Augmented Reality Based Assembly Guidance for Spacecraft Conductive Network

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Huajun Chen[1, a], Gang Sun[2, b], Changyu Chen[3, c] and Bile Wan[4, d]

[1]Science and Technology on Reliability and Environment Engineering Laboratory Beijing Institute of Space Environment Engineering Beijing, China
[2]Division of Product Assurance Beijing Institute of Space Environment Engineering Beijing, China
[3]Division of Spacecraft Integration Technology Beijing Institute of Space Environment Engineering Beijing, China
[4]Division of Human Resources Beijing Institute of Space Environment Engineering Beijing, China

[a]1120840113@hit.edu.cn, [b]13501342722@139.com, [c]chenchangyu_cast@163.com, [d]wannsfc@163.com

Abstract. Conductive network is an important component that affects the electromagnetic compatibility (EMC) of spacecraft. Manual work-based paste and overlap of copper tape is the main installation way of conductive network. Work patterns dominated by human experience have problems of low efficiency, high error rate and high learning cost, which cannot guarantee the operation requirements of speed, quality and precision. In order to solve these problems, the augmented reality (AR) based guidance technology for assembling spacecraft conductive network is proposed. Firstly, the virtual-real fusion method and the guidance information modeling method are studied. Then an AR based guidance system is built with HoloLens and Unity3D, which can help worker paste and overlap copper tape efficiently and verify the superior experience of applying AR technology to conductive network assembly.

1. Introduction

The electromagnetic compatibility (EMC) performance of the equipment is a key factor affecting the quality and life of a spacecraft. In order to achieve the goal of EMC, all electrical performance equipment on the spacecraft must have the same reference potential. Establishment of a conductive network over a spacecraft is the basic method to realize the reference potential. By connecting the network to grounding terminals of all electrical devices, the potential consistency between the devices can be effectively ensured [1].

In existing spacecrafts, the conductive network is usually made up of overlapping copper foil tapes. Due to the high density of spacecraft devices, and tight operating space, the bind and lap of copper tape are all dependent on manual operation. When the conductive copper tape is laid, the bonding position and lap treatment of copper depend on the subjective consciousness of the personnel. Work patterns dominated by human experience have problems of low efficiency, high error rate and high learning cost,

which cannot guarantee the operation requirements of speed, quality and precision. In order to effectively improve the quality of manual operations, it is necessary to enhance the working instruction ability of the manufacturing execution system (MES), enhance the process cognition ability of the operators, and reduce their task information memory burden.

The application of augmented reality (AR) in the conductive network assembly process will provide a new way to solve the above problems. Augmented reality technology blends real-world scenes with both virtual objects and information to help operators understand the various assembly relationships in the scene. As shown in Figure 1, AR simplifies the interpretation of the process rules by the visual and easy-to-understand instructions, responds to the operator's operation intentions in a natural human-computer interaction manner, and reduces the error-prone links of human participation through intelligent means. Therefore, there is great potential in improving the manual assembly work ability of the copper tape.
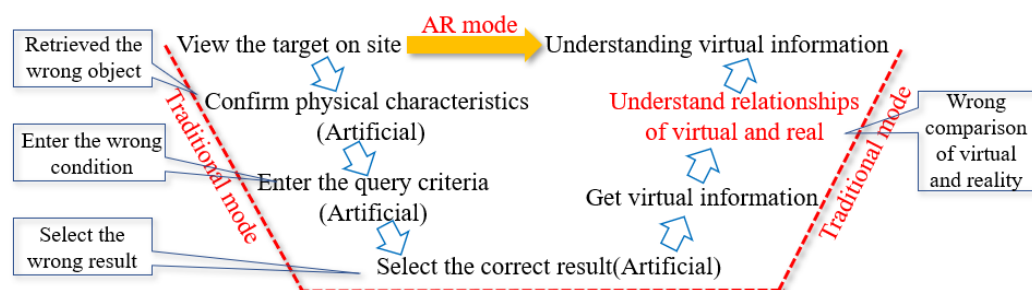
Figure 1. AR helps to understand the scene information.

