Software Requirements Specification

for

Recreating Pelvic Trauma Surgery in Virtual Reality

Version 1.0 approved

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1. Introduction

1.1 Purpose

This introduction to the Software Requirements Specification (SRS), covering its purpose, scope, definitions, abbreviations, acronyms, and references, provides an overview of the system - Recreating Pelvic Trauma Surgery in Virtual Reality (VR). The main goal of this document is to provide an in-depth requirement of the VR application for pelvic trauma surgery training purposes.

1.2 Document Conventions

VR	Virtual Reality
DRR	Digitally Reconstructed Radiographs
SSL	Secure Sockets Layer
UI	User Interface

1.3 Intended Audience

The intended audience for this percutaneous pelvic fracture surgery VR training environment project includes the following kinds of users. The first kind of users is surgical residents and trainees. The primary audience for this VR training environment is medical students, residents, and fellows who specialize in orthopedic surgery and can benefit from this training environment to enhance their understanding of pelvic anatomy and gain experience in performing the procedure before transitioning to real patients. Moreover, for orthopedic surgeons who need to develop and refine their skills in performing percutaneous pelvic fracture surgery under C-arm fluoroscopy. The simulation will provide a realistic and safe environment for practicing the procedure without exposing patients or clinical staff to ionizing radiation. The third is medical schools and teaching hospitals. Educational institutions that offer orthopedic surgery training programs can utilize the VR training environment as a supplemental teaching tool to provide hands-on experience and improve surgical proficiency among their students. Even the medical device companies that manufacture and sell C-arm fluoroscopy machines and surgical tools for orthopedic procedures may use this VR training environment to demonstrate the proper use of their equipment and provide training for surgeons who purchase their products.

By targeting these audience groups, the percutaneous pelvic fracture surgery VR training environment aims to improve the overall quality of surgical training, reduce training costs, increase patient safety, and enhance the accessibility of C-arm fluoroscopy training for orthopedic surgeons.

1.4 Product Scope

The goals of this project are threefold: (1) create a baseline VR environment simulating percutaneous pelvic fracture surgery, (2) incorporate an interactable C-arm and surgical tool for enhanced functionality, and (3) develop a realistic simulation of K-wire and screw-body insertion interactions.

The technical approach will involve the use of the Unity game engine to develop the VR environment, ensuring compatibility with any SteamVR compatible VR headset. DeepDRR technology will be connected through a socket-based server, allowing for real-time radiograph requests and accurate simulated X-ray imagery. The surgical simulation will involve C-arm model and kinematics, K-wire simulation, and a VR interaction framework for an immersive and realistic training experience.

By achieving these objectives, the project aims to deliver a state-of-the-art training environment that accurately simulates percutaneous pelvic fracture surgery, enabling easy collection of detailed operation data, reducing training costs, improving patient outcomes, and increasing accessibility to C-arm fluoroscopy training for orthopedic surgeons.

1.5 References

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1.6 Overview

Following the section headings is a general description, including information about the target users of the project, the hardware of the system, and the functional and data requirements of the system. A general description of the project is discussed in section 1. Section 2 describes the functional requirements, the data requirements, and the constraints and assumptions made used in development. Section 2 also discusses the external interface requirements and gives a detailed description of functional requirements. Last, sections 3 and 4 give detailed nonfunctional requirements and supporting information.

2. Functional requirements

2.1 Product Functions

This application can allow users to select different pre-loaded patient model cases for creating an effective and realistic VR training environment for percutaneous pelvic trauma surgery. The following functional requirements have been identified:

User Authentication

The system shall provide a secure login interface for user authentication, ensuring that only authorized users can access the training environment.

Patient Model Selection

The system shall allow users to select from a variety of patient models, each with different pelvic fracture types and anatomical variations, to enhance training diversity.

C-arm Interaction

The system shall provide an interactable C-arm model that can be manipulated in real-time using VR hand controllers, allowing users to position and orient the C-arm as required during the surgical procedure.

