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Generation of AR-enhanced Assembly Instructions based on Assembly Features

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Abstract

Writing assembly manuals for workers is a tedious and time-consuming task. After discussing some of the challenges in the field of Computer-Aided Assembly Planning, we introduce our approach to alleviate the burden of this task. We use different methods to firstly determine the assembly sequence of a product and second to assign each edge in the graph the appropriate assembly feature. Using a library of animation templates, AR-enhanced instructions are instantiated for each edge and positioned in the real world using the anchoring feature of the HoloLens. Our approach is showcased and evaluated using the Cranfield Assembly Benchmark.

Keywords: Augemented Reality; Cranfield Assembly Benchmark; Assembly Features

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1. Introduction

The assembly process has a great influence in the pricing of a product and represents a majority of the product costs [1,2]. Therefore, the planning of assembly processes is an important factor of success in manufacturing. In the early phase of the planning process, changes can easily be considered, but often faults are going to be recognized only during the implementation or even the execution of the assembling [3]. Changes which are recognized later on in the process are very costly and difficult to correct [4]. These can result from inadequate planning or insufficient human involvement, especially in times of shorter development times, rising demand for flexibility and increasingly complex products [5]. With the help of advanced guiding and planning systems like Augmented Reality (AR)-enhanced applications, failures can be avoided and already rectified in the early stage of the assembly planning process.

The Process Planning is an important act in the production engineering, which describes the ways from the design ideas to the production itself [6]. Kardos et al. [7] describes the field of automated process planning as one of the hardest issues in the area of production engineering, since it has to deal with the design and the production process. Certainly, also the idea of fully automated process planning has its limitations. In order to overcome the mentioned planning issues, a more flexible and intuitive tool can complement the vision of a sophisticated assembly planning technology. The specialty of this investigation is certainly not to generate assembly sequences automatically. It is rather an approach to create assembly instructions faster and more intuitive with the aid of virtual guidance. The ultimate goal of this research topic will it be to develop a highly flexible and particularly intuitive assembly planning tool, which is able to integrate the human and makes use of their expert knowledge. This paper presents an approach in this direction with the aid of AR technology and an advanced assembly strategy.

Based on the wide range of application AR received during the past two decades, a growing amount of scientific attention in the community of manufacturing technologies was roused. [8]. However, there are still issues to overcome even with our technology today. Until this day, there is no precise tool to automatically generate assembly sequences properly. For that

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reason, this concept relies on a human-related approach and its cognitive beneficial knowledge.

2. Assembly Planning

The increasing demand to cover customer requirements more comprehensively and the increasing range of product differentiation means that over the years, manufacturers will be struggling with more and more products and product variants. The rising diversity of variants consequently results in the need of flexibility. However, the increasing number of products and product variants leads to higher costs, higher complexity and higher efforts to coordinate the assembly processes [9,10].

In order to leverage the benefits of flexibility, manufacturers now need to rethink their assembly strategies and procedures. To achieve this target, it requires more agile and adaptable assembly processes. Certainly, the assembly process, in the traditional industrial manufacturing, is a critical process, which is able to claim up to the half of the entire production time and consume over 20% of the total production costs [11,1]. To optimize the manufacturing process, the ideal assembly sequence of the components has to be determined by conducting an assembly sequence plan [12]. Assembly sequence planning affects how cost-effective and fast the final product is going to be build [1].

To simplify this intend within the past years, an automated assembly planning approach was established. The idea of the so called computer-aided assembly planning (CAAP) or also computer-aided assembly process planning (CAAPP) is to generate the optimal assembly sequences by analyzing the disassembly process of the product [1]. Therefore, some assembly features can be extracted automatically from CAD files like STEP by recognizing the necessary features, like geometrical features or form features [13–15].

However, generating assembly sequences underlies technical restrictions and must yet overcome some serious challenges. Leu et al. [1] mentions three major limitations of CAAP systems. The first limitation is the high number of possible assembly sequences for an assembly group. Every additional part in an assembly will lead to an exponential increase of possible assembly sequences, which again will make it more difficult to find an optimal or even a near-optimal assembly sequence [16,1]. Secondly, CAAP is not able to use the expert knowledge of designers or assemblers [17,1,18]. The human has always been an important factor of success in manufacturing, as well as a source of innovation and should not be overlooked. It is exactly that expertise which has to be used to get a successful generation of assembly sequences. The third mentioned reason is the missing interaction with the human himself [1]. Assembly products often have to be assembled by workers and should thus be designed for human handling. Important factors which have to be considered are consequently human-related aspects like ergonomics or accessibility.

