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Enabling live data controlled manual assembly processes by worker information system and nearfield localization system

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Abstract

Existing localization solutions cannot be directly integrated into production systems. This article describes a nearfield localization system which can be installed on tools due to its small dimensions. Live data controlled manual assembly processes are enabled. In combination with worker information systems, the manual assembly process can be supported more precisely compared to common systems. The benefits are shown within product-specific assembly scenarios. One benefit is enabling work out of sight (non-visible range) guided through a virtual model on a screen. Error prevention (zero-defect assembly) can be realized by monitoring and matching the actual position to the assembly location. Even without augmented reality devices, comparative 3-D representations of real and virtual world are feasible, supporting employees in mobile workshop with complex repairs. In particular, difficult accessibility can be easily determined when carrying out maintenance work by knowing the complete product structure.

Keywords: Assembly; Information; Worker information system; Nearfield localization;

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1. Introduction

Manual assembly processes are very important in today's production as the cognitive abilities of humans are necessary for customer individual products and a rising number of variants per product [1]. There is a lot of research work concerning worker guidance. This results in the creation process of worker information during product development [2]. This is also true for virtual validation [3] and qualification processes [4]. Several ideas lead to a concept of digital information provision instead of paper-based documents [5]. Augmented Reality (AR) was introduced for worker guidance [6][7] as well as web-based systems [8]. In industry, worker information systems (WIS) are widely used. Most systems have a direct connection to the intranet of a company and provide information on a fixed screen next to the workplace. There are little variations of these standards.

1.1. New industrial information concepts

Expressions like cyber-physical system or Smart Factory in the context of the fourth industrial revolution (Industry 4.0) indicate a fundamental evolution in industrial production. Also for manual assembly, the integration of informational flows from Enterprise Resource Planning (ERP), Manufacturing Execution System (MES) to shop-floor and back have to be adapted to the new concepts. There is requirement for information efficiency [9] in order to cope with the challenge of a large volume of information. Another development is the direct access to worker's movements. In planning phase, a Motion Capture System (MCS) can be used for tracking assembly movements [10]. However, this technology is not applicable during series production. An optical method to obtain the worker's postures is presented

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in [11]. Another option is a radiolocation system to have direct access to position and orientation.

1.2. Need for action

Most existing localization solutions cannot be directly integrated into production systems. Either their accuracy is not high enough or their devices are too voluminous and, thus, only suited for mounting on vehicles. Some systems are vulnerable to disturbance in production environments. Based on miniaturized electronics assemblies for radiolocation systems, modern assembly and interconnection technology is able to facilitate nearfield localization in assembly lines. This contributes to a real-time connection between real production and virtual images in corresponding service provision. [12]

To have a concrete example for a production process, screwdriving as an example for a joining technology is chosen. There are discrete screwing locations to evaluate the accuracy of a positioning system. The screwdriving technology needs a distinct mapping between the assembly plan and the real production in order to guarantee product safety and quality. Existing localization systems based on ultra wideband (UWB) can only differentiate screwdriver locations among single workplaces [13]. Further, ultrasonic and optical localization systems have a resolution up to a few centimeters. There are commercially available ultrasonic systems such as Quality Assist from Sarissa GmbH or a corresponding low-cost variant resulting from a research project [14]. The latter is suited for locating the worker’s hand or tools. The functionality is proofed in laboratory environment but not in industrial production environments. In general, ultrasonic systems can be disturbed by sound sources such as pneumatic nut runners. Optical localization systems are commercially available. An example for a research-based system is light-responsive radio frequency identification (RFID) for fastening screws with cordless screwdriver in manual assembly verification [15]. This approach does not only depend on optical sensors but also on inertial sensors. This is comparable with our approach using a Motion Capture System for virtual validation of manual assembly processes [10]. Both approaches are only suited for planning phase, but not for production. Besides, pure optical systems are susceptible to interference by dust, steam or smoke.

