AUGMENTED REALITY BASED TECHNOLOGIES FOR SUPPORTING ASSEMBLY WORK

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Abstract

This paper presents a methodology and a system for augmented reality aided assembly work. We concentrate in particular on the requirements on information processing and data flow for implementing augmented assembly systems in real life production environments. A pilot case with an augmented assembly task at the Finnish tractor company Valtra is described. The system is emulated with a simplified assembly task, a 3D puzzle, as a demonstrator and as a test-bed to evaluate different means for augmented assembly setups.

The growing number of product variants, shorter life-cycles, smaller lot sizes and accelerated time to market of products has increased demands on production equipment and concepts. In order to master these challenges, innovative approaches and technologies are required. The performance of existing production techniques is often insufficient. As a solution to this problem human integrated approaches are proposed. The idea is to combine human flexibility, intelligence and skills with the advantages of sophisticated Augmented Reality systems. Such systems have many benefits for human workers and enterprises. The 3D puzzle emulates a simplified assembly task in a factory, and is used to study how to implement the augmented assembly system to a real setting in a factory. Preliminary system evaluation results are presented, the user experience is discussed and some direction for future work are given.

Keywords: Augmented reality, assembly work, assembly instruction, CAD/CAM

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1 Introduction

In industrial production, the growing number of product variants, and the need for customized products, shorter life-cycles, smaller lot sizes and accelerated time to market have increased demands on production equipment and concepts. The production companies strive for increasing the performance of production and innovative approaches and technologies are required. One challenge is assembly work that requires skilled manpower to perform work tasks in a specified sequence with careful attention and particular skill [1]. The use of Augmented Reality (AR) has been proposed as a solution to this challenge. The development of AR technology initiated in the 1990's as a parallel technology from Virtual Reality. In Augmented Reality, virtual objects are combined with the user's view of the real world. The augmented view is for example projected to computer screen or a miniature PC, or seen through data glasses. AR systems can combine human flexibility, intelligence and skills with the computing and memory capacity of a computer. Such systems have many benefits for human workers and enterprises, see [2] for a general overview of AR technology.

2 Objectives

One of the main challenges is to the generate concepts for a human worker to operate in complex, short series or in a customized production factory environment. Each individual product may have a slightly different configuration: the order of assembling parts may vary for different products and/or the number of phases in the assembly line may be large. Often the human memory capacity error-prone to handle all the required information.

The traditional approach is to use assembly drawings (blueprints) and possibly instruction manuals to check content of each work task. How to do the assembly work itself is learned by doing with the senior co-worker. The disadvantage is that finding, reading and verifying this assembly information takes time and breaks the actual assembly work. An on site augmented reality system can give the information automatically via a suitable device and the assembly work can be made more fluent and efficient.

The main objectives are to:

- streamline content development from design systems for Augmented Reality system and
- creation a system with a natural user interface and use devices that do not interrupt the actual assembly work, e.g., allow for hand-busy interaction.

3 Methodology

The AR based manufacturing instructions affect different information processing systems of the company in many ways. To implement augmented reality based assembly instructions we see that there should be a novel information processing architecture shown in Fig 1. The majority of the product data is created in design systems and stored to PDM/PLM system. Sales configures and customizes the individual product, the instance, and it is also stored to the PDM/PLM with AR based instructions. The ERP system controls production planning, and assembly server, which manage augmentation to the worker.

