Application of camera controlled laser projection systems for manual mounting tasks

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Abstract
This article presents an approach of an assistance system for manual mounting tasks. For this, the three main requirements usability, flexibility and reliability are identified. A mounting assistance system is implemented in a test scenario, with consideration to the previously established requirements. It consists of an industrial laser guidance system that is controlled by a software using machine learning based image recognition. The software determines the status of the actual mounting progress and the location of product components. It controls the laser projection system, thus eliminating the need for any user interaction. Additional instructions are projected onto the work surface to increase the system usability. The results of a structural user test evaluating the mounting efficiency, effectiveness and perceived usability are presented. Finally, the article gives an outlook to further developments.

Keywords
mounting assistance, cyber-physical systems, image recognition, machine learning, Viola-Jones

1 Introduction
The increase of product variety and decrease of lot-sizes because of individualization of products leads to growing challenges for manufacturing companies [Hol17]. Additionally, research studies indicate that human work force remains an important factor for modern assembly tasks [Gan13]. Due to societal developments such as aging, assembly personnel vary in their qualification and affinity for digital interfaces. The question arises which functionality an assistance system shall offer and
how such systems should be designed to efficiently support the aging work force in an increasingly digital environment [Pei13].

Traditional systems, which are designed to support manual mounting tasks, reach their technological limitations due to the aforementioned factors [Dom13]. A typical example for this are industrial laser projection systems. They are used in various industries supporting manual mounting and fabrication tasks by projecting work instructions on objects and tools. Usually, these instructions are controlled by the assembly personnel [Jec17]. This however can prevent full concentration on the assembly task.

Motivated by the identified challenge, this paper describes three main requirements which modern assisting systems should fulfill: Usability, flexibility and reliability. Based on this approach, a laser projection system which is enhanced with machine learning image recognition is implemented in an industrial test environment. A reliable image recognition algorithm using input from a camera system recognizes the progress of the mounting process and automatically controls the system. Users can thereby fully concentrate on the mounting task. The provision of digital mounting instructions at the right point of time in an ergonomically well-suited position improves the mounting efficiency and overall usability of the system. The system is flexible and only requires CAD data of the mounting objects.

2 State of technology
A variety of mounting assistance systems is available to support manufacturing companies in their operational challenge to increase process efficiency. One can choose between multiple technologies such as video projection, augmented reality, light signal or speech instructions [Kas14]. The systems themselves are controlled by manual interaction, gesture tracking, voice commands or other input mechanisms. Merkel et al. present a capability based selection model to select the best fitting assistance system [Mer17a]. Merazzi and Friedel present a value based concept to select the most feasible system for a specific mounting task. The concept highlights that projection based mounting systems are beneficial for complex mounting tasks. Furthermore, a combination of picture recognition for inline quality control in real time is proposed to reduce the training period and increase production efficiency [Mer17b].

One way of projecting information are laser projection systems. It is possible to project CAD data onto work pieces or working surfaces. In comparison to a video projector, a laser projection is well visible at challenging ambient light conditions. Additionally, due to its preciseness the laser supports tasks with high requirements on accuracy.

Users traditionally control the systems using the graphical user interface or a system specific remote control [Lap18]. Alternative intuitive control concepts have been analyzed in user studies showing preference for system control using voice commands. However, a human system input is still required and the system itself has no capabilities to react to the user’s actions [Mue18].

The user input frequency automatically increases with the number of product variants, decreasing batch sizes and the complexity of the manual mounting tasks. The work process is interrupted, thus reducing the efficiency of the actual mounting task. Therefore, system providers are challenged to improve their existing operation and control mechanisms on the human machine interface. Besides an increased usability and process efficiency they target an improved company image in terms of quality and innovation by enhancing the human machine interface [Gan13, Pei13].