This paper uses the HoloLens of Microsoft Corp to implement an AR based spacecraft conductive network assembly guidance system, which validates the feasibility of the application of AR technology in this field. The article is organized as follows: firstly, the present situation of the application of augmented reality in the field of manufacturing and assembly is introduced, and then the key technologies needed to realize the enhancement of the conductive network assembly are discussed. Finally, the design method and application effect of this guidance system are presented.

2. Present status of related Application

The AR technology has attracted wide attention in the industry, and the application has deeply promoted its development. Many applications come from Boeing and other aerospace manufacturers, as well as European Space Agency (ESA) and other space agencies. This chapter will sort out the contents and effects of some applications.

In Boeing Co., early in the early 1990s, Tom Caudell proposed the concept of "augmented reality" and applied it to the assembly of electric cables in aircraft manufacturing [2]. The application at that time saved Boeing a lot of space and cost for storing wiring boards. At present, based on customized Google Glasses, the error rate of cable assembly for workers has been reduced by 50%, and the assembly time has been reduced by 25% [3].

European Aeronautic Defense and Space Corporation (EADS) uses the Arvika system [4] to aircraft assembly and repair. The assembly worker can retrieve virtual information by voice. According to guidance information of each step, workers easily complete the high-density wiring work on the board. Many wiring efficiency and quality problem to manufacture is solved.

At AIRBUS Military Co., Servan applied AR technology to the aircraft workshop "Assembly Instruction", which is able to replace the traditional paper process documents [5]. Furthermore, the MOON (Assembly Oriented Authoring Augmented Reality) project was built to take use of Industrial Digital Mock-Up (iDMU) in AR system, which made assembly of A400M a successful case. The MOON system structure is shown in Figure 2.
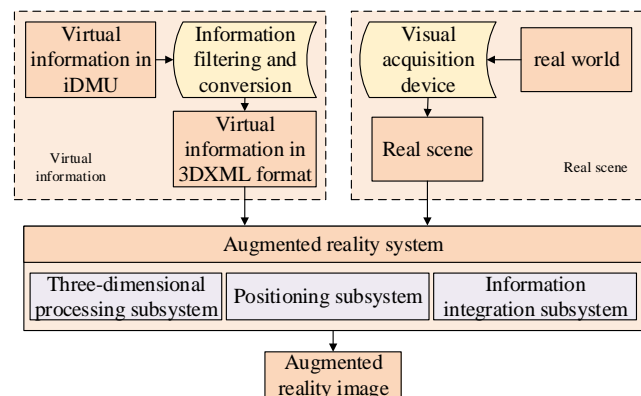
Figure 2. MOON Functional Scheme [5].

ESA uses AR technology to provide precise assembly operation information for astronauts of the International Space Station (ISS). Through the EdcAR project, a general architecture and workflow of AR application for space task is defined. The workflow covers the whole process from the definition of spatial engineering data to the application of AR. The project confirmed the key technologies of AR system supporting spatial mission and defines the solution architecture and system design method of the system. In this project, three representative use cases were implemented for proof-of-concept of augmented reality [6], [7], [8].

National Aeronautics and Space Administration (NASA) and Microsoft Co. collaborated on the Sidekick project. Astronaut Scott Kelly used the HoloLens on the ISS for space station operation and maintenance [9]. NASA's Grubb and his team created a collaborative augmented reality environment where users can assemble spacecraft with head-up, gesture control, pre-defined parts and virtual tools.

At Bavarian Motor Works (BMW), Stefan Werrlich evaluated the assembly task process through a HoloLens based assembly guidance application, and proposed usability evaluation and programming guidelines for AR applications. It uses 3D animation information to indicate fastener locations of cable, tube, and screw. While search time was saved, picking errors ware also avoided. It also provides a single backward fading learning method that allows detection and judgment of worker operation [10].

In addition, some companies, including Volkswagen, PTC, and General Electric, have achieved remarkable results in the research and application of augmented reality assembly.

