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Design and implementation of CT installation, commissioning and maintenance virtual simulation teaching software based on job capacity training

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Abstract: Computed Tomography (CT) is a crucial imaging modality in clinical practice. As medical facilities continue to update, there is an increasing demand for CT equipment in primary medical institutions. This demand necessitates a large number of technically skilled personnel to carry out maintenance and repairs. The Intelligent Medical Equipment Technology major equips students with the technical expertise required for handling intelligent medical equipment installation, commissioning, operation, maintenance, quality assurance (QA), and medical asset management. The installation, commissioning, clinical operation, maintenance, and QA of CT equipment require staff to possess core knowledge and skills. However, there are issues with insufficient training and lack of effective practical training. To address these issues, a virtual simulation software has been developed that integrates teaching demonstration, independent learning, job training, and assessment for CT installation, commissioning, and maintenance. The purpose of the software is to address the "three highs and three difficulties" problems related to vocational education courses and practical training. The software can be applied to the teaching and assessment of CT practical training in the specialty of Intelligent Medical Equipment Technology and related majors. It is designed to meet the national demand for high-end medical equipment technology personnel.

Keywords: CT; virtual simulation teaching software; intelligent medical equipment technology major; job capacity training

1. Introduction

Computed Tomography (CT) is a crucial imaging modality in clinical practice owing to its widespread availability, high spatial resolution, short examination time, and affordable costs[1]. Currently, with the rapid implementation of healthcare reform and the digital transformation and upgrading of hospitals at the grassroots level, provinces and cities across the country are actively renewing basic medical facilities. As a result, there has been a significant increase in demand for CTs in primary medical institutions. As of the end of 2021, China has over 65,000 CTs at all levels of medical facilities [2]. It is known that the parameters have an important impact on the performance of a CT scanner, so during the CT installation, application, maintenance process ,it is required to carry out quality assurance to ensure the stability, reliability and safety of the equipment. Therefore, there is an urgent need for a large number of CT personnel who are proficient in the installation, commissioning, application, maintenance, and quality assurance (QA) to ensure the high-quality operation of CT scanners.

The major in Intelligent Medical Equipment Technology is tailored to the intersection of the biomedical and medical equipment industries. This training prepares students with the technical expertise necessary for engaging in intelligent medical equipment installation and commissioning, operation and maintenance, quality testing, and medical asset management. The installation and commissioning, clinical operation, maintenance, and quality assurance of CT devices are the core responsibilities of this specialty. Therefore, during the training process, a focus on cultivating the core job competencies is essential.

2. The significance of simulation teaching software development

The installation, commissioning, and maintenance of a CT are intricate processes involving numerous steps. In traditional teaching methods that rely primarily on textbooks, multimedia resources, videos, and limited hospital internships, it is challenging for teachers to effectively demonstrate these intricate processes. CT-related programs and courses often utilize CT simulation machines without x-ray tubes or second-hand CT devices for maintenance and disassembly practices. The high cost and bulky nature of CT simulation machines make it challenging for schools to acquire a sufficient number of them. Additionally, the repeated disassembly and installation of CT devices during practicing cannot be avoided, leading to increased wear and tear on the equipment and increased consumption. Furthermore, the limited availability of devices results in limited opportunities for students to gain practical experience, which compromises the quality of their training. Therefore, there is a pressing need to establish a practical training approach that aligns with real-world scenarios and workflows, enables students to safely practice repeatedly, and eases assessment and evaluation by teachers.

Virtual simulation technology, due to its multi-sensory, immersive, interactive, and conceptualization capabilities, is widely utilized in vocational education to train and enhance students' skill levels. It can address the challenges of practical training, internships, and other vocational education issues. However, the current CT virtual simulation software available on the market is primarily geared towards medical imaging technology majors, focusing on CT equipment introductions and operational skills training. There is a significant lack of simulation software for CT equipment installation and commissioning, clinical operation, maintenance, QA, and other job capacity training. It is imperative to develop virtual simulation teaching software that is tailored to the needs of CT engineers and other related positions. This software should incorporate installation methods and processes, calibration techniques, maintenance procedures, common failures, their causes, and solutions. This approach will provide students with more opportunities to practice and allow teachers to offer targeted guidance based on students' practical training experiences.

