Intelligent and Flexible Worker Assistance Systems

Assembly Assistance Platform for Planning Assisted Assembly and Rework as Well as Execution of a Worker-Centered Assistance

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Abstract: In assembly, reworking stations are often barely automated work places, where no technical equipment supports the worker, validates the process execution or documents process results. However, worker assistance systems are used to guide and support the worker through manual assembly. Nevertheless, the concept of providing information to the worker is limited to screen based output media and assistance systems are just compatible to supplier selected devices. The objective of the presented research and development in this paper is an interactive worker assistance system which combines qualification-based worker support and intelligent process validation especially for rework stations. Beside the worker assistance system, a planning environment is developed for an efficient generation of work plans and content for the worker assistance system.

1 INTRODUCTION

Nowadays, manufacturers are confronted with many challenges such as market demands for high quality products and decreasing prices. At the same time, the demand for individualized products raises which results in an increasing product variety and in smaller batch sizes at the manufacturer's side. To satisfy these customer demands, manufacturer have to find the right way to combine the flexibility of manual processes and the reliability of automated systems. (Mueller, 2016a)

In most industrialized countries, the described challenges paired with the demographic development intensifies the situation and the need for supporting systems in manual assembly. According to (Weidner et al., 2015), supporting systems can be distinguished between technical systems that substitute humans and systems that support humans. Furthermore, they state that a technical system can be considered as supporting system if it fulfills the following points:

1. The technical system supports the worker with his tasks, without replacing him
2. The technical system can always be overruled by the worker
3. The worker operates the technical system
4. The system does not pose any danger for the worker

Beyond that supporting systems consider physical, psychological, communicative or organizational improvement. An assistance system is a supporting system that can be distinguished in systems for physical or informational support (Hinrichsen et al., 2016).

In final assembly lines, these supporting systems are frequently implemented to guide the worker through the assembly process. Whereas in rework areas, experienced workers do the rework without the help of an assistance system because standard assistance systems do not possess the ability to handle dynamic failure conditions. Furthermore, these systems obstruct the worker during his work because they do not consider the experience level of the worker. Due to the minor application of assistance systems at rework area, failures occurring during manual rework process aren't detected in time and cause expensive reworks again.

This paper presents the development of an assembly assistance platform. The platform's purpose is planning assisted processes through use of the worker assistance system, guiding the worker through the job and rework process validation in industrial production. The platform consists of a planning

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environment to design dynamic process flows and a control system. The control system connects planning environment, worker assistance system and intelligent resources.

The ongoing research and development of the assistance platform is presented in following chapters: Chapter 2 gives an overview of the state of the art. Chapter 3 de1scribes the current situation and requirements for worker assistance in the rework station of an automotive supplier. In Chapter 4 the developed solution is presented, beginning with a short analysis of current worker assistance systems which are found in manufacturing companies nowadays. Chapter 5 summarizes the results of the research work and gives an outlook towards future work.

2 STATE OF THE ART

To support the worker cognitively during manual processes, conventional media such as paper, tables and other drawings are widely used (Wiesbeck, 2014). However, these traditional concepts have the disadvantage that employees have to look at different objects and search for the correct information by flicking through the instructions. This is time consuming (Lusic and Fischer, 2016) and hinders the parallel handling of the product. The information supply is not efficient by using this unsuitable display techniques and can lead to assembly errors e.g. due to misinterpretation. These manuals are time-invariant, and therefore cannot represent information in temporal sequences directly. Hence, they burdens more cognitive load to the worker (Lusic and Fischer, 2015). Furthermore, manuals have to be updated contently and physically if they are available as printouts because they do not have any direct link to a digital planning environment. Process instructions written down on paper are more likely to be ignored, due to the extra handling effort.

Therefore, analogue and conventional information carriers have to be substituted by digital media and to provide the information in the most ergonomic way to the worker. The information representation is just one part of the assistance. It avoids failures by providing the worker with information for the right execution of the process. However, the second part is to check if a supposed completed process is executed as specified. Thus, assistance systems are equipped with sensors to evaluate the process. For example, camera technology is widely used to compare target state and actual state of a process.