3. Key technologies for ar based assembly

The AR based assembly process guidance includes four key technologies, such as 3D part registration, camera calibration and tracking positioning, virtual-real fusion, assembly real-time spatial modeling. The general framework of the virtual-reality fusion scene construction is shown in Figure 3.
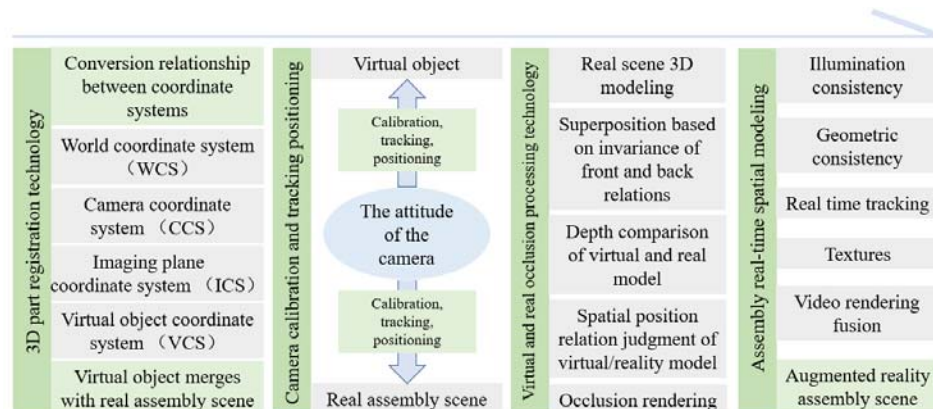
**Figure 3.** The construction framework of the augmented reality scene [11].

In this paper, 3D part registration is solved by using Vuforia, which is provided by PTC Co., and is able to recognize pattern as mark of 3D part in space; camera calibration and tracking positioning is original function of HoloLens, which is easy to apply in any AR program; virtual and real occlusion processing is realized by application built on Unity3D and HoloLens APIs; assembly real-time spatial modeling is realized according to real conductive network operation.

In this section, the methods for virtual-real fusion and virtual assembly information modeling are discussed.

3.1. Virtual-real Fusion

HoloLens provides function of tracking and positioning, which is based on Simultaneous Localization and Mapping (SLAM) technology. It can quickly establish the scene model through scanning, and then track and identify the scene features. By recognizing scene image changes in the camera, HoloLens can inversely calculate its position and posture in the scene [12]. In our method, HoloLens SLAM is used to scan and mold assembly working environment. The 3D environment mold is then downloaded and imported into Unity3D for processing, and the feature planes such as the ground and the spacecraft deck can be identified. A "virtual anchor" can be fixed to a certain position in the 3D environment, which is bound to virtual information such as assembly part. When HoloLens maps this virtual environment to the real world, virtual information can be also submitted to the real world through its "virtual anchor".

The Unity3D application can store assembly guidance information in HoloLens and display the information in real time. The information flow is shown as Figure 4. By Light-guided Transparent Holographic Lenses (Waveguides), LCos (Silicon Liquid Crystal) projection technology, and tracking and positioning function, the virtual assembly guidance information are accurately integrated into the real assembly scene.
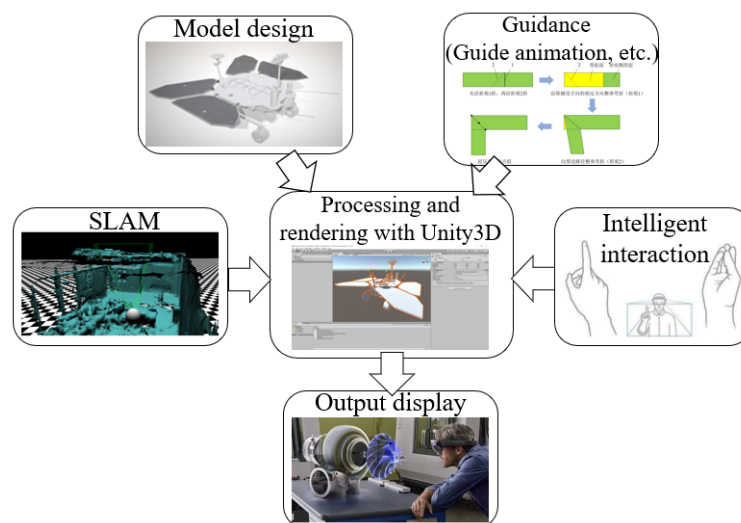
Figure 4. Unity-based visualization method.