Commercially available screwdriving systems consist of a controller, an electrically or pneumatically powered screwdriver and a display for workers. In general, these systems can differentiate among screwing locations by mechanical positioning systems and feature appropriate control programs. Regarding the data representation on screens, text or tables combined with engineering drawings are mostly used, but 3-D models are not usual. An example for the latter is provided by ZF in cooperation with Atlas Copco.

There are reasons for a detailed worker guidance and recording of screwing locations. The screwdriving process is very safety-critical and important for product quality. Data for each screw hole and its relating joining process is relevant.

There is a demand for zero-defect production [16]. This goal can be reached through quality control of raw material, visual control of workpiece and in-process actions such as real-time loop controls [17]. For the latter, all steps of machinery or worker interaction have to be detected. In one of our cases, a distinct assignment of work step to the joining location is necessary. The parameters of the device controller are also available for analysis. Thus, predictive maintenance methods based on these parameters are feasible [18].

In Industry 4.0 respectively Industrial Internet, there is a demand for connected devices. E. g. a screwdriver can be embedded into networks via cable or wireless local area network (WLAN). However, the question for positioning is not solved by that. A localization system for traceability is a precondition so that a screwdriver has awareness of his current status und is able to offer services based on his status. [19]

Manual working processes are in the focus of efficiency improvement. In contrary to machine data recording, the method of analyzing efficiency of manual work is not obvious as some actions are not traced. The travel paths of workers between workplace and central feedback terminals are often long and time-consuming (see Fig. 1). It is not clear how often a worker goes to the terminal and how long he stays there. A personal device next to the workplace spares several travel paths as a worker has access to current information and can immediately give feedback. In this case, the waste of working time is avoided. This finding is a result of industrial practice and contributes to the concept of zero-waste.

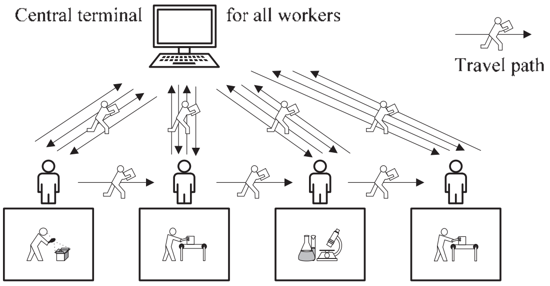

Fig. 1. Frequent travel paths to central terminal for giving inputs.

2. System approach

The use case in the project “Wireless Localization of Systems in Production and Assembly Lines” (abbreviation NaLoSysPro) is a screwdriving process combined with manual assembly steps. Our demonstration scenario is a manual workstation with a manually guided nut runner. The use of autonomous positioning systems based on radar for joining processes within manual assembly is one of the main goals (see Fig. 2). One further objective is the miniaturization of electronics for the transponder on the screwdriver.

The research work also covers an innovative locating with accuracy down to one screwing location as well as an intuitively understandable 3-D visualization of target/actual comparison. In contrary to the above-mentioned, commercially available systems, we derive the actual data sets from 3-D computer-aided design (CAD) models (see Fig. 2). Thus, we do not need to take photos or teach each screwing location. Technological data such as screw tightening torques is also counted among the actual data. The screwdriving tool is not fixed in a mechanical positioning system but a worker can move it arbitrarily.

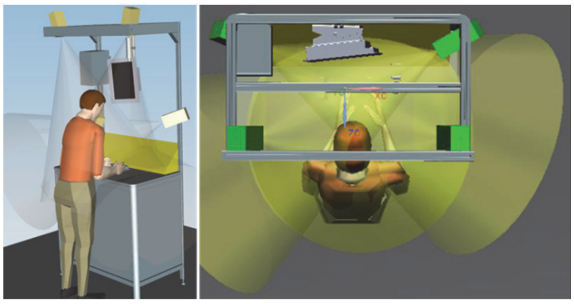

Fig. 2. Workplace with manual guided screwdriver and visualization of radiation cones.