Currently, there are several worker assistance systems available on the market. Looking at them reveals different stages of assistance. The main component of assistance systems is their information-displaying character. Moreover, they often have an evaluating component like cameras to detect differences between actual status and target status of the process or rather of the product.

A closer look at the available cognitive assembly assistance systems reveals that these systems consist mostly of two parts. The first part is the planning environment, whereas the second part is used to support the worker during the processes. In the planning environment, the user or a planner defines the processes and parameters which are used during the process later. The following characteristics are found in most worker assistance systems:

- Listing of processes to be executed
- Pointing to the current process (to be finished)
- Illustration of the process
- Manual quitting of the process

These systems are often restricted to the provider's specific resources. Even though they integrate several systems like pick-by-light, the amount of available resources integrated in the assistance system is limited. Moreover, most common worker assistance systems are limited to a worker guidance which appears in the form of a monitor with a job list and further human readable information like figures. Sometimes, there is only one sensor like a push button for quitting the process. Planning environments are used to configure the assistance systems, but are limited to integrate further resources. Because of this, processes with other resource requirements cannot be listed on the job list. E.g. camera based systems cannot validate the torque applied in a tightening process. Especially in the manual assembly or rework station where a lot of complicated and different kinds of processes have to be validated, the limitation of hedging technologies can be seen as insufficient. Most environments generate process lists by defining them step by step. These static job lists are unsuitable for a huge amount of variants as well as error code dependent rework processes. An error code corresponds to a defective behavior of the product and allows to determine the reason of the failure. It is provided by a test bench. However, changing the rework job is quite common because another failure reasons can be detected by the worker during the process execution.

Therefore, the system must pose the functionality to change the rework job dynamically on an error code, which is not provided by common systems.

3 ANALYSIS OF THE INITIAL SITUATION

As the assembly assistance platform is developed for the application in real production environment, the conditions and initial situation are analyzed beforehand. The case is the assisted and ensured rework on faulty automatic transmissions after the final assembly and commissioning in production. As an automotive supplier, the transmission manufacturer faces high quality demands and is obligated to secure and document its processes. Due to the operational structure and economic reasons, this is achieved in the final assembly but not in the rework area.

An automatic transmission is made of a large quantity of parts which are assembled through complex processes. In the final assembly, (semi-)automated assembly lines are installed which provide a high degree of process validation as well as an extensive process documentation. The process validation results in high quality manufactured products. To validate the processes, the assembly lines are equipped with sensors and electronic resources that ensure the correct assembly process execution. In a testing bench, additional tests are performed to validate the quality and functionality. Faulty transmissions are sent together with an error code to the rework stations in order to get repaired and brought in a salable state.

In contrast to the final assembly lines, rework stations are structured as single workplaces and are dominated by a high degree of manual assembly processes. This allows a required degree of flexibility to repair all kinds of product variants and perform different rework jobs and processes at one workplace. But compared to the final assembly lines, the process validation and documentation in the rework station are insufficient, due to the lack of automated and technical equipment. Hence, highly skilled workers are needed which additionally undergo a special training program to be able to handle the rework job. Especially the lack of process validation can lead to mistakes during the process. In the final assembly line, the process validation ensures the correct and scheduled performance of a process as well as process documentation, which is necessary for traceability purposes to customers.

Since rework jobs require highly qualified workers with many years of experience, in case of sudden absence personal replacement cannot be found easily. Furthermore, experienced worker undergo a capacity intensive training to be qualified to work at the rework area. Thus, one objective of the proposed assembly assistance platform is to reach a similar degree of process validation as in final assembly lines, but maintain the workers' adaptivity and ability to make situation based decisions. Another objective is to cover worker qualification and training on the job. Therefore, the assembly assistance platform consists of four important modules:

- Assistance system for guiding and qualifying workers
- Intelligent resources to validate and document the processes
- A control system that distributes planning data to resources and assistance system and connects all systems with each other
- A planning environment for creating dynamic and parametrized processes lists

The worker assistance system has to guide the worker through the rework job and support him to avoid any mistakes.