Surgical Tool Interaction

The system shall enable users to interact with various surgical tools, such as K-wires, screws, and guidewires, using VR hand controllers, simulating the process of inserting orthopedic hardware.

Real-time X-ray Simulation

The system shall utilize DeepDRR technology to generate realistic, real-time simulated X-ray images based on the position and orientation of the C-arm, patient model, and surgical tools.

Haptic and Audio Feedback

The system shall provide haptic and audio feedback during C-arm and surgical tool interactions, enhancing the immersive experience for the user.

Performance Metrics and Evaluation

The system shall automatically collect and analyze performance metrics, such as procedure time, the accuracy of hardware placement, and the number of C-arm adjustments, to enable users to evaluate and improve their surgical skills.

Tutorial and Guidance System

The system shall include a tutorial and guidance system that provides step-by-step instructions, tips, and best practices for percutaneous pelvic fracture surgery, helping users to familiarize themselves with the procedure and VR environment.

Scalability and Customization

The system shall be designed to support future scalability and customization, allowing for the incorporation of new patient models, surgical tools, and advanced simulation features as needed.

Cross-platform Compatibility

The system shall be compatible with a variety of VR headsets and controllers, ensuring accessibility and adaptability for different hardware configurations.

2.2 Design and Implementation Constraints

The following design and implementation constraints have been identified for the pelvic trauma surgery VR training environment:

Hardware Requirements

The system requires a user with a VR headset compatible with SteamVR, such as HTC Vive, Oculus Rift, or Valve Index, and VR hand controllers for interaction. The user's computer shall have a minimum of 16 GB RAM, a dedicated GPU with at least 8 GB VRAM, and a modern multi-core CPU to ensure smooth performance during the simulation. The system shall require no more than 1 GB of storage space for the base application, with additional storage required for patient models and performance metric data.

Software Requirements

The system will be developed using the Unity game engine, which supports cross-platform VR development and has robust support for creating complex VR interactions and user interfaces. DeepDRR, a Python package for Linux computers with an NVIDIA CUDA-capable GPU with >11 GB of memory, will be used to generate realistic Digitally Reconstructed Radiographs (DRRs) from 3D CT data. ZeroMQ networking library will be used for socket communication between the Unity application and the DeepDRR server.

Compatibility

The system shall be compatible with multiple VR headset models and controllers, ensuring accessibility and adaptability for different hardware configurations. The VR training environment should be developed with scalability and future expansion in mind, allowing for the incorporation of new patient models, surgical tools, and advanced simulation features as needed.

Security and Privacy

The system shall provide a secure login interface for user authentication, ensuring that only authorized users can access the training environment. Any sensitive user information and performance metrics should be stored securely, with data encryption techniques (like SSL) and anonymized processing implemented to protect user data.

Network and Server Requirements

The system will require a stable internet connection for communication between the Unity application and the DeepDRR server. The DeepDRR server can be hosted on the same computer as the Unity application or on a separate computer connected via Ethernet or Wi-Fi to the computer running the Unity application.

Performance

The system shall maintain a minimum frame rate of 15 FPS during the simulation to ensure a comfortable and immersive user experience. The system shall minimize latency in generating and displaying simulated X-ray images using DeepDRR technology, ensuring real-time feedback during the surgical procedure.

User Experience

The system shall provide intuitive and user-friendly interfaces, allowing users to quickly become familiar with the VR training environment and surgical simulation. Haptic and audio feedback shall be implemented to enhance the immersive experience and facilitate seamless interaction between users and the virtual surgical environment.

3. External Interface Requirements

3.1 User Interfaces

The UI requirements for this VR training environment must be intuitive, user-friendly, and designed to facilitate seamless interactions between users and the virtual surgical environment. The following UI requirements have been identified:

Main Menu Interface

The main menu shall provide users with access to essential features, such as selecting patient models, starting a new surgery simulation, accessing tutorials, viewing performance metrics, and logging out. The main menu shall be easy to navigate using VR hand controllers, allowing users to point and click on the desired options.

