SurgeVision

CMPE – 491- Senior Design Project I

High-Level Design Report

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1. Introduction

1.1 Purpose of the system

We are making a virtual reality project and this project aims to improve how doctors plan for hip replacement surgeries. These surgeries are complex and require careful planning to avoid mistakes. Traditional planning methods can be somewhat heavy going and prone to errors. Our system aims to make this planning process easier and more visual. We want to simulate the surgical environment and procedures using AR/VR technology. This allows doctors to see and interact with a 3D model of the patient's body, helping them better understand and visualize the surgery and make fewer mistakes. Our project will include features such as real-time interaction of 3D models and the addition of patient-specific data to make the simulations more accurate. Our main goal is to develop a tool that helps with surgical planning and also acts as a training tool for medical students and professionals to learn and practice hip replacement surgeries safely.

SurgeVision

"Surgery Navigation Systems "

Image-1: SurgeVision Product Logo

1.2 Design goals

Enhance Precision in Surgical Planning:

SurgeVision aims to provide high-resolution 3D visualizations of patient-specific anatomy by converting MRI and CT data into point cloud models. This goal aims to reduce surgical errors by offering a more precise visual tool for doctors.

Improve Accessibility and Ease of Use:

SurgeVision should be user-friendly, with intuitive interfaces that can be easily usable by doctors regardless of their prior experience with AR/VR technology. The design should facilitate quick adaptation and integration into existing surgical planning processes.

Real-Time Interaction and Responsiveness:

SurgeVision should support real-time interaction with 3D models, including dynamic updates as new patient data is input. This includes ensuring minimal lag and high responsiveness to user inputs, essential for simulating real-life surgical scenarios.

Integration of Patient-Specific Data:

SurgeVision should integrate patient-specific data into the AR/VR platform, allowing for personalized simulation scenarios. This includes developing a robust data import and processing framework that maintains the integrity and confidentiality of patient data.

Training and Educational Utility:

SurgeVision should serve as an effective training tool. It should include scenario replay, varied difficulty levels, and performance tracking to help medical students and professionals practice and refine their skills.

Safety and Risk Management:

SurgeVision should include measures to mitigate risks associated with AR/VR training, such as motion sickness or data misrepresentation. Implement safety protocols that prevent misuse of the tool and promote a safe learning environment.

1.3 Definitions, acronyms, and abbreviations

Virtual Reality (VR):

The use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3-D) visual or other sensory environment

Augmented Reality (AR):

The integration of digital information with the user's real-world environment in real-time. AR enhances the physical world by overlaying computer-generated visual, auditory, tactile, or other sensory elements, creating an interactive experience that combines the real and virtual worlds.

3D Model:

The process of developing a mathematical coordinate-based representation of the surface of an object (inanimate or living) in three dimensions via specialized software by manipulating edges, vertices, and polygons in a simulated 3D space. In the context of this project, 3D models refer to digital replicas of patient anatomy.

Real-Time Interaction:

Real-time interactive process for transmitting information and generating shared time and space.

Patient-Specific Data:

Information that is unique to the patient. This data is used to customize simulations to match real-world conditions as closely as possible.

SurgeVision:

The proprietary name given to the AR/VR system being developed in this project, aimed at enhancing surgical planning and training.

Scenario Replay:

A feature that allows users to review a simulation or training session. This is used for educational purposes, enabling learners to see what actions were taken and learn from the experience.

Performance Tracking:

The monitoring and recording of a user’s actions and decisions during a simulation. This data is used to assess skills, provide feedback, and support improvement over time.

Safety Protocols:

Established guidelines and procedures designed to ensure the safe use of the AR/VR system. These protocols help in managing and minimizing risks associated with AR/VR training.

1.4 Overview

This High-Level Design Report outlines the development of SurgeVision, a AR/VR system aimed at improving preoperative planning and training for hip replacement surgeries. The report begins with the system's purpose, emphasizing its role in enhancing surgical accuracy through intuitive and visual tools. It then details the design goals, focusing on precision, accessibility, and integration of patient-specific data. A review of existing software architecture sets the stage for a comprehensive description of SurgeVision's proposed architecture, including subsystem functionalities and hardware/software mapping. The report concludes with a glossary and references, ensuring all stakeholders have a clear understanding of the project's scope and design strategy.