Following, the user profile is described. The developed system addresses women and men alike and there is no difference in the information/ content provided by the system or how the content is displayed. The user's age varies from early 20s to 60. Therefore, IT-affine and non-affine people alike are confronted with the system in their daily work. To address both types of users, users will be qualified and trained for working with the system. Furthermore, the user is involved in the design phase of the system and has the opportunity to give feedback concerning the design of the assistance system. As mentioned before, the average user is a skilled worker with at least three years of work experience in a similar production department, where similar but often "easier" tasks have to be performed. Hence, the user is familiar with the basic functionalities of the product (automatic transmission). Because a lot of product variants and different process have to be mastered, three skill levels (beginner, advanced and expert) have to be considered. Beginner starting in the rework area are supported by experts and trained for about half a year. He needs a higher grade of assistance e.g. of difficult processes and resource because he is still in learning phase and has to be trained. Users exceeding the training phase are of course more experienced. On this level, they don't need small stepped assistance and further explanation of processes, but additional hints or information e.g. during a bolt tightening process considering the tightening sequence or during the rework on a variant, which they don't handle / repair very often. Experts on the other hand don't need any hints. On this level, assistance is seldomly needed and detailed information is considered disturbing rather than helpful. Therefore, the assistance system will provide only information about major repair steps and most importantly, give feedback to successful or faulty processes during repair. This last point was addressed by beginners and experts alike. To close the loop between human action and system behavior or rather the performed task a feedback from the assistance system is given. The feedback informs the user if a process is quit as planned or if something needs to be considered there. It needs to be considered that workers considered experts don't have more decision rights. The main difference is the degree of assistance, which is needed to complete the task.

The rework job is a set of processes which consists of three stages: the disassembling, the repairing process and the assembling of the product. Because of many different error codes in combination with a high amount of product variants, the worker assistance system has to generate the process and job list dynamically. Since the relationship between error code and job list is not unique, the worker should have the opportunity to take another process and job list, if he detects another reason for the error aside from the given job list code. Therefore, the assembly assistance platform has to allow a dynamic and resource independent generation of process sequences and an easy integration of resources.

Since the assembly assistance platform is used at the rework area, there are four requirements formulated which are similar to (Aehnelt and Urban, 2015):

1. Information
2. Parametrization of resource and process execution
3. Monitoring and checking
4. Documentation

Information considers the ability of a system to provide the user with human readable data. A visualization complements the pure textual information as well as other forms of visualization by showing how and where to handle parts.

Parametrization and process execution concerns the data for smart resources. E.g. electronic resources can be configured through parametrization. Electronic bolt tightening tools often have the capability to drive a predefined bolt tightening curve and tighten bolts with certain parameters.

Continuous *monitoring and checking of* the process can be validated. As long as the current process is not quitted the worker knows that the process is not completed as planned. In case of a system failure, most assistance systems allow the worker to quit a process manually if the worker is sure that a process is finished correctly.

Documentation is mostly the last action of a process. If the process is finished certain process parameters have to be stored due to traceability purposes.

Every requirement listed above is fulfilled by a resource of the assembly assistance platform. E.g. the first requirement of the assembly assistance system is to provide the worker with information. The resource which can be used for that is a monitor. The second requirement is to execute the process. For this, a smart resource can be used. So for every requirement listed above a resource can be used to fulfill it.