Our approach for positioning is a radiolocation system [12] based on 24 GHz Frequency Modulated Continuous Wave (FMCW) radar instead of ultrasonic or camera systems in order to cover specific environmental conditions. The nearfield localization system is composed of four base stations on the top edges of the workplace. Each base station consists of a Radio Frequency Module and a Digital Signal Processing Unit. The signal processing chain starts with the antenna array which passes the 24 GHz signal to the demodulator. After the down conversion, the intermediate frequency signal is sampled by an Analog to Digital Converter (ADC) and finally processed in the digital backend. The digital backend consists of a Field Programmable Gate Array (FPGA) combined with a microcontroller. A transponder with reduced electronics in comparison to a base station is mounted onto the screwdriver. The signals from the base stations are recognized in the transponder and trigger the transmission of the FMCW Chirp. After reception, the phases at the individual antenna elements are evaluated and the Angle of Arrival (AOA) is calculated at the base stations. After this calculation, the reception angles are computed into 3D position and transferred to a central server within the manual workstation (see Fig. 3).

Beside the nearfield localization, a visualization of worker guidance is needed. A web-based worker information system is implemented to guide workers through all assembly steps. Its advantages are distribution over intranet and its need for only thin clients installed at workplace. It is a test carrier for new kinds of information transfer. The web-based WIS serves as a system integrator for radiolocation and tool controls. Based on geometry and process data from the 3-D CAD system NX, the WIS is able to assign order-specific target data and compare it with current data from tracking and control systems (see Fig. 3). The WIS graphically presents necessary data to the worker in a lean, ergonomic manner (see Fig. 4). Two 3-D models of a tool represent target and actual position. The worker has to move the real screwdriver to the target positions. Furthermore, the WIS can be used for documentation of measurements within an application scenario. These values can be deployed for evaluation and for improving the nearfield localization system regarding accuracy and robustness.

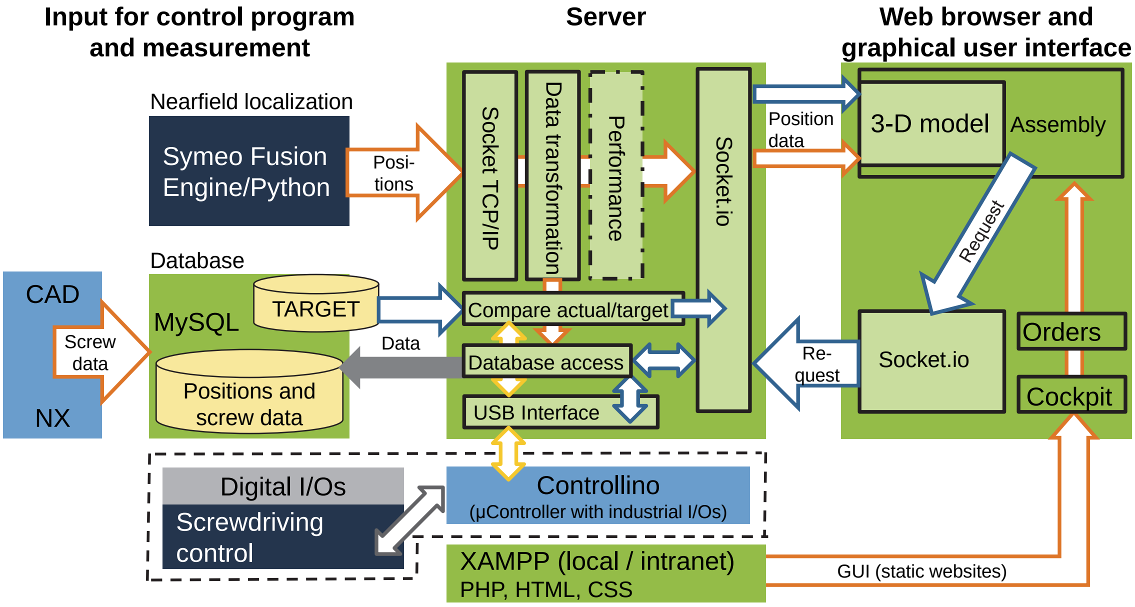

Fig. 3. Structure of web-based worker information system connected to localization system and screwdriving system.

