Augmented Reality Based Visualization Method for Spacecraft Cable Assembly Process

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Abstract. At present, the spacecraft cable assemble process has problems such as inconvenient process reading and great difficulty for process understanding. Based on the advantages of augmented reality technology, this paper proposes a visualization method for spacecraft cable assembly process to solve these problems. Firstly, the tracking method based on Vuforia and SLAM technology is used to improve the accuracy of registration while expanding the tracking range. Secondly, this paper adjusts and lightweights the spacecrafts design model, uses Unity3D to create visual guidance, and then deploys the prototype system to HoloLens. Finally, verifies the application in the cable assembly process of a certain type of spacecraft, which proves the advantage of the method based on the augmented reality.

1. Introduction
Cables are important components for transmitting current and electrical signals in spacecraft systems. The number and installation paths of cables of different spacecraft vary greatly, and the assembly position is narrow and the operating conditions are complicated. Therefore, the assembly of spacecraft cables is currently heavily dependent on manual work. In order to complete the cable assembly process, the operator first needs to obtain the required information from drawings or 3D models distributed across multiple files. (including cable net structure, cable assembly path, associated cable bracket and hole location, electrical connector number, and required redundancy length at the end of the cable branch, etc.) Then the assembly position confirmation, lashing and adjustment work is carried out in the spacecraft cabin. At present, the cable technology information is displayed through the kanban system, which has problems such as low work efficiency, high probability of error, and high learning cost. It is mainly reflected in the inconvenient process reading method, difficulty in understanding and memory, etc. Therefore, it puts high demands on the operator's experience judgment ability and memory [1].

The augmented reality-based visualization method combines real-life scenarios with virtual process information. It automatically matches the cable assembly process information with the real physical environment, helping the operator understand the various assembly relationships on site [2]. Therefore, it is possible to reduce the effort of the person to move the body and the line of sight between the kanban and the operating station; It simplifies the operator's interpretation of the process specification through visual and easy-to-understand instructions, which can significantly reduce the burden on the operator under complex working conditions, and improve the operation accuracy and prevent operational errors.
The augmented reality system responds to the user’s operation intention in a natural human-computer interaction manner, and improves the efficiency of the two-handed collaborative work. The comparison between the traditional mode and the augmented reality process visualization mode is shown in Figure 1.

![Figure 1. Comparison of AR mode and traditional mode in cable assembly applications.](image)

Research on augmented reality in cable assembly has received widespread attention and successful cases. Boeing applies AR technology to the connection of power cables and the assembly of connectors in aircraft manufacturing. Therefore, Boeing has saved a lot of space and cost for storing wiring boards, but it is limited by the technology at the time, and it has problems such as cumbersome equipment, poor timeliness, and high creation cost [3]. The European Aeronautic Defense and Space Corporation (EADS) uses the Arvika system to assemble and repair aircraft and cars. The assembler can call the virtual information by voice and perform high-density wiring work efficiently according to the prompt of each step [4]. Airbus applied the MiRA augmented reality system to cable assembly and inspection of the A400M aircraft. The system enables operators to perform tasks precisely, including the installation of hundreds of kilometers of cable and tens of thousands of connectors [5]. In the assembly operation of wind turbine hub cables, General Electric relied on the visual guidance of smart AR glasses to connect hundreds of cables to the corresponding interfaces, increasing productivity by 34%.

At present, the development of augmented reality applications for cable assembly does not have a fixed technical route, the application objects and implementation goals are different, and new difficulties arise due to different assembly environments, process steps, and quality requirements. Based on the current situation of domestic spacecraft cable assembly, this paper studies the visualization method of cable technology based on augmented reality. Then, a prototype system was developed in Microsoft HoloLens, and the application was verified in the actual spacecraft cable assembly process.