Based on the reasons listed above, the CAAP moves away from a pure computer-based approach to a Virtual Reality (VR) or Augmented Realty (AR) based assembly planning approach, which is able to combine the previous automated assembly planning with important human interactions [19,1].

VR and AR technologies are capable to simulate assembly operations and the corresponding interactions. These computer-aided systems are skilled to guide users through visual, auditory or haptic influences and enable an easy way to evaluate the efficiency of the assembly sequences. This kind of evaluation is already possible in the early stages of the developing process, even by the time when no material prototype is available. Based on the unsolved limitations in CAAP mentioned by Leu et al. [1], the approach of a Virtual Assembly Planning becomes increasingly more interesting. Based on Compendex & GEOBASE databases Figure 1 displays the evolutionary steps of the publications in the field of CAAP and virtual assembly simulation in the period from 1972 to 2011 [1]. Thus, CAAP had its peak already before the year 2000, whereas virtual assembly simulation was rising progressively until 2011. Regarding all appearances, it looks like the complex algorithmic approach of CAAP is going to be replaced by the approach of a Virtual Assembly Simulation [1]. Noticeable is also the rising number of publications dealing with enhancements for a more realistic use of virtual technologies, like improvements of a haptic feelings [20] or a better recognition of hand movements [20]. Due to the current market and thus development dynamics of VR and AR devices, the enthusiasm for this technology has also been transferred to the consumer market. This means that high availability, comparatively low costs for such hardware and hence a strong increase in usage can be expected within the coming years.

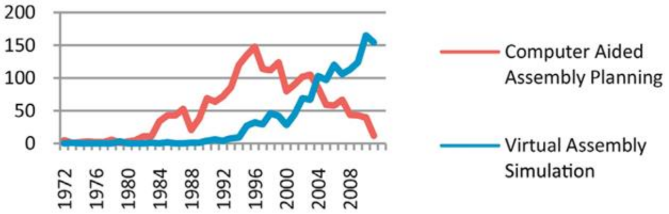

Fig. 1. Past publications of CAAP and Virtual Assembly Simulation [1].

Nevertheless, Virtual Assembly Simulation cannot be considered as a comprehensive solution to CAAP and its drawbacks. The main task of Virtual Assembly Simulation is not to develop assembly sequences autonomously and automatically, it shall specifically help to bridge this gap with a human-related and simulated guidance. The above mentioned findings clarify that traditional approaches do not lead to a universal solution. Through the systematically inclusion of humans and a virtual support, assembly sequences can be generated. However, this must happen in a simple and intuitive way and it need not require a broad prior knowledge.

However, it should also be noted that VR-based approaches often encounter decoupling effects from the real world, according to that they are unable to simulate their environment in the real world adequately [2]. Distinguished from VR systems, the AR technology is able to visualize enhanced artificial information and virtual objects in a real-world environment. As a consequence, it allows the operators to see a known environment with added virtual aspects. This enables the wearer of a AR device to work in his well-known workplace environment which results in an ideal surrounding for AR assembly applications. In contrast to purely virtual environments, which to a certain extent always represent an abstraction, a feeling for the spatial perception, proportions of the objects and the relation to reality is preserved, which simplifies a natural and intuitive interaction. In this way, AR also promises a better transfer of knowledge. [27,28]. As an example, virtual assembly parts can be superimposed over real machine parts to show workers their next steps. In the center of this augmented environment is the human and the vision to reduce costs, shorten the assembly time and increase the operator safety by improving the assembly efficiency. AR has been applied to several areas of industrial assembly applications and becomes more and more popular [1]. The fields of planning manual assembly stations [21], assembly guidance [22] and design of the workplace [23] are of particular importance to the topic of CAAP.

3. Assembly Instructions

The last decade showed massive developments in the field of Assembly Automation. Human-robot Interaction (HRI), sensor-controlled assembly or Cybertronic Systems are just three aspiring technologies to automate assembly operations. Despite these advanced technologies, manual assembly operations will still represent a significant number in the planning of assembly processes. To guide human operators in an assembly process, a corresponding assembly instruction will be necessary. In this case it is crucial for the operator to have an extended knowledge of the components and their assembly sequences in order to perform a successful assembly. Often times, the operator has to switch his attention between the available instructions as paper manual or soft copies and between the actual assembly operations [1]. This switching of attention however can lead to mistakes, due to the double burden of theoretical and practical input for the human workers. Consequently, this may lead to a less efficient assembly process, which is also not very suitable for a process that should be changeable at any time.

