VR Driving Learning Simulator

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Project report submitted in partial fulfilment of the requirements
for the Degree of M.Tech. in Computer Engineering (Specialized in Software Engineering)

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Project Guide

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Student Declaration

I hereby declare that the work presented in the report entitled **"VR Driving Learning Simulator"** submitted by me for the partial fulfilment of the requirements for the degree of *M.Tech. in Computer Engineering(Specialized in Software Engineering)* at Veermata Jijabai Technological Institute, Mumbai, is an authentic record of my work carried out under the guidance of **Dr. V.B.Nikam** . Due acknowledgements have been given in the report for all material used. This work has not been submitted elsewhere for the reward of any other degree.

Ritvik Babre **Place & Date:** November 16, 2025

Certificate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dr. V.B.Nikam **Place & Date:** November 16, 2025

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Chapter 1

Introduction

1.1 Background

The integration of Virtual Reality (VR) technologies in the field of driver training has opened new avenues for creating realistic and safe learning environments. Traditional driving instruction often faces limitations due to safety concerns, vehicle costs, and environmental constraints. Additionally, training on high-end or luxury vehicles such as Mercedes-Benz, BMW, or Audi models is often impractical for driving schools because of their operational and maintenance costs. To overcome these challenges, VR-based driving simulators have emerged as an effective alternative, allowing learners to experience authentic driving conditions without the associated risks or expenses [1].

With advancements in modern VR hardware such as the Meta Quest 3, it has become feasible to develop highly immersive simulations that closely replicate real-world vehicle dynamics, visual fidelity, and driver feedback. This project aims to design and develop a **VR-based Driving Simulator for Driving Schools**, focusing on high-end vehicle simulations. The system will leverage custom-built input hardware—including a rewired steering wheel, accelerator, brake, and clutch assembly—connected via Bluetooth to the simulation platform. These components will provide realistic control feedback and allow for seamless integration with both automatic and manual vehicle modes.

1.2 Problem Statement

Conventional driving simulators are often expensive, bulky, and lack realistic tactile feedback from vehicle controls. Furthermore, most commercially available simulators are targeted at entertainment rather than driver education, leading to a gap in the availability of accurate and affordable driver training systems. There exists a need for a modular, scalable, and hardware-accurate VR driving simulator that can be customized for specific vehicle models and used effectively in a driving school setting.

1.3 Objectives

The primary objective of this project is to develop a patentable, high-fidelity VR driving simulator that provides an immersive and realistic driving experience. The specific goals include:

- Designing a VR-compatible driving simulation system for Meta Quest 3 and PC platforms.
- Developing realistic vehicle physics and environmental models using Unity or Unreal Engine.
- Integrating physical driving controls (steering, pedals, gear shifter) with Bluetooth-based input communication.
- Providing accurate feedback mechanisms and data logging for performance assessment.
- Creating an extensible system architecture that allows for both automatic and manual transmission modes.

1.4 Scope

The system will initially focus on simulating automatic vehicles, with the potential extension to manual transmission as a secondary phase. The prototype will be tested using a Meta Quest 3 headset connected to a PC equipped with an NVIDIA RTX 3060 GPU. The developed system will be optimized for standalone operation on Meta Quest devices, with scalability for PC-VR tethered mode. In the long term, the simulator can be expanded for collaboration with government agencies such as the Mumbai RTO for standardized driver education and testing.

1.5 Report Overview

This report presents the design, implementation, and evaluation of a VR-based driving simulator that integrates realistic physical controls with an immersive headset platform. The document first explains the motivation and technical background for the project, then presents the system architecture, hardware and firmware design for the control rig, and the software components implemented in the VR application. Subsequent sections describe the prototype development process, testing methodology, evaluation metrics, and experimental results. The report concludes with a discussion of limitations, future work, and potential routes for commercialization and IP protection.

Chapter 2

Literature Review

This chapter reviews prior research related to Virtual Reality (VR) and Augmented Reality (AR) systems used in autonomous driving and driving simulators. Table 2.1 summarizes key studies focusing on training effectiveness, physiological engagement, and human factors analysis within VR-based driving environments.

