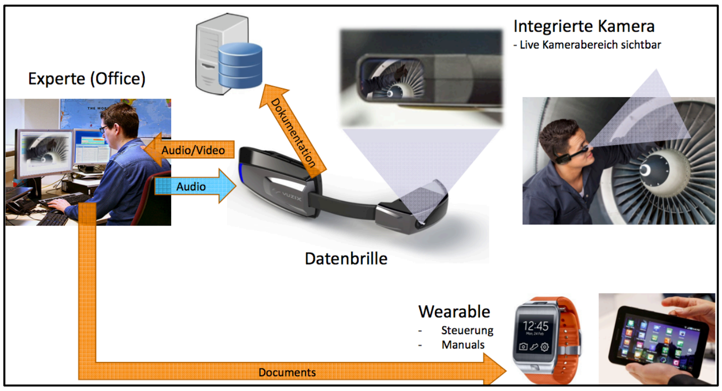

Figure 27: Bi-directional audio-/video support [240]

3.16.2 Mobile production support

By applying a mobile production support (see Figure 28), the production staffs are supplied with important and relevant information to make current and future decisions. Thereby the main applications are the provision of live data, monitoring of the production facilities, mobile order management on shop floor level, mobile basis for decision making based on an intelligent backend system, rapid feedback in the case of reference value deviation and provision of proposed solutions as well as the combination with preventive maintenance.

Functions:

- Important order- and machine data can be checked at any time
- Facilities signal automatically, if maintenance or load is necessary
- Continuous track and trace of tools or semi-finished products
- Exact and voucher less approve and accept by the use of head-up-display and integrated camera
- System with indoor navigation and position indicator of machines, facilities and semi-finished products
- Order assigned directly to the nearest machine

The main resulting advantages are optimizations due to continuous loadings, a reduction of empty runs as well as an optimization of the workload. Thereby error sources of orders, facilities and semi-finished parts are reduced, urgent orders can be treated more flexible and the cycle time can be lowered. Relevant information is in the focus either independent or dependent from the location and the information provision can be based on augmented reality.

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[240] Kittl (2014), p.10

Figure 28: Mobile production support [241]

3.16.3 Mobile maintenance and predictive repair

The area of mobile maintenance can benefit from step-by-step service calls, a maintenance with automated documentation, ordering of spare parts, preventive maintenance as well as on-the-job training by step-by-step instructions (see Figure 29).

Functions:

- Predictive maintenance based on historic data, mean-time to failure or maintenance plans
- Standardized maintenance and repair instruction
- Live documentation, maintenance history and maintenance management
- Statistical analysis (e.g. mean-time between failure, mean-time to repair, etc.)
- Highlighting of relevant plant sections and storing of additional information

The main resulting advantages are improvements of the efficiency due to context-based information and edited information for a special application. Thereby relevant information are visible directly in front of the eyes and can be controlled by voice commands that lead to a better performance because both hands are useable for the task fulfilment.

[241] Kittl (2014), p. 12

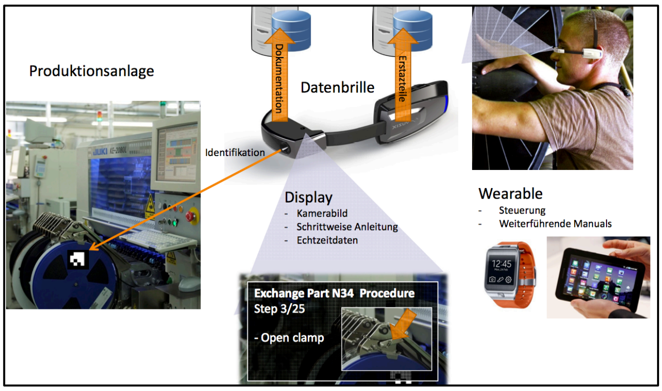

Figure 29: Mobil maintenance and predictive repair [242]

3.16.4 Smart picking solution

The main objective of applications in the fields of smart picking tasks is a correct as well as voucherless task execution. It can be performed easily through mobile devices, ideally with data glasses (see Figure 30).

Functions:

- The worker is able to see exactly the required position as well as the quantity
- Optical control takes place, if the worker obtained the correct part and the correct quantity
- Evidence if something is wrong
- Worker confirms the fulfilment and gets displayed automatically the next task

The main resulting advantages are a minimization of the error rate and an increasing number of commissions. Furthermore a simultaneous documentation is possible.

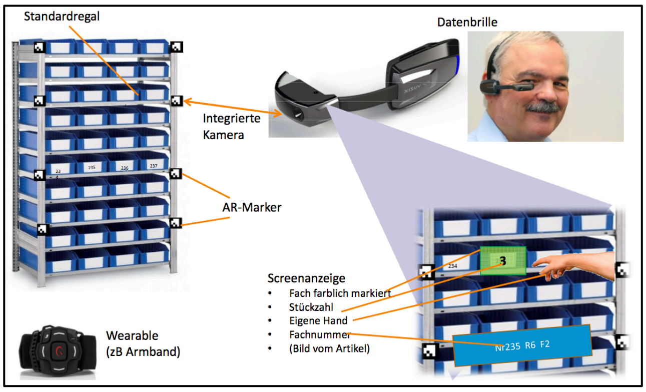

Figure 30: Smart picking solution [243]

[242] Kittl (2014), p. 14
[243] Kittl (2014), p. 16

3.17 Google Glass for industrial automation [244]

The Google Glass device is suitable for different industrial applications such as visualisation, diagnostics as well as for different service purposes. These functions can be realized due to the integrated head-up display, camera, microphone, loudspeaker, vibration sensors and touchpad. Data glasses belong to the group of wearables and are innovative technologies to increase the connectedness of peoples in their daily use. The technology that is used in these devices is very similar to commercial available smartphones, but with the big advantage of hands-free operations due to a semi-transparent visor. Furthermore these devices do not limit human's sensory perceptions as well as physical movements.

The company Beckhoff uses their own automation software TwinCAT to integrate the device in a control technology and to allow a communication between the data glass and a web server. This server provides the required machine status controlled by the automation software TwinCAT. Then Google Glass displays this information directly in his visual range of the user and furthermore allows the user to confirm as well as to reset the machine status. It enables direct as well as indirect applications. Direct applications include the monitoring of a machine as well as the setting of actions without being on site. A big potential emerges in large production factories where the operator has to walk around, checks the process status at different critical points and simultaneously has to watch the operating machine. Based on the fact that both hands are free by using the data glass, the operator is able to take manual actions. Indirect applications include the gathering and saving of necessary information such as manufacturer's documentation, searching for information as well as interactions with other persons through video support, chat or e-mail. Direct and indirect applications can be combined as well. Google Glass is able to visually inform the operator in the case of occurring errors and draws his attention to the error through gently vibrations. Furthermore the operator can confirm the message directly at his device. The fields of application are multivarious and allow for example an operator to capture a QR code with the integrated camera and retrieve appropriate information about the current status or additional features. The display has a resolution of 640x360 pixels. To browse websites directly on the device, an appropriate formatting of the material is required. This novel representation enables the operator to retrieve machine settings directly from the manufacturer. Another possibility is to run special apps directly at the Google Glass. Thereby the control functions of Google Glass take place very intuitive and allow

[244] Cf. Metzner (2014), p. 21ff.

hands-free operations. The device can be switched on with a simple upward nod of the head and a browsing through menus can be realized by gently nodding the head up and down. The desired item is then activated by a voice commands or by touching the side of the data glass.

A very important fact is that data glasses would never be able to replace a traditional control panel as well as traditional operating concepts completely. They will only act as an additional outstanding device to improve operations and control concepts and not to substitute them. Some reasons therefore are the higher resolution and better readability of conventional screens as well as the availability of critical control elements such as an emergency switch. Security risks that are related to the data and the machine itself, will not increase by the usage of Google Glasses because Google as a business enterprise respectively Google Cloud are not always involved in operations with the device. The data glasses can be seen as safe as conventional cell phones. The company Beckhoff for example encapsulated Google Glass and embedded it in the Intranet of the enterprise by WLAN. This allows a protection with standard IT procedures. Additionally the use of effective as well as approved security technologies such as emergency switches are further on required to avoid dangerous actions.

