Project ID: R26-IM-004

FEASIBILITY STUDY REPORT

Individual Research Component

Feasibility Study for the Motion Rendering and Control for Embodied VR Navigation

ST ID: IT22082992

ST Name: Gunawardena L H

5/13/2026

Executive Summary

This feasibility study evaluates the development and implementation of the Motion Rendering and Control for Embodied VR Navigation component of the broader research project titled Immersive Multisensory VR Motion System for Full-body Navigation. The component addresses a major limitation in current seated Virtual Reality (VR) navigation systems, where visual movement is not properly matched with synchronized physical motion feedback. This sensory mismatch reduces immersion, weakens embodied interaction, and contributes to cybersickness during VR experiences.

The proposed solution is a motion rendering and control framework for a broom-based seated VR navigation system. The component converts VR flight parameters such as direction, acceleration, tilt, and movement transitions into synchronized actuator control signals that drive a physical motion seat. The system generates perceptually meaningful motion cues through controlled seat movement, allowing users to physically feel aspects of virtual aerial navigation rather than relying solely on visual simulation. The framework is integrated with Unity-based VR navigation and microcontroller-driven actuator control to support real-time interaction between the virtual and physical systems.

The feasibility assessment finds the project viable across all evaluated dimensions. Technically, the required technologies including Unity, Arduino Uno, microcontrollers, serial communication interfaces, and actuator control systems are mature, affordable, and well-supported by existing development resources. The modular motion-seat approach significantly reduces the complexity and cost associated with full-scale industrial motion simulators while still supporting meaningful physical feedback. Operationally, the system is designed as a controlled seated VR platform with constrained motion ranges to ensure safe and repeatable interaction. Financially, the development cost remains within a realistic undergraduate research budget due to the use of accessible hardware components and open development tools. Market feasibility is supported by the increasing demand for immersive VR experiences in gaming, simulation, and location-based entertainment, combined with the lack of accessible embodied motion systems designed for scenario-focused VR aerial navigation.

Based on the analysis, the project is considered feasible and is recommended to proceed. The primary risks identified include actuator response inconsistency, synchronization delays between VR events and physical motion output, and mechanical stability limitations during rapid motion transitions. Each identified risk has practical mitigation strategies involving iterative testing, constrained motion control, and continuous synchronization evaluation. The recommended next step is to develop the initial motion rendering pipeline and integrate a basic actuator-controlled seat prototype as a working proof of concept for early-stage validation.

Table of Contents

1.Introduction....1
1.1 Background....1
1.2 Objective....1
1.3 Scope....2
2. Problem Statement....2
3. Project Description....3
3.1 Proposed Solution....3
3.2 Key Features....3
3.3 Methodology....4
3.4 System Overview....4
4. Feasibility Analysis....5
4.1 Technical Feasibility....5
4.2 Market Feasibility....5
4.3 Financial Feasibility....6
4.4 Operational Feasibility....6
4.5 Ethical Feasibility....7
5. Risk Analysis....8
6. Recommendations....9
6.1 Feasibility Summary....9
6.2 Overall Conclusion on Feasibility....9
6.3 Suggested Next Steps....10
7. Conclusion....11
8. References....12
9. Appendices....13

1.Introduction

1.1 Background

Modern Virtual Reality (VR) systems provide strong visual immersion, yet most seated VR navigation experiences still lack synchronized physical motion feedback. Users visually experience acceleration, turning, and directional movement inside the virtual environment, but their bodies remain physically stationary. This sensory mismatch reduces immersion, weakens embodied interaction, and frequently contributes to cybersickness, discomfort, and reduced realism during prolonged VR experiences. Traditional VR locomotion approaches such as joystick-based navigation and teleportation further increase the disconnect between user action and perceived motion, making aerial and movement-intensive VR experiences feel artificial and physically ungrounded.

Motion simulation technologies have demonstrated the ability to improve realism and user perception in immersive environments, yet existing high-end VR motion simulators are expensive, mechanically complex, and inaccessible for small-scale research and entertainment applications. At the same time, many existing haptic and motion-feedback systems focus only on isolated vibration effects without translating VR navigation behaviour into perceptually meaningful physical motion cues. Limited research has explored scenario-focused motion rendering specifically for broom-based seated VR aerial navigation, where virtual flight parameters must be converted into synchronized actuator-driven motion feedback.

This feasibility study focuses exclusively on Component 1, Motion Rendering and Control for Embodied VR Navigation, which investigates how VR navigation parameters such as acceleration, tilt, directional movement, and flight transitions can be translated into synchronized physical motion cues within a modular seated VR motion platform.

1.2 Objective

The objective of this feasibility study is to determine whether the proposed Motion Rendering and Control for Embodied VR Navigation component can be successfully designed, developed, integrated, and evaluated within the technical, financial, and operational constraints of an undergraduate research project. The study aims to assess the practicality of translating VR aerial navigation parameters into synchronized physical motion cues using a modular motion-seat platform, while identifying potential risks related to actuator control, synchronization accuracy, system stability, and user safety before full-scale development begins.

1.3 Scope

This feasibility study evaluates the following dimensions of the proposed component:

- Technical feasibility - the suitability of the technologies required for VR motion rendering, actuator control, and real-time synchronization between the virtual and physical systems.
- Market feasibility - the potential demand for immersive motion-based VR experiences and the limited availability of affordable embodied VR navigation platforms.
- Financial feasibility - the estimated development cost of hardware, fabrication, VR setup, and software implementation within an undergraduate research budget.
- Operational feasibility - the practicality of developing, integrating, and operating the