Writing assembly manuals for workers is resumed a tedious and time-consuming task. These instructions are basically created manually without any real guidance. So the worker must assign the components by himself and determine his sequence. This procedure can lead to complications, especially with small or very similar parts. But also the use of this manual can be very complex. Particularly the reading or the understanding of the single steps can be very overextending. A concept is needed, which on one hand is able to generate these assembly manuals accurate and easily and on the other hand it must be very intuitive to use. An AR-based approach like ours would therefore be a potential solution to this kind of problem.

With the aid of AR systems, the needed assembly information can be displayed in the right time, in the right place and in a real environment. In best case, the human is going to be supported by an intelligent system, which allows the worker to focus on the actual operation resulting in more efficient and flexible assembly operations.

These benefits of an AR-based assembly approach are able to compensate [1] mentioned drawbacks of traditional CAAP and CAAPP systems. First of all, there is the difficulty of the high number of possible assembly sequences, in which every additional part leads to an exponential increase of its possible assembly sequences [16]. An algorithmic approach, used in traditional CAAP systems, has to deal with every possible assembly sequence available, even if some of them are nonsensical. These systems check upfront every possible assembly sequence, independent from their connectedness of the parts among each other. Thus, these systems also consider unmountable or illogical assembly sequences, if present. Only in the next step it is possible to check which assembly sequences are worth for further investigations and which are not. The difference between a human and computer would therefore be a manual but cognitive efficient preselection of possible assembly sequences by the human. Admittedly, an AR approach is also not able to solve this kind of problem, but they help to deal with it within a certain scope. Based on a more intuitive handling of the parts, the worker can eliminate some assembly sequences manually during the virtual assembly. The second and the third mentioned limitation of CAAP systems are the missing consideration of the human knowledge and the lack of human collaboration in general. Since AR technologies have been built for human use and supported human interaction, this method can be at least more accommodating towards the last two limitations. To summarize, the less extensive algorithmic scope of the AR approach is, the more it is capable to complement traditional computer-aided tactics and to compensate them if necessary.

Early research already proved the effectiveness of AR based assembly instructions decades ago [24]. Compared to physical manuals on paper, the results presented that the operators are able to work much more effectively with advanced instructions from AR systems and also made fewer errors [24,1]. Furthermore, past research also proved that difficult assembly tasks are more suitable with AR based instructions [1,25]. Due to the real-time guidance in the actual workspace it is easier for the operator to focus on the complex tasks and to build on the available instructions.

4. Concept

In the past a vast amount of AR applications have been proposed to teach or assist assembly [2,8,11,22,23,27,28]. The basic process of showing instructions to a user was done several times and there is a good understanding about what cues are needed. Out of our own experience, however, one of the top concerns coming from the industry is the cost and time-consuming task to create new instructions.

One of the key factors to enable AR technologies for assembly guidance is then to determine ‘‘what’’ information should be ‘‘where’’ and also ‘‘when’’ [1]. An appropriate instruction should contain all this key information. As stated earlier we assume that this is a task best executed by a human, in the best case an expert who understands the product. Next thing to consider is that new machine models are developed in CAD. The application should be able to integrate and display these models without much effort [28]. Thus, to bring these CAD data into a form that can be represented as an instruction in an AR application, an intermediate step is proposed. An expert arranges the individual parts of a component using a software on a computer. This process should be easy and almost playful. In this manner, it can be assured that the instructions keep editable for everyone and expertise can be reused and made available to thirds.

After the complete instruction has been created on the PC, it can be forwarded to the actual AR application. In order to enable a flexible use of the application it should be mobile. This includes short setup times for the needed equipment. For a decent implementation of AR in the assembly process a certain understanding of the assembly workspace is required. A common work environment for assembly tasks is a work desk surrounded by small storage boxes containing the individual parts of a product.