A clear trend for the commercial usage of data glasses can be seen right now but the technology is still in its infancy. Several manufacturers are signalizing that they will come up with similar solutions to the Google Glass and further developments will take place as visible in the smartphone sector. These developments are well supported by the Industry 4.0 Smart Factory concept because this technology is able to reach more efficiency in cases of visualisation, diagnostics and services within the framework of industrial applications. Furthermore data transparency together with the factor mobility can be realized. As a result, the status and the performance data of all industrial components get visible anywhere and at any time.

3.18 EU-Project VISTRA

Also the European Union promotes the usage of assistance systems in manufacturing with their Virtual Simulation and Training *(VISTRA)* project. The task was the development of a comprehensive platform that is applicable for simulations as well as for trainings in manual assembly processes for automotive engineering. The duration of this project was from September 2011 till August 2014. The platform of VISTRA captures, updates, enriches and transfers the product and manufacturing data in an interoperable knowledge representation. The outcome is a cross-disciplinary knowledge sharing between the product design and the production engineering. Possible areas of application are trainings for complex manual manufacturing processes.[245]

Arising challenges for manufacturing enterprises are especially the globalization (increased competition and cost reduction), increased customer expectations (quality and personalization), faster response to market requirements (less time to introduce new models), increased competition, market fluctuations and limited resources (less waste).[246] This leads to the necessity of shorter innovation lifecycles and time-to-market as well as to reduced costs for the development and production. Virtual prototyping and simulation tools help to fulfil these requirements. VISTRA aims to close the gap between product design and manufacturing engineering as well as production. It can be seen as a possibility for an international exchange and collaboration as well as development of virtual training, simulation and manufacturing methodologies. The project partners are DFKI, Fraunhofer IGD, Fraunhofer-Chalmers Centre, University of Nottingham, SGI, Volvo Technology Cooperation and Adam Opel AG.[247]

Before a company is able to start the production, the operators usually have to gain knowledge according parts, tools and sequences. In a state of the art production, the operator is trained physically. Virtual methods and tools – virtual prototypes – can be used for product and manufacturing engineering. VISTRA provides a combination of both.[248] The disadvantages of the conventional training with physical stages are high parts costs, a required time to prepare, changed part conditions and only few options for training. The advantages of the complement virtual training are the possibilities of repeated trainings, reduced training times, reduced assembly and disassembly efforts, trainings of variants and improved flawless launches.[249] As can be seen in Figure 31, the VISTRA platform consists of the VISTRA knowledge platform (captures and stores

[245] Cf. Gorecky (2014)
[246] Cf. Gorecky (2011), p. 5
[247] Cf. Gorecky (2014)
[248] Cf. Gorecky (2011), p. 2
[249] Cf. Gorecky (2011), p. 9

relevant knowledge and geometry data), VISTRA training simulator (interactive and virtual simulator for manual assembly processes) and VISTRA knowledge-sharing centre (overview of manufacturing and training knowledge).[250] To achieve a high user acceptance, the environment should be as realistic as possible, natural interactions should be used, different levels of difficulty should be provided, demographic factors should be considered and distractions such as films or mini-games should be contained. Arising challenges in game based trainings that are suitable for industrial applications are the extreme complexity (minimized authoring time, flexible simulator, simulation of physical behaviour), the high system quality (different technologies in parallel processes, quality instead of quantity) and the end user acceptance (as realistic as possible, diversity of end-user).[251]

A big problem for many European manufacturers is the existing information gap between the virtual product, the manufacturing engineering as well as the physical start of the production. A platform to present the knowledge of products and processes to different user roles is currently missing, but such a platform would enable a cross-disciplinary knowledge sharing throughout the product life cycle. Because of the complexity and incompatibility of product and process data, the planning as well as the training of manual assembly processes are still carried in expensive physical stages. A virtual training can overcame most of the problems of a physical training.[252]

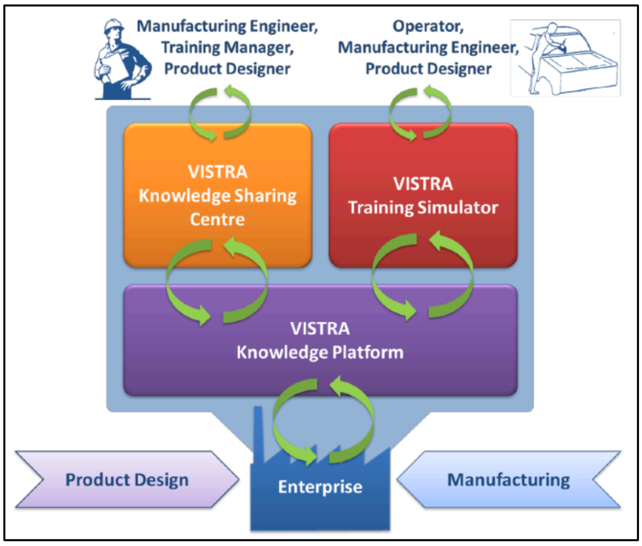

Figure 31: VISTRA platform [253]

[250] Cf. Gorecky (2011), p. 11
[251] Cf. Gorecky (2011), p. 14 f.
[252] Cf. Schlick (2011), p. 1
[253] Schlick (2011), p. 2

4 Application of assistance system in the LeanLab

The task of the practical part of this master thesis “Important Requirements for innovative Assistance Systems in Manufacturing” is to implement a demonstration system in the university-intern LeanLab with the objective to point out the practical benefits of assistance systems. The main task of this system is to reduce the error rate and simultaneously improve the economics by reducing the cycle time. The following chapters deal with a short description of the LeanLab, an explanation why the treated use case is that important, how this use case is solved within this master thesis and what the occurring benefits are that result from this implementation in contrast to the conventional paper-based procedure.

4.1 LeanLab at the IBL-Institute

The LeanLab, located at the Institute of Industrial Management and Innovation Research *(IBL)* (Kopernikusgasse 24, 8010 Graz, second floor) at Graz University of Technology is an excellent physical training factory for students including an assembly line for scooters. The LeanLab deals especially with topics concerning **Industrial Engineering** (LEAN management, ergonomics and environmental influences at work, failure prevention and visual management), **Logistics Management** (factory design, material- and information flow design, material provision and supply chain management), **Industry 4.0** (RFID technology, measuring physiological and psychological exposure or workers and big data) as well as **Industrial Energy Efficiency** (energy value stream method, theoretical limit method and finding energy saving potentials). This laboratory consists of many different facilities to simulate and optimize real industrial processes such as an assembly station, packaging station, Kanban material slides, material supermarket, 3D printer, CNC milling machine, electric screwdrivers, milkrun wagon and much more (see Figure 32).

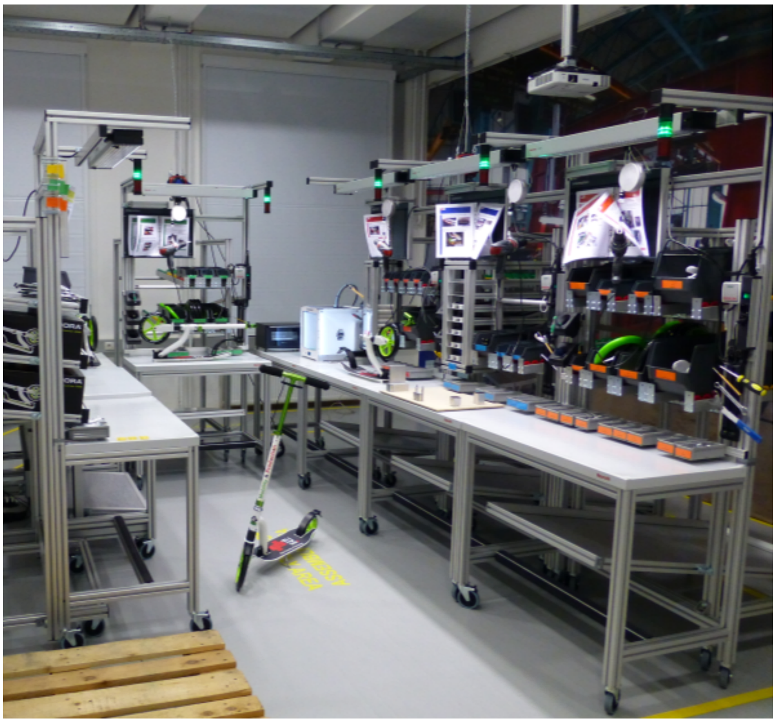

Figure 32: IBL LeanLab [254]

4.2 Use Case

Before the implementation of the assistance system, the workers in the LeanLab got displayed each step of the procedure through paper-based instructions. As mentioned in the theoretical part of this thesis, this type of information procurement is no longer state of the art because it is inefficient, confusing, error prone, ambiguous and often small changes will not get updated. These facts lead especially to higher training periods, search times, assembly errors as well as to poor ergonomics at the workplace.

