Inspection Method for Satellite Grounding Network based on 3D model

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Abstract. This paper reviews the traditional grounding network inspection method based on 2D drawings in assembly and integration process of satellite. Due to the huge difference between different satellites grounding network, the symmetry of the satellite structure and the similarity of the deck structure, the grounding network assembly and inspection is error-prone. An effective and accurate grounding network assembly information transmission method from designers to inspectors is designed, the dedicated 3D model and 2D catalogue are created, and the AR technology is used to check the integrity and continuity of the grounding network. The successful application of this method provides a new solution for satellite grounding network inspection.

1. Introduction

Overall assembly is one of the main stages of satellite development. According to the statistics of the Russian space department, the final assembly work accounts for 35% of the total satellite processing volume. The total assembly quality will directly affect the overall performance of the satellite[1]. The satellite grounding network makes the instruments on the satellite and the whole structure equipotential, which is important to ensure electromagnetic compatibility. The satellite structural board is made of carbon fibre material to reduce the structural weight, but the carbon fibre structural board has poor conductivity with respect to the aluminium skinned structure board. In order to ensure the good grounding of the equipment of satellite, it is necessary to arrange the grounding network on the structure. The components of the satellite grounding network mainly include the conductive copper foil, the instrument grounding wire, and the deck grounding wire. Due to the huge difference between different satellites grounding network, the symmetry of the satellite structure and the similarity of the deck structure, the grounding network assembly and inspection is error-prone. As the satellite design changes from the traditional 2D mode to 3D digital mode, the operators and inspectors at the satellite assembly plant need to obtain the required information from 3D design model, which is complicated to use on desktop computers. The inspectors perform the inspection in the cabin with the memory of the grounding network information, and needs to constantly switch the viewing angle between the display screen and the satellite due to the poor openness of the satellite cabin. The disadvantage of this type of method is that the relevant design information is manually matched to the real physical environment. Work efficiency is reduced significantly because inspectors have to bear a lot of additional cognitive burden to confirm the correctness of grounding network assembly.

Lu yi studied the degradation mechanism of the grounding performance of satellite’s copper foil[2], and many enterprises have researched the assembly and inspection method based on augmented reality.
in the field of complex mechanical assembly\cite{3-4}, but cannot meet the needs of satellite single-piece production and unable to systematically solve the problem of automatic grounding network assembly information transmission from designers to inspectors based on 3D model. In order to improve efficiency and quality of satellite grounding network inspection, we designed an effective and accurate grounding network assembly information transmission method from designers to inspectors. This method based on AR technology automatically matches the grounding network information with the real physical environment, and guides the inspectors to check the integrity and continuity of the grounding network.

## 2. Inspection Method for Satellite Grounding Network

The components of the satellite grounding network mainly include the conductive copper foil and ground wire, while ground wire is composed of instrument ground wire and deck ground wire. The conductive copper foil currently used is a tape made of a copper strip with single sided back-coated conductive polypropylene glue. This conductive adhesive is a pressure sensitive adhesive with uniformly distributed conductive particles. One end of the ground wire is soldered with a square conductive copper foil, and the square conducive copper foil is pasted on the copper foil strip. The process of conductive copper foil installation and inspection in AIT process of satellite is showed in Figure 1, the diagram of conductive copper foil assembly is showed in Figure 2. Copper foil strip installation which contains assembly on deck and cross-cabin is completed before ground wire installation; Copper foil strip installation of deck is completed before cross-cabin. The check of installation location and path and the ground resistance measurement is performed after grounding network installation.

### Figure 1. Process of Grounding Network Installation and Inspection

![Diagram](image1.png)

### Figure 2. Diagram of Conductive Copper Foil Assembly

![Diagram](image2.png)

As the satellite design changes from the traditional 2D mode to the 3D digital mode, the satellite assembly and inspection also enters the 3D mode. In the process of grounding network inspection, inspector needs to frequently confirm grounding network status back and forth between satellite and computer stations. The current 3D model based on desktop computer has poor human-computer interaction, so new technology is needed to improve grounding network inspection efficiency.

## 3. Augmented Reality

Compared with Virtual Reality technology, Augmented Reality technology can not only see virtual scenes, but also superimposes virtual scenes in real scenes by calculating operator position and perspective in real time. The Microsoft HoloLens\cite{5-6} was released as a development edition in 2016 and is now available as a consumer version. The Google Glass was marketed as an AR device, however it is merely a transparent display lacking many necessary features, such as spatial mapping and a usable display, to interact with the real world and provide true AR capabilities. The Daqri Smart Helmet was designed for industrial use but is currently still in development. Therefore, the Microsoft HoloLens is the ideal choice for investigating an AR assembly application.

The decision to use the HoloLens to investigate an AR assembly application on a HMD is strengthened by its’ state of the art capabilities. Unlike AR HMDs in the past, the Microsoft HoloLens is a completely self-contained HMD, i.e, it does not require the HMD to be tethered to a separate device.
computing device. The HoloLens features four Intel Atom x5-Z8100 1.04 GHz Intel Airmont Logical Processors, a HPU/GPU Holographic Processing Unit, 64 GB Flash, 2 GB RAM and 2-3 hours of active battery life that allows standalone operation of this device. All of this processing power is used to run 2 HD 16:9 light engines that project light through holographic lenses leading to a total resolution of 2.3 million light points. High resolution spatially located 3D content is generated by this system. The HoloLens also consists of an Inertial Measurement Unit (IMU), 4 environment-processing cameras, an RGB camera, and 1 depth camera to map its surroundings and allow interaction between the real and virtual world while tracking the device’s position. Other features include 4 microphones, gaze tracking, gesture input, spatial sound and voice support. The HoloLens is shown in Figure 3 below.