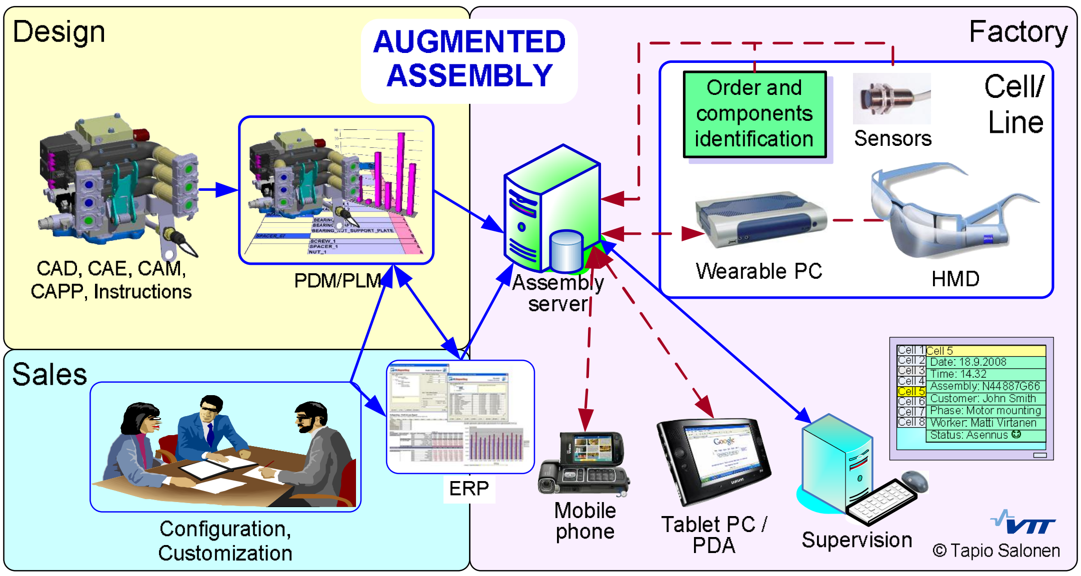

Figure 1 The proposed augmented reality based information processing architecture.

Information integration is one of the key issues in utilization of augmented reality. In order to gather information requirements in design-production interoperability the current information creation process is defined and thereafter possible bottlenecks and deficiencies are described. The enhanced process is developed so that the interactive and augmented assembly is taken into account.

3.1 Marker-based augmented reality technology

The characteristic features of AR systems are [2]]: the combination of real and virtual objects in a real environment; interactivity in real time; and registration (alignment) of real and virtual objects with each other. The computer-generated graphical augmentation is integrated in the user′s view of the real world. This can potentially make tasks easier to perform, since hopefully relevant information is provided at the right position at the right time.

A display, a camera and a computer with AR application are basic components (there are many hardwares to implement this, camera mobile phones, PDAs, laptops, etc). Computer vision techniques are used to find (track) the marker and determine the exact pose of the camera relative to it. Once the position of the real camera is known, a digital 3D-model can then be exactly overlaid on the marker. The users experience a video seethrough augmented reality, seeing the real world through the video camera with virtual models. Figure 2 summarizes the tracking process.

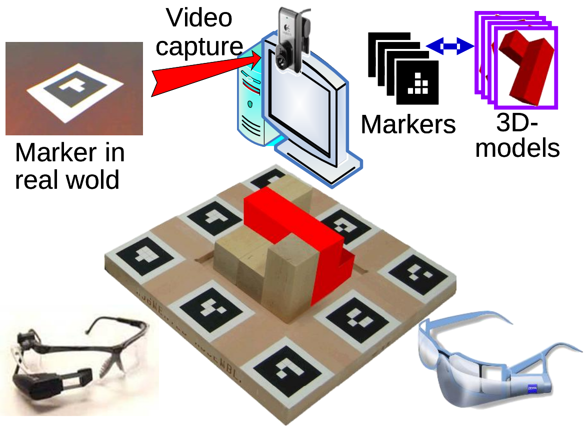

Figure 2 The tracking process description.

The potential of wearable augmented reality has been investigated at the early stages of this research, but the wearable AR systems have often been too heavy and big for industrial use. Wearable AR has been used more successfully for fun application and games [3]. However, the rapid development of mobile devices has lead to small devices with enough processing capacity and long lasting batteries to enable light-weight mobile AR systems. Recently PDAs, camera phones [4, 5] and mini PCs [6] have been successfully used in AR applications. At present, mobile augmented reality was listed as one of the ten most potential technologies in the annual MIT Technology Review [7].

Most human-computer interfaces employ tactile (keyboard and mouse) input and graphical output. Recently, traditional graphical user interfaces have been augmented or redesigned to include natural language, speech, haptic and gestural input. Speech interfaces are natural and prove especially valuable for mobile application where the devices are too small to support efficient and convenient tactile interaction. This is also true for eyes-busy and/or hands-busy interaction where graphical user interfaces with tactile input are disruptive to the user's task.

The assembly work is represented for the system with a XML-file describing the marker board file, the 3D-models and their identifiers (the markers), the work phases and parts which belong to each phase. Every model in the file can be translated, moved and scaled on demand. User starts the assembly work by selecting the corresponding XML-file describing the assembly tasks.

The application recognizes markers through web-camera and computes the orientation and the parts to the head mounted display. At first a marker is pre-filtered so that "individual big swings" will be removed. After this the matrix is filtered either with a Medium or Kalman filter so fluttering will be removed. The filtration always causes a small delay but that is not disturbing.

When a work phase is going on, the application visualises the part which belongs to that work phase and shows the required action.