3. Methods

3.1. Software designs

To simulate CT installation, commissioning, clinical operation, maintenance, and QA processes, we conducted an in-depth analysis of real-world work tasks and scenarios. We replicated work scenes, refined workflows, and developed a software design plan based on these scenarios and processes. To conduct simulations, we opted for a 64-row spiral CT, which is widely utilized in municipal hospitals in China. Each component of the CT room, CT system, main components, and key circuit boards have been meticulously replicated in 3D. The simulation software offers comprehensive interactivity, allowing students to manipulate components in 360° freedom, visualize the device's operational process in real-time, and receive prompts to guide them through the process, thereby enhancing their comprehension and mastery of the subject matter.

3.2. Implementation pathways

3.2.1. Job competency analysis and software module design

Through our research with industry professionals, we have gained a comprehensive understanding of the essential competencies required for installation, commissioning, clinical application, maintenance, and QA of CT. These competency requirements include a solid knowledge of the equipment's structure and principles, mastery of operational specifications, proficiency in maintenance and quality control procedures, as well as the ability to troubleshoot common issues. Additionally, candidates must demonstrate the ability to operate CT according to established standards and possess the skills to install, maintain, and ensure the quality of CT devices.

According to the job tasks discussed earlier, we have designed six software modules to cover CT structure and layout display, clinical operation, component display and disassembly & assembly module, image quality calibration, common failure analysis and troubleshooting, as well as practical assessment. These modules can be accessed through teaching demonstration, independent learning, and teaching and assessment functions. The block diagram of the teaching software is presented in Figure 1.

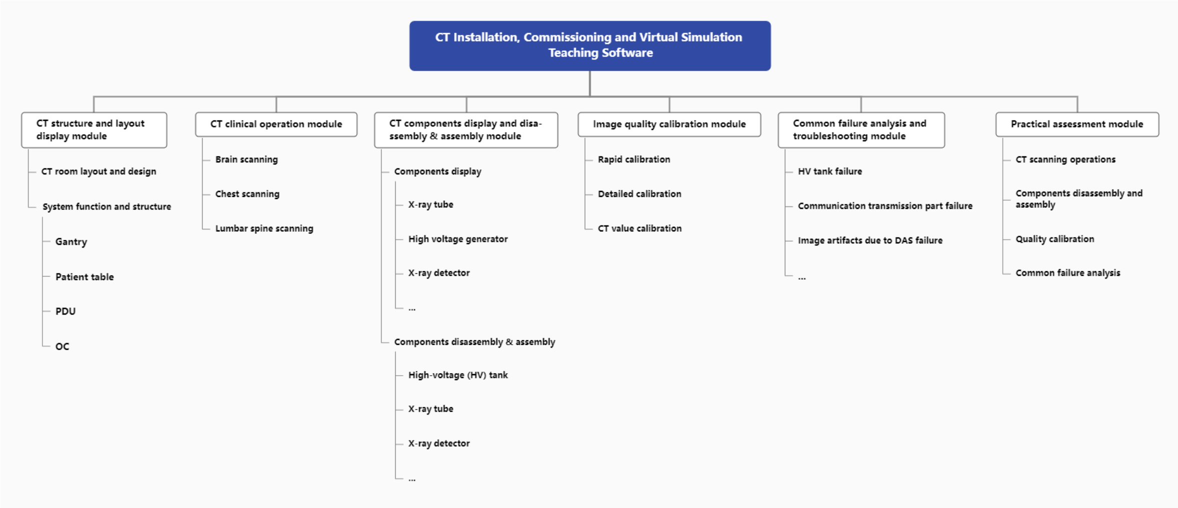

Figure 1. Block diagram of CT virtual simulation teaching software.

3.2.2. Function of the software modules

(1) CT structure and layout display module

This module covers five distinct tasks, including the underlying principles of CT room layout and design, a thorough examination of the CT system's function and structure, an exploration of the scanner gantry, patient table, power distribution unit (PDU), and the operator console (OC) structure.

To fulfill the needs of CT installation and commissioning, the CT room layout and design task carefully reconstructs the authentic environmental layout of a CT room. This enables learners to gain a thorough understanding of the intricate workings of the CT system. Furthermore, the module delves into the intricacies of power supply, grounding, shielding, temperature, humidity, and grounding in both the operation room and scanning room. Simultaneously, it highlights the functions and key components of a comprehensive CT machine, aiding learners in comprehending the precise location and requirements of major CT components, including the OC, gantry, patient table, and PDU installation. As exemplified in Figure 2, this module offers a comprehensive and enriching learning experience.