Patient Model Selection Interface

The patient model selection interface shall display a list or gallery of available patient models, each with a preview image and a brief description of the pelvic fracture type and anatomical features. Users shall be able to scroll through the list, select a patient model, and proceed to the surgical simulation environment.

In-Simulation Interface

The in-simulation interface should display a virtual operating room, complete with an interactable C-arm, patient model, and surgical tools. A virtual monitor shall be positioned next to the patient, displaying real-time simulated X-ray images generated by DeepDRR technology. Users shall have access to a virtual tool tray, from which they can select and interact with surgical tools using VR hand controllers.

Tutorial and Guidance Interface

The tutorial and guidance interface shall provide step-by-step instructions, tips, and best practices for percutaneous pelvic fracture surgery through text, images, and/or videos. The interface shall be context-sensitive, offering relevant information based on the user's current stage in the surgical procedure. Users shall be able to access the tutorial and guidance interface at any time during the simulation by pressing a designated button on the VR hand controller.

Performance Metrics and Evaluation Interface

The performance metrics and evaluation interface shall display a summary of the user's performance, including metrics such as procedure time, the accuracy of hardware placement, and the number of C-arm adjustments. The interface shall allow users to view a history of their past performance metrics to track their progress over time. Users shall be able to access the performance metrics and evaluation interface from the main menu or upon completing a surgical simulation.

Settings Interface

The settings interface shall allow users to customize various aspects of the VR training environment, such as the level of haptic feedback, audio settings, and graphical quality. Users shall be able to access the settings interface from the main menu or during the surgical simulation by pressing a designated button on the VR hand controller.

Help and Support Interface

The help and support interface shall provide users with access to a comprehensive user manual, frequently asked questions, and contact information for technical support. Users shall be able to access the help and support interface from the main menu or during the surgical simulation by pressing a designated button on the VR hand controller.

3.2 Hardware Interfaces

The VR training system requires a compatible VR headset (e.g., HTC Vive Pro, Oculus Quest 2, etc.) and hand controllers to provide an immersive and interactive training experience. These devices will allow users to view and interact with the virtual environment, manipulate the C-arm, and perform surgical procedures using virtual tools. The system shall be compatible with Wi-Fi and Ethernet connections, enabling users to access and download new patient models, simulation scenarios, or software updates. This connectivity will also allow for the collection and analysis of operational data for further improvement of the training environment. For X-ray image generation, the system requires a computer with a powerful GPU, CPU, and sufficient RAM to handle the complex simulations and real-time rendering of the virtual environment. This will ensure smooth operation and optimal performance during the training sessions. While not mandatory, an additional motion tracking system (e.g., HTC Vive Tracker, Oculus Insight, etc.) can be used to enhance the realism and accuracy of the user's movements in the virtual environment. This may provide a more immersive and effective training experience for users.

3.3 Software Interfaces

The core of the VR training environment will be developed using the Unity game engine, which offers a versatile and powerful platform for creating interactive 3D applications. Unity provides built-in support for various VR headsets and hand controllers, making it an ideal choice for this project. The Unity version of this project shall be 2021.3.14. Another core component is the DeepDRR Framework. The DeepDRR machine learning framework will be used to generate realistic Digitally Reconstructed Radiographs (DRRs) from 3D Computed Tomography (CT) data. This integration will provide accurate and real-time x-ray visualizations during the simulation, enhancing the realism and effectiveness of the training environment. For the network communication between the DeepDRR server and the Unity VR application, the ZeroMQ networking library will be used. This library offers robust pub-sub messaging patterns and allows for easy communication between the server and the client applications.

3.4 Communications Interfaces

The VR training environment may require a USB interface to connect various peripherals, such as VR headsets (such as HTC Vive), hand controllers, or other input devices. The USB connection offers a hot plug-and-play capability, allowing users to easily connect and disconnect devices without needing to power down the system. With USB, a single controller can support up to 127 peripherals, and the distance between each peripheral can be up to 5 meters. However, some VR headsets (such as the Oculus Quest 2) and controllers utilize Bluetooth technology for wireless communication. The application should support Bluetooth connections to enable seamless pairing and data transfer between the VR devices and the user's computer or mobile device.