3.2 Content creation

To apply AR technology generally in real and different production environments, the related product and assembly information should be produced from 3D CAD systems into forms suitable for AR display as automatically as possible; cf. [8]. Besides finding suitable 3D data representations and conversion methods for AR use, automated procedures are required to include the assembly related guidance information (annotations, animations etc.) into the AR visualisations, independently from the user's orientation/view. After analysis of the current information creation (authoring) processes and with the extended product model for augmented reality purposes, new content creation techniques in industrial settings are developed.

Figure 3 shows the methodology how the AR instructions are created from the product's 3D model. From the CAD system the standard STEP [9] format file is created. Because of the designer's preferences, company specific part libraries and features of typical CAD systems the generated product structure usually does not conform to the real parts to be assembled in assembly line. Therefore, the assembly structure (this means the definition of the assembled parts) and work phases have to be re-configured.

The geometry of 3D CAD models is translated into triangles. The exactness of the tessellation should be calibrated according to the needs of visualising the assembly tasks and the capacity of AR system. One of the challenges is also manage the position and orientation of parts from CAD system to AR system. The work phase definition includes for instance work order, used tools, instructions, etc. We are using a design for assembly tool for analyzing the quality of assembly. For example: "Fix the component KZ8884761 with four M8 bolts to the assembly and use the torque 2.4 ± 0.2 Nm. Use the tool number 147. First oil the bolts." At the following stage the visual information required for every work phase will be created. Such are for example the animation of the transition of the component to the right position, appearance of bolts to the right positions in fixing order, tool to be used and its possible movement, texts, numbers and symbols. Finally the assembly work instructions are simulated.

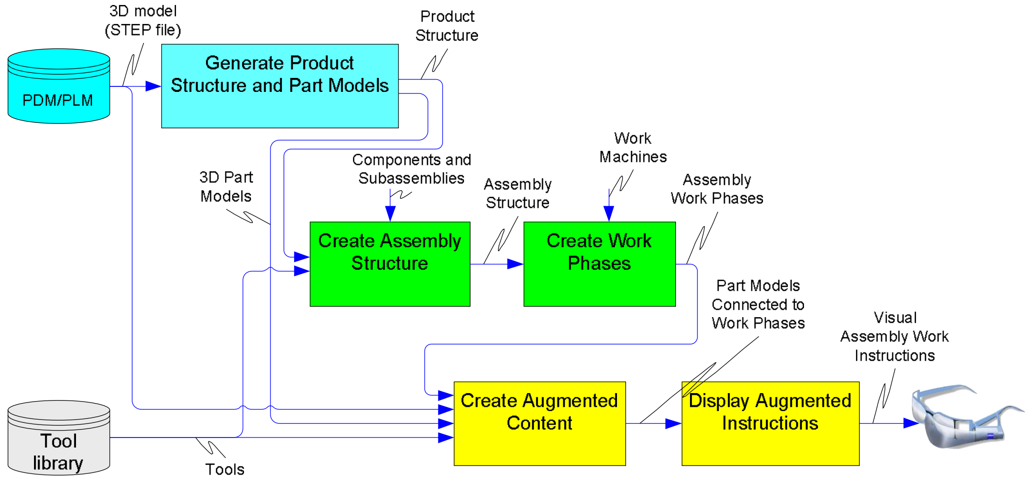

Figure 3 3D data from CAD system to the head mounted display.

4 A 3 D puzzle case study

In the preliminary tests we use a simplified assembly task that simulates a real assembly work (cf. similar previous work by [10]). The task is to put parts in a puzzle box (see Fig. 5). For tracking, we use a modified version of ARToolKit [11] with some additional features and improvements for augmentation; cf. [12].

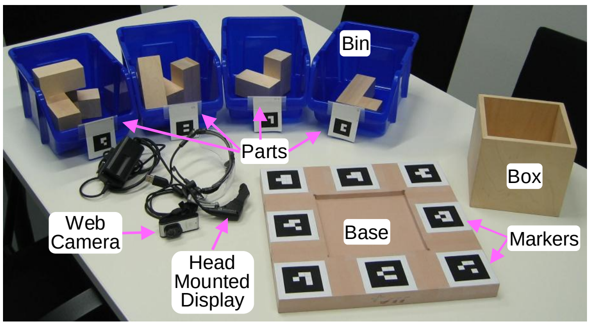

Figure 4 Overview of the demonstration system: the base, parts of assembly in bins and the box containing the parts

The user follows instructions and puts the desired parts piece-by-piece according to augmented instructions at the right place and in the right order (see Fig. 5). The parts fit in only if assembled in the right way and order. For our system development, this task has various advantages compared to real assembly task. First this set-up is cheap, portable and adjustments and changes are easy to make. However, the task is real-enough and the actual devices are used (HDM, camera, etc). With this simplified task we can test the robustness of the augmented system and get valuable feedback for designing the actual factory tasks.