The task of this master thesis is now to optimize the current information procurement situation in the LeanLab by implementing a state of the art assistance system to minimize the non-value adding activities and thus to save valuable seconds of non-productive time. These measures influence especially the data inputs, training periods, search times as well as the troubleshooting. The desired results will be a decrease of the production time and thus an improvement of the overall efficiency. Through a step-by-step guidance, knowledge is available without learning effort and thus does not fall into oblivion. Furthermore the right information is available at the right time, directly at the place of action and thus allows the worker to perform his task on a higher level.

[254] own representation

4.3 Implementation

The assistance system implemented in the LeanLab is applied for the assembly line of the scooters (currently only Workstation 5) and thus represents a stationary system with a clearly defined workplace. The main components of this assistance system are a Leap Motion sensor for touchless data inputs to select the respective workstation, a Microsoft Kinect camera system to enable gesture-based control commands during the task execution and an All-in-One computer to visualize the instructions and to perform the required calculations (see Figure 33). The biggest benefit of a touchless data input with systems such as Leap Motion and Microsoft Kinect is the independency to dirt, dust and splash water that typically occur in industrial environments. Another big advantage results from the fact that conventional data inputs require an interruption of the current work process. In contrast to this, the operation through head based gesture control commands is possible while working with both hands on the primary task. As a result, seconds of non-productive time are saved.

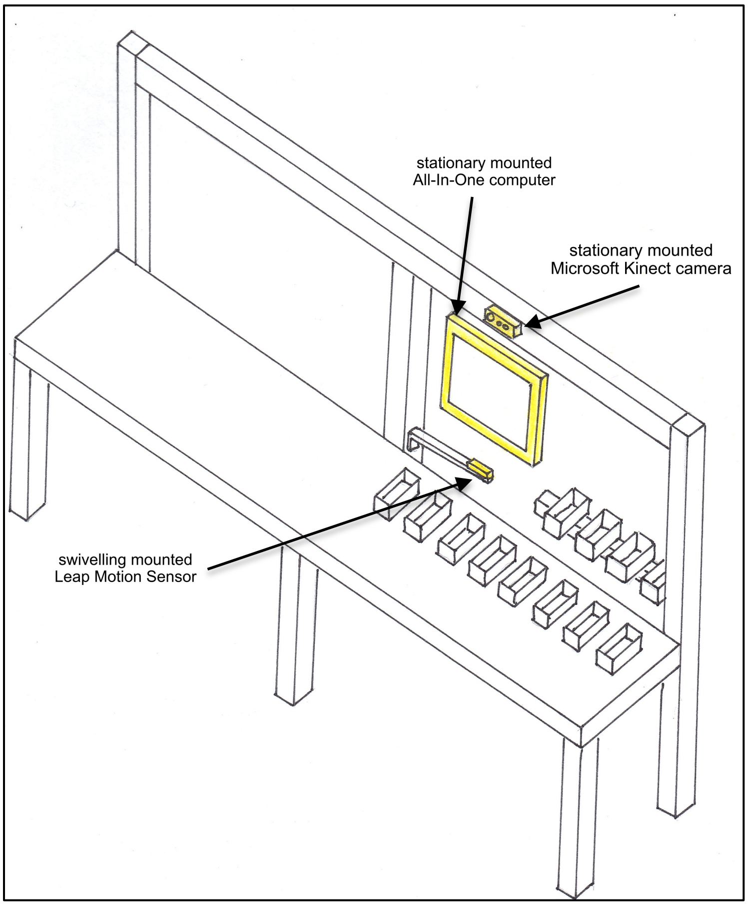

Figure 33: LeanLab Assistance System [255]

[255] own representation

The implemented Leap Motion sensor is a 76x13x13 mm small and 45 grams light high tech computer device that enables the tracking of every small as well as big movement of each finger or the whole hand with a rate of over 200 frames per second and an accuracy of 1/100 of a millimetre. Above the device an 8 cubic feet interactive as well as three-dimensional space is created with a field of view of 150°. Thereby the system recognizes point, wave, reach and grab gestures.[256]

A detailed description of the Microsoft Kinect camera system, its functions, applications, advantages and disadvantages are described in chapter 3.15. The used computer is a commercial available All-in-One PC, to perform the required calculations of the Kinect System as well as the Leap Motion sensor and to visualize the required step-by-step instructions.

4.4 Difficulties

One of the biggest difficulties of implementing such an assistance system in industrial applications can be traced back to worker's acceptance concerning new and unknown technologies. Furthermore these devices (Microsoft Kinect, Leap Motion) have mostly not proven their worth in industrial applications and will change their conventional, proven as well as familiar procedure. Another barrier occurs through the total cost of ownership *(TCO)* because it is to be expected that the gained benefits in production time and quality assurance outweigh the occurring costs of implementation.

Additional difficulties occur particularly through the approach to implement all basic requirements of assistance systems mentioned in chapter 2.7.2 in the demonstration system. The implemented functions deal especially with the **flexibility of the system** (selection of many different instructions by using the Leap Motion device) and the **simplified user interface** (worker has only the choice between instruction selection and a Kinect based forward/backward switch). An automated scalability of the system is impossible to realize within the scope of this master thesis because it will require a continuous monitoring of the worker with an automatic detection of all occurring errors as well as an inclusion of the assembly experience of the worker. However, a manual selection of different assistance levels (**manual scalability**) is implemented at the main page of the interface where the worker has to choose the respective assembly instruction (see Figure 34).

[256] Cf. Leap Motion (2014)

4.5 Interface

The user interface is realized for the first time with a simple Power Point presentation because it is relatively easy to generate as well as to modify at a later date without additional programming effort. Therefore the main page of the interface is used to select the desired assembly instruction (workstation) as well as the associated level of assistance. The available options for the scalability are:

- **H (high):** The assistance at the highest support level presents a detailed description of the assembly process by using text and pictures. It is suitable only for workers that perform this task the first time.
- **M (medium):** The assistance at the medium support level presents a description of the assembly process only with really necessary text and pictures. It is the normal support for the day-to-day work.
- **L (low):** The assistance at the lowest support level presents a description of the assembly process only with pictures of the end assembly to enable the worker a final monitoring of his work. It is only suitable for very experienced workers.

This subdivision in different levels of assistance is very important, because otherwise the performance of the worker may be limited. The reason therefore is that the cycle time gets longer without gaining any additional benefit. In this disadvantageous case the worker has to confirm each step although he already knows the correct assembly sequence (detailed description in chapter 2.4.1 Learning process vs. assistance).

The selection of the desired assembly instruction (workstation) takes place by using the Leap Motion sensor and the associated “Touchless for Windows” App that can be downloaded from the Appstore for free. The user holds his hand above the device (approximately 15-30cm) and controls the mouse courser by moving his index finger to the respective position in front of the screen. If the correct position of the mouse is reached, a simple touch gesture in screen direction will activate the virtual button and thus executes the respective command (acts as a touchless touchscreen).

A switching between the different steps of work instructions is possible with a simple head tilt in the respective direction by using the Microsoft Kinect camera system and the chargeable “Kinesic Mouse” App from Xcessity. Therefore a head tilt rightwards leads to a forward switching of the single steps that have to be performed and a head tilt leftwards leads to a backward switching. If the end of the respective sequence is reached, the user is able to return to the main page after pressing the virtual start-page button. This start-page button is available at the lower right hand corner on each page and enables a cancelling of the process.