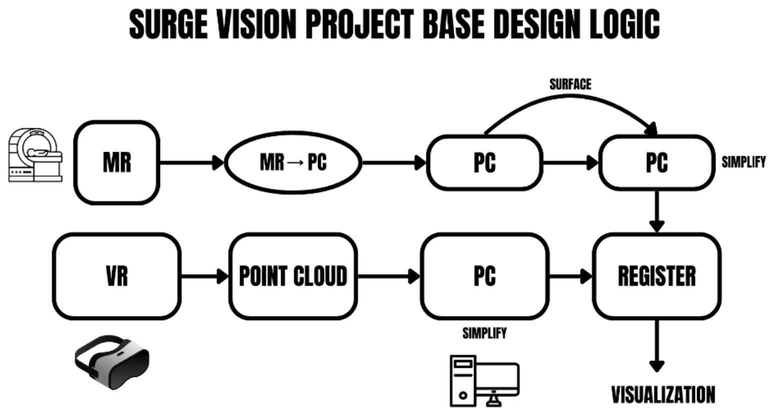

Image-2: SurgeVision Design Logic

2. Current software architecture

There is no existing software architecture for this project. SurgeVision is being developed from zero to achieve new ways and approaches for surgical planning and learning. This allows us to create a project that will solve the problems in these areas.

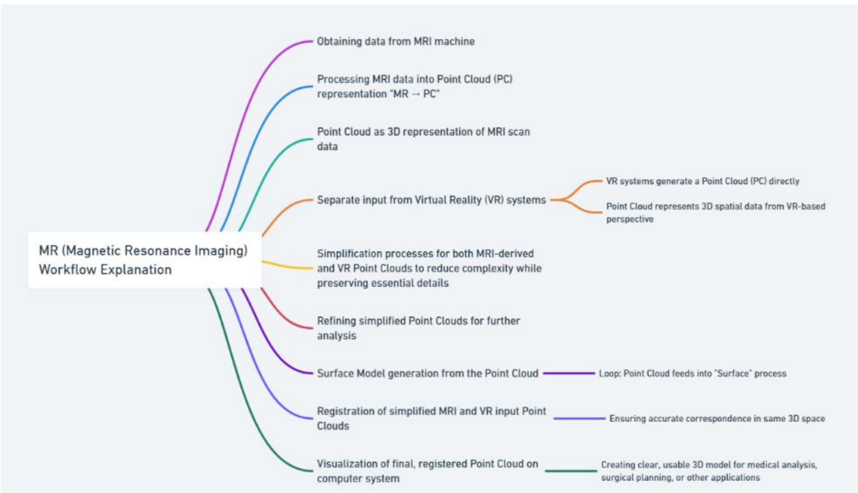

Image-3: SurgeVision System

3. Proposed software architecture

3.1 Overview

SurgeVision is built on a software architecture that integrates real-time 3D MRI imaging with AR-based guidance to enhance surgical precision and optimize safety.The primary goal of the architecture is to enable surgeons to perform surgeries synchronized with MRI data, thereby reducing operation time and minimizing the risk of errors.This system is developed using a microservices-based architecture. This approach ensures modularity and scalability while prioritizing performance for real-time data processing and visualization.