(2) CT clinical operation module

This module encompasses three distinct scanning cases: brain scanning, chest scanning, and lumbar spine scanning. It immerses learners in authentic clinical scenarios, offering simulation operations of brain axial scanning and chest spiral scanning. This practical approach aids learners in familiarizing themselves with and mastering the process and rules of CT scanning operation.In the practice mode, learners are guided through the process of completing a CT scanning operation, prompted by the software. For example, during the brain scanning process, learners are instructed to pose the patient, position the laser light, register the patient information, select the scanning area, prescribe a scanogram, set scanning parameters, confirm the exposure, and ultimately complete the scan and transmit the images. Figure 3 provides an illustration of this process.

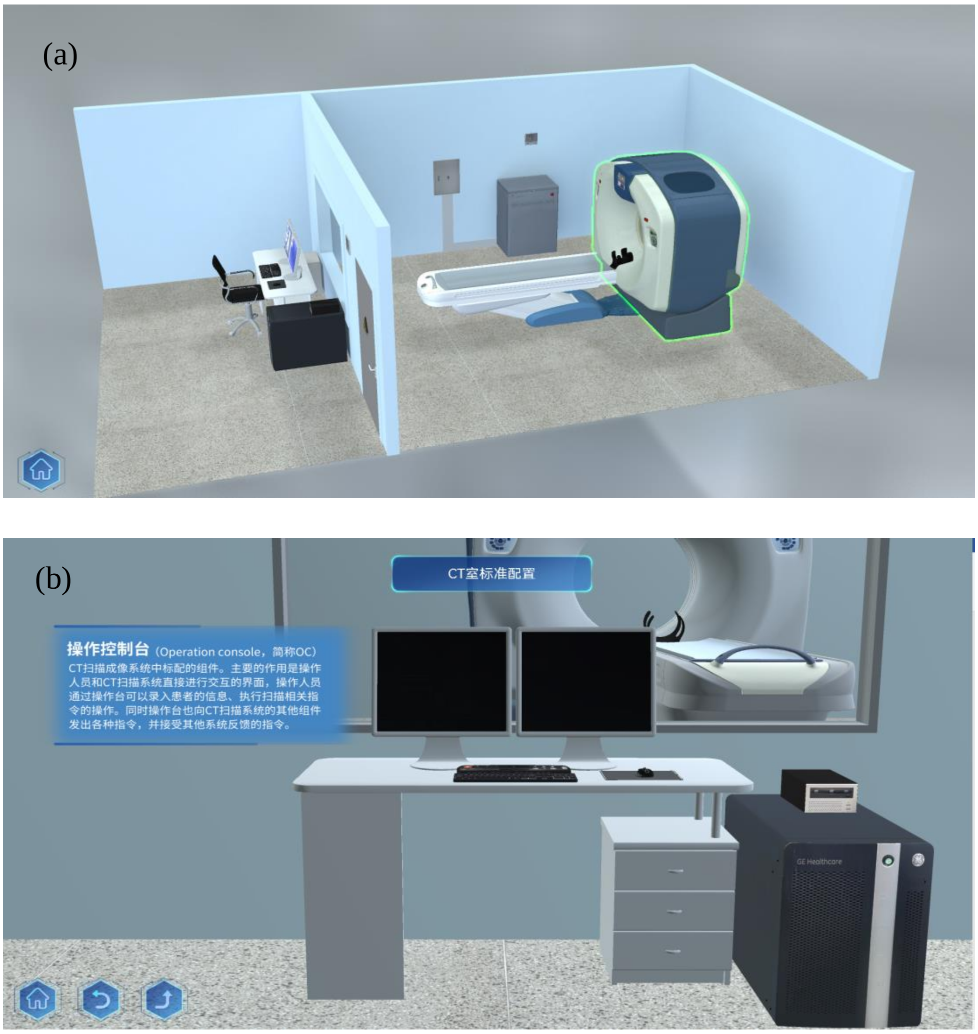

Figure 2. Cross-section of CT structure and layout module. (**a**) CT room layout and design task interface; (**b**) CT operator console structure display interface.

Figure 3. Brain scanning interface of the scanning operation module of the CT machine.

(3) CT components display and disassembly & assembly module

The module contains 30 major component displays and 6 disassembly & assembly tasks. Designed for individuals in CT assembly and maintenance positions, it emphasizes high-frequency disassembly parts encountered in actual work. The module's operations are based on the CT technical manual's disassembly process and vocational requirements, aiding learners in familiarizing themselves with the main components of CT and its disassembly process.