Up to this point the instructions contain information of how to assemble parts. But the worker must still know which box contains which component. The next step is therefore to enrich the individual components of a machine with position information. In AR this has traditionally been done with markers that tell the device where parts are relative to the world [27,28]. However, this has the disadvantage that workstations must be specially prepared for these kinds of operations. The Microsoft HoloLens[1] is a AR device which has the ability to build its own map of its surroundings by the use of an advanced depth camera system. Using this and a build-in feature called World Anchors, an application doesn't have to use markers and can still save positions of virtual objects in context of the real world. After this step all information is gathered to assemble a product in another AR application. The primary requirement for interaction in the AR application is to enable workers to assemble machines. The interaction must be intuitive, but limited at the same time, so as not to distract from the didactic context. In addition, some feedback mechanisms should be used that support the user during the assembly and indicate when a work step has been completed [29].

Our approach primarily focuses on a fast and intuitive generation of assembly manuals and a guided and easy understandable application. This results in a better respond to flexible productions and a better involvement of human-related aspects. In this manner, the expertise of the first worker, who is generating the manual with the guidance, can be included in the generation process and passed on to the subsequent worker, which is finally using the system. Furthermore, it has also shown that the worker is not conducting unnatural or complex movements during the teaching of the assembly steps. This is based to the fact that the worker has to conduct the movements by himself during the guided generation of the manuals.

A further feature of this approach is the easy and quick use for trainings, workplace induction and practice. Due to the intuitive handling and the easy understandable visualization the end-user do not need an extensive familiarization or technological background knowledge. Furthermore, our systems run on generally accessible commercial Hardware and is therefrom easy available.

5. Implementation

To implement a first prototype, it was decided to use the Unity 3D engine[2]. The engine is designed for the development of 3D and 2D video games. Right now, this is the preferred way to use the HoloLens as it is officially supported by Microsoft. Additionally, the official HoloToolKit software library was used to speed up development. To evaluate our concept we chose the well-known Cranfield Assembly Benchmark as an assembly example (see Fig. 2). This model provides several basic assembly steps and is also not too complex to display on the HoloLens.

Fig. 2. Photo of the Cranfield Assembly Benchmark used.

For a first prototype, the various proposed software components were implemented. The application parts were named ARAssembly-PC and ARAssembly-HoloLens for easier differentiation. ARAssembly-HoloLens contains both the part to create the instructions and the part to display them. In the main menu of the application one can choose between the corresponding options. The final systematic scheme used for the applications is shown in Fig. 3.

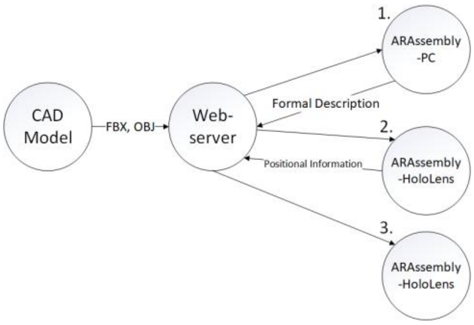

Fig. 3. Simplified systemic presentation of the final prototype.

One of the standard CAD exchange format is STEP. As game engines are not capable of handling CAD formats directly, the STEP file was exported as an FBX object by the free modeling software Blender. A webserver is used to data exchange more convenient. Models and instructions are saved on this server and can be accessed by basic REST calls.

ARAssembly-PC contains various steps to connect to a server, choose a model from the server and then to create the instruction itself. An instruction is composed of steps which in turn consist of parts. As seen in Fig. 4 there is an overview page where the user can create steps and then add assembly parts to them. In the detail view colors and animations can be assigned to each part. For example, a component could have to be plugged on from above and a screw would be animated rotating. He also can write some description for the step that is

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[1] Microsoft HoloLens Website: https://www.microsoft.com/en-us/hololens

[2] Unity 3D Website: https://unity3d.com

then later displayed in AR application. After each part is assigned to a step all the information is stored in a JSON file which is, as well, uploaded to the server and associated to the corresponding model.

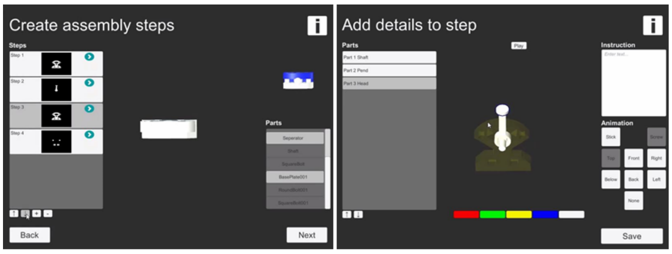

Fig. 4. Screenshots of the ARAssembly-PC application.

