Interactive Human Liver System in Augmented Reality (AR)

A Project Report submitted by

MONISHA GOVINDARAJ

in partial fulfillment of the requirements for the award of the degree of

M.Sc./M.Sc.-M.Tech./M.Tech. and M.Tech.-Ph.D.

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Indian Institute of Technology Jodhpur

Name of the Department

October 2024

Declaration

I hereby declare that the work presented in this Project Report titled Interactive Human Liver System in Augmented Reality (AR) – Executive M.Tech AR/VR submitted to the Indian Institute of Technology Jodhpur in partial fulfilment of the requirements for the award of the degree of Executive M.Tech AR/VR is a bonafide record of the research work carried out under the supervision of Dr.Sumit Kalra. The contents of this Project Report in full or in parts, have not been submitted to, and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.

Signature

Monisha Govindaraj

M22AI82

Certificate

This is to certify that the Project Report titled Interactive Human Liver System in Augmented Reality (AR), submitted by Monisha Govindaraj(M22AI821) to the Indian Institute of Technology Jodhpur for the award of the degree of Executive M.Tech AR/VR. is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Signature

Name of the respective supervisor

Abstract

The MTech Program of Study requires each student to undertake research in the chosen area of study and to submit a thesis on it in consultation with the faculty member(s) supervising the same. The MTech Project is included in the curriculum with a view to synthesizing the various components of the research work undertaken during the MTech. Program at IIT Jodhpur. Creating a Project Report document of the research undertaken is part of the skill-building training of the student in technical communications. Here, the emphasis is on presenting a technical matter in an objective written form.

This document is a record of the mandatory guidelines to be followed while preparing the of the *Project Report* document to be submitted at the end of the MTech. Program. It prescribes typical contents that an MTech Project Report document usually should contain, and provides the format of its presentation. While most of these guidelines are prescriptive, some are subjective; but towards ensuring a relatively uniform style of presentation of all MTech Project Reports being submitted at the Institute, these subjective guidelines are expected to help in setting at least a reasonable minimum expectation of the presentation level of the work accomplished in the research program.

All students pursuing the MTech *Program* are urged to read the contents and form of this document carefully and prepare their Project Report document as prescribed. It is hoped that this document will lead to a modest beginning at the Institute towards imparting education in professional written presentations.

Contents

1.0 Abstract

The project "Interactive Human Liver System in Augmented Reality (AR)" aims to develop an immersive educational tool that provides real-time, interactive visualization of liver anatomy and pathology. With liver diseases such as cirrhosis, hepatitis, and liver cancer being among the most prevalent and complex diseases, this project focuses on creating a system where users can explore liver diseases in an engaging manner. Using AR technology, the project intends to offer a visual representation of the liver and demonstrate the effects of various diseases on its function and structure.

The project caters primarily to medical students, educators, and professionals, enhancing traditional learning methods by making it easier to visualize and understand liver diseases. By selecting specific diseases within the AR environment, users will be able to see how the disease manifests in the liver and interact with detailed explanations of symptoms, causes, and treatments. This interactive system will not only help with academic learning but also act as a practical tool for better understanding the anatomy and pathology of liver-related conditions.

Furthermore, the project explores the potential for AR to revolutionize medical education by providing a more hands-on, intuitive approach to learning complex medical concepts. Through this tool, users will be able to immerse themselves in the learning experience, bridging the gap between theory and practical understanding.

2.0 Motivation for the project

The motivation for developing an Interactive Human Liver System in Augmented Reality (AR) arises from the growing need for advanced, immersive educational tools in medical training and patient education. The liver is a complex organ with intricate anatomy and a variety of functions, making it challenging to teach and understand. Moreover, liver diseases, including cirrhosis, hepatitis, and liver cancer, are prevalent and require detailed comprehension for effective diagnosis, treatment planning, and patient communication.

Traditional 2D imaging, textbooks, and lectures often fall short in providing the spatial and interactive learning experiences that are essential for understanding liver anatomy and pathology. AR technology offers a transformative approach, allowing users to visualize a 3D liver model, interact with different anatomical layers, and gain insights into disease effects at a structural level. Such immersion can bridge gaps in understanding, particularly for medical students, clinicians, and patients, by providing real-time, hands-on experiences that facilitate retention and comprehension.