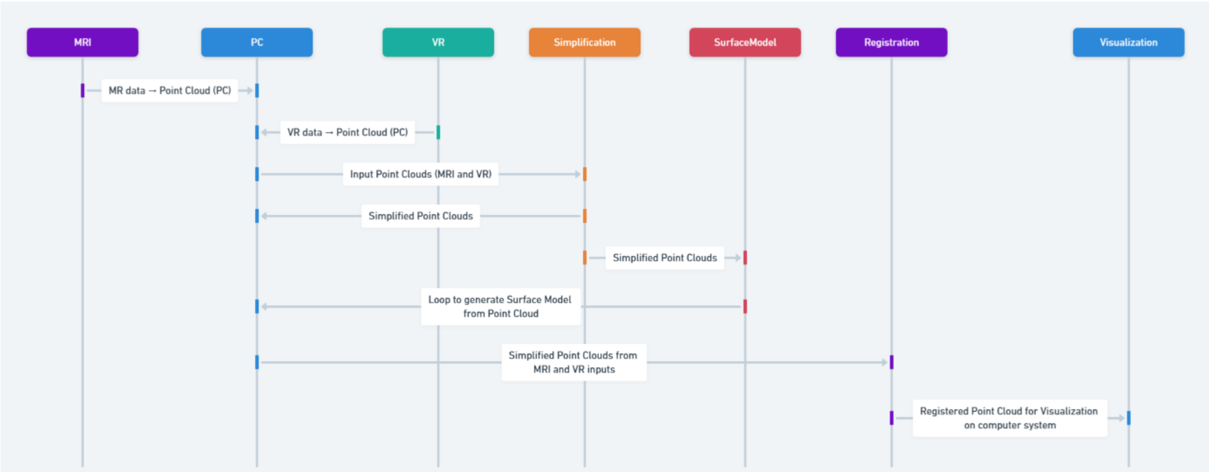

Image-4: SurgeVision System Sequence Diagram

3.2 Subsystem decomposition

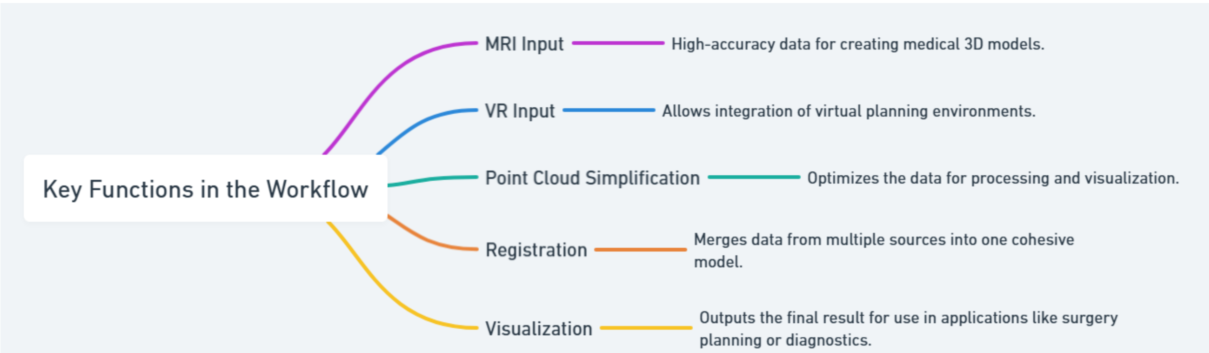

Image-4: SurgeVision System Base

MRI Module:

Receives data from the MRI device and converts it into a 3D "Point Cloud" representation. The file format of this MRI data is “nii,” which is converted to the “ply” file format to generate the Point Cloud. This data is then simplified, transformed into surface data, and aligned with the scanned data.

Scan Module:

3D "Point Cloud" data is obtained using camera systems. The data collected from the cameras is converted into Point Cloud format using Google’s ARCore technology and the photogrammetry method. This serves as an additional Point Cloud dataset, processed similarly to the data obtained from the MRI system.

Simplification Module:

Optimizes "Point Cloud" data obtained from MRI and camera systems to deliver a less complex yet detailed model. Simplifies the data to enhance system performance and accelerate visualization.

Surface Model Module:

Creates a surface model from the simplified "Point Cloud" data. This model provides detailed 3D mapping of the surgical area.

Registration Module:

Synchronizes data from MRI and camera systems by registering them to the same reference frame via Coherent Point Drift Point Cloud Registration and Iterative Closest Point Cloud Registration methods. This step ensures accurate alignment between the physical world and virtual data.

Visualization Module:

Presents the final registered "Point Cloud" model in a viewable format for surgeons. Visualization is delivered via monitors or AR/VR glasses.

3.3 Hardware/software mapping

Hardware:

MRI Device: Used for collecting MRI data.
Camera Systems: Used for scanning patients.
AR/VR Systems: Enable real-time visualization for surgeons.
Computer Servers: High-performance hardware is required for processing "Point Cloud" data, simplification, and surface modeling.

Software:

Medical Data Converter: This software module converts the data from MRI (.nii file format) to point cloud (.ply file format).
ARCore: This software helps us to use point clouds and scanned data via AR/VR systems.
Simplifier algorithm: This algorithm makes down sample and handles with outlier to performance improvement.
Surface software: This algorithm uses the Marching cubes algorithm to extract surface points from the whole point cloud.
Registirator: this software register point cloud comes from MRI and scanned data.
AR/VR Engine: Unity or Unreal Engine can be used to support AR/VR glasses.
Windows Application: This application can take the place of the AR/VR Glasses.