At start-up the user selects the model to assemble (i.e. the correct instruction xml-file). At each phase the system shows by an arrow to the user which part to pick next, and then animates it to the correct position (Fig. 6).

Figure 5 User assembling the 3D puzzle box.

The commands that the user can give to the system are to move forward to the next phase, move backward to the previous phase. In addition to augmented instruction, the system provides user feedback in textual and visual format on the display.

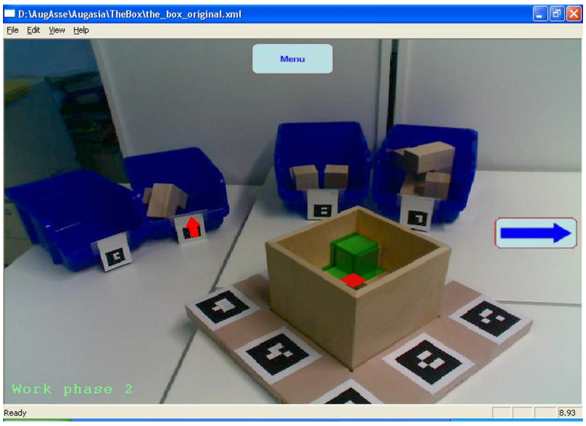

Figure 6 Augmented view: the right arrow indicates that "next phase" control has been acknowledged.

Assembly task is a hand-busy, eye-busy interaction and the use of tactile input, e.g., keyboard, to command and control the application is both unnatural and inefficient [13]. Our experiments also cover evaluating different modalities (keyboard, audio, gesture) and multimodality for user input to enable natural interaction between the user and augmented reality system [14]. We implemented and tested a simple gesture based virtual menu based on skin colour detection and audio commands using a speech recognition system. The test bed system structure allows adding new modalities and test different combinations of modalities if needed.

In the real assembly work the wearable system should be as light weight as possible to enable real work. Currently we use the Micro-Optical PC Viewer display that can be attached to safety glasses (used e.g. at Valtra in any case) to ensure minimum amount of parts/devices to be carried by the user. Lightness was also one criterion for selecting the input modalities; the selected modalities do not require additional equipment (except for small microphone).

The system was evaluated by a small case study (five persons). Their experience of augmented reality varied from none to some and experience of virtual or augmented reality and previous use of data glasses/see-through displays varied.

Some other users than our case study group users tried to solve the same task with printed instructions. For this simple task people who used the printed instructions were able to perform quicker than those using the augmented system. However some users were confused by the printed instructions, especially with the orientation and identity of one puzzle piece. This was not an issue for the augmented system where users were able to turn the base box and reveal the structure of the parts.

All users found the feedback from the system insufficient. They were often unsure whether the system understood their command or not, and if the system really moved to the next work phase.

5 An industrial case study

In an ongoing research project "AugAsse – Increasing efficiency in assembly work with Augmented Reality" 2006-2008, we are focusing on an industrial use case: assembly of a tractor accessory's power unit at the Finnish tractor factory Valtra Plc.

Valtra's production is quite unique wordwide, as all their tractors are custom manufactured according to individual customer orders. In general in the vehicle manufacturing industry, products are made in series and options fitted later. At the Valtra tractor plant, all major components, such as the cab, engine and power train, have the customer's name on them.

Depending on the order, the different tractor components can have up to hundreds of variations. Each and every tractor on the production line has a customer waiting (production capacity is many dozens a day). The final assembly of each tractor is made within one working day, and customers can visit the factory to watch their own tractor being built.

The assembly tasks at Valtra are currently supported by manual assembly drawings and instruction manuals. Any mistakes in the assembly process are expensive and difficult to fix. Because of the customer-order system, providing computer-driven visual assistance to the assembly tasks call for even more sophisticated methods than in the more simple serial production cases.

5.1 Hydraulic block

The CAD model of the finished block, our case study, is shown in Fig. 7, and the corresponding real-life workplace in Fig. 8.