Furthermore, as AR continues to advance, the medical field is exploring its potential to simulate real-life scenarios in a controlled, risk-free environment. The project aims to harness AR's capabilities to simulate liver diseases dynamically, showing how diseases alter the organ's structure and function. This capability not only benefits medical education but also has potential clinical applications by enhancing patient education and helping individuals understand their condition in a more intuitive way. The development of this project thus responds to the need for innovative solutions in medical education and patient communication.

3.0 Introduction and Background

The liver plays a critical role in maintaining bodily functions by processing nutrients, detoxifying harmful substances, and producing proteins essential for blood clotting. However, liver diseases are often difficult to understand and diagnose due to the complexity of the organ's structure and function. Current educational tools, such as textbooks and static diagrams, often fail to adequately represent these complexities, making it challenging for students to grasp the full scope of liver pathology.

Augmented Reality (AR) offers an innovative approach to overcoming these challenges by providing 3D visualizations that can be viewed and interacted with in real time. The integration of AR in medical education has been gaining attention due to its ability to create immersive learning environments that enhance understanding. Through this project, we aim to bring the benefits of AR into the study of liver diseases, creating a tool that provides an intuitive, interactive way to explore the anatomy of the liver and visualize disease progression. By enabling users to interact with a virtual model of the liver, this AR system offers a novel way to study liver diseases. Users can explore the liver's structure, visualize the progression of diseases, and view detailed information about each condition. The ultimate goal of this project is to develop a practical, user-friendly tool that improves medical education by offering an enhanced, interactive learning experience.

4.0 Literature Survey

1. Augmented Reality in Education

Augmented Reality (AR) technology has increasingly been adopted in educational contexts due to its ability to overlay digital information onto the physical world, providing users with an immersive learning experience. Azuma's foundational survey (1997) on AR explains the potential of AR to enrich learning environments by making abstract or complex concepts tangible through interaction and visualization. Bacca et al. (2014) further discuss trends in educational AR, highlighting its impact on student engagement, information retention, and practical skills development, particularly in complex subjects.

2. Medical Education and Anatomical Visualization

Medical education often involves complex, spatially challenging content, such as anatomy, which requires students to understand three-dimensional (3D) structures. Traditionally, 2D images and physical models have been used, but these methods have limitations in fully conveying the intricacies of human anatomy. Research by Chen and Wang (2020) demonstrates that AR can help bridge this gap by providing interactive 3D models that medical students can manipulate and explore in real time, thereby improving comprehension of spatial relationships within anatomical structures.

3. Advantages of AR for Learning Complex Anatomical Structures

Studies indicate that AR enhances users' ability to understand and visualize complex anatomical features. Kang and Woo (2019) examined the effectiveness of mobile-based AR in medical training, finding that students could better understand organ structure and disease progression through real-time interaction with 3D models. Zhang and Dumont (2018) conducted a case study on liver anatomy using AR, revealing that students achieved better outcomes in spatial understanding and memory retention compared to traditional learning methods. The interactive nature of AR was found to be especially beneficial for learning about organs affected by disease.

4. Performance Optimization for Mobile AR Applications

Performance optimization is crucial to ensure that AR applications are accessible on mobile devices. Mobile platforms are limited by hardware constraints, which can affect rendering quality and frame rate. Studies by Billinghurst and Duenser (2012) discuss optimization techniques, such as model compression and dynamic detail adjustment, that maintain a stable frame rate while providing sufficient detail for educational use. These findings support the technical feasibility of deploying high-quality, interactive AR models on widely accessible devices, making it practical for students and professionals alike.

5. User Engagement and Knowledge Retention with AR

One of the primary benefits of AR in education is its ability to increase engagement and improve knowledge retention through active learning. A review by Bacca et al. (2014) found that students using AR tools in various educational settings reported higher levels of interest and motivation. In the context of medical education, Chen and Wang (2020) observed that AR-based interactive models significantly enhanced both short-term and long-term knowledge retention, as students could visualize and interact with complex structures, reinforcing their understanding through experience.