4. Other Nonfunctional Requirements

4.1 Performance Requirements

4.1.1 Timing and Capacity

The pelvic trauma surgery VR training environment is designed to be available for use 24 hours per day, 365 days per year. However, as a VR application, it does not rely on an internet connection for normal operation, but it does require the local network for DeepDRR, and the availability will depend on the user's hardware and software setup.

The simulation's response time for generating Digitally Reconstructed Radiographs (DRRs) from 3D CT data using DeepDRR shall be limited to 10 seconds per image, ensuring a smooth user experience. All other interactions within the virtual environment, such as adjusting the C-arm or using surgical tools, should have a response time of less than 500 milliseconds to maintain an immersive and realistic experience.

The VR training environment shall be capable of supporting at least 50 concurrent users, assuming that each user has their own VR headset and compatible hardware setup. This capacity is primarily limited by the hardware resources of the individual users, as the VR application runs locally on each user's machine.

The maximum number of supported users per virtual training session depends on the intended usage scenario. For individual training, a single user will be able to use the system without any constraints. For group training sessions, such as in a medical school or training center, the system shall support up to 10 concurrent users in a single virtual environment, allowing for collaboration and guided instruction.

The maximum number of supported virtual training sessions is limited by the hardware and software resources available at the institution or organization using the system. As the VR application runs locally, the system can support multiple concurrent training sessions, provided there are sufficient VR headsets and compatible hardware setups.

4.1.2 Ease of use

To ensure the ease of use for the pelvic trauma surgery VR training environment, there are different metrics for different kinds of users. For novice surgeons and trainees, such as surgical residents and trainees, shall be able to familiarize themselves with the VR training environment and its functions within 30 minutes of self-exploration or guided instruction. After they become familiar with the system, the average number of errors made by novice users should not exceed three per day of system use. For the experienced surgeons who are experienced with percutaneous pelvic fracture surgery and C-arm fluoroscopy should be able to operate the VR training environment without any obstacles, given their prior experience with similar sophisticated applications. These users should be able to adapt quickly to the VR environment and utilize the system effectively from the beginning. For non-surgical users who have no experience with surgery or related medical procedures are not recommended to use this VR training environment, as the system is specifically designed for orthopedic surgeons and trainees. Finally, all users shall be able to access clear and concise instructions within the user interface at any time during their training session. The average search time for the "help button" or other guidance features should not exceed 2 seconds, ensuring that users can quickly find the information they need to operate the system effectively.

By focusing on ease of use, the percutaneous pelvic trauma surgery VR training environment aims to provide an efficient and user-friendly platform for surgeons and trainees to improve their skills in a realistic and immersive virtual setting.

4.1.3 Reliability and Robustness

The VR training system is designed to be flexible and accommodating to users, with no restrictions or penalties for periods of temporary inaccessibility, even up to several weeks. This allows users to return to their training at their own pace without losing progress or facing difficulties. The rate of failure occurrence from the VR training system server should not exceed 1 time per 50 requests from users. This ensures that the system remains reliable and stable for users during their training sessions, minimizing interruptions and enhancing the overall learning experience. The VR training system should be designed with robust error handling and recovery mechanisms to minimize disruptions during training sessions. In the event of a system failure or unexpected error, the system should provide clear and concise error messages, enabling users to identify and address the issue effectively. The system should also be capable of recovering from errors and resuming normal operation as quickly as possible.

By prioritizing reliability and robustness, the percutaneous pelvic fracture surgery VR training environment aims to provide a dependable and efficient platform for surgeons and trainees to enhance their skills in a realistic virtual setting.

4.2 Safety Requirements

Under construction for version 1.0

4.3 Security Requirements

Under construction for version 1.0

4.4 Business Rules

Under construction for version 1.0