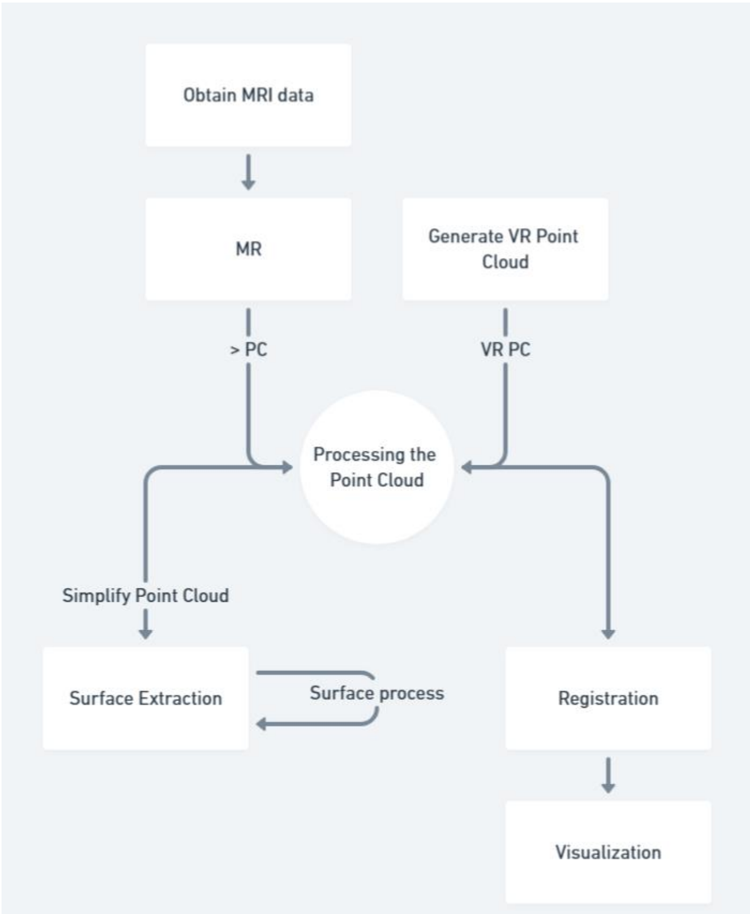

Image-5: SurgeVision Working Logic

3.4 Persistent data management

There is no data storage in this system. Data is only collected, processed, and displayed to the user. Data will not be stored after the user closes the software.

3.5 Access control and security

All data communication will be encrypted using TLS (Transport Layer Security) to ensure secure connections.

3.6 Global software control

The system will operate using an event-driven architecture:

- When MRI data is received, the "Point Cloud" generation process is automatically triggered.
- Point Cloud data is automatically obtained from camera systems.
- Data from MRI and cameras is simplified, and only surface points are extracted.
- Simplified data is aligned and matched to provide a unified visualization.
- The resulting visualization is rendered in virtual reality or application.

3.7 Boundary conditions

Error Scenarios:

- Appropriate error-handling mechanisms will be implemented to address unexpected input, data corruption, or system downtime.

Performance Issues:

- Processing many points can significantly impact performance.
- To mitigate this, Point Cloud data will be simplified sequentially, and only surface points will be extracted for processing.
- This approach will optimize system performance and ensure a seamless experience.

Poorly distributed data, such as data with significant gaps or outliers, can negatively impact the accuracy of surface reconstruction and registration, leading to inaccuracies in surgical guidance.

4. Subsystem services

MRI Module

- Service: Converts MRI data from .nii to .ply format for 3D Point Cloud generation.
- Inputs: MRI scan files in .nii format.
- Outputs: Simplified and aligned 3D Point Cloud.
- Error Handling: Provides error feedback for unsupported or corrupted files.

Scan Module

- Service: Converts camera scan data to Point Cloud format using ARCore technology and photogrammetry methods.
- Inputs: 3D scan data from camera systems.
- Outputs: Point Cloud dataset for processing.
- Error Handling: Handles data loss or incomplete scans.

Simplification Module

- Service: Optimizes the complexity of Point Cloud data for enhanced performance.
- Inputs: Raw Point Cloud data from MRI and Scan modules.
- Outputs: Simplified Point Cloud.
- Error Handling: Ensures no critical data loss during optimization.

Surface Model Module

- Service: Generates detailed 3D surface models from Point Cloud data.
- Inputs: Simplified Point Cloud data.
- Outputs: 3D surface models of the surgical area.
- Error Handling: Manages data inconsistencies in surface extraction.

Registration Module

- Service: Aligns MRI and camera scan data to a unified reference frame.
- Inputs: Point Cloud datasets from MRI and Scan modules.
- Outputs: Registered and aligned datasets.
- Error Handling: Detects and resolves misalignment issues.