4 DEVELOPMENT OF AN ASSEMBLY ASSISTANCE PLATFORM FOR THE MANUAL ASSEMBLY

To use the assembly assistance platform in a modern factory environment, the following requirements and boundary conditions are considered:

1. The planning environment can use already existing data e.g. from the product design department
2. The planning environment is user friendly and can be used easily without any programming experience
3. The planning environment can handle multiple product variants
4. The planning environment can store the plan data in a suitable way so that a control system can use these data
5. The control system can read error codes and variant codes to generate a rework job list from an existing overall process list dynamically
6. The worker assistance system allows to dynamically expand the rework job if another failure reason is assumed
7. Additional resources can be easily integrated into the worker assistance system
8. The worker guidance offers reporting and feedback possibilities

Beside the analysis of final assembly as well as current state of rework area, the requirements considering the product and processes are also analyzed. Based on the analysis of the initial situation and a performed Failure Mode and Effects Analysis (FMEA), the critical product parts and processes which have to be validated during rework by the resources and functions of the assembly assistance platform are documented. As a result, the following requirements have to be considered and provided by the assembly assistance platform:

1. Checking if the right part is removed or assembled as well as positioned (e.g. tolerances) correctly
2. Checking if a disassembled part is placed in a defined component tray
3. Checking if a disassembled part is disposed as anticipated
4. Checking if the correct part is picked and assembled in the product
5. Checking if a process is performed as planned e.g. if a bolt tightening operation is executed correctly regarding tightening process, torque, angle and sequence

With the understanding of product, process and resources as well as the boundary conditions and requirements, the concept for the assistance platform is developed. The assembly assistance platform consists of four different modules. In Figure 1, the concept and framework of the platform with different modules is shown and unites the planning environment as well as the worker assistance system. Besides, the human role can be seen. The role is mainly to perform processes on the product. The worker guidance is the main interface between human and worker assistance system. It provides the user with main information about the product as well as the process but also allows to give feedback e.g. when a process needs to be quit. Another way to provide information to the user is by using the smart resources. Whenever the resources are not supposed to be used, they are disabled, which is a hint to the user that he eventually missed a step before or didn’t commit it correctly.

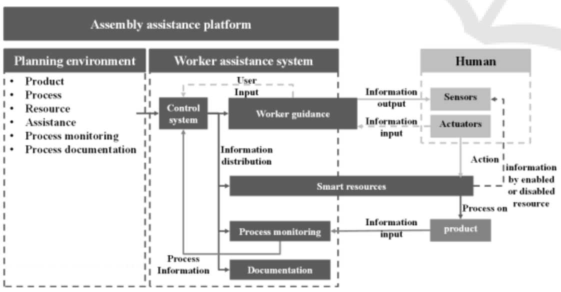

Figure 1: Worker assistance platform consisting of a planning environment and worker assistance system.

In Figure 2, the current state of the worker assistance system with implemented resources is shown. As for now, it consists of a 2D camera, an IR-Camera, a laser projector and a worker guidance system. Further resources and functionalities to fit the described requirements are planned.

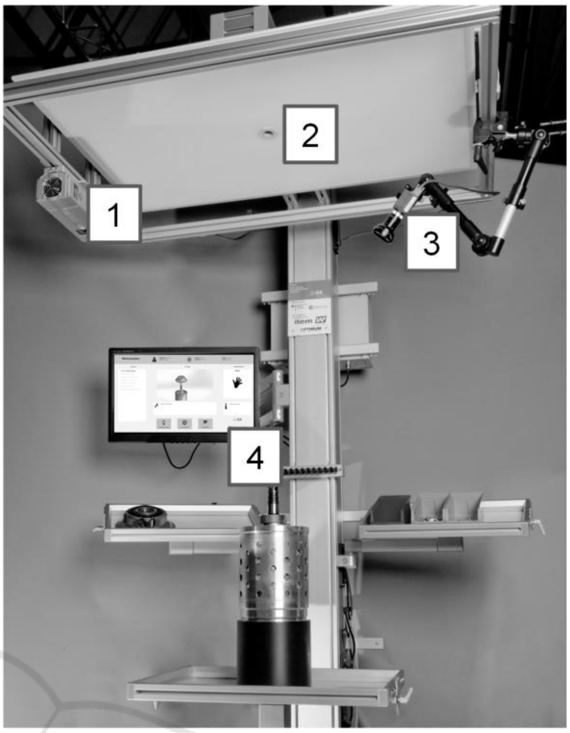

Figure 2: Current state of the work station with laser projector (1), 2D Camera (2), IR camera (3) and a worker guidance system (4).