3.2. Virtual Assembly Information Modeling

The process of creating AR based assembly instruction is shown as Figure 5. In the "Product design" phase, 3D model of conductive network generated form software such as CATIA and Creo. In the "Model adjustment" phase, the 3D model is processed to form a lightweight model and output by software such as 3DMAX and Maya. In the "Assembly planning and analysis" phase, Lightweight model is integrated with assembly orders, instructions, and tools. In the "Create Content" phase, the visual enhanced assembly instructions were created using the software Unity3D, and finally deployed to HoloLens.
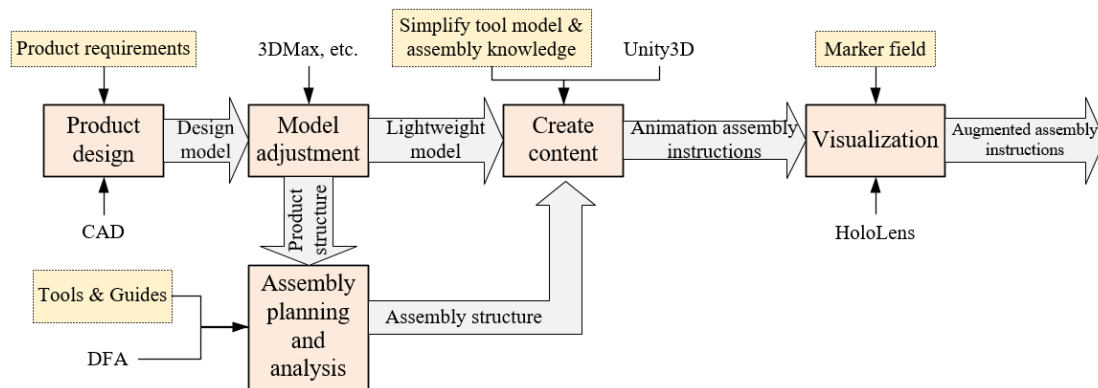
Figure 5. AR assembly instruction creation process [13].

Creation of AR based visualization process requires necessary information for assembly guidance included in the digital model. The design of the visual assembly guiding process is the basis for enhancing the realization of the assembly guiding technology. Aiming at the large-volume customization requirements of the virtual and solid fusion guiding process of the spacecraft conductive network assembly process, the structural assembly process documents of the corresponding format are output according to the corresponding standards, replacing the current process definition mode based on text description and process drawing. In the information storage process, various assembly process information is stored in a structured and object-oriented manner.

In above process, model-based Model Based Definition (MBD) approach is required. MBD can express product definition information and process information in an integrated 3D model, which ensures accuracy and continuity of design data. By the way, the readability of the process documents can also be improved. By using MBD technology, data sharing and reuse between upstream and downstream of manufacturing links can be realized. It helps to realize the data transfer between the three-dimensional design model of spacecraft and the augmented reality assembly guidance model [13].

4. Ar based conductive networks assembly

A typical operational process of copper tape paste based on HoloLens is shown as Figure 6. Its basic functions include: (1) After the operator wears HoloLens, the system displays quality and safety requirements. (2) The system marks path of the copper tape on decks with virtual-real fusion. (3) The system reminds operator to clean the surface of the deck before paste. (4) The system guides the operator to paste the copper tape along the path and make overlapping according illustrations as shown in figure 7. (5) The system guides the operator to check the pasting position. (6) The system prompts the operator to perform grounding resistance measurement. (7) The operator completes the execution record signing in the system.
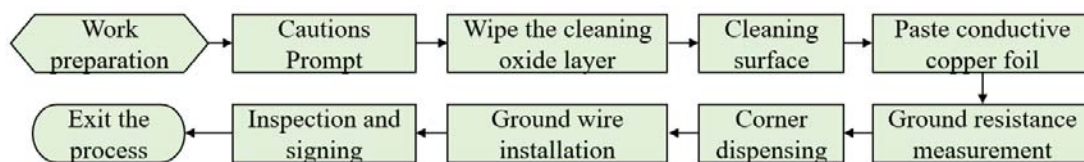