The displays tasks include critical components such as the OC, gantry, PDU, x-ray tube, high voltage generator, x-ray detector, data-acquisition system (DAS), and many more. Each component is accompanied by a textual description on the top right corner of the interface. Users have the option to view the components either integrated within the CT system or individually. The interface allows for zooming in or out, rotation, and viewing from any angle. Please see Figure 4(a) for a visual representation.

The disassembly & assembly tasks cover essential procedures like high-voltage (HV) tank disassembly and assembly, x-ray tube disassembly and assembly, x-ray detector disassembly and assembly, *etc*. All disassembly and assembly procedures are strictly based on the steps outlined in an original CT maintenance manual, and can be demonstrated repeatedly with textual descriptions and functional prompts.The disassembly & assembly tasks interface is depicted in Figure 4(b).

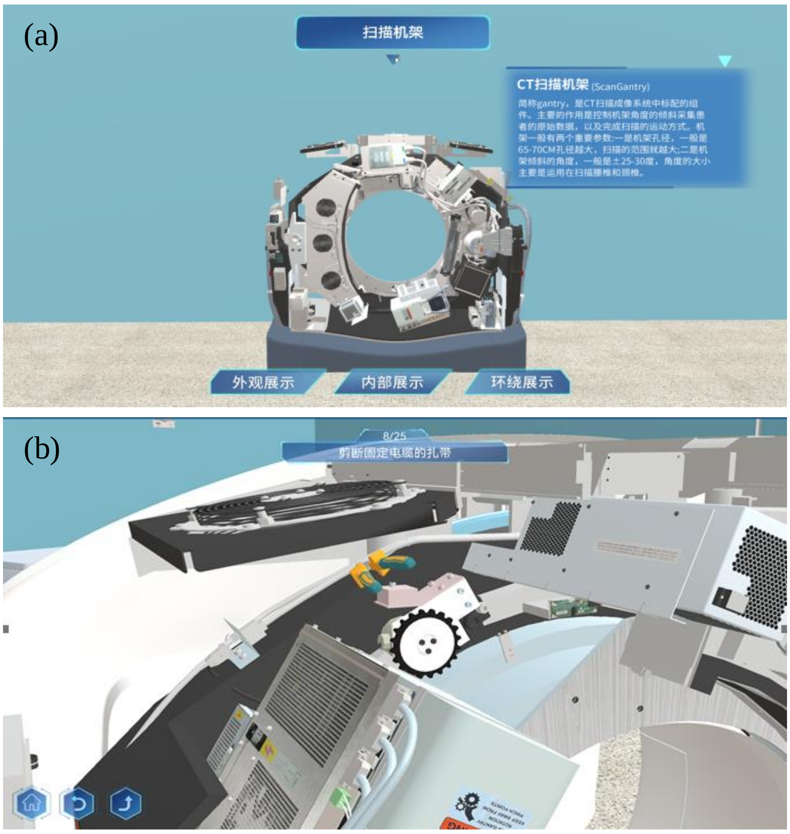

Figure 4. CT scomponent display and disassembly & assembly module interface. (**a**) Component display interface (Gantry); (**b**) A Component disassembly & assembly task interface.

(4) Image quality calibration module

This module encompasses three calibration tasks: rapid calibration, detailed calibration, and CT value calibration. These tasks are often integral to the CT QA procedures. Designed for students or junior engineers involved in CT quality control tasks, it replicates the common calibration processes used in CT systems. The detailed calibration task, in particular, consists of 37 steps such as system setup, water model placement, positioning, and water model calibration exposure. The software provides an authentic representation of the calibration process, simulating the actual scene and procedures. This module aids learners in mastering the standard CT calibration process and practicing calibration operations. The interface for the image quality calibration module is presented in Figure 5.

Figure 5. Image quality calibration module interface.

(5) Common failure analysis and troubleshooting module

The module covers the analysis of 10 troubleshooting cases, including HV tank failure, communication transmission part failure, and image artifacts due to DAS failure. Designed for individuals in CT maintenance positions, it draws upon the extensive maintenance experiences of skilled CT engineers. It selects high-frequency, typical equipment failures and incorporates fault analysis steps into the software, aiding students in clarifying the logic of failures and familiarizing them with troubleshooting procedures.The interface of HV tank failure task is shown in Figure 6.