To reduce the control interaction needed by the user, an assistance system needs to fulfill more functions than the output of process information [Zae09]. By adding capabilities for process recognition and analysis, the user is relieved of this workload and can concentrate on the main process (e.g. a mounting task). This extended system fulfills the definition of a cyber-physical system by connecting the physical world with data accessing and processing mechanisms [Bah11].
There are several approaches to mounting assistance similar to the system developed here. Kosch et al. present a system developed in the MotionEAP project that supplies the user with mounting instructions and provides process feedback. During the project, several types of user feedback have been evaluated. Visual feedback had been found to be the best solution with a good usability by the users. The feedback is being projected directly on the working surface with a video projector [Kos17].

Commercially available industrial solutions support picking and mounting processes by evaluating the process with a camera or camera-sensors. The user then receives feedback whether the component is correctly chosen and mounted. The corresponding information is displayed on a screen or using a video projector [Opt18, Uli18].

Common to the aforementioned approaches for mounting assistance systems is a direct evaluation of the mounting and picking process on the workbench. This is only possible because the user either assembles the product on the workbench or puts assembled parts in specified areas for process control, therefore interrupting the mounting process. An approach giving instructions based on mounting processes which do not happen directly on the workbench or in a designated area is not yet evaluated.

To provide sustainable feedback on a system’s function and usability, a suitable evaluation method is required. Among several evaluation methods, the System Usability Scale (SUS) developed by Brooke is widely recognized as a standard procedure. The method uses a questionnaire of ten questions in which a system’s perceived usability is assessed on a scale from one to five. The ratings are then converted to a value between zero and one hundred. A SUS value above 68 represents a good perceived system usability [Bro96]. The After-Scenario Questionnaire (ASQ) is applied to measure the efficiency and effectiveness of task completion [Lew91].

3 Requirements for intelligent mounting assistance systems

A changing manufacturing environment leads to modified requirements on modern mounting assistance systems. This section identifies three main requirements resulting from the targeted functionality and user group: Usability, flexibility and reliability. While these requirements are not new, new technological advancements render them increasingly important. Currently, manufacturing facilities are on the verge to change towards systems commonly referred to under the term “Industry 4.0” and “Smart Factories”. This includes improved and connected information flows as well as user-friendly, intelligent cyber-physical systems.

3.1 Usability

As mentioned before, the workforce is increasingly aging while digital technologies are entering the shop floor. Resulting from that, an assistance system should not only be well designed in terms of ergonomic aspects but also be able to support the user independent of their affinity for technology and digital change. The information provision should follow good design principles for visual communication [Agr11]. Furthermore, it is important not to distract workers from their tasks and support them situationally when needed. For that, the provided information should be easy to read and be displayed in the user’s field of view. At the same time, any input which only serves the control of the system should be avoided.

3.2 Flexibility

The rising of product individualization leads to smaller batch sizes and larger amounts of product variants. To satisfy varying customer needs, a production system must be able to flexibly produce different product variants. With rising variants, it is not feasible for users to learn and remember multiple work instructions. Therefore, a mounting assistance system must provide the correct instructions at the time of assembly. For this guidance, it must be able to identify the progress of the mounting process. During production, the system must
switch the variant with minimal or no input from the user. Additionally, it must be easy to add new variants to the system.

Another aspect concerns the parts handling. With multiple variants, standardized load carriers are used for component variants. A system which identifies components must be able to recognize them in various positions. Otherwise, each new assembly process would need to consider the design of the assistance system, which is not feasible. Furthermore, the system should also be able to instruct the user which component to pick from which tray position in order to reduce overall commissioning times.

3.3 Reliability
The final aspect concerns the systems reliability. With intelligent, highly connected systems, a design focusing on reliability is crucial to ensure an uninterrupted production. Manufacturing companies work with optimized processes, and any unplanned interruption of the production process results in financial loss and is therefore not accepted.

Since the system needs to be able to recognize the mounting process, it is highly important that this recognition is performed flawlessly. Therefore, the system must be able to recognize parts or part movements independently of ambient light conditions or other influencing factors. Furthermore, human errors by wrong system interaction shall be eliminated to increase the overall system reliability.