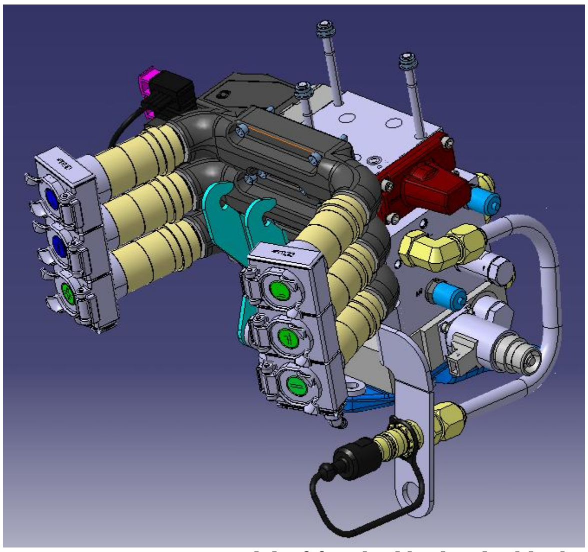

Figure 7 3D CAD model of finished hydraulic block (Courtesy of Valtra Plc).

Figure 8 Industrial pilot case (Courtesy of Valtra Plc). The round plate includes the markers to track the orientation of the hydraulic block.

Assembled parts are shown to the worker task by task according to the work phase instructions (Fig. 9). In the AugAsse project, we consider several alternative approaches both for display devices and tracking. In the simplest setup, the PC monitor (already present at the workplace) could be used for displaying augmented presentations from a static camera view, and markers to track the part's orientation More sophisticated approaches may involve the use of head-mounted displays, tracking the user's head orientation from external camera(s), and e.g. mechanical sensors to track the assembly platform's orientation. Further challenges are: how to provide feedback to the system, and how to integrate flexibly other than geometric information to system (Fig. 10). Altogether, we consider the augmentation part of the system to be quite a big task but still relatively straightforward to implement, while the real challenges are found in streamlining the augmented content from individual customer orders to the workplace.

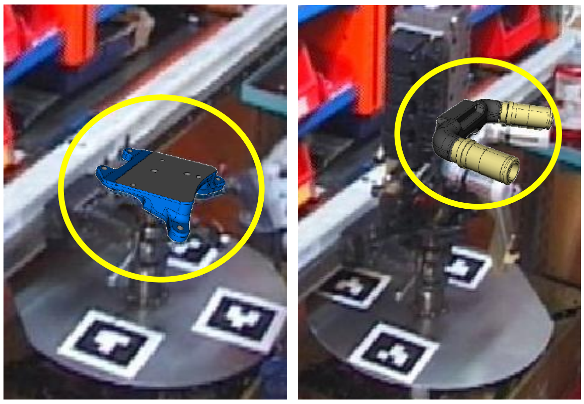

Figure 9 On the left the first part is assembled to the fixture. On the right the real parts are assembled, and the worker is shown the next virtual part.

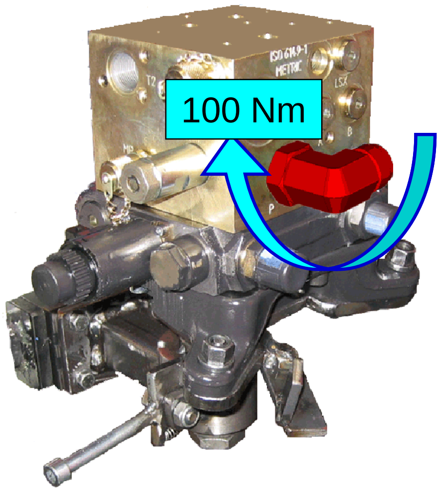

Figure 10 Augmented annotations integrated to the industrial case.

6 Conclusion

Augmented Reality supported assembly work provides a powerful means for the rationalization of manufacturing systems. Important for the usability of AR are appropriate efficient data flow from design systems (PLM), sales support systems and enterprise resource planning systems (ERP). According to our preliminary results our approach of bridging the gap between PLM systems to AR systems seems be a promising one.

Our ultimate goal in future work is to combine product design and assembly; cf. our similar approach for plant model design [15]. This would bring up benefits like consideration of assembly requirements already in product design phase, shifting the information created in design phase to assembly without translation (that is a possible error source), static assembly instructions can be changed dynamic (product changes are to be seen on assembly site real-time) and feedback from tools with sensors that guarantee right setups (e.g. torque moment). The breakthrough of this project shall be to reconcile the requirements of product design and production, especially assembly phase with the help of AR.

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