Main page of the user interface for workstation as well as support level selection:

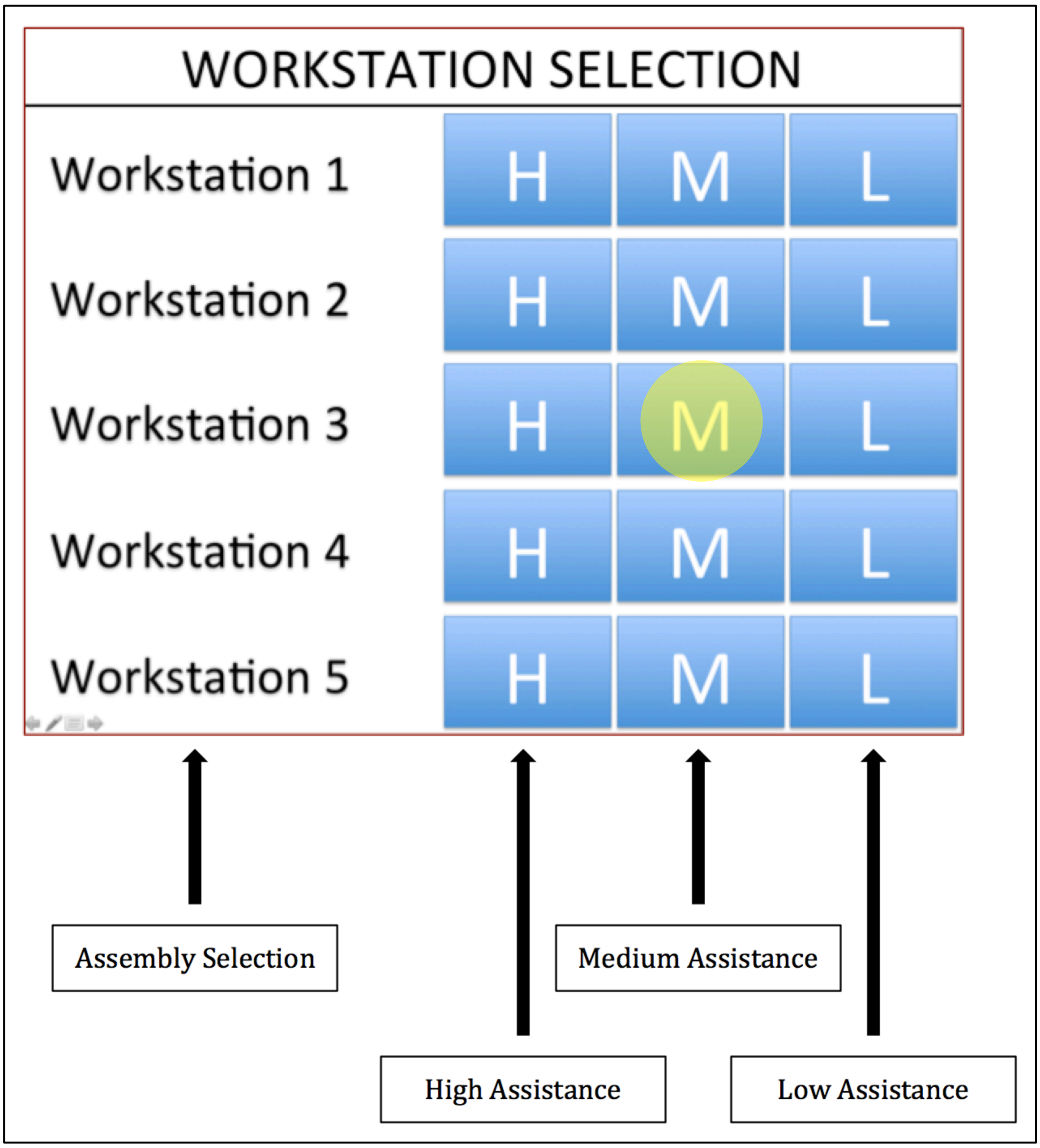

Figure 34: User Interface – main page [257]

Example: The selection of Workstation 3 with a medium support level is executed through pointing with the index finger directly at the appropriate position in front of the screen (highlighted in yellow).

[257] own representation

Sub-pages of the user interface including the step-by-step instructions:

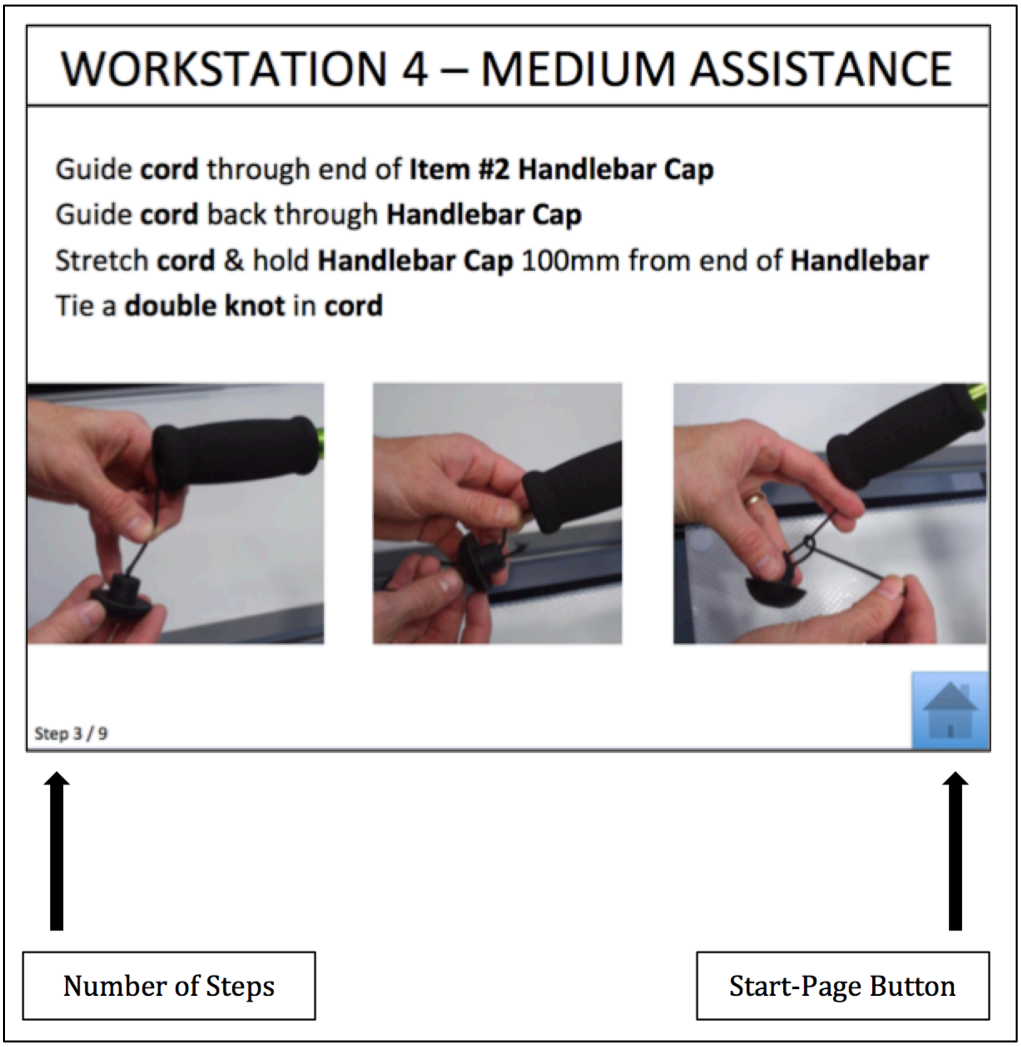

Figure 35: User Interface – instruction [258]

[258] own representation

4.6 Necessary improvements

The LeanLab represents a test environment under ideal conditions but it does not meet the real prevailing conditions. Usually the workstations in factories are influenced from several factors such as dust, temperature, humidity, no careful handling and permanent use. Therefore the used components have to be prepared with additional measures. For example an additional housing is necessary for the Leap Motion sensor as well as for the Microsoft Kinect camera system. Thereby it has to be considered that the housing is antireflective to avoid inaccurate operations as well as the housing is ventilated for devices with a separate cooling system (required for Microsoft Kinect). Industrial computers are perfectly suitable for such applications because they are usually equipped ex-works with the required protection. Important is also the consideration of legal as well as company specific regulations (e.g. protection class, accuracy, personal protection, etc.) because for example a gesture control is not permitted for safety-critical applications such as an emergency switch. Finally typical industrial situations have to be considered, so that interactions are also possible while wearing protective clothing (gloves, safety glasses, etc.) and are possible for workers that originate from different cultures (thus voice control is not optimal). However, these mentioned points are highly situation dependent and are not generally valid. For example in the assembling area of the body of a car other factors are important than in the installation of the interior.

