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Architecture and Key Techniques of Augmented Reality Maintenance Guiding System for Civil Aircrafts

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Abstract. Augmented reality technology is introduced into the maintenance related field for strengthened information in real-world scenarios through integration of virtual assistant maintenance information with real-world scenarios. This can lower the difficulty of maintenance, reduce maintenance errors, and improve the maintenance efficiency and quality of civil aviation crews. Architecture of augmented reality virtual maintenance guiding system is proposed on the basis of introducing the definition of augmented reality and analyzing the characteristics of augmented reality virtual maintenance. Key techniques involved, such as standardization and organization of maintenance data, 3D registration, modeling of maintenance guidance information and virtual maintenance man-machine interaction, are elaborated emphatically, and solutions are given.

1. Introduction

Civil aircrafts are highly technology-intensive large-scale electromechanical systems with extremely complex structures. In the traditional aircraft maintenance and repairs process, maintenance personnel often need to consult technical and maintenance manuals or rely on personal skills and experience. Therefore, work efficiency is low, and significant manpower and material resources are consumed. Moreover, because of temporal, conditional and environmental constraints, maintenance cost is difficult to control, and maintenance related errors and maintenance quality problems are highly likely. With the development of digital mockup and virtual reality technologies[1], virtual maintenance technology has offered an opportunity for changing the maintenance mode of aircrafts. Augmented reality (AR) technology is developed on the basis of virtual reality technology, which generates virtual objects that do not exist in the real environment by utilizing computer graphics and visualization technologies and accurately "places" these virtual objects in the real environment via sensor technology. With the help of display device, the AR technology integrates virtual objects into real environment to presents users with a new environment with realistic sensory effects[2-3]. Introduction of AR technology into the maintenance related field can improve the maintenance personnel's perception of information about real-world environment, thereby enhancing maintenance capability and reducing maintenance costs and time[4].

2. Characteristics of AR virtual maintenance

AR maintenance guiding system superimposes various computer-generated virtual assistant maintenance information such as graphics, images, videos and texts in real time to the sight of maintenance personnel through AR technology[5]. Integration of real maintenance scenario with virtual information enhances the scenes observed by the maintenance personnel and generates a rich aircraft maintenance information cognition platform to help the maintenance personnel complete their repair work step by step and achieve "WYSIWYG" maintenance guidance. AR-based virtual maintenance not only avoids the tedious work of building complex real environment, but also has authentic and interactive characteristics[6].

- Authenticity: Different from virtual reality where the users and the actual surrounding environment are isolated[7], in AR, maintenance personnel utilize AR tracking devices such as head-mounted display (HMD)[8], and during the maintenance, real scene images are sent to the server, and detailed aircraft technical and maintenance manuals are displayed in 3D graphics through computation. Virtual information is mapped in real time to the real-world scenarios to achieve scene augmentation or expansion on the maintenance personnel's vision system, in order to strengthen the users' perception and experience, thereby increasing the amount of information and level of understanding of human perception on the real scenarios
- Interactivity: AR maintenance guiding system allows natural interaction between maintenance personnel and virtuality-reality combined scenes[9]. The platform provides natural, humane feedbacks to maintenance personnel's various behaviours according to the relevant data of participants such as gesture, voice and eye movements. It also delivers valuable information to maintenance personnel through real-time interaction. When the user's location in the real world changes, the virtual information also changes accordingly.

3. Architecture of AR virtual maintenance system

The architecture of AR maintenance guiding system created for aircraft maintenance guidance and simulation is shown in Figure 1.