Figure 3. The Microsoft HoloLens

4. The Process of Satellite Grounding Network Inspection Based on 3D Model
A grounding network inspection method based on AR technology is designed to improve efficiency and quality of satellite grounding network inspection, the flow chart of the method is showed in Figure 4. Compared with the traditional method, this method automatically matches the grounding network with the real physical environment, and guides the inspectors to complete inspection.

![Figure 4. Process of Satellite Grounding Network Inspection](image)

4.1. Dedicated 3D Model Generation
While inspecting the grounding network of a satellite, the inspector need to know the starting and ending position of the conductive copper network, paste avoidance location, detailed dimensions on the deck, and the cross-cabin position. As the satellite design changes from the traditional 2D mode to the 3D digital mode, the 3D digital mode of a satellite contains much information, such as structural, cable, instrument and thermal control unit. It is necessary to simplify the data by creating a dedicated 3D model which removed unused component parts. Dedicated 3D model without cabin structure can be used in AR inspection system to inspect the integrity and continuity of the conductive copper foil. The annotation information of the grounding network which is created in the deck model is hidden in the cabin model by default, the parameter of “visible_annotaions_scope” in ProE option settings can changed from “active model only” to “all” in order to display the annotation information directly in the cabin model, this model is easy to view on computer or pad.

4.2. 2D Catalogue Generation
Since the 3D model requires a computer to be turned on, it is not convenient to use a fixed computer for on-site inspection. Therefore, it is necessary to create a 2D catalogue of the grounding network which contains detail size information to facilitate on-site implementation and inspection. The 2D catalogue is comprised of 2*N pages while N represents the number of structural decks, each page contains a 2D map of the copper conductive tapes of the 2 sides of the deck. The deck name, deck code and coordinate direction is displayed at the same time.
4.3. 3D Registration
The three-dimensional registration technology mainly realizes the correct fusion of virtual grounding network and real assembly scenes through the conversion between coordinate systems. Accurate 3D registration of virtual and real scenes is a key technical problem to be solved in the real-time fusion of grounding network, to accurately register the virtual assembly object in the corresponding position in the real environment, the conversion relationship between the virtual space and the real space coordinate system must be established in the grounding network inspection system. In this grounding network inspection system based on AR technology, 2D QR codes which can be recognized very quickly are pasted on satellite deck structure and used in 3D registration.

4.4. Fusion and Display of 3D models and objects
The grounding network inspection system based on AR technology was developed by Unity3D, Vuforia and the Microsoft HoloLens. Unity3D is an excellent development tool for the Microsoft HoloLens. To achieve higher precision, the embedded Vuforia system was used to perform marker based tracking. After 3D registration, the HoloLens can properly track position as the user moves around in the assembly area using its IMU and environment processing cameras. An assembly application with a user friendly UI has been built to improve the user experience.

5. The Typical Case of Application of Grounding Network Inspection Method
The new grounding network inspection method is tested during the AIT process of a remote sensing satellite in the paper. Remote sensing satellite comprises service module and payload module, dedicated 3D model of grounding network were built. Simplification of dedicated 3D model of the service module is showed in Figure 5 and Figure 6, the outer deck structure and all devices are deleted, dedicated 3D model of the service module is showed in Figure 7 and Figure 8, the annotation information of the grounding network is created in the deck model, and displayed directly in the cabin model by change parameters in ProE option settings. Dedicated 3D model of the service module without cabin structure which is showed in Figure 8 can be used in AR inspection system, and 2D catalogue of copper foil paste location is also needed while checking the detailed size. The copper foil paste location of one deck of a satellite is showed in Figure 9, and the coordinate direction is displayed at the same time.
As is showed in Figure 10, the 2D QR code is printed on paper and pasted on the satellite deck structure where is easy to determine the location. The inspector must first wear Microsoft HoloLens before grounding network inspection and use the gesture to enter the corresponding module of the remote sensing satellite, secondly, scan 2D QR code in the satellite deck structure to complete 3D registration, and then select grounding network module from the UI interface. The process of this system is very simple, and the grounding network information is clear at a glance, thereby greatly improving the visibility of the 3D model. Figure 11 and Figure 12 shows a typical case of application in a satellite grounding network inspection, the conductive copper foil, instrument grounding wire, deck grounding wire and nylon base on the structure is displayed in the real assembly scenes. The integrity and continuity of the conductive copper foil is easy to check, furthermore, the nylon base mounting nail opening on the conductive copper foil is also easy to find. With the help of the
grounding network inspection system based on AR technology, the efficiency of inspection in one module of a remote sensing satellite can be increased by 200%, and there will be no missed detections.

6. Conclusion
The satellite grounding network is important to ensure electromagnetic compatibility of satellite. As the satellite design changes from the traditional 2D mode to 3D digital mode, an effective and accurate grounding network assembly information transmission method from designers to inspectors is designed. The dedicated 3D model and 2D catalogue are created, and the AR technology is used to check the integrity and continuity of the grounding network. The successful application of this method provides a new solution for satellite grounding network inspection and marks a new step in the digital assembly capacity.

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