4.7 Outlook for future implementations

The number of possible valuable implementations in the LeanLab is manifold. The simplest and most efficient possibility is to implement the same assistance system as already implemented in workstation 5 in all other stations. Therefore an adaption on the software side is not necessary, because the user interface already includes the required step-by-step instructions. Necessary are only additional Microsoft Kinect camera systems, Leap Motion sensors as well as computers to visualize the instructions and to perform the calculations. The installation process is equal to workstation 3. Due to the accruing high investment costs for all workstations, attention must be paid on the TCO. Crucial is especially the procurement of new computers.

A very cheap, but absolutely effective extensions is the replacement of the currently used text and picture based step-by-step instructions with animations of the assembly process. However, it should be considered that additional functions to stop, rewind, fast-forward and skip of animations have to be possible without making the user interface more complicated. Otherwise the user will be confused and the performance will not increase as desired.

Another option is the implementation of gamification elements to motivate the worker in recurring, monotonous tasks. A simple gamification element (step X from Y) is already implemented. Possible additional elements can be an optical or acoustical feedback, e.g. if the worker performs a single step faster than scheduled or if the error rate gets reduced.

Additional useful functions can be implemented in the LeanLab by using a beamer to replace the currently used screen. The beamer is able to project additional symbols or light signals to the respective position directly in the field of view of the worker (augmented reality). It demonstrates from which position parts have to be taken and how the assembly has to be performed. A context sensitive help is possible by a continuous monitoring of the situation to determine the progress and thus to adapt the instructions to it. By extending the system with an automated comparison of the current with the ideal workflow, an automated scalability is possible. Thus the support depends especially on the performance of the worker, the error rate and on the experience at this workstation, not on a manual selection. Similar solutions are already available, for example in the Light Guide System (see chapter 3.2).

Furthermore the Microsoft Kinect camera system can be used to monitor the attention rate of the worker by evaluating his response time, cycle time as well as error rate. If necessary, the system can set possible countermeasures such as a recommendation for a break or an increase of the assistance level. On the one hand, a higher assistance level will increase the cycle time, but on the other hand it will reduce dramatically the error rate and thus improves the satisfaction of the worker as well as the economy. Furthermore a change of the instructions (e.g. representation, colour, layout etc.) will improve the attention of the worker because the worker has to adjust to the new situation.

Finally mobile solutions can be implemented especially for the milkrun wagon due to the application of assistance systems based on wearables or tablets. Currently the worker at the milkrun wagon has to convince oneself that all workstations have enough rough material. If boxes are empty he has to deliver new ones. By using the assistance system, the worker can be informed fully automatic at which station, what parts are missing and can provide replenishment on time. The realization of this function is relative easy by implementing the IBIN system from Würth electronics (see chapter 3.9). The worker can be guided to the associated workstation by mobile devices.

5 Summary and Outlook

Nowadays a big change is taking place within industrial environments based on the necessity of an efficient flexible production with high qualitative customized products to be competitive. High quality requires the fulfilment of customer expectations and results in different product variants. The manufacturing of small series or unique parts requires the involvement of humans but often leads to unforeseeable negative implications based on the higher error rate of rarely occurring, variant specific operations. These errors are caused by inexperience, inadequate qualifications as well as inadequate availability, timeliness and completeness of necessary information. Trends within Industry 4.0 – the fourth industrial revolution – are a consistent digitalization as well as the linking of innovative information and communication technologies together with conventional production technologies. The aim is to improve productivity and enhance manufacturing companies to benefit from humans' biggest advantage over automated solutions, the flexibility. Thereby the purpose is not to replace humans by technologies anymore, but rather to emphasize humans to perform on a higher level with the support of technologies. This bears a huge economic potential especially for high cost of labor regions such as Europe.

Assistance systems, especially information-provision systems using augmented reality, lead to a minimization of non-value adding activities by focusing on data inputs, training periods, search times as well as assembly errors. A reduction of the error rate leads to a saving of valuable production time by avoiding rework and thus to an improvement of the productivity. Furthermore after the implementation of assistance systems, knowledge is available without learning efforts and usually does not fall into oblivion because the worker can be guided step-by-step if required. Workers are also supported in frequently changing conditions because they get the right information at the right time directly at the place of action. Thereby the support takes place only as detailed as necessary to avoid useless information that may limit the performance. The objective is to completely saturate the information requirements on workplaces.

The fields of application are manifold including complex assembly and logistic tasks, general tasks in the production engineering such as packaging and maintenance as well as an assistance to support employees with disabilities or changed abilities due to the demographic change. Thereby the information provision is possible directly on-site by using mobile assistance systems or in a specific defined workspace by using stationary assistance systems. Last but not least intuitive, simple as well as efficient interactions with human-computer-interfaces are possible especially by using gesture recognition.

Furthermore it is not possible to point out all necessary requirements of assistance systems for applications in manufacturing, because these requirements are mostly situation specific. Robotic co-working systems usually deal with other requirements than stationary augmented reality systems or mobile systems with wearables. The most important basic requirements can be summarized such as flexibility and scalability of the assistance system, a simplified user interface, mechanisms for motivation, a context-sensitive help and an improvement of the process orientation. New manifold assistance systems can be developed, if the basic requirements are extended. By the way there are also some standardized requirements available such as the protection class according DIN EN 60529 or standards for human-system-interactions according to DIN EN ISO 9241.

The implementation of the assistance system in the university-intern LeanLab demonstrates the reduction of non-value adding activities by making the right information available at the right time, directly at the place of action as detailed as necessary. The investment costs for one workstation are very low, because only a commercial available computer, a Microsoft Kinect System as well as a Leap Motion sensor are required. The implementation of all mentioned requirements is proved to be extremely difficult and thus only the flexibility, manual scalability and the simplified user interface are realized within the scope of this Master-Thesis. The other functions require an extension of the assistance system with functions such as an automated monitoring and comparison of the current with the optimal workflow, in-situ projection, etc. One of the biggest advantages is the possibility to interact with the user interface without an interruption of the current work steps due to gesture-based commands.

The possibilities for improvements in the LeanLab are manifold especially due to the availability of new technologies (see Appendix 1). A relative easy realizable function is the implementation of the assistance system from workstation 5 in all other workstations, because the necessary software is already installed. Furthermore the replacement of text and picture based instructions with animations, the extension with more gamification elements as well as the IBIN system can be done without huge effort. More complex is the implementation of context sensitive help, in-situ projection as well as attention monitoring, but also realizable.

Especially augmented reality systems in combination with wearables have huge potentials in future industrial applications because no interruption of the work process due to hands-free interactions is necessary. To arrange the assistance function as efficient as possible, cognitive systems are essential. These systems consider the current data of the workflow through a continuous monitoring as well as data from prior analyses and combine all influences (speed, experience, error rate, attention, etc.) to generate an optimal sequence of actions. Furthermore these systems are able to learn, improve their experience and plan further steps. A successful realization of such a cognitive system is the CoWeldRob developed by Fraunhofer IPA and described in chapter 3.11. In this case the welding robot is able to absorb the knowledge of the worker and thus to improve its own performance. Therefore the system is able to give suggestions that are assessed by the worker. Nowadays this technology is still in its infancy, but for certain it will be the future!