Our approach is to set up a fully web-based system for the assembly cell using node.js as data server, Apache web server (HTML, PHP), database (MySQL) and web client (JavaScript). Apache is executed within the open source cross-platform XAMPP. Also, the 3-D hardware acceleration deployed by Web Graphics Library (WebGL) is used within the Three.js framework for representing 3-D models.

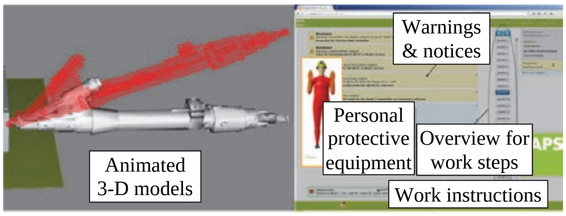

Fig. 4. Visualization of target (red) / actual (grey) comparison for the localization of a screwdriver embedded into WIS

3. Industrial use case

The focus of our project is on a manual workstation with a fixed WIS display on a swinging arm (see Fig. 2). The worker is bound to this scenario and can adjust all devices for an ergonomically correct position. However, we also think about mobile scenarios. We have appropriate prerequisites in form of wireless data connections (WLAN) and wireless positioning systems (radiolocation). Beside the use case nearfield localization in production lines, three further scenarios are described in the following paragraphs.

3.1. Mechanic within a garage

A mechanic works at a vehicle on a hydraulic ramp and takes his mobile tool cabinet with him. Depending on his installation or repair tasks, he needs to know the correct position of his tools. Our system approach can be adapted for this use case. The car is fixed to the position of a hydraulic ramp and the model data of a vehicle type are also well known as they are necessary for repair instructions. The nearfield localization system is installed around each hydraulic ramp within the garage. Thus, the localization system generates a relation between vehicle, repair location and tool. The mechanic's tools must be registered for each workplace. The display of the WIS is mounted onto the tool cabinet. Only a little computer with a web-browser is needed and can be embedded into the display. A mechanic has nothing to carry in comparison to an AR tablet, which would have to be held between mechanic and vehicle. A next evolutionary step could be a change to AR glasses, but they still need to be developed for further industrial use. During his working steps, the mechanic can have a look onto the WIS. If he changed his position in relation to the vehicle, he takes his tool cabinet and also his personal WIS with him. There is no extra expenditure. This is also true for similar production environments such as assembling large machines.

3.2. Maintenance within a production line

A maintenance worker has got a task to repair a failure within a production line. In order to guide him to the relevant location, which can be the exact position of a small component within the entire production system, a wearable can be used. One innovative example is a glove with add-ons such as barcode scanner or other electronic devices. One product approach to this scenario is addressed by ProGlove [20]. It can be equipped with a transponder of the nearfield localization system. Thus, this wearable respectively its virtual instance is an anchor on the screen of our WIS and easy to recognize by the worker. On the display, the worker sees a 2-D drawing of a production line or a 3-D model of an assembly cell and can be navigated to a failure location. An unconditional requirement is a maintenance system identifying the failure location. One example for such a maintenance system is condition monitoring [18]. The display may be a tablet computer or AR glasses. There are approaches to present web-based applications on these devices [6]. Another option would be a display on a tool cabinet like above-mentioned. Information about repair steps will be added as text or 3-D model. Tools for reparation such as a screwdriver can also be equipped with a transponder and instantly located.