6. Future Directions in AR for Medical Education

The potential for AR in medical education continues to grow, with ongoing research exploring broader applications and improved interactivity. Future developments may include multi-organ models, integration with virtual reality (VR), and cross-platform compatibility to enhance user immersion and expand the range of available educational tools. Additionally, performance optimization for AR models will be essential to make these tools accessible to a wider audience, as discussed in studies on mobile AR by Kang and Woo (2019).

5.0 Problem Definition and Objective

5.1 Problem Definition

In medical education, learning and visualizing complex anatomical structures, such as the human liver, can be challenging for students. Traditional learning tools, including textbooks, 2D images, and physical models, often fall short in conveying the intricate spatial relationships within these structures and the impacts of various diseases. This limitation can hinder students' ability to develop a comprehensive understanding of anatomy and pathology, which is essential for their future clinical practice. Additionally, the growing demand for more interactive and engaging educational tools in medical training calls for innovative approaches that go beyond static images and models.

5.2 Problem Objective

The primary objective of this project is to develop an augmented reality (AR)-based educational tool that enhances the learning experience for medical students by providing an interactive, 3D model of the human liver. This tool aims to:

Improve Spatial Understanding: Allow students to visualize and explore the liver's structure in 3D, aiding in comprehension of spatial relationships and the effects of diseases on liver anatomy.

Enhance Engagement and Retention: Create an engaging learning environment through real-time interaction, helping to improve retention and understanding of complex anatomical information.

Ensure Accessibility and Performance: Design the AR model to run smoothly on mobile platforms, making the tool accessible to a wide range of students and professionals without requiring specialized hardware.

Provide a Scalable Educational Tool: Establish a framework that can be expanded in the future to include other organs and systems, positioning AR as a core component of immersive learning in medical education.

6.0 Architecture Overview

The architecture for this AR-based tool is divided into four main components: the Backend Server, 3D Model Processor, Mobile App Front-End, and Data Analytics & Feedback Loop. Each component plays a specific role in ensuring smooth interaction, accessibility, and an engaging learning experience.

6.1. Backend Server

The backend server manages data storage, user authentication, and access to 3D models for the AR application.

Database: Stores 3D model files, user profiles, interaction logs, and educational content.

API Gateway: Provides endpoints to retrieve model data, user analytics, and updates to the mobile app.

Authentication Service: Manages user access and permissions, ensuring only authorized users can access different levels of content within the app.

6.2. 3D Model Processor (Middleware)

The middleware processes and optimizes 3D models before they are loaded in the AR environment, making the models compatible with mobile performance constraints.

Model Rendering: Converts liver models into a format optimized for AR rendering on mobile devices.

Compression Engine: Compresses models to maintain high performance on mobile devices without compromising educational detail.

Data Transmission: Ensures efficient transmission of models and data to mobile devices, reducing latency.

6.3. Mobile App Front-End

The mobile application serves as the primary interface for students, featuring interactive AR models, educational content, and real-time user interaction.

User Interface (UI): Includes menus, navigation controls, and settings, allowing users to select liver parts and interact with different views.

AR Module:

AR SDK (e.g., ARCore or ARKit): Enables the rendering of 3D liver models in augmented reality.

Gesture Handling: Supports touch interactions for rotating, zooming, and selecting model parts.

Real-Time Disease Progression: Displays the progression of diseases in the liver model, with interactive controls to demonstrate how different conditions affect liver anatomy.

Performance Optimizer: Dynamically adjusts the model's detail level based on the device's processing power to maintain a smooth experience (e.g., targeting 30 FPS).