2. Tracking and registration method for spacecraft virtual model

The traditional tracking and registration method based on mark recognition has low computational cost and high accuracy of virtual and real registration. However, it is necessary to keep the complete mark within the visible range of the camera throughout the tracking process. As an improved method, this paper uses the combined method of Vuforia mark and SLAM technology, firstly using HoloLens' RGB-D camera scanning working environment to reconstruct the 3D model of the scene. The camera pose is then tracked by matching the feature points of the current frame image to the global feature point cloud. The results of the mark recognition and location will be passed to the SLAM system. The virtual 3D model is then anchored in the real scene space by visual SLAM techniques. This approach avoids the tracking process requiring markers to be continuously visible, thus extending the tracking range and providing better robustness and accuracy.
PTC's Vuforia is a standalone library. Vuforia uses image feature recognition and matching algorithms to match the image captured by the camera to the reference image, as shown in Figure 2.

![Figure 2. Mark recognition and location based on Vuforia.](image)

The predefined position of the virtual image target must be consistent with the actual mark pasting position to ensure the accuracy of registration. At the same time, the height and width parameters of the target are set to the actual measured size of the image to maintain the geometrical consistency. The geometric consistency setting method is shown in Figure 3(a)(b)(c).

![Figure 3. Virtual and real geometric consistency settings and registration results.](image)

At initialization, the camera captures a continuous image containing preset mark. On the one hand, the system recognizes the image features of the mark and uses it as a unique identifier for different objects, and then searches its information in the target database to obtain a reference to its associated instance; On the other hand, the system uses the correspondence between the image feature points and the target feature points to determine the spatial pose of the mark, and then renders the content to a
fixed spatial position. The results of the registration are shown in Figure 3(d). These steps generally includes:

1) Vuforia's target tracker identifies the target;
2) Initialize target tracking;
3) Estimating the target pose in the scene;
4) Vuforia submits the pose data of the target to the SLAM coordinate space of HoloLens;
5) HoloLens takes over tracking and disables the Vuforia tracker.

3. Visualization method of assembly process

The process of creating an AR assembly instruction from a spacecraft 3D model is shown in Figure 4[6]. CAD systems are required in the “product design” phase: CATIA V5 from Dassault Systemes, Creo from PTC, etc. In the "model adjustment" phase, tools such as PiXYZ Software need to be used to lighten the design model and output it in a corresponding format, which will effectively reduce the graphics rendering pressure of AR device. In the "Assembly Planning and Analysis" phase, refer to the cable assembly process specification and other documents, add tools, instructions and assembly structures, and design for assembly (DFA). In the "Content Creation" phase, visual assembly instructions are created using the software Unity3D. It is then released as a UWP project and finally deployed to HoloLens.

3.1. Model reconstruction and lightweight

The spacecraft design model is usually built by the overall department in CAD software. Making adjustments based on the design model avoids refactoring the model in Unity3D, which can reduce the amount of programming preparation time. In order to transform the overall design model into a visual process model, there is a problem that the product structure tree does not meet the application requirements, the model format is incompatible, and the rendering pressure on the hardware is too large. The existing design model needs to be adjusted and lightened. The visual digital prototype is constructed by reconstructing the BOM without changing the product assembly relationship. The process is shown in Figure 5.
Figure 5. Spacecraft digital prototype reconstruction process.

Model lightweighting generally uses a layer-by-layer compression simplification method, as shown in Figure 6. Under the premise of not affecting the complete expression of the process, the model is reconstructed with simple geometric data to obtain a lightweight PBOM. Then the encoding compression method is used to further reduce the required storage space and ensure the security of the data.

Figure 6. General process of model lightweighting.
3.2. Visual process guidance information creation

For the process requirements of the spacecraft cable assembly process, the process data needs to be bound to the 3D model of the digital prototype to establish an association map between the non-geometric information and the geometric model. The three-dimensional process design method is used to realize the definition of the visualization effect required for the process guidance, and the process data is correctly mapped to the visual form [7]. The three-dimensional process guidance information is distributed to the frontline operator's field of vision through a visual interface of virtual and real fusion. The main process information includes: cable assembly path, cable electrical connector port number, cable port device number, cable bracket and nylon base, text description of other process requirements [8].