In ARAssembly-HoloLens the user can now finish an instruction by adding positional data to it. First the whole model of the product is positioned to where it should be displayed during the assembly (see Fig. 5). This can be done by using a click gesture. After that, each individual virtual part must be set to the storage box containing the real counterpart using gesture clicks. All this information is again added to the JSON instruction file and uploaded. This step must be redone for each new workplace that should be supported, as the positions are unique. Internally the HoloLens will remember the work desk environment and when the positions are later loaded again set the virtual objects accordingly.

Fig. 5. Placing the model and parts in ARAssembly-HoloLens.

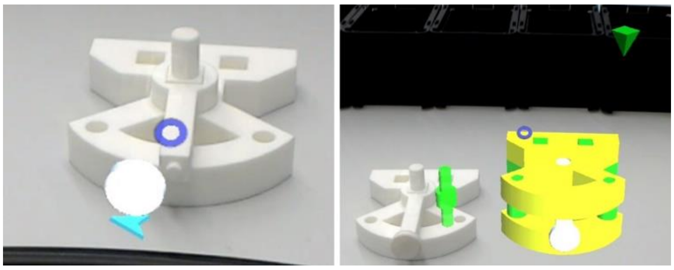

Fig. 6. Animations and Cues displayed during assembly.

Now that the instruction is finished a worker can recall it by again using ARAssembly-HoloLens. All the information gathered earlier in form of the JSON instructions gets loaded from a server and is then displayed in the view of the worker. Alongside a virtual representation of the final product, each part is shown accordingly to the current step with the previously chosen animation. The box containing the appropriate real material is highlighted by a green arrow. The worker can either assemble the product step by step or he can possibly decide to first watch the whole process. The interaction of going to the next step is made available by voice commands, to make sure an overloaded graphical user interface does not distract the user.

6. Conclusion and Future Work

In this paper we discussed the implications of AR technology on the field of CAAP. We presented a human-driven approach for creating instruction sets for assembly tasks and a prototype that is derived from this idea. The aim of the work was also to see what could be possible obstacles to further expansion.

In testing sessions with four expert users, with a background in AR and industrial assembly, we let them go through the whole process of creating an instruction and assemble the final product. We found that there are some technical issues with the HoloLens which needed to be overcome so that the device will actually be applicable for industrial use. The battery right now only supports use up to three hours in one session before it needs to be charged up. One could then either change the device or try to use a power pack for some additional battery time. In its current state, we see the device more fit for training purposes but not for long time use in real assembly environments. The field of view in which you are able to see the augmentations is around 35 degrees. Most of the users we did demonstrations for considered this to be far too less and distracting. Finally, many users complained about the comfort of the device. All these factors indicate that the device is not yet suitable for long-term use.

While testing the application we experienced slight difficulties with the HoloLens anchoring system. Because the device is constantly trying to remap its surroundings, even slight changes to the environment can make the stored positional information obsolete. In addition, the anchors indeed are persistent between uses of the application, but they are deleted when the application receives an update or is reinstalled. This is not practical for use in an industrial, productive environment. For upcoming versions of the software, we are therefore considering using marker based tracking to identify the position of the assembly. Because the HoloLens is mobile, it has limited computing power. For the models we tested so far that wasn`t a problem. Nevertheless, for complicated CAD files this has to be taken into account by decreasing the details of the model by using existing algorithms or by hand.

The first expert evaluations for our approach seem promising, but we have to conclude our findings in more industrial environments with actual users. In the near future, we like to carry out proband tests to compare our AR application to instructions purely shown on desktops. Furthermore, it is shown that even with this relatively lean computer-based approach of creating instructions it still takes too long for more complex products. One of the next steps will be a more semi-automatic approach. Different algorithms have shown promising results in getting assembly information directly from CAD files. We like to enhance our method of complete manually created instructions by making the application itself smarter. Our vision is that the software will be capable of giving the expert a prefilled instruction manual, that the expert just would have to check and make slight corrections.

In our opinion, AR support for assembly tasks will be one of the keys to enable workers to compete in the increasingly complex manufacturing industry of tomorrow, even if today, there are still some technical issues to overcome.

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