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10 List of Abbreviations

AR	Augmented Reality
CAD	Computer Aided Design
CamP	Computer assisted manual Production
CIM	Computer Integrated Manufacturing
COMESCO	Connectivity MES Control
CoWeldRob	Cognitive and Collaborative Welding Robot
CPS	Cyber Physical System
HCI	Human Computer Interface
HMI	Human Machine Interaction
HRI	Human Robot Interaction
HSI	Human System Interaction
IAO	Institut für Arbeitswirtschaft und Organisation
IBL	Institute of Industrial Management and Innovation Research
IoE	Internet of Everything
IOSB	Institut für Optronik, Systemtechnik und Bildauswertung
IP	Ingress Protection
IPA	Institut für Produktionstechnik und Automatisierung
ISI	Institut für System- und Innovationsforschung
IT	Information Technology
M2M	Machine to Machine
MES	Manufacturing Execution Systems
OSHA	Occupational Safety & Health Department
P2M	Person to Machine
P2P	Person to Person
PROMIMO	Prozessintegrierte Mitarbeiter-Unterstützung in der Montage
QM	Quality Management
TCO	Total Costs of Ownership
US	United States
VISTRA	Virtual Simulation and Training

Appendix 1: New technologies for assistance systems

Microsoft Kinect 2

It allows natural interactions with computers by simply gesturing and speaking. The sensor uses a depth sensing technology, a built-in colour camera with 1080p, an infrared emitter and a microphone array. The system enables to sense the location and the movements of individual humans as well as their voices. The big advantage of the second version is the improved depth sensor that allows the visualizing of small objects as well as all other objects more clearly and to view objects in 3D. The system is able to track as many as six people and 25 joints per person. Furthermore the second version of Kinect improves the overall precision, the responsiveness and the intuitive capabilities to accelerate the voice and gesture experiences on computers.

Facts:

Improved skeletal, hand and joint orientation; support for new development environments (publish apps in windows store); powerful tooling; advanced face tracking (resolution increased 20 times); simultaneous multi-app support

Technical data:

Depth sensing:	512x424, 30Hz, FOV 70x60, one mode: 0,5-4,5 meters
Colour camera:	1080p, 30Hz (15Hz in low light)
Infrared sensor:	512x424, 30Hz, produce a light independent view

Infrared in V2 Depth sensing in V2 1080p color camera in V2

(http://www.microsoft.com/en-us/kinectforwindows/meetkinect/features.aspx), (date of access 21.08.2014)

Leap Motion

This system senses how persons naturally move there hands and fingers and thus allows point, wave, and reach and grab gestures. The device is very sleek, light and tiny and can be placed on the desk. For a working with this device, the space above is used. Thereby the Leap Motion system is able to sense nearly every little or big move of the hands and fingers. The system creates 8 cubic feet interactive and three-dimensional space about it.

Facts:

Tracking of all 10 fingers up to 1/100 of a millimetre; field of view of 150°; z-axis used for depth and enables a 3D tracking; movements are tracked with a rate of over 200 frames per second

(https://www.leapmotion.com/product), (date of access 21.08.2014)

Ractiv Touch+ (Haptix Multi-Touch)

This system is able to transform any flat surface into a 3D multi-touch surface. Multi-touch is very natural to use, as can be seen on tablets and smartphones, but it is very hard to beat the classical mouse/keyboard combo in cases of productivity. Haptix tried to combine the advantages of both. The system can be clipped on elements such as tables, windows or screens and allows a control of the computer by tap, pinch, zoom, swipe or scroll gesture. If the fingers are above the surface, the device allows a 3D multi touch. The fingers appear on the screen and thus the exact position is visible. The three basic functions of the system are multi-touch, track-pad or mouse. Haptix generates a 3D sensing layer and a multi-touch layer simultaneous. The biggest advantages of this system are that it is not necessary to hold the hands in the air or to touch a screen.

Facts:

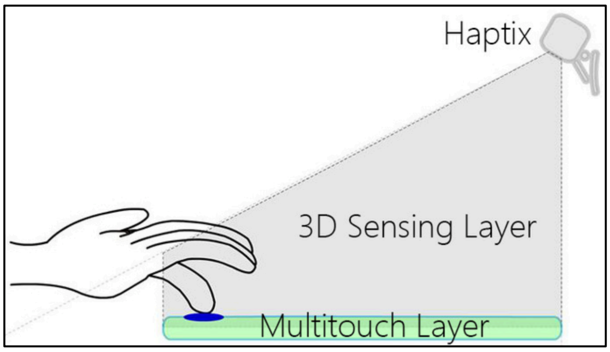
Tactile feedback, rest hands on surface, define space of operation, control things on a surface with precision, improving productivity

Function:

The system is able to track the 3D coordinates of the fingers. Furthermore it is possible to calculate the position relative to the surface. Haptix is not based on infrared or thresholding and thus it works under any light conditions.

Technical data (prototype):

Dimensions:	3x3x8cm
Field of view:	120° → moving to 150°
Camera:	2 CMOS image sensors, 640x360



(http://www.ractiv.com/touch.html bzw. https://www.kickstarter.com/projects/haptix/haptix-multitouch-reinvented), (date of access 21.08.2014)

Softkinetic Depthsense camera

Two different systems are offered, one for hand and finger tracking (DS325), the other system for full body tracking (DS311). The DS325 camera allows the use of hands and fingers for short-range interactions with computers. The interaction can be realized without touching anything such as screen, keyboard, trackball or mouse. The basic functions of the camera include 3D (depth) and a high-definition 2D (colour) camera. The DS 311 camera is able to track the full body as well as hands and fingers. The size of this camera is bigger than DS325 and thus not perfect for portable applications.

Technical data:

Distance: hands: 0,15-1,0 m (DS325)

hands: 0,15-1.0 m, full body: 1,5-4,5 m (DS311)

Size: 10,5x3,0x2,3 cm (DS325), 24x4x5 cm (DS311)

Operating temperature: 10-40°C

Applications: for indoors and outdoors use

Microphones: dual microphones

Resolution (depth): 320x240 (DS325), 160x120 (DS311)

Field of view (depth): 74x58x87° (DS325), 57,3x42,0x73,8° (DS311)

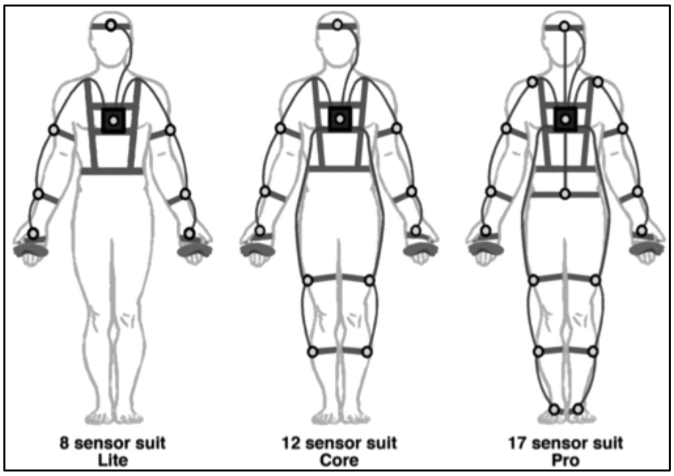
Resolution (colour): 720p (DS325), 640x480 (DS311)

Field of view (colour): 63,2x49,3x75,2° (DS325), 50x40x60° (DS311)

(http://www.softkinetic.com/products/depthsensecameras.aspx), (date of access 21.08.2014)

PrioVR

This system uses high performance inertial sensors and provides 360 degrees of low-latency and a real-time motion tracking without requiring a camera, optics, line-of-sight or other large, awkward equipment. The sensors are located on key points of the human's body to capture the movements. After that the system translates the movements on-screen in real time. The system works with WLAN and supports multiple simultaneous users. The biggest advantage is that it works everywhere, indoor and outdoor. Hand-controllers with action buttons, triggers and joysticks are applicable additional to the sensors. Three different systems are available including 8, 12 or 17 sensors.



(http://www.priovr.com), (date of access 21.08.2014)

INDUSTRIAL HEADSETS

Bluetooth Headset Xpressway II

- Very high noise suppression of about 93,1 %
- Range of about 20 m
- Weight only 17g
- Talk-time of about 7 hours, standby-time of about 150 hours
- Developed for the most difficult working conditions

B250-XT+ Bluetooth Headset

- Very high noise suppression of about 95,1 %
- Range of about 20 meters
- Weight 70g

- Talk-time of about 20 hours, standby-time of about 500 hours
- Developed for loud ambient noise levels

(http://www.best-headsets.de/xpressway-2.html), bzw. (http://www.best-headsets.de/b250xt-plus.html), (date of access 21.08.2014)

RAZER NABU

By turning the wrist the message screen of this wearable gets activated and presents the required information. The smartband also reacts to other commands such as shaking the wrist. Furthermore it can be customized relatively easy through apps. Currently supported activities are calls, email, sms, reminder, wechat, Google maps, Twitter, Instagram, Facebook and Skype. NABU is also able to track daily activities by using advanced algorithms to calculate the captured raw data and display the burnt calories, steps taken, floors climbed, distance travelled, hours slept and personal goals.