Display of the cable assembly path: The code of the cable to be assembled is retrieved in the model structure tree by the GameObject.Find() method. In Unity3D, the model's Renderer component is used to display it separately in the operator's field of view. The accurate model tracking registration ensures that the cable virtual model always shows the location to be assembled. At the same time, obtain the name of the cable electrical connector port in the model and its coordinate position, and then assign the parameters to the 3D text prefab in the scene. The visual effect of the cable assembly guide is shown in Figure 7.

4. Application verification

The general flow of augmented reality spacecraft cable manual assembly operations is shown in Figure 8. In the preparation phase, the operator wears HoloLens, scans the assembly environment, and the spatial mapping system automatically generates a dense SLAM map of the scene. After entering the assembly guidance system, the camera scans the markers attached to the spacecraft deck and the system anchors the corresponding virtual model in space. The user performs the corresponding assembly work according to the guidance information. During the assembly process, the user receives the guidance information in the process sequence or actively queries the cable information to be assembled. After the assembly is completed, the inspector can perform the assembly and error detection. The inspector compares the assembled component information through an additional augmented reality display system or monitoring screen to check whether the assembly positions of the assembly objects in the real scene are correct.

![Figure 8. Cable assembly operation flow.](image-url)
A cable assembly application for a spacecraft service cabin based on augmented reality is shown in Figure 9. According to the results of the recording of the cable assembly process, it can be known that by using the augmented reality process visualization method, the assembly time of a single cabin is shortened from a predetermined seven days to four days. This method effectively improves work efficiency by more than 40%.

**Figure 9.** Cable Assembly Application Scenario Based on Augmented Reality.

5. Conclusion
In this paper, the visualization method of spacecraft cable assembly process based on augmented reality is studied, which effectively solves the problems of inconvenient process reading and large error probability in the current spacecraft cable assembly process. The model tracking registration method based on the Vuforia logo and SLAM technology can ensure that the mobile virtual registration deviation is within 5 cm. Utilizing the overall design model adjustment and lightweight method, the application can be quickly changed and released, and it can adapt to the spacecraft assembly task with fast-paced and multi-change. Then, according to the cable process requirements, visual three-dimensional process guidance information, including cable orientation, electrical connector number, nylon base, etc., is created to effectively improve the readability and execution efficiency of the process information. Finally, the application of the cable assembly of a spacecraft service cabin is verified, which proves that the cable assembly efficiency is improved by more than 40% based on the method of this paper.

References
[1] Gang S, Wangmin Y, Weibing D, et al. Analysis and Consideration of Process Optimization of Spacecraft Assembly Process [J]. Spacecraft Environmental Engineering, 2008, 25(4): 8+89-91.
[2] Chi X. Research on virtual and real fusion technology of enhanced assembly system [D]. Huazhong University of Science and Technology, 2007.
[3] Information on http://www.po.tue.nl/homepages/mrauterb/presentations/HCI-historyAsld09.htm
[4] Friedrich W. ARVIKA — Augmented Reality for Development, Production and Service [C]// Dare 2000 on Designing Augmented Reality Environments. ACM, 2000:151-152.
[5] SERVÁN J, MAS F, MENÉNDEZ J L, et al. Using augmented reality in AIRBUS A400M shop floor assembly work instructions [J]. American Institute of Physics, 2012,1431(1):633-640.
[6] Salonen T, Saaski J, Woodward C, et al. Data pipeline from CAD to AR based assembly instructions [J]. Proceedings of the ASME/AFM world conference on innovative virtual reality, 2009:165-168.
[7] Werrlich S, Lorber C, Notni G, et al. Design Recommendations for HMD-based Assembly Training Tasks [C]// SmartObjects: Sixth Workshop on Interacting with Smart Objects. 2018.
[8] Falin W, Yu G, Shanshan Z. Assembly System Construction and Its Key Techniques of Cable Harness under Virtual and Real Scene Fusion for Complex Mechatronic Products [J]. Journal of Graphics, 2018