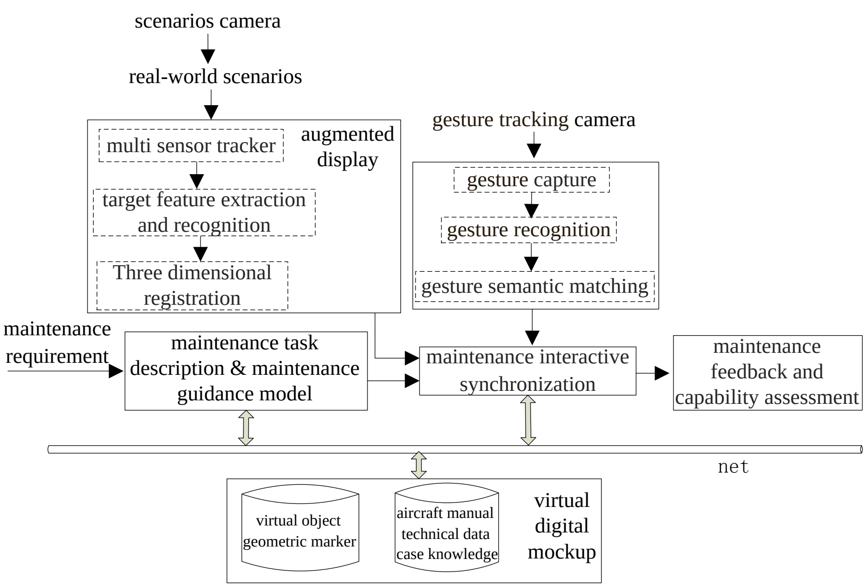

Figure 1. Architecture of AR aircraft maintenance guiding system

The maintenance guiding system consists mainly of five parts.

- Maintenance-oriented virtual digital mockup is the digital product model built using computer technology, which includes computer models for aircraft maintenance object, maintenance tool, maintenance environment, etc. To improve the modeling efficiency and the quality of models, geometry and assembly data of aircrafts can be acquired on the basis of aircraft design department's CAD, PDM models, which are converted or secondarily developed to the information model available for the AR maintenance guiding system. Meanwhile, on the basis of aircraft reliability system, data like aircraft maintenance resources and technical maintenance requirements are acquired to form spatial, temporal and DOF constraints that can support the entire virtual maintenance process.

- To allow the maintenance personnel to perceive changes in the status of surrounding scenarios and maintenance objects, the augmented display module automatically tracks targets such as maintenance objects, maintenance tools and personnel gestures in real-time with tracking devices like camera. It also computes the position and angle information between the tracking device and targets; calculates the precise position of targets in the real scene; determines relevant digital maintenance guidance information; and seamlessly synthesizes the guidance information with real-world scenarios and displays them in real time on the optical see-through HMD based on the line-of-sight and voice commands using 3D registration display technology to present maintenance personnel with a new environment with realistic sensory effects.
- Maintenance task & guidance information module analyzes the maintenance task demands and reorganizes the virtual maintenance assistant information. Maintenance task description model within the module abstractly describes the actual maintenance job process based on the job card and other maintenance requirements. Maintenance task is hierarchically decomposed from top to bottom to give a number of control levels and flow chart of interrelated, mutually restraint maintenance actions varying in level of details. Maintenance guidance model primarily considers how to reorganize and synchronize videos, audios, images, texts, logos and other maintenance assistant information based on the maintenance personnel's maintenance operation process, so that they can be reproduced in accordance with the characteristic virtual-real combination, real-time interaction and 3D registration requirements of the AR system.
- Man-machine interaction module constructs a sight, voice and gesture multi-mode guiding platform, where two interaction-related issues need to be addressed. On one hand, implementation of human interaction with virtual and real scenes not only emphasizes the visual sensory interaction, but also includes behavioral interactions such as language, posture or gesture interactions, so that the maintenance assistant information in the virtual scene are fed back in real time based on the human interactions with real maintenance scenes, state changes, etc. On the other hand, synergy between the two interactions needs to be resolved. The entire system can be maintained by responding to the input information and managing the output information.
- Maintenance feedback & evaluation module provides an objective, accurate evaluation system, which assesses the maintenance capability of maintenance personnel according to the actual operations. Besides, the module analyzes the barriers and difficulty of maintenance and finds defects in the maintenance plans based on the qualitative and quantitative data obtained from the maintenance simulations, which provides maintenance personnel with workable solutions for trying and comparing multiple complex maintenance actions and support plans to find better resource allocation option and the best maintenance scheme.

Based on the above five modules, maintenance guiding system can provide maintenance personnel with an environment for maintenance guidance and assessment where virtual information guidance and real object operation are synchronously integrated. To implement this prototype system, many techniques need to be broken through[10] of which 3D registration, modeling of maintenance guidance information and virtual maintenance man-machine interaction are the key ones to implementing AR virtual maintenance platform.

4. Key techniques of AR maintenance guiding system

4.1. 3D registration technique

AR virtual maintenance guiding system tries to achieve "seamless connection" between the maintenance scenes and virtual information as far as possible. The process of implementing "alignment" and spatial unification between real-world scenes and virtual objects is referred to as the 3D registration display. Generally, two types of registrations are completed with HMD device: 1) registration of wearer's head, i.e. identification of the spatial location of wearer's head and gazing direction; 2) registration of virtual objects, i.e. location of virtual objects in the real space.