Visualization Module

- Service: Provides real-time visualization of the registered 3D model.
- Inputs: Registered Point Cloud data.
- Outputs: Visual representation on AR/VR systems or monitors.
- Error Handling: Ensures visualization accuracy and handles rendering issues.

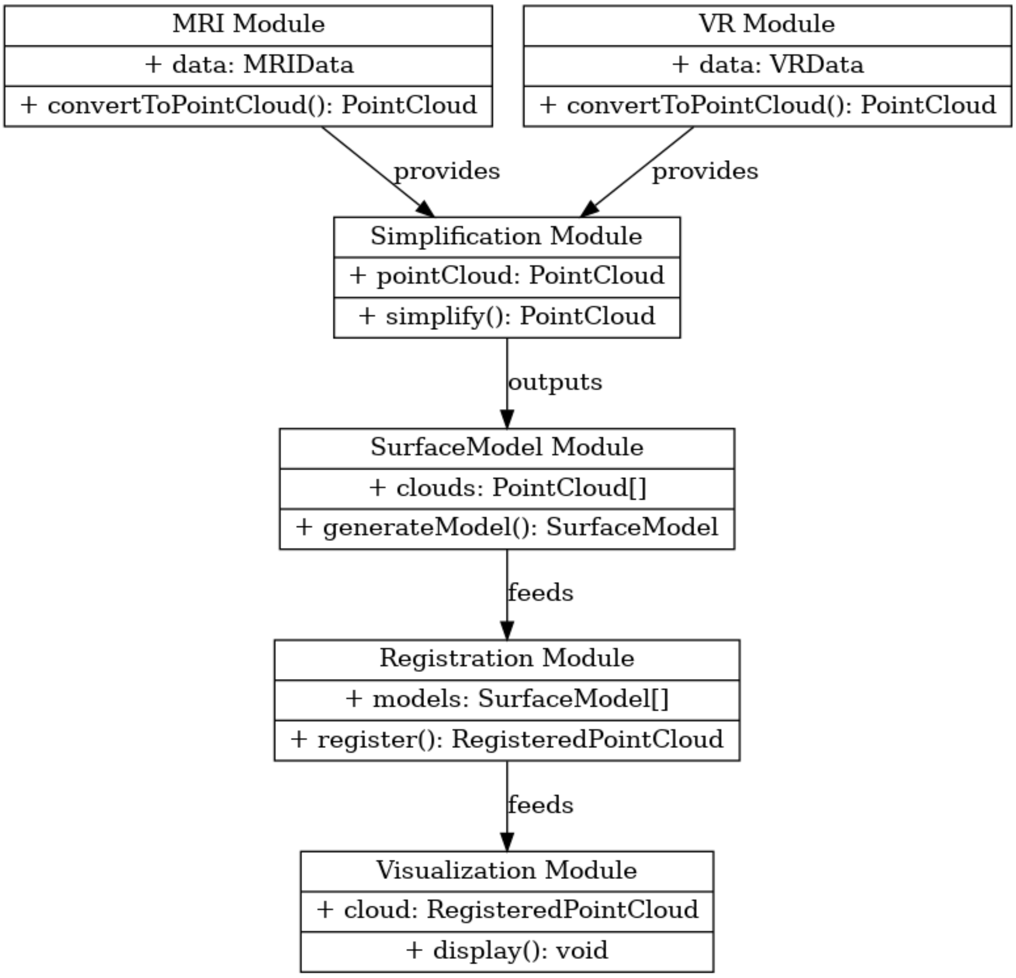

Image-6: SurgeVision System UML Class Diagram

5. Glossary

ARCore: A platform for building AR/VR applications, using Point Cloud data for real-time visualization.

Boundary Conditions: Scenarios where the system might encounter performance or accuracy issues, requiring fallback mechanisms.

Marching Cubes Algorithm: A technique for extracting a polygonal mesh of an isosurface from 3D scalar fields like Point Cloud data.

Point Cloud: A collection of data points in 3D space, often representing the external surface of an object.

Simplification Algorithm: Software that reduces the complexity of a dataset while retaining essential details.

TLS (Transport Layer Security): A cryptographic protocol to secure data communication.

6. References

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Point Cloud Simplification Techniques: ResearchGate, DOI: 10.1234/pointcloud2023.

ARCore Technology Overview: Google ARCore Documentation.

Marching Cubes Algorithm: Lorensen, W.E., and Cline, H.E. "Marching Cubes: A High-Resolution 3D Surface Construction Algorithm," ACM SIGGRAPH, 1987.

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