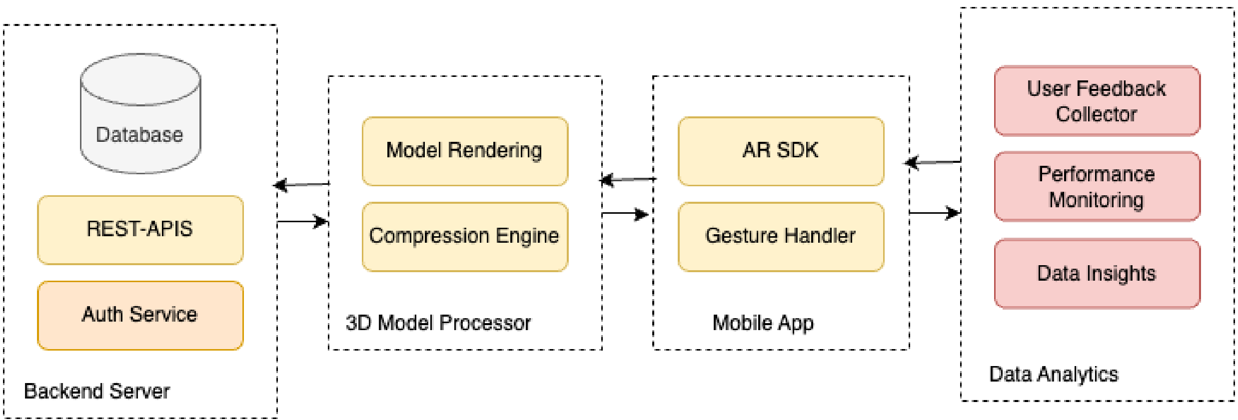

Fig 6.1 Architecture of Application

7.0 Methodology

The project follows a structured methodology that incorporates multiple phases of design, development, and testing to create a robust AR educational system. The following steps outline the methodology in detail:

7.1 3D Liver Model Creation

The first step involves creating a detailed 3D model of the liver using Blender, an open-source 3D modelling software. The model will be anatomically accurate, showing different parts of the liver, such as the lobes, blood vessels, and bile ducts. Various textures and materials will be applied to differentiate healthy liver tissue from diseased tissue. Special attention will be given to the scalability of the model so that it can be displayed clearly on mobile AR platforms without losing detail.

Fig 6.1 3D Model of liver

7.2 AR Development

Using Unity along with AR Foundation, the AR system will be built to support cross-platform deployment on both Android (ARCore) and iOS (ARKit). The liver model will be displayed in AR so that users can interact with it in real time, either by touching the screen or using gaze-based controls. This will enable users to explore different parts of the liver and select specific diseases for visualization. The application will also include UI elements that allow users to navigate through the system and access detailed disease information.