Figure 6. General procedure for copper tape pasting guide.
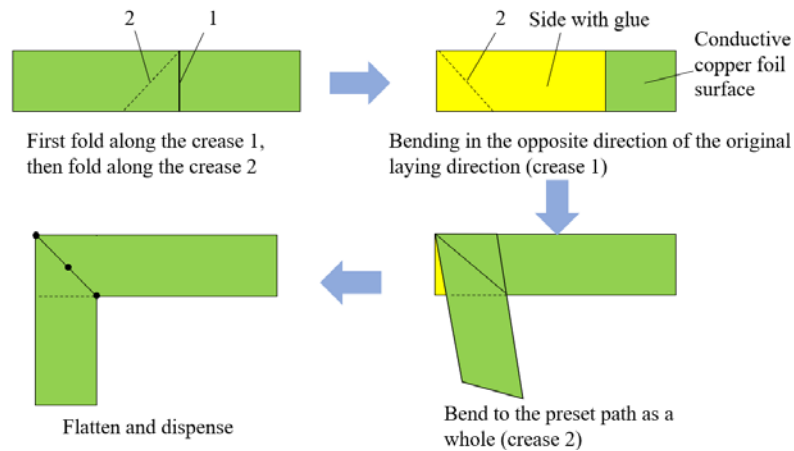
Figure 7. Schematic animation of copper tape overlapped at right angles.

As shown in Figure 8, the system performs a virtual and reality fusion effect diagram for guiding the copper tape of the top plate of a certain type of spacecraft. In the display interface of the HoloLens, the yellow highlighting indicates the position of the copper tape pasting, and the adaptive information indicates the material type and operation procedure of the copper tape pasting process through the text information.
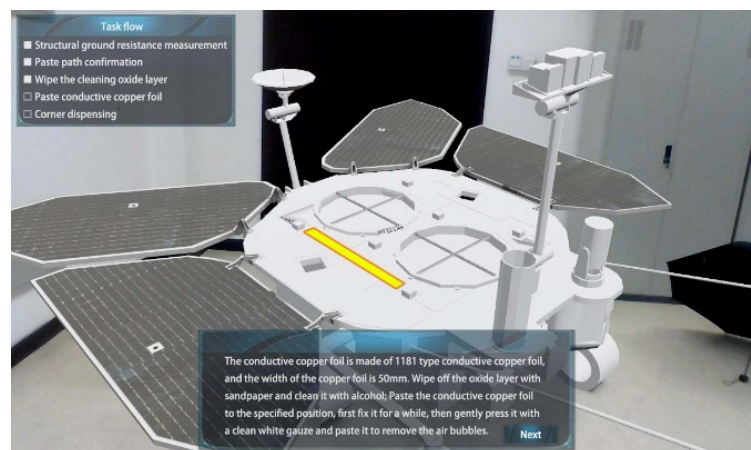
Figure 8. Conductive networks assembly guide with AR.

During the manual assembly operation, the operator obtains the necessary process guidance information in real time through this visualization method, which avoids the difficulty in traditional process access method, process execution and heavy memory burden. Therefore, the workload of the operator is greatly reduced, and the judgment and execution efficiency of the operator are improved.

5. Conclusion
In this paper, AR based guidance technology for conductive network of spacecraft are proposed. The technology utilizes the virtual-reality fusion feature of AR, which can effectively solve the problems of heavy process understanding and execution burden and many operational errors in the traditional manual operation process, and improve the accuracy, quality and efficiency of manual assembly work.

Current AR system still has limitations, including a time-consuming creative process, insufficient integration with process data, and a lack of user interface and interaction. In the future, we should also strengthen research on emotional perception and other aspects to further improve the efficiency of human-computer interaction.

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