(6) Practical assessment module

The module comprises both theoretical and practical training assessments. The theoretical assessment evaluates learners' knowledge of CT principles, structures, operation process and specifications, and other must-have knowledge points. The practical training assessment focuses on high-frequency work tasks, including CT scanning operations, disassembly and assembly of major components, quality calibration, and common failure analysis (Figure 7). Learners are required to complete these practical training tasks within a limited timeframe, with limited assistance requests, and the system automatically assigns assessment scores based on their performance. This allows learners to self-assess their mastery of practical training operations and enables teachers to objectively evaluate their mastery of practical training.

Figure 6. Common failure analysis and troubleshooting module (HV Tank Failure task) interface.

Figure 7. Practical assessment module (CT x-ray tube disassembly task) interface.

4. Software features and implementation

4.1. Software features

(1) We have conducted thorough analysis of real-world work tasks and scenarios. Based on these scenarios and processes, we have replicated the work environment, refined the workflow, and developed a plan for software design. This approach fosters on-site maintenance thinking among engineers and offers a highly immersive, robust, and practical experience.

(2) The simulation software's interactive practical training tasks, including the disassembly and assembly of CT components, image quality calibration, *etc.*, adheres strictly to the repair and maintenance manuals for CT equipment. By utilizing this simulation software to repeatedly practice and familiarize oneself with the operational steps, learners can effectively enhance their post-work abilities.

(3) The software's assessment module enables learners to conduct self-testing, while also serving as a tool for teachers to evaluate students' abilities. Based on the assessment results, teachers can provide targeted feedback and address any knowledge gaps, thereby creating a closed-loop learning environment that enhances the overall learning outcome.

4.2. Implementation

The simulation teaching software has been utilized in the theoretical and practical instruction of “CT Devices Analysis and Maintenance”, the core course of our Intelligent Medical Equipment Technology program. This teaching tool provides students with an intuitive and immersive learning environment, transforming abstract descriptions of CT devices into tangible and visual 3D representations. This approach aids students in better comprehending the knowledge points. Additionally, the simulation software offers numerous practical opportunities, enabling students to practice and perfect their work abilities through repeated training sessions. The flexibility of the simulation software in terms of time and space facilitates students' independent learning and exploration.

Teachers have integrated this simulation software into the theoretical lessons and production of course resources, thereby enriching teaching methods. This approach also enables teachers to flexibly adjust experimental plans to meet the diverse training needs of different students and courses. Following the integration of this simulation software, students majoring in intelligent medical equipment technology have significantly improved their mastery of CT structural principles, practical skills, and problem-solving abilities.

For instance, in the teaching experiment on x-ray tube replacement, students who used the simulation software excelled in both practical operations and theoretical tests compared to those who used traditional teaching methods. These achievements demonstrate the simulation software's effectiveness in enhancing students' work capabilities.

5. Conclusion

In this paper, we have designed and developed a virtual simulation teaching software for CT installation, commissioning and maintenance based on job competency requirements. This software combines teaching demonstration, independent learning, job training, assessment into a comprehensive and scalable platform. The implementation of this teaching software addresses the challenges of "three highs and three difficulties" in practical training for vocational education courses, that are high requirements, high costs, high risks, difficult teaching, difficult training, and difficult assessment.

This software can be utilized for practical training and assessment in intelligent medical equipment technology, medical imaging technology, and other related professional courses. Additionally, it can support personnel who will engage in CT installation, commissioning, maintenance, QA, and other positions in their knowledge and skills learning to adapt to the country's demand for high-end medical equipment technology personnel.

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Conflicts of interests

There is a contract between Chongqing Medical and Pharmaceutical College and Guangzhou Werich Technology Service Co., Ltd. for the integrated virtual simulation software of CT installation, debugging, and maintenance (Contract No.: GQYGZZB(2022) No. 119). The application for the Registration Certificate of Computer Software Copyright of the People's Republic of China has been made, and the software name is: CT Installation, Debugging, and Maintenance Virtual Simulation Teaching Software (abbreviated as CT Simulation Teaching Software) V1.0. The copyright holder is Chongqing Medical and Pharmaceutical College, and the certificate number is: Software Registration No. 1151388. The authors declare no conflict of interest.

Authors' contribution

Conceptualization, Wenzhu Wu and Junquan Tang; methodology, Junquan Tang; software, Yuhua Guo; validation, Wenzhu Wu, Junquan Tang and Yuhua Guo; investigation, Wenzhu Wu; resources, Yuhua Guo; writing—original draft preparation, Wenzhu Wu; writing—review and editing, Junquan Tang; project administration, Wenzhu Wu; funding acquisition, Wenzhu Wu. All authors have read and agreed to the published version of the manuscript.

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