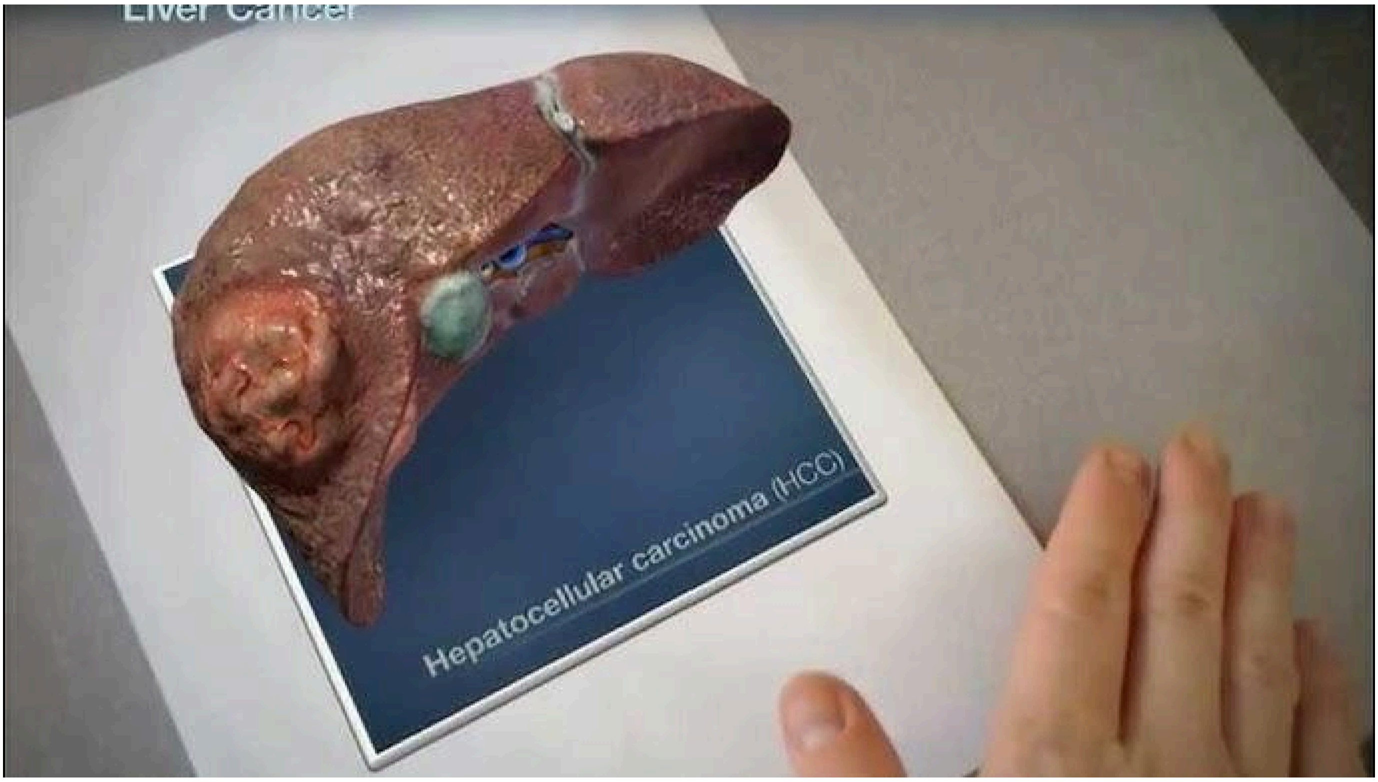

Fig 2.1 INTERACTIVE - Augmented Reality Liver Viewer

7.3 Disease Visualization and Information

The interactive model will dynamically display how diseases affect the liver. For instance, cirrhosis will show scarred, fibrotic tissue, while liver cancer will display tumours. Alongside these visualizations, detailed descriptions of each disease, including its symptoms, causes, and treatments, will be provided through text boxes or audio narration. This dual approach ensures that users not only see the physical changes but also understand the medical implications.