In the aircraft maintenance guiding application field, maintenance personnel must be able to see the real world. Besides, human eyes' field of view should be large and intuitive perception is required to be high. Matching precision between virtual objects and real scenes should at least be within the millimeter level, as large registration error will undermine maintenance personnel's correct perception of their surroundings. According to the maintenance and inspection characteristics of aircraft system, natural feature-based registration tracking technique is adopted for implementation of virtual-real fusion, thereby providing maintenance personnel with a maintenance guidance environment with synchronously integrated virtual information guidance and real object operation.

The natural feature-based registration tracking technique is not limited by scene changes. Its specific method is as shown in Figure 2. Firstly, 3 DOF head attitude parameters of maintenance personnel are detected in real time by the sensor, and their gazing direction is calculated. Meanwhile, real scene images are captured through the camera, and natural feature points (such as points and lines that can reflect the shape of objects and pixels that can reflect the texture of objects) are extracted using the machine vision technology. Feature information acquired by the sensor and visual tracking are fused and filtered, thereby estimating the camera pose information to obtain the target objects needing augmented information display. Based on the priori knowledge on scenes stored previously in the database, virtual object database is queried according to the presently identified target information to obtain virtual augmented information (including texts, images, 3D prototype disassembly & assembly processes, etc.) that match with real scenes. Afterwards, spatial coordinates of the virtual camera are adjusted, so that they coincide with the spatial coordinates of camera captured real scenes. Finally, the virtual-real synthesized images consistent in direction with the maintenance personnel's line of sight are output to the optical see-through HMD to achieve the AR effect.

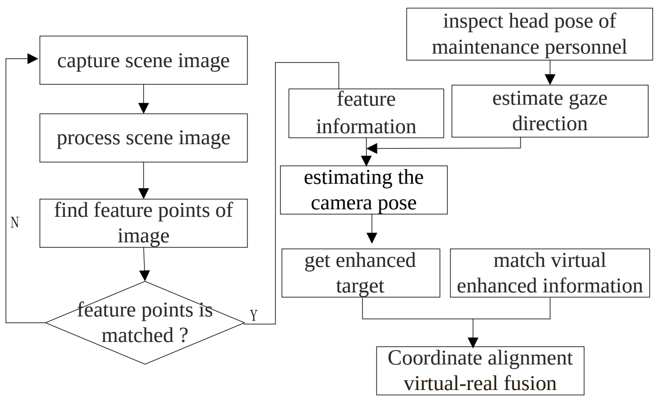

Figure 2. Schematic diagram of natural feature-based registration tracking technique

4.2. Maintenance data standardization technique

AR maintenance guiding information are from aircraft maintenance manuals, catalogs, design department's existing prototype data, etc., which are characterized by different sources and diverse types. To display these information in the augmented scenarios, research on standardization and storage of maintenance information is needed.

Maintenance information standardization primarily studies the extraction of maintenance material from existing aviation maintenance technical manuals (AMM, IPC, EBOM etc.) or other relevant documents; conversion of file formats; and addition of necessary information for generating information data in the forms of audios, videos, images and texts that conform to the requirements of maintenance guiding system, in order to ensure the correct understanding and application of guidance model.

Maintenance information storage technique constructs the data description and storage-retrieval relationship utilizable by the entire system. Through the maintenance relational database, various types of maintenance assistance information are linked together. For example, to organize disassembly and assembly information for typical parts, specific part removal procedure is obtained from the aircraft maintenance manual (AMM) firstly, then corresponding part numbers and their assembly relationship information are acquired via the EBOM. Next, corresponding virtual prototype data are acquired through the part numbers, and removal procedures for corresponding parts are obtained via the illustrated parts catalog (IPC) to form a complete set of disassembly information storage mechanism within the computer, in order to support the implementation of AR maintenance guiding system.

Maintenance storage needs to consider the expandability, scalability and flexibility of the system. Data organizational structures are relatively independent of each other, with weak coupling. When part of the information data is updated, the maintenance guidance information can be granularly changed.

4.3. Maintenance guidance information modeling technique

Maintenance guidance is a process of maintenance information reproduction and interpretive execution. As shown in Figure 3, maintenance guidance information modeling requires creation of model to solve the maintenance task analysis and maintenance job guidance problems[11].