4 Test scenario
To analyze and evaluate the defined requirements, a test environment has been chosen which resembles the aspects discussed before. In this environment, a ballpoint pen is produced in a manual mounting process. The production takes place in a showcase factory. The pen is individualized and consists of six parts. The basic parts lead to 36 variants. Personalized laser engraving and riffle performed in previous process steps increase the possible variants endlessly resulting in a batch size of one.

While parts like the end piece and the refill can vary in color, other parts have different shapes and are customizable by the user, see figure 1.

![Ballpoint pen and part variations](Tb/94401©IFW)

Figure 1: Ballpoint pen and part variations

The single parts of the pen are stored in a tray with corresponding compartments, see figure 2. This tray is used during the whole pen production process and allows an easy customer identification via RFID. It can be put in a holding device in the center of the workbench, which contains an integrated RFID reader.

![Tray with pen parts](Tb/94402©IFW)

Figure 2: Tray with pen parts

To mount the pen, the user has to fulfill two subtasks: 1) Picking the parts from the compartments of the tray, and 2) Mounting the parts in the correct way. The component position on the tray is unknown to the system, since the user commissions the tray in the previous steps of the production process. The commissioning system in the previous process does not indicate in which compartment of the tray the user should place the part. Even with an indication, a wrong placement would not be recognized. The mounting assembly system
can therefore not rely on position information of parts placed on the tray.

After finishing the mounting, there is a storage compartment on the tray for the completed ballpoint pen. The storage compartment is located in the top area of the tray, see figure 2.

5 System implementation

The goal of the design process was to develop a system, which fulfills the requirements identified in section 3. For the chosen test environment, a laser projection system is used to display the mounting instructions while a camera allows the system to follow the mounting progress. This section presents the implementation and details how each of the requirements influenced the system design.

5.1 Workbench setup

From the perspective of the chosen test environment, the user should be assisted with the assembly of the pen by showing which components to pick from which compartments of the tray and how to assemble them. In terms of usability, the information provided by the system must be easy to read and interpret. This refers to the software functionality as well as the system ergonomics. The user should be able to stay focused on the task without needing to control the assistance system in each step. This directly influences the implementation of hardware elements, as seen in figure 3 and 4.

The camera and the laser projection system are mounted on top of the workstation, above the user’s head without interfering with the user’s sight. The camera points to the tray, allowing a top down view on it and effectively creating a seemingly two-dimensional image. The computer is located behind the workbench in a non-disturbing position. A passive display is placed in an ergonomic position behind the tray. The passive display is black coated to secure good visibility of the work instructions projected by the laser system. The height of the overall workbench is adjustable to specific individual needs.

Figure 3: Workbench layout

It should be emphasized that the system does not use any external control devices, like a remote control or a keyboard.

5.2 Program flow

The software assists the user during the whole task, starting with the identification of the tray in the holding device and ending with the user putting the finished pen in the designated compartment of the tray. To create a flexible system, product components need to be recognized in all locations on the tray.

The program flow is presented in figure 5. After the user puts the tray in the holding device, the software begins to identify the components on the tray. Once the recognition is finished, the component location is compared to a table of compartment coordinates. The resulting allocation information is then used to project the first pick instruction on the tray using the laser projector. With the beginning of the projec-
tion, the software starts to perform the recognition of the component to pick. After the part is removed from its compartment, the recognition leads to a negative result, which initializes the projection of the mounting instruction. While the user is mounting the picked components, the next projection is started after a predefined time.

![Diagram of Program Flow](image1)

This process repeats until all parts are removed from the tray and the final mounting projection is shown to the user. After this, the compartment in which the fully mounted pen should be stored is highlighted on the tray, together with a storing instruction on the passive display. Once the fully mounted pen is recognized on the tray, the process is finished and can start again with a new tray.