4.1 Planning Environment to Configure Assisted Job Lists

To setup the worker assistance system, a planning environment is needed. To reduce programming effort, the planning environment has a GUI. Since the execution of the processes leads to the completion of the rework, the aim of the planning system is primarily to generate a resource afflicted generic process list (generic rework job list). The list allows to repair any component of any product variant and even helps handling the worst case scenario in which all components need to be replaced (or repaired). Therefore, the list contains all assemblies, subassemblies and parts (hereinafter referred to as product components) of the product’s variant group. The approach to create that list is to begin with analyzing the product, derive the processes and assign the appropriate resources.

Initial point for the planning are the product data. Since there are always product variants which are similar to one another, a generic Bill of Material (BOM) can be used, representing all product assemblies, subassemblies and parts of the variant group. The first plan data to be specified is the error code. It has to be attached to the products assemblies, subassemblies or parts. The error code determines which product part needs to be handled, repaired or replaced and allows the control system to calculate the disassembly path. The product data and requirement which determine how the product is assembled can be received from other department, like the development department.

Knowing the product requirements, in the next step all disassembly as well as assembly processes are derived and linked to product components. Thus, for each component a corresponding process exists and a generic process structure (similar to the BOM structure) is created. Since the planning data are used later to control the worker assistance system, process data needs to be enriched with resource configuring data, which are human readable as well as machine readable. Machine readable data are meant to be used as input data for resources or contain information to receive data from the resource to validate the process. For example, process parameters such as bolt-tightening-torque, bolt-tightening angle, article number, guidance information, etc. are some of these parameters.

The next step after creating the generic process structure is to create variant specific process structures by loading variant specific BOMs. In case of matching, the according process steps are kept whereas not matching process steps are removed. Process parameters have to be received from other departments or derived from the product structure. By known process parameters, the last step is to define variant specific resources to execute the processes.

The job list in the planning environment contains the disassembly as well as the assembly. In Figure 3, an overall rework job list is shown which represents the worst case scenario, meaning that every product component needs to be handled and the whole product needs to be disassembled and assembled. The dark squares represent the processes. Since the assembly and disassembly can vary considering the used resource, the assembly process is marked with a dash to symbolize the difference. Up shifted (and down shifted) process (e.g P2.1, P2.2, P2.3) are attached to subassemblies. The upper (bright) layer contains the disassembly path while the bottom one (dark) contains the assembly path. The repairing process is not regarded yet. They are defined separately and attached to the error code. A rework process can contain:

- Replacing a presumably defect part
- Assembling a missing part skipped (forgotten) in the final assembly
- Checking for craze or damage during assembling
- Exfoliation and cleaning the parts afterwards

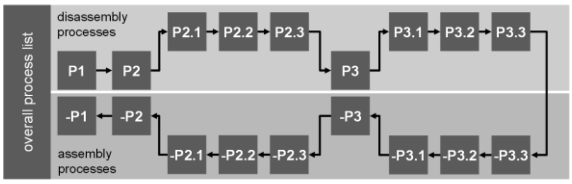

Figure 3: Overall process list with disassembly (bright lane) and assembly (dark lane) processes, repair processes are not considered yet.

However, the overall process list does not pose any rework job list. The work job list depends on the error code and lists process steps that lead the worker to the affected product component and consists of a disassembly stage as well as a repairing and an assembly stage. The rework list is generated by the control system.

4.2 Control System to Generate Error Code Dependent Rework Jobs and to Distribute Data to the Right Resources

Since the planning environment and worker assistance system are separated, there needs to be a control system which executes the rework job as generated based on product variant and error code. The control system needs two initial information to generate the rework job. The first information is the product variant and the other the error code. Based on the error code, the faulty product part is determined and a rework job list is generated. The rework job list contains all processes which are necessary to get to the product repaired. In Figure 4 and Figure 5, two different rework job lists for different rework cases and different degrees of disassembly are shown. Using the plan data set in the planning environment, the job list is dynamically created by the control system and depends on the given error code. The repairing process is settled in the turning point between disassembly (upper lane) and assembly (bottom lane).