3.3. Manual work within non-visible installation space

This use case should be seen as a possible combination with workplaces in productions lines or garages. One benefit is enabling work out of sight (non-visible range) guided through a virtual image on a screen. A worker often has working steps without direct sight on the parts to assemble (see Fig. 5). One example is clipping cables into place within a vehicle body. When dealing with obstacles in the worker's line-of-sight, a nearfield localization system can find its transponder on the tool or on the worker's wearable and therefore help fulfilling his task. The base stations of the localization system are installed around a workplace in a distributed way. Thus, the possibility to get signals from a transponder within a vehicle body is definitely higher than the direct visibility by a worker. The latter concentrates his view onto the display of the WIS and compares target and actual positions of parts and tools. Transponders on hands respectively gloves and tools are required. Perhaps, this kind of working needs getting used to, but it makes assembling easier. An advantage in comparison to an optical system is the further usage of a nearfield localization system for more tasks such as material flow. An optical system is only installed for one purpose and has also constraints regarding occlusion. If the direct line-of-sight is obstructed between camera and targets on a human body, position recognition is not possible any more. To find a remedy, further sensors such as an inertial navigation are necessary. We have evaluated the Motion Capture System with both optical and inertial targets during virtual validation of assembly scenarios (see Fig. 5). This is called hybrid suit, which a person carries during the Motion Capture session. In a car that is designed as tube frame with missing powertrain and outer body parts, the optical way fails because of occlusion. Using the hybrid suit, we obtain good results and realistic movements of virtual humans [10]. However, this necessitates large expenditures for sensor fusion. Thus, using the hybrid suit is only feasible for assembly planning and virtual validation, but not for real production. For assembly scenarios, we prefer the nearfield localization system based on radar.

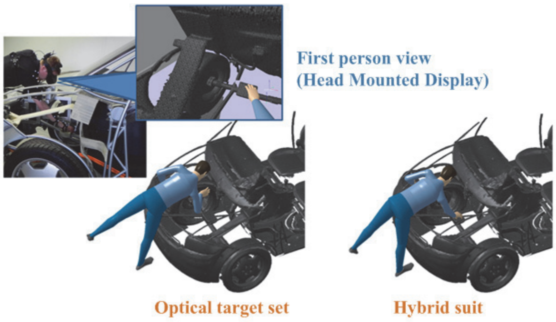

Fig. 5. Occlusion with optical target set leads to wrong position of arm and improvement by using hybrid suit (example from Motion Capturing) [10].

4. Benefits

The benefits of our system integration are shown in the fields of traceability, zero-defect and zero-waste assembly as motivated in chapter 2. There are also benefits within product-specific assembly or maintenance scenarios as described in chapter 3. Error prevention (zero-defect assembly) can be realized by monitoring the actual positioning and, therefore, a correct assignment to screwing locations. Analogous, other manual guided tools in production and maintenance can be located and this leads to a correct assignment of tasks and locations. The demand for quality assurance is high in industry as many commercial approaches are covering this field. Our system integration of nearfield localization and screwing process aims to differentiation of each screw hole.

The demand for a garage information system is exemplarily documented in the MARTA system (Mobile Augmented Reality Technical Assistance) for Volkswagen XL1. We pick up such concepts in our system. Even without AR devices, comparative 3-D representations of real and virtual world are capable supporting employees in mobile workshop with complex tasks such as repair. Worker's cognitive load is reduced due to intuitive usage of a web-based system. The latter has a high recognition value as workers know the graphical user interfaces (GUI) from private applications on end user devices. Workers get a direct feedback from a color-coordinated representation, e. g. green for positive and red for negative issues. However, this coloring refers to 3-D models and is not only applied to pictures or pictograms. As we have the position of worker (digital glove) and the point of view in the virtual 3-D scene, both virtual and real world are synchronized. This is immediately recognizable for a worker.