Technical data:

128x32 OLED Screen

Splashproof

Technique: Accelerometer, altimeter, vibration motor, Bluetooth 4.0 LE

Compatible: IOS, Android

Battery life: 5-7 days

(http://www.razerzone.com/nabu), (date of access 04.09.2014)

BRAGI

BRAGI is a wireless in ear headphone including an MP3 player, microphone, Bluetooth headset, fitness tracker and heartrate monitor. It is waterproof and has a touch sensitive surface to control the smartphone by sliding motions and taps.

The device is able to track daily activities including distance, steps, pace, rotation, turns, speed, cadence, time, g-force, airtime as well as heart rate, heart rate variability, oxygen saturation, body temperature and calories burned. BRAGI has an open system that allows the creation of different apps for all kinds of applications.

Facts:

Crisp and clear sound, no cables, music playback from the device, music playback from the phone, easy and intuitive controls, perfect fit with different silicone sleeves

Voice recognition is possible through ear bones to reduce ambient noise. A swipe gesture on the surface enables or disables ambient sound to pass through. Furthermore an additional external battery pack is available to charge the device anywhere within 1 hour. With one pack, 5 full loads are possible. The dimensions of the battery pack are very low (90x80x20mm).

Technical data:

Weight: 13,8 grams

Sensors: RED + infrared LED and optical sensor, thermometer, ear bone microphone, ambient microphone, 3-axis accelerometer, 5 field capacitive sensor

Technique: 4GB flash storage, Bluetooth 4.0 with aptX, 32 bit ARM processor, digital signal processor, analog frontend with 22bit ADC, Battery with 100mah (3hours music playback by a charging time lower than 1 hour), LED lightning

(http://www.bragi.com), (date of access 04.09.2014)

LG LifeBand Touch FB84

Facts:

Able to track steps, distance, speed, runtime, calories, pace and climbing distance. Furthermore it allows a real-time tracking of the heart rate, music control and phone compatibility.

Technical data:

0,91” 128x32 OLED touch-scroll screen

Sensors: 3-Axis accelerometer, altimeter

Splash proof

Bluetooth 4.0 LE

Compatible: IOS, Android

Battery life up to 5 days (without Bluetooth), 2-3 days (with Bluetooth)

(http://www.lg.com/us/fitness-activity-trackers/lg-FB84-BM-activity-tracker), (date of access 04.09.2014)

Samsung Gear Fit R350

Facts:

The device is able to track the steps, training and heart rate and also allows the communication with mobile phones to receive notifications and allows media control. Gear Fit only works with Samsung Galaxy phones.

Technical data:

1,84” 128x432 curved super AMOLED display

Bluetooth 4.0

Battery life 3-4 days with 210mAh

Sensors: heart rate sensor, accelerometer and gyro sensor

Weight: 27g

(http://www.samsung.com/at/consumer/mobile-phone/wearables/galaxy-gear/SM-R3500ZKAATO), (date of access 04.09.2014)

Samsung Gear 2

Facts:

The device is able to track the heart rate and the steps as well as to stream audio files from the mobile phone and to receive notifications. Furthermore it allows an IR remote control, S Voice and Watch ON. Gear 2 only works with Samsung Galaxy phones.

Technical data:

1,63” 320x320 super AMOLED display

1,0 GHz processor

2,0 Megapixel camera

512 MB RAM + 4GB

Battery: Li-ion 300 mAh

Bluetooth 4.0

Water and dust proof according IP67

Sensors: accelerometer, gyroscope, heart rate, IR LED remote control

(http://www.samsung.com/at/consumer/mobile-phone/wearables/galaxy-gear/SM-R3810ZKAATO), (date of access 04.09.2014)

Samsung Gear S

Facts:

It has the possibility to receive updates from social networks, appointment reminder as well as notifications. The received notifications can be answered by using the integrated display keyboard or the improved S voice. Furthermore the Gear S includes a Turn-by-Turn navigation as well as a fitness tracking.

An additional device “Samsung Gear Circle Headset” can be used to transfer music, entering voice commands or receive calls via Bluetooth. This headset also informs the user through vibrations according incoming notifications.

Technical data:

2” 360x480 curved super AMOLED display

3G, Bluetooth 4.1, WiFi and USB connectivity

Sensors: improved multi-sensors (accelerometer, gyroscope, compass, heart rate, ambient light, UV, barometer), integrated GPS, S Health features

512 MB RAM, 4GB internal memory

Dual core 1,0 GHz processor

Battery life about 2 days with 300 mAh Li-ion

(http://www.samsung.com/at/discover/smart-wearables-gear-s-and-gear-circle), (date of access 04.09.2014)

Sony Smartwatch 3 SWR50

The Smartwatch can be controlled by voice recognition and it uses vibrations to announce incoming calls, notifications and other information. The touchscreen allows tip and swipe gestures and the device is able to act as an Android remote access to control the music player as well as apps.

Facts:

Smartwatch supports the following functions: search for any information, weather, traffic information, notifications, reminder and personal information. Additional apps can be downloaded for the Smartwatch.

Technical Data:

1,6” 320x320 transfelctive display

Sensors: light sensor, accelerometer, compass, gyroscope and GPS

Quad ARM A7 1,2 GHz processor

512 MB RAM

4GB internal memory

Waterproof against IP68

Battery life about 2 days through normal use with 420 mAh

Connections: Bluetooth 4.0, NFC and micro USB

(http://www.sonymobile.com/at/products/smartwear/smartwatch-3-swr50/), (date of access 04.09.2014)

Sony Smartband Talk SWR30

Functions:

Smartband can be used for fitness tracking as well as for a remote control of the smartphone to accept calls, notifications and other information.

Technical data:

1,4” 296x128 curved mirror-free E-Ink display

Waterproof against IP68

Battery life up to 3 days with 70 mAh

Integrated microphone and speaker

Weight: 24g

Bluetooth 4.0 BLE

(http://www.sonymobile.com/at/products/smartwear/smartband-talk-swr30/), (date of access 04.09.2014)

Optinvent Ora

The dataglass has a see-through full colour landscape mode with a resolution of 33 pixels/degree. It allows two different modes: In the first mode the image can be centered for augmented reality, in the second mode it can be placed in the peripheral vision for info snacking (glance mode). The system uses the patented Clear-Vu technology that enables a see-through vision while displaying a virtual image at the same time. Furthermore Clear-Vu is very lightweight and cost effective. The operating system is based on Android 4.2.2.

Functions:

Different hands-free wireless mobile computing applications are available including location-based services, logistics, maintenance, sports, messaging and situation awareness. The dataglass can operate as a standalone wearable computer or can be connected via Bluetooth and WiFi to any smart device. The control of the glass is done by trackpad.

Technical data:

Full colour landscape mode 4:3 with 33 pixels/degree

Field of view: 24° (84" at 5m)

Weight: 80g inclusive battery

Battery life: 8 hours (typical use) and 4 hours (full on)

Connections: Bluetooth 4.0 and WiFi, USB

Shatter proof

Dual core processor (1,2GHz), 1GB DDR + 4GB Flash, Camera (5 Megapixels), microphone, sound, inertial sensors (orientation sensor: 9 axis with tap mode, accelerator, gyroscope), GPS, ambient light sensor, photochromic lenses

Product	See-through	Form Factor	"Flip-Vu" (2 positions)	AR capable*	Diagonal FOV (Display Size)	Resolution	Weight	Camera	Other Comments
Google Glass	Distortion /Parasitic Reflections	Monocular	No	No	14°	640x360	50g	Yes	Need to look at upper right corner to see image. Small display w/ low Brightness.
Epson Moverio	Yes	Binocular Glasses	No	Yes	23°	960x540	240g	No	Bulky, heavy, and blocks peripheral vision on both sides. Wired connection.
Optinvent ORA-S	Yes	Monocular Sunglasses	Yes	Yes	24° (~70" at 4m)	640x480	80g	Yes	Largest FOV and Highest brightness
Recon Jet	No	Monocular Sunglasses	No	No	16°	240x400	60g	No	Need to look at bottom corner
Vuzix M100	No	Monocular Eyepiece	No	No	16°	240x400	Not Published	Yes	Form factor issue for consumer

*AR Capable is defined as true see through display in front of the wearers field of vision

(http://optinvent.com/see-through-glasses-ORA), (date of access 04.09.2014)

3 Gear System

The classical Microsoft Kinect system works perfect for capturing large and full body actions. Thereby the optimal distance is several meters away from the sensors. The 3

Gear system uses 3D cameras that are based on Kinect to reconstruct a finger-precise representation of the hands and thus allows interactions based on small and comfortable gestures such as pinching and small wrist movements. The system can realize a millimetre-level accuracy. The camera (PrimeSense Carmine 1.09 bzw. Asus Xtion PRO) is mounted about 70cm above the desk. The high position of the camera avoids the “gorilla arm” problem by recognizing gestures a couple of centimetres above the desk. The application-programming interface of the system is open and free for academics, hobbyists and small commercial entities.