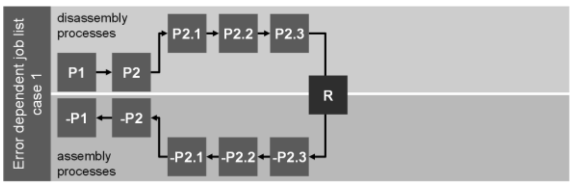

Figure 4: Case 1: Rework job shown as graph. The repair process is the turning point between disassembly and assembly.

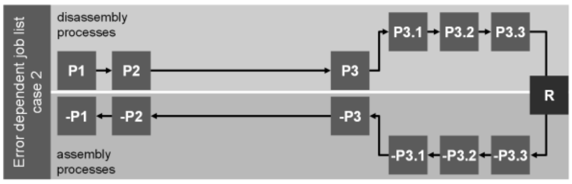

Figure 5: Case 2: Upstream assemblies are not disassembled, but taken out all in one.

However, during the rework another reason of failure can always be discovered than suggested. Therefore, the worker assistance system has to allow to switch the path to another part, if another reason is assumed. When the rework job list is set, the control system reads the first process and distributes the machine data to the corresponding resource.

When the process is executed, it awaits a feedback signal from the monitoring resource. If the feedback is positive, the process data are stored for documentation purposes and the next process can be executed. However, the worker has the possibility to choose another reason of failure. The control system then calculates the path from the current position to the new targeted position.

The combination and connection of planning and control system allows to generate new rework jobs based on defined reference products and processes, also new paths during rework. This and the description of process parameters beforehand make a dynamical system possible, without modelling every single rework job and product variant with their processes.

4.3 Worker Assistance System to Support Worker during the Rework Job

The worker guidance in form of a user interface (UI) is the access point for the worker to interact with the assistance system. The UI presents data similar to (Aehnelt and Bader, 2015) considering the process, the product as well as the resources. The data are human readable as shown in Figure 6. The processes are listed on the left side (1) and are ticked green by the system whenever they are finished according to plan. In the same list, the next process is already highlighted and hints to the task to be carried out next. The current process execution is presented by a picture or an animation (2) based on the product data. This visualization helps the worker to find the right assembly place at the product. Especially for beginners or less experienced workers, an animation is helpful to find the right mounting place on the product. Another advantage is that a picture can be easily created from given a CAD (Computer-aided design) model. On the right side of the UI, information considering the resource to be used (3) is provided. Beneath the resource information there is an extra field for additional background information considering the process or certain product (4). Its purpose is to explain why certain processes need to be done to develop awareness and avoid attempts passing processes, due to the lack of knowledge. Beneath the product part, there is a detailed explanation of the process in case that the worker does not know the process at all (5). At the bottom, there are three buttons placed. The first button allows the worker to demand more information considering the current process (6). The second one quits the process manually (7). Manual process quitting is shown in the process list by an orange tick beside the process. The third button allows the user to toggle between expert and beginner mode (8). The purpose of these modes is to provide beginners and inexperienced worker with sufficient information but avoiding annoying experienced worker with an information overflow. This mode is designed for beginners as well as trainings and qualification for certain variants. Moreover, if an experienced worker needs more information for just one process, he always has the option to do so. The UI is implemented as a web application and can be used platform independent. Being an important part, the UI is considered a resource and a part of the worker assistance system. A further visualization system is the laser projector (1 in Figure 2) which can be used to show the exact order of bolt tightening processes or highlighting a component which has to be handled or dis/assembled.