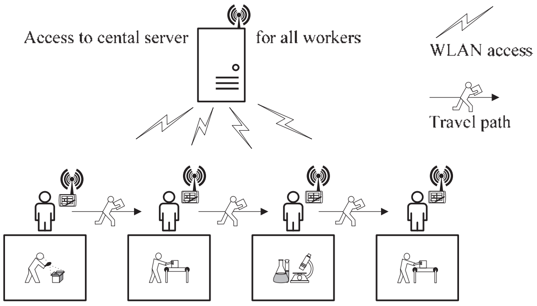

Fig. 6. Avoiding travel paths to a central terminal by substitution with data transfer over WLAN and positioning by radiolocation.

Regarding traceability, the mobility of workers and flexibility in tool usage originate from radiolocation system. It is free from any cables for data or power supply. The worker does not need to concentrate on such a system and is not physically hindered. Instead, the worker's focus does apply to value-added processes. To reach these goals, the electronic for the transponder of the radiolocation system is miniaturized in the project NaLoSysPro. If the WIS is also connected over WLAN, the worker has shorter travel paths (see Fig. 6) due to avoidance of a central terminal.

Time saving depends on the amount of wasted time. This is calculated as the sum of the ways to a wrong location, the action to recognize a mistaken situation and the way back to assembly position. As a worker can be wrong several times there is a distinct multiplier which has to be evaluated concerning the particular use case. Thus, statistics is needed for an exact calculation. This makes sense if an economically decision is required. In this case, the times for each action of a worker have to be determined. Exemplarily, Methods-Time Measurement (MTM) can be applied, but this is not integrated into our system. Mostly, estimation is sufficient as large time savings can be identified. Time saving contributes to zero-waste of working time.

Table 1. Comparison of contribution of our approach considering four use cases.

Use Case	Zero-defect	Traceability	Zero-waste
Manual workplace with screwdriving process	No wrong screw and torque	No missing screw hole	No manual confirmation
Mechanic within garage	No wrong exchange	No missing work steps	No reading of manuals
Maintenance within production line	No wrong repair method	No wrong failure location	Short time for searching
Manual work within non-visible installation space	No wrong parts or installation	Confirmation of target/actual on screen	No tactile search of parts

Difficult accessibility can easily be determined when carrying out maintenance and repair work by knowing the complete product structure. We obtain good experience concerning immersion for workers using Motion Capturing. This leads to our approach of integrating information of the Virtual Reality into maintenance scenarios. The demand for supporting maintenance processes is pointed out by commercial products like Fieldbit Ltd. service platform.

Practical research takes place in the area of screwdriving process and non-visible installation space. Experiments for evaluation of industrial robustness are outstanding. The approaches for a mechanic within garage and maintenance were created as ideas. They base upon studies in industrial experience. Regarding the four use cases of chapter 3, the benefits as responses to the need for action are accentuated in Table 1.

5. Summary and Outlook

This paper introduces a nearfield localization system which enables detecting the position and orientation of assembly tools or assembler's hands more precisely than by using existing localization systems. Thus, live data controlled manual assembly processes are enabled. In combination with worker information systems, such kind of radiolocation enables a more precise and effective assembly as shown within the illustrated use cases.

Use case 1 contributes to following current movements of a worker applying an electrical screwdriver. Quality and safety issues can be addressed by analyzing the resulting data. Use case 2 shows its benefit by eliminating the need of initialization of tools at central terminals since the tool is detectable. A worker can always stay at his workplace and long travel paths are avoided. All necessary information is available on screens next to his working position. In use case 3, the benefit occurs within maintenance tasks. An employee is directly guided to the failure location. In use case 4, it is explained how manual work within non-visible working areas is enabled due to target/actual comparison in a worker information system.

Future research work aims to locate worker's movements for live ergonomic analyses and reducing fatigue. In general, new information models based on assembly processes are to be developed which join manual and hybrid production lines. With regards to content, services deploying this data must be identified and implemented.

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