Title	**Authors**	**Key Findings**	**Gaps / Limitations**	**Relevance / Context**
Virtual Reality Tour for First-Time Users of Highly Automated Cars: Comparing the Effects of Virtual Environments with Different Levels of Interaction Fidelity (2021) [1]	Rayan Ebnali Harari, Richard Lamb, Razieh Fathi, Kevin Hulme	High-Fidelity VR — using steering wheel/pedals — significantly improved automation trust, takeover time, and takeover quality for first-time users compared to Low-Fidelity VR.	Participants knew takeover events were coming; short driving sessions (1 hour); limited generalization of training protocol for highly automated driving (SAE L3/L4).	High interaction fidelity in VR training is crucial for effective motor skill transfer. Demonstrates VR's efficacy for SAE L3 automation training.
Feasibility of AR-VR Use in Autonomous Cars for User Engagements and its Effects on Posture and Vigilance During Transit (2023) [3]	Joseph Muguro, Pringgo Widyo Laksono, Yuta Sasatake, Muhammad Ilhamdi Rusydi, Kojiro Matsushita, Minoru Sasaki	In-car VR engagement tasks maintained vigilance (measured by EDA, pupil size) compared to a no-task baseline. Tasks delayed hazard recognition time by less than one second. Mixed tasks improved posture.	Small sample (15); limited test scenarios; motion sickness not fully investigated.	Provides physiological evidence (EDA, pupil size) that VR/AR tasks can maintain vigilance in Autonomous Driving Systems (ADS).
User Monitoring in Autonomous Driving System Using Gamified Task: A Case for VR/AR In-Car Gaming (2021) [4]	Joseph K. Muguro, Pringgo Widyo Laksono, Yuta Sasatake, Kojiro Matsushita, Minoru Sasaki	Gamified AR tasks did not significantly impair hazard recognition. Game score trends (learning, saturation, decline) can infer driver state and maintain vigilance. Gaze data confirmed focused attention.	Simulated VR setup instead of a real car; small, young participant sample (13 students).	Confirms utility of gamification in ADS to maintain vigilance. Proposes game performance metrics as indicators for automated driver monitoring.
Driving Performance Evaluation Correlated to Age and Visual Acuities Based on VR Technologies (2020) [2]	Sooncheon Hwang, Sunhoon Kim, Dongmin Lee	Dynamic Visual Acuity was a stronger predictor of unsafe driving behavior than Static Visual Acuity. Poor DVA linked to higher lane deviation.	Small sample (65); VR driving differs from real roads; identical thresholds used for SVA and DVA.	Shows VR simulators' value for studying visual acuity's correlation to driving performance and safety.

Table 2.1: Summary of key prior research on VR and AR systems for driving and autonomous vehicle simulation.

The studies summarized in Table 2.1 collectively indicate that interaction fidelity, physiological engagement monitoring, and gamification significantly influence driver training outcomes and user vigilance. These insights directly inform the system design of the proposed VR-based driving simulator presented in Chapter **??**.

Chapter 3

System Analysis

3.1 Overview

The **VR Driving Simulator** project aims to provide a high-fidelity training and evaluation environment for driving schools. The simulator models real-world driving dynamics using virtual reality and custom-built physical input devices (steering wheel, pedals, and gear shifter). This chapter outlines the system analysis, including its functional components, workflows, and overall system architecture.

3.2 Objectives

- To design a modular VR-based driving simulation environment replicating realistic car control and behavior.
- To integrate Bluetooth-enabled hardware input devices for steering, acceleration, braking, and gear shifting.
- To ensure compatibility with the Meta Quest 3 headset (and optionally PC VR link) for immersive interaction.
- To provide performance analytics for driver evaluation and training improvement.

3.3 System Components

The proposed system consists of three major components:

1. **Hardware Interface:** The physical control setup — steering wheel, pedal set, and gear lever — connected via Bluetooth or USB.
2. **Software Simulation:** Developed in Unity or Unreal Engine, containing vehicle physics, 3D environment, and UI.

3. **VR Interface:** The Meta Quest 3 headset provides head tracking, stereoscopic rendering, and real-time feedback.

3.4 Model Diagram

Figure 3.1 illustrates the logical relationship between the hardware, software, and VR components.