5.3. Component recognition
A robust process recognition is significant to create a reliable mounting assistance system. The developed software uses the Viola–Jones object detection framework to identify the components [Jen08]. The algorithm, which was originally designed for face recognition, works well for the situation in the depicted mounting scenario. It needs a low amount of training images to work reliably. The required number of images had been determined through several test runs. During these runs, classifiers trained with ascending numbers of images had been used in different ambient light conditions. A training set of almost 5,000 positive and 10,000 negative images was used by Viola and Jones to train a face detection classifier with high detection accuracy. For the mounting scenario, 50 negative images and 30 positive images per component were sufficient to get satisfying results. Components are detected fast and independently of different ambient light conditions, providing reliable information of component location.

5.4. Projection of picking and assembly instructions
To fulfill the requirement of flexibility, the software must be able to handle different variants of components. These components can be located in different positions during the assembly process. The pen tip for example can be found in any of the seven compartments on the tray. To show the correct compartment for picking the next part, a green line is projected onto the trays surface, according to its position determined by the software, see figure 6.

![Figure 6: Projection assistance of pick instruction](image2)
steps including different components or already mounted parts. However, the projection system allows the usage of generic CAD data. In this case, existing 3D CAD models have been converted into 2D images and supplemented with basic drawing objects (e.g. arrows and lines) using standard CAD software. The mounting instructions have been optimized so that users can understand the work instructions fast and easy in the system context [Agr03]. All projection data is prepared in the work preparation process and sent to the laser projector by the software during the mounting process. An example of the projection on the passive display can be seen in figure 7.

![Figure 7: projection assistance of assemble instruction (detail)](Tb/94407©IFW)

6 System evaluation
To measure the perceived usability, efficiency and effectiveness of the implemented system, a structural user test (n=7) has been conducted at the showcase factory. The goal of the study was to gain information about the systems advantages and drawbacks by gathering feedback from users who were not involved in the design process. Additionally, the system was used in the showcase factory over a period of three months proving the reliability in a stress environment. This section presents the study and the corresponding results.

6.1 Testing procedure
The sample group consisted of seven manufacturing trainees from a Small Medium Enterprise (SME). They received a brief introduction of the test environment and filled out a questionnaire preceding the testing. Apart from socio-demographic information (gender, age and educational background), the participants were asked for their expectations towards an assistance system. The participants were then individually challenged to mount the pen using the mounting system.

Following the completion of the assembly process, the participants received the second questionnaire consisting of twelve defined statements that should be rated based on a Likert-scale from zero (strongly disagree) to four (strongly agree). The set of statements was based on the SUS measuring the perceived system usability and extended by two statements from the ASQ evaluating the efficiency and effectiveness of task completion. The statements were alternating positively and negatively formulated:

1. I can imagine myself using the system regularly.
2. I think the system is unnecessarily complex.
3. I think the system is easy to use.
4. I think I would need technical support to use the system.
5. I think the system functions are well integrated.
6. I think there are too many inconsistencies in the system.
7. I can imagine that most people learn to use the system quickly.
8. I think the operation is inconvenient.
9. I felt confident using the system.
10. I needed to learn a lot before I could work with the system.
11. I am happy with how easy I could handle the task.
12. I am happy with the time I needed for handling the task.

The answers to each of the twelve questions were stored as values from the Likert-scale ranging from zero to four. The values from the positive statements 1, 3, 5, 7, 9, 11 are added up. The answers from the negative statements 2, 4, 6, 8, 12 are each subtracted from the maximum value four and added up. The final score was calculated by adding up both sub-sums.
The score is then normalized to provide a final result between zero and one hundred whereby one hundred represents the best value. During the assembly process, the participants were observed to identify problems concerning the interaction between the system and the user.

Following the second questionnaire, the participants were asked to mount the pen again, this time using paper instructions commonly used in manufacturing environments. The paper instruction described a different assembly order to prevent the participants from mounting the pen from memory. A coffee break created further distance between the testings. A third questionnaire, similar to the second one, was filled out and an open discussion concluded the study. A more thorough assessment of these paper instructions was not performed in this study since the participants already knew the process while assembling the pen with these instructions. Future work with additional sample groups could focus on this subject matter.