(http://www.threegear.com/index.html), (date of access 11.09.2014)

Asus Xtion Pro

Body movements are detected very precise in real time based on an infrared sensor and adaptive depth detection. To simplify the development, the system comes with a set of developer tools and avoids complex programming algorithms. The recognized actions are push, click and circle as well as wave motions.

Technical data:

Distance of use:	0,8m – 3,5m
Field of view:	58° horizontal, 45° vertical, 70° diagonal
Sensors:	depth
Depth image size:	VGA: 640x480, 30fps; QVGA: 320x240, 60fps

(http://www.asus.com/Multimedia/Xtion_PRO/), (date of access 11.09.2014)

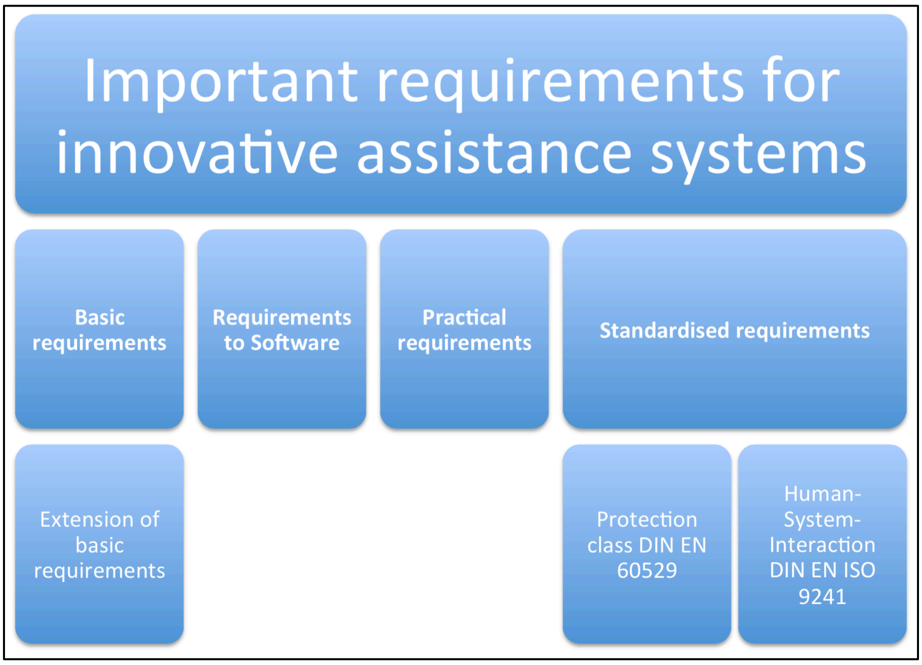
ProGlove

ProGlove is a wearable that is based on a glove for production processes. The objective is to enable a simple usage as well as a faster and more efficient working condition. The changeover is very easy, because gloves are already used in industrial processes. The device includes a display, RFID scanner, WIFI and Bluetooth connectivity and is able to pick up information from hands (temperature, electricity, etc.) as well as to monitor the worker what he is doing and to train the worker. The areas of application are the production and logistics.

(http://www.proglove.de), (date of access 14.11.2014)

Appendix 2: Requirements Specification

The requirements specification is used to summarize the most important requirements for innovative assistance systems to ensure a successful implementation in industry. These requirements can be divided into basic requirements for the assistance system itself and into requirements for the software used within these assistance systems. Furthermore an extension of the basic requirements is possible as well as standardised requirements that include the protection class according DIN EN 60529 and human-system-interactions according DIN EN ISO 9241.



(**Requirements overview** – own representation)

Requirements to assistance systems:

- Flexibility of the system (applicable for different tasks)
- Scalability of the system (adaptable to worker's skills)
- Simplified user interfaces (intuitive, easy & quick use)
- Mechanisms for motivation (motivate worker & improve workflow)
- Context-sensitive help (support in all situations, no rigid guidance)
- Increase of the process orientation (system in background, support only if necessary)

Requirements to the software used within assistance systems:

- Modifiability (enable later modifications)
- Robustness (handle wrong inputs)
- Reliability (worker relies on the system)
- Usability (simplify the usage)

Extension of the basic requirements:

- Detect current work steps
- Compare current work steps with predefined optimized work steps
- Support is based on ideal workflow
- Optical, acoustical or haptic feedback
- Cancel process if necessary

Protection class DIN EN 60529:

- Required for electrical equipment
- Protection against load through foreign objects and water
- Does not consider external influences or electrical shocks
- First key number (contact and penetration of solid bodies and dust)
- Second key number (damaging ingress of water)
- Voluntary additional letter (personnel protection against access to hazardous parts)
- Voluntary optional letter (specify additional information)

Human-System-Interactions DIN EN ISO 9241:

DIN EN ISO 9241-110:

- Task suitability (consider information requirements of the worker, additional information with explicit help function)
- Self-descriptiveness (purpose and scope of the dialogue system can be explained, dialogue step is easy to understand or can be explained)

- Controllability (user is able to influence the speed, selection and sequence of work equipment or nature and extent of inputs and outputs)
- Expectation conformity (user's expectation arising from existing workflows or trainings, user manuals or gained expectations are fulfilled)
- Error tolerance (interaction also possible in an error containing behaviour, intended outcome can be achieved either with or without a minimum correction despite recognisable incorrect entries)
- Customizability (allow adjustments of dialogues and workflows to individual worker or group of workers)
- Learning promotion (system assists and guides the user in learning the dialogue system)

DIN EN ISO 9241-11:

- Focuses on usability
- It is the extent in which a product can be used from a specific user in a specific usage context to reach specific goals effective, efficient and with satisfaction. It considers the user, task, organisation and environment.
- Effectiveness (how accurate the worker is able to fulfil the work content)
- Efficiency (expenditure of time required to generate work instructions)
- Satisfaction (necessary for acceptance & influenced from ergonomics)

Practical (additional) requirements:

- Additional housing is necessary for sensitive devices such as Leap Motion or Microsoft Kinect
- Housing has to be antireflective to avoid inaccurate operations
- Housing has to be ventilated for devices with a separate cooling system (e.g. Microsoft Kinect)
- All used components have to correspond to the company specific regulations (e.g. protection class, accuracy, etc.) as well as to the local prevailing conditions (e.g. temperature, humidity, brightness, etc.)
- Interactions should be possible for workers originating from different cultures (voice control not optimal)

- Interactions should be possible while wearing protective clothing (gloves, safety glasses, etc.)
- Consideration of the Total Costs of Ownership (TCO) before implementing such a system
- No application of gesture control for safety-critical applications (e.g. emergency switch)

Overall objectives of assistance systems:

- Reduction of search times (>80 %)
- Reduction of assembly errors (>80 %)
- Improvement of ergonomics (>80 %)
- Reduction of training periods (>50 %)

Most important functions of assistance systems (>80 %):

- Employee identification
- Storage and application of employee profiles
- Workpiece localization
- Recognition of the progress of assembly
- Recognition of assembly errors
- Reaction to assembly errors

Additional functions of assistance systems (>66 %):

- Automatic adjustments of the output according availability of components
- Automatic adjustment according to the tool availability
- Recognition of the assembly sequence of the worker
- Automatic adjustment according to the assembly sequence
- Independence of the representation