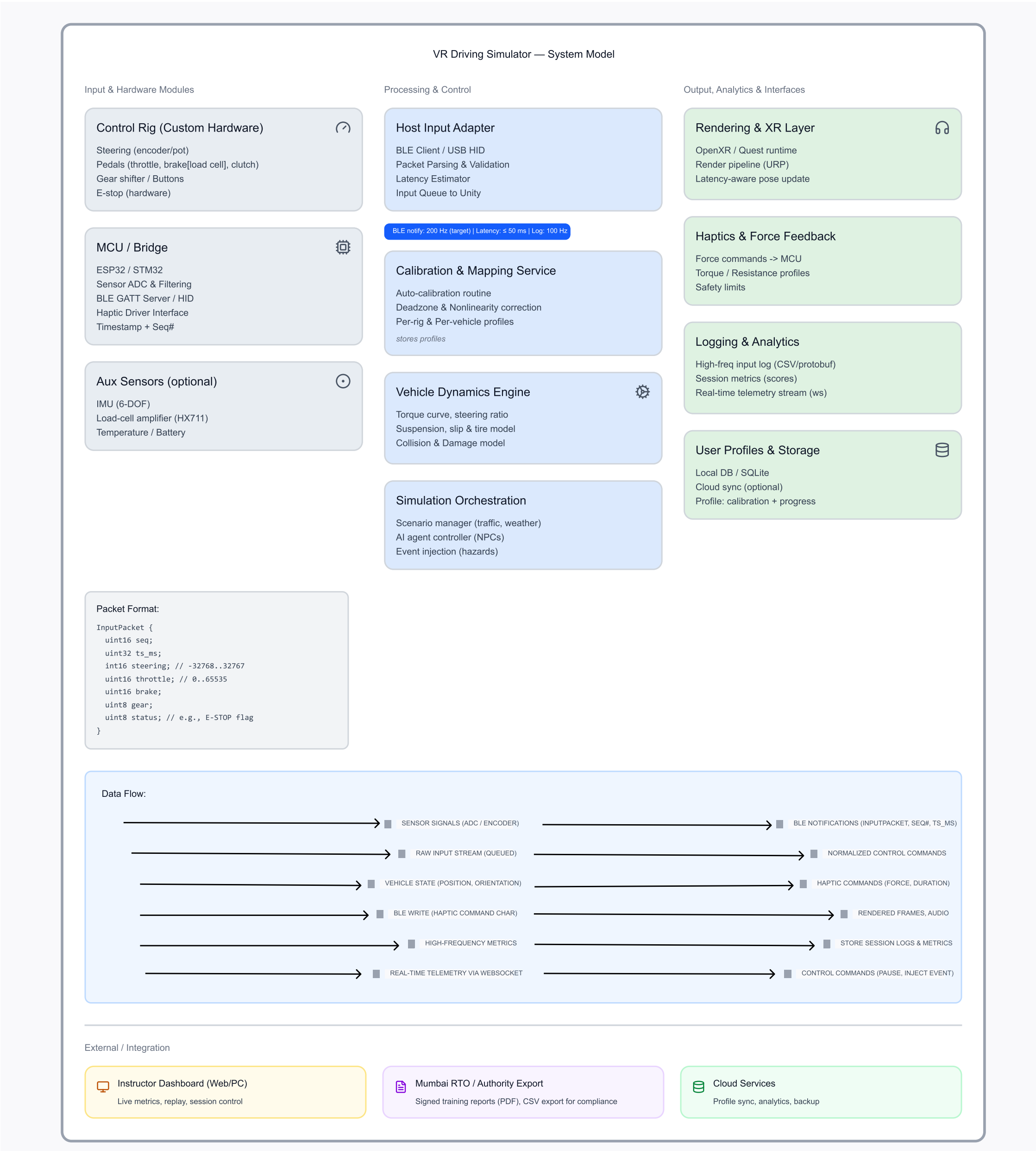

Figure 3.1: Model diagram of the proposed VR Driving Simulator system.

3.5 System Architecture

The system architecture describes how hardware inputs, simulation logic, and VR rendering interact. Data from the steering and pedal modules is transmitted to the main simulation engine, which processes it through a physics module and updates the rendered environment in real time.