6.2 Results

The participants named multiple expectations towards mounting assistance systems. These expectations can be clustered into three key areas, as shown in table 1. Almost every participant named expectations connected to usability: Participants mentioned that a system should be easy to use and understand.

Table 1: Expectations towards a mounting assistance system (number of mentions) [m]

<table>
<thead>
<tr>
<th>Expectation</th>
<th>Mentions [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good usability</td>
<td>8</td>
</tr>
<tr>
<td>Robustness</td>
<td>7</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>3</td>
</tr>
</tbody>
</table>

All participants completed the mounting process successfully. They needed on average 59 seconds (6 sec. standard deviation) to complete the mounting task. During this time, no mounting errors were observed. All participants understood the instructions given by the system.

After completion, six participants stated that their expectations were fulfilled by the system. The camera-controlled system reached a high average perceived usability score of 81.8 on the adapted 12 question SUS, characterizing a high system usability. Overall, the system received a very good feedback for being easy to learn and to use, as shown in table 2.

Table 2: Average agreement values [A] (scale: zero and four) and standard deviation [σ]

| 1. I can imagine myself using the system regularly. | 3.00 | 1.00 |
| 2. I think the system is unnecessarily complex.   | 0.71 | 0.95 |
| 3. I think the system is easy to use.             | 3.14 | 1.21 |
| 4. I think I would need technical support to use the system. | 1.29 | 1.70 |
| 5. I think the system functions are well integrated. | 3.57 | 0.53 |
| 6. I think there are too many inconsistencies in the system. | 0.71 | 0.95 |
| 7. I can imagine that most people learn to use the system quickly. | 3.71 | 0.49 |
| 8. I think the operation is inconvenient.        | 0.57 | 1.13 |
| 9. I felt confident using the system.             | 3.00 | 1.15 |
| 10. I needed to learn a lot before I could work with the system. | 0.00 | 0.00 |
| 11. I am happy with how easy I could handle the task. | 3.29 | 0.76 |
| 12. I am happy with the time I needed for handling the task. | 2.86 | 1.35 |

Using paper instructions, the participants needed seven seconds longer (66 seconds on average) to complete the task. At the same time, 1.6 mistakes on average were caused by the participants, e.g. by completing steps in a wrong order. This was mostly caused by participants handling the task from memory in-
instead of following the given instructions. Furthermore, the system was highly rated regarding the efficiency and effectiveness of mounting task completion represented in the statements 11 and 12.

7 Discussion and outlook

Based on current developments, this paper identifies three main requirements an intelligent mounting assistance system has to fulfill. First, usability presents a key requirement given aging assembly personnel and new digital production systems. The second aspect concerns the system’s flexibility, which is increasingly important due to rising product individualization and variation. A system’s high reliability is of utmost importance in the production environment.

Due to multiple component variants and a flexible tray loading, the ballpoint pen assembly is a fitting representation of a modern assembly scenario. Subsequently, a mounting assistance system derived from the identified requirements is implemented in a showcase factory. The system uses an input-free strategy to assist the user with the mounting task without distraction. It reacts to different tray loading situations by identifying components using machine learning based image recognition. The conducted structural user test shows good results for the system’s perceived usability. The participants were able to understand and follow the presented instructions without any guidance. Furthermore, users rated the system highly regarding the efficiency and effectiveness of task completion.

While the approach already supports the user in the chosen test environment, the pilot study results show potential for further examinations and developments. These can be separated in two categories: 1) The first field of examination concerns the aspects of flexibility and reliability. Further studies should analyze how well the system fulfills these two requirements, for example by analyzing long-term behavior or by introducing different, more complex products which require a higher flexibility. On a technological level, approaches using artificial intelligence could help to shorten the implementation phase, e.g. by automatically identifying new product parts. Additionally, the implementation of new technology, like motion tracking systems, is currently considered to improve the process tracking capabilities of the system. 2) On a higher level, the system’s role as a cyber-physical system could be evaluated. It is especially interesting to analyze an extended system which includes workplaces for the next and previous work steps being able to interact dynamically.

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Literature