In the current state of the work station setup, the process checking/ validation is done by two different systems. First of all, there is a 2D camera (2 in Figure 2) which will only check if the live captured image matches the reference image. In case it does, the process is triggered as correctly carried out. This kind of checking is only applicable if the monitored product property is limited to a completeness control. The 2D camera can be replaced by 3D cameras to ensure that an element is placed correctly e.g. regarding the depth. Since the image evaluation technology is processing intensive, it is mostly reduced to a small area and is not suitable for every assembly process. Since reference images mean that appropriate processes need to be recorded once, an alternative can be to generate the reference data from CAD to avoid media disruption. Other technologies involve camera technology (C) too, but reduce the range of processed wavelength. In this case e.g. only infrared LEDs can be detected and used to determine the position and orientation of an IR-LED afflicted object.

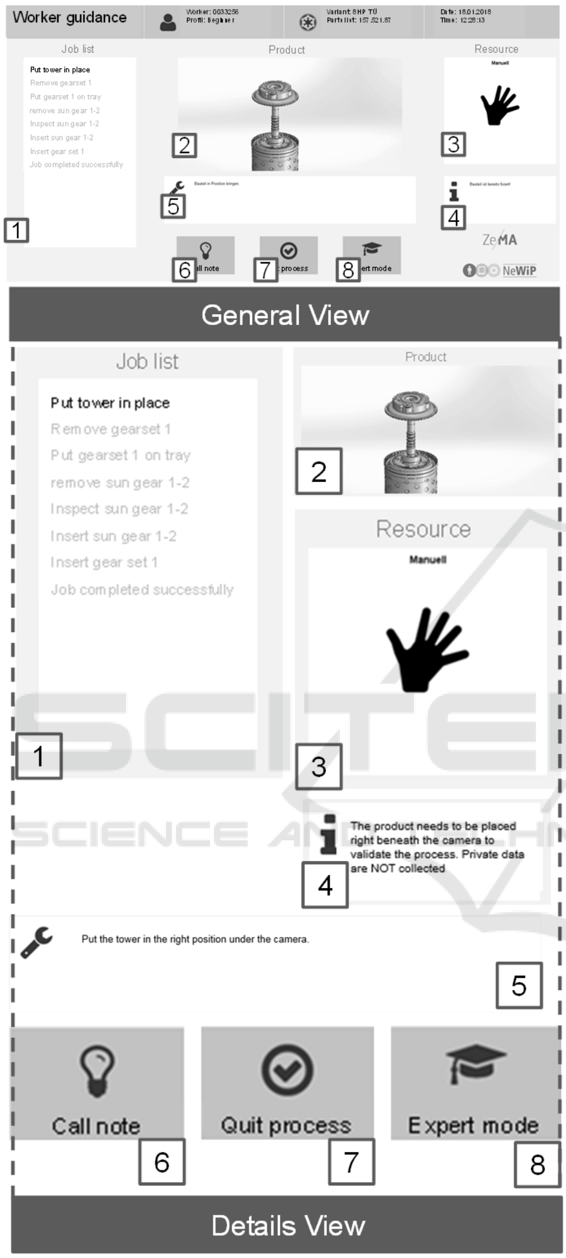

Figure 6: Worker guidance to lead the worker through the assembly and allow him to interact with the worker assembly system.

5 CONCLUSIONS AND OUTLOOK

This paper describes the development of a human centred assembly assistance platform which allows to design and configure the worker assistance system. To configure the worker assistance system and setup the job list with less programming knowledge, a planning environment for assembly planning engineers is developed. In this environment, information about parts, processes and resources are linked with each other to create the maximum job list for rework. Depending on an error code the job list is dynamically modified by the control system. For the modification and reduction of the maximum job list, a specific rework process is added which describes the repair work to be executed. The information of the job list is processed by a worker guidance system to provide human readable information to the worker. The worker assistance system is equipped with resources to document process results like cameras and EC-driver. Moreover, the worker assistance system allows short termed change of rework jobs as well as different stages of disassembly, if the worker detects unexpected failures.

For the planning environment, a concept exists which will be implemented as a software solution in the near future. On the worker assistance system side, development considering the process evaluation are still ongoing and concentrated on the development of a 3D camera based completeness checking. This shall improve the reliability of recognition and allow easy creation of reference data by using CAD models, which can configure any rework station.

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