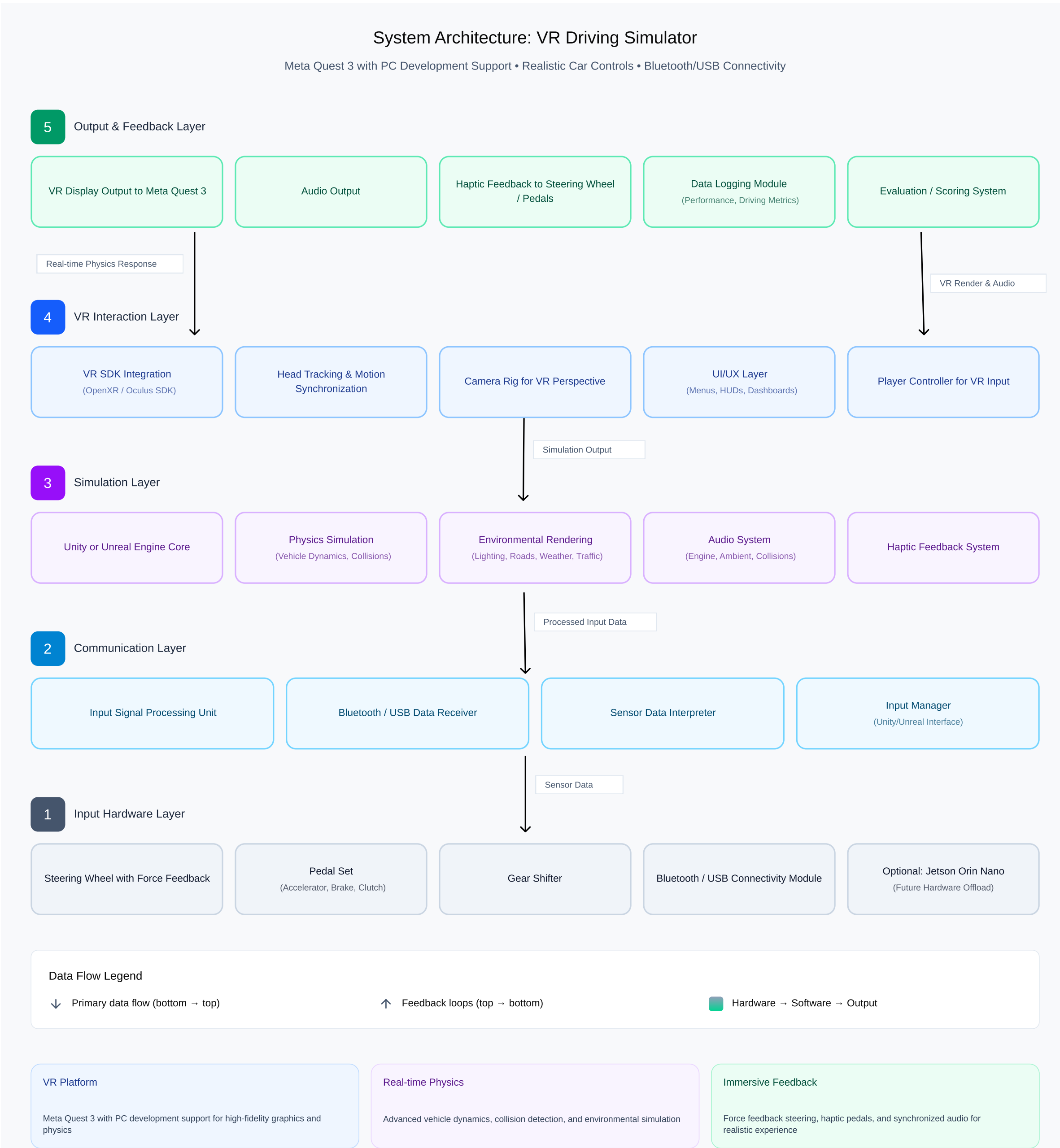

Figure 3.2: System architecture of the VR Driving Simulator.

3.6 Workflow Diagram

The workflow diagram (Figure 3.3) shows the sequential process of system operation — from initializing the simulation to user interaction and evaluation.