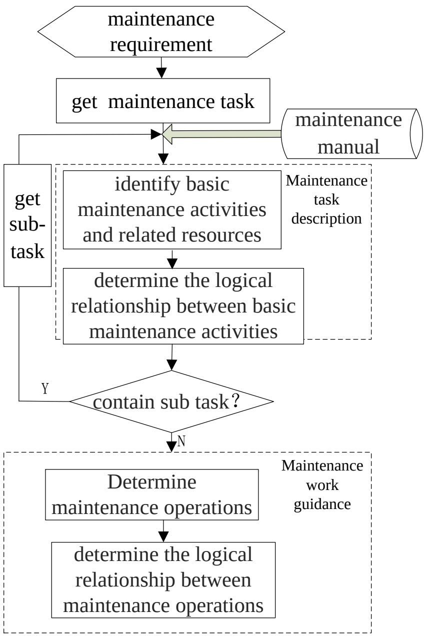

Figure 3. Maintenance guidance modelling procedure

Maintenance task description model focuses on the relationship between maintenance actions, as well as analysis of sequence. A maintenance task can be regarded to comprise a number of maintenance actions, such as preparation, diagnosis, replacement (removal, replacement, installation), adjustment & calibration, maintenance, inspection and original repair. From the perspective of job cards and other maintenance requirements, maintenance tasks are decomposed layer by layer into several actions from top to bottom by consulting the maintenance manuals. Interactive relationship between the maintenance actions is analyzed, as well as resource changes. Maintenance action objects are interconnected into a sequential process. For relatively complex maintenance actions, maintenance work is described using a hierarchical model. Each sub-task is analyzed to determine their respective attributes, behaviors and links to other sub-tasks.

Maintenance work guidance model, on the other hand, emphasizes the relationship between maintenance operations and analysis of sequence. Each maintenance task or action can be completed by specific sequential maintenance operations. Specific maintenance operation is the most essential behavioral unit that cannot be further decomposed. For maintenance actions already decomposed in the maintenance tasks, Maintenance work guidance models are established to expand specific maintenance operation details and therblig unit decomposition. Meanwhile, the models analyze the interactive relationship between maintenance operations and changes in resources then interconnect the maintenance operations into a sequential process. To present the complex operational process, model with conflicting, cyclic and parallel structure is needed, in order to resolve the conflicts between and synchronization of various media information.

4.4. AR virtual maintenance human-computer interaction technique

Real-time natural human-computer interaction can ensure the smoothness of maintenance guidance process. To guide the maintenance "invisibly" and reduce the cognitive load of maintenance personnel, two interaction related issues, i.e. scene interaction and interaction coordination, need to be addressed. Human interaction with virtual + real scenes by sight, voice and gesture multi-modes can achieve good human-computer interaction effect. Among them, gesture interaction is the most natural and intuitive mode. Techniques like machine learning are applied to train large amounts of humanoid image data. In the actual maintenance, human postures or gestures are recognized and tracked. Human postures are recognized by estimating changes in the position of human skeleton and joint points. Semantics of these postures are preset by the user to achieve interaction by controlling virtual objects with simple gestures and body movements.

Interaction coordination is responsible for coordinated control over the maintenance guidance process, which links the specific maintenance actions, maintenance guidance information and AR virtual prototype together, while handling the possible conflicts between various modules. the maintenance guidance procedure is as follows: on the basis of maintenance task description and maintenance work guidance models, personnel –centred maintenance instructions are presented one by one progressively according to the information needs of maintenance personnel with status information as the "drive". Fixation point coordinates are obtained based on gestures, voice commands or eye gaze tracking system, while pose information of objects is acquired by extracting the features of operational objectives in the present scene images combined with digital prototype identification. For the identified targets, appropriate augmentation information is matched from the virtual prototype database for conversion and rendering. Fused display of virtual and real information is completed using AR registration algorithm. Synchronous integration of virtual information guidance with real object operation is achieved.

5. Conclusion

AR maintenance guiding system can complete the assistant maintenance implementation, maintenance guidance and assessment by utilizing 3D registration, image recognition, guide information modeling and human-computer interaction technologies to achieve image acquisition, stereoscopic display and virtual-real fusion functions. AR has obvious advantages in lowering the maintenance difficulty, reducing maintenance errors, and solving the problems of insufficient maintenance staff and massive technical data. With the deepening of research and development of technology, application of AR in civil aircraft maintenance is bound to gradually move towards practicality, which has great significance for optimizing the existing aircraft maintenance mode and bringing new development to the traditional aircraft maintenance industry.

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