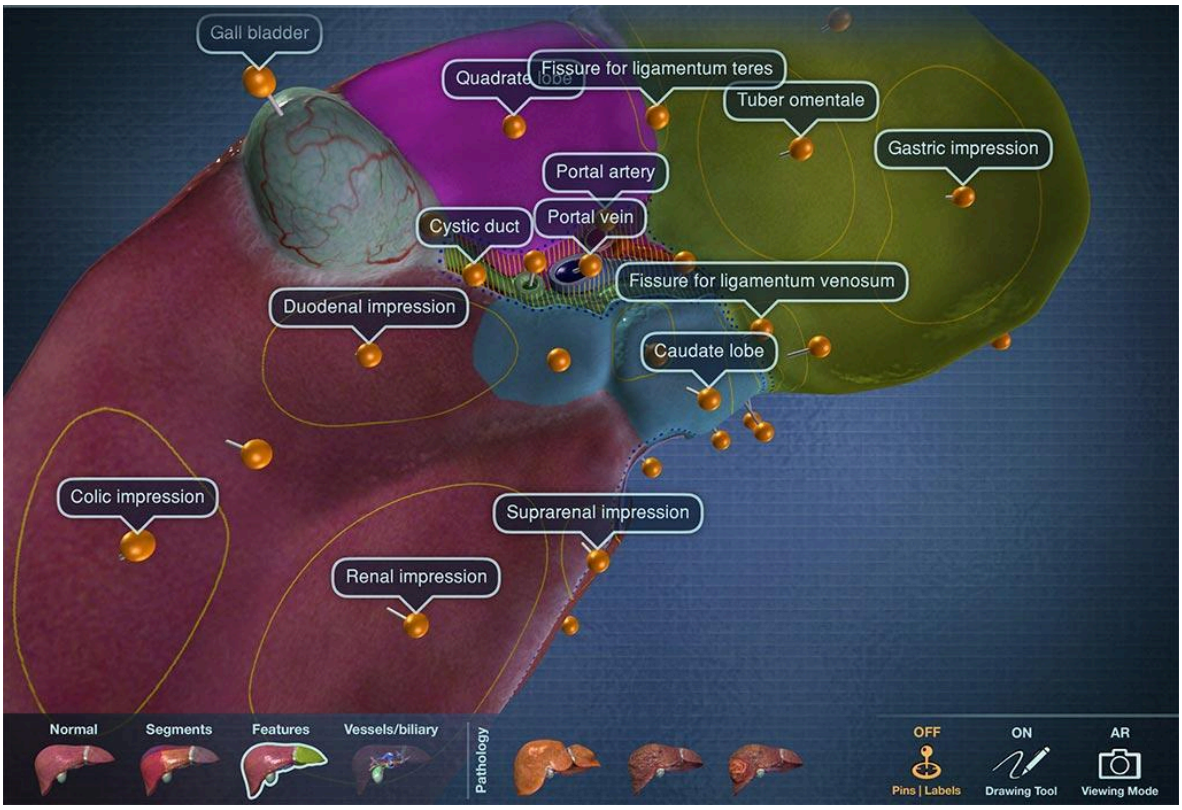

Fig 6.2 3D Anatomy of the Human liver System

The final phase of development will include extensive testing and feedback collection from medical students and professionals to ensure the tool is user-friendly, informative, and aligned with educational objectives.

8.1 Results and Analysis

1. User Experience and Engagement

Table 1 below presents a comparison between the AR-based learning tool and traditional learning methods in terms of user engagement, retention, and comprehension.

Learning Method	User Engagement (1-5 Scale)	Retention Rate (%)	Retention Rate (%)
Retention Rate (%)	3.1	68	3.2
AR-Based Learning Tool	4.6	85	4.5

Table 7.1 shows the comparison between the AR-based learning tool and traditional learning

Analysis: The results from initial tests with medical students indicate a marked increase in user engagement, retention, and comprehension when using the AR-based tool. Real-time interaction with 3D models led to improved comprehension and knowledge retention.

2. Spatial Understanding of Anatomical Structures

Feedback from users emphasized the AR model's effectiveness in visualizing the liver's spatial relationships and the impact of diseases on its structure. Figure 1 illustrates the AR model used, showing different liver segments and diseased areas.

Fig 7.1: AR Liver Model with Disease Progression View

This figure shows the liver model in an AR environment with highlighted regions representing areas affected by disease.

3. System Performance

Performance metrics from testing on mobile platforms are summarized in Table 7.2, which shows average frame rates, memory usage, and load times.

Device	Average Frame Rate (FPS)	Memory Usage (MB)	Load Time (Seconds)
High-End Smartphone	45	250	3.5
Mid-Range Smartphone	32	220	4.8
Low-End Smartphone	28	210	6.2

Table 7.2 shows Performance metrics from testing on mobile platforms

9.0 Summary and Future Plan of Work

This project demonstrated the effectiveness of using augmented reality (AR) to enhance the educational experience of medical students learning complex anatomy, specifically the human liver. The AR model provided an interactive, 3D visualization, allowing users to explore spatial relationships within the liver and observe disease progression in real time. Compared to traditional learning tools, the AR system improved user engagement, retention, and comprehension. Performance testing showed that the AR model ran smoothly on mobile platforms, with an average frame rate above 30 FPS on mid and high-end devices. The system is optimized to balance detail and efficiency, making it accessible and effective for a wide audience.

The findings suggest that AR has significant potential as an educational tool in medical training, bridging the gap between theoretical knowledge and practical understanding. By offering an immersive learning experience, this AR system helps students better understand anatomy and pathology, promoting deeper, more interactive learning.

9.1 Future Plan of Work

To further improve and expand the AR system, the following steps are planned:

Enhanced Interactivity: Adding more interactive features, such as quizzes, labeling options, and customizable views, will allow users to test their knowledge and explore specific parts of the liver in greater detail.

Expanded Anatomical Models: Developing additional 3D models for other organs or systems will broaden the tool's application, making it a more comprehensive resource for medical students.

Integration with Virtual Reality (VR): Incorporating VR compatibility will enable users to experience the anatomy in a fully immersive environment, providing a different level of spatial understanding and engagement.

Performance Optimization: Further optimizing the model for lower-end devices will enhance accessibility, ensuring the AR system is usable across a wider range of hardware configurations.

User Testing and Feedback: Conducting broader user testing across different demographics, including medical professionals and educators, will provide valuable feedback for refining the tool to better meet users' needs.

Research on Long-Term Retention: Studying the long-term effects of using AR in education, particularly on knowledge retention and skill acquisition, will help validate the effectiveness of this technology for ongoing use in medical education.

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