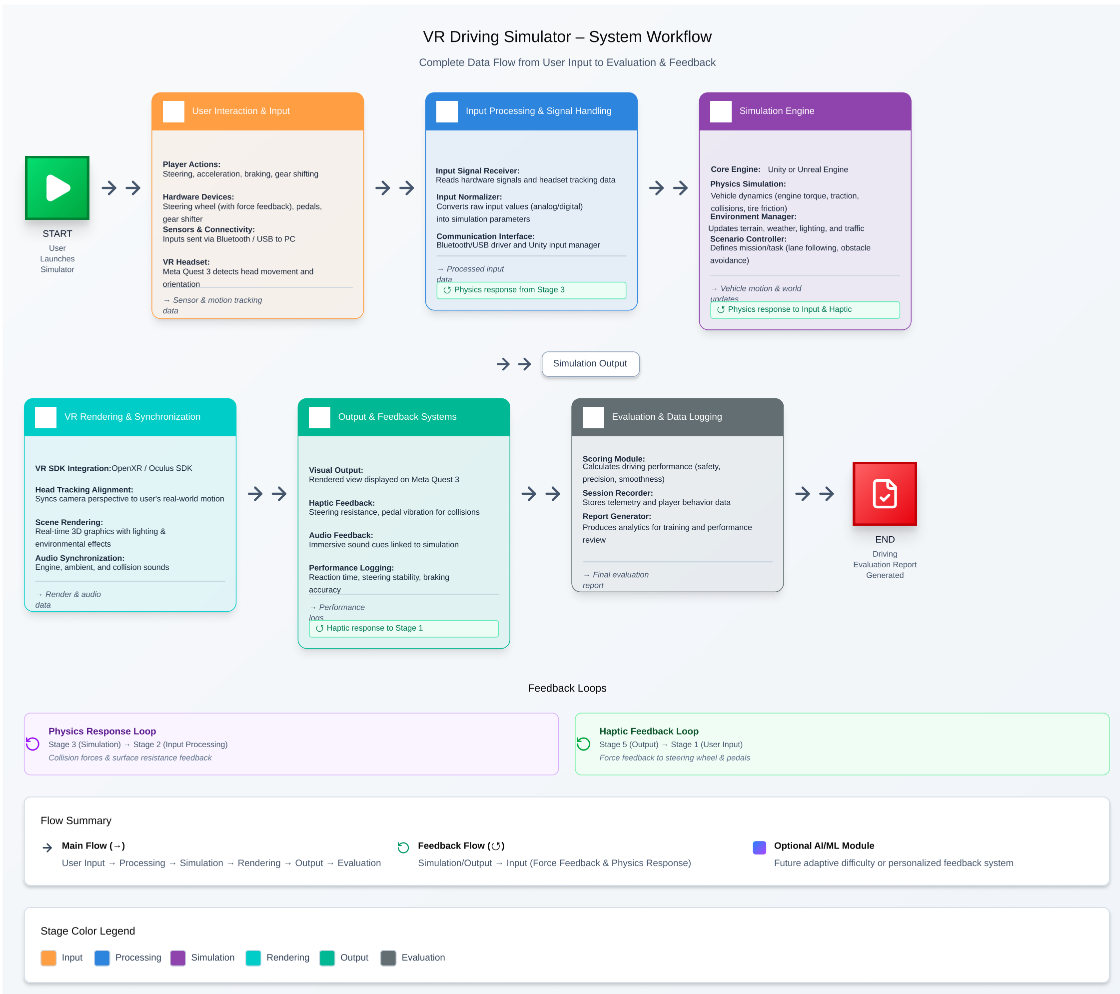

Figure 3.3: Workflow of the VR Driving Simulator system.

3.7 Functional Flow

1. **Initialization:** Load vehicle and environment assets.
2. **Hardware Connection:** Establish Bluetooth or USB input from the control devices.
3. **Simulation Loop:** Capture input data, process physics, and update visuals.
4. **VR Rendering:** Display stereo visuals through the Meta Quest 3 headset.
5. **Performance Evaluation:** Record metrics such as braking efficiency, lane deviation, and speed consistency.

3.8 Conclusion

This system analysis outlines how the proposed simulator integrates custom hardware, immersive VR visualization, and realistic physics. The subsequent chapter will focus on implementation and integration details.

Bibliography

[1] Rayan Ebnali Harari et al. "Virtual Reality Tour for First-Time Users of Highly Automated Cars: Comparing the Effects of Virtual Environments with Different Levels of Interaction Fidelity". In: *Proceedings of ...* 2021. DOI: 10.3389/fpsyg.2021.628484. URL: https://doi.org/10.3389/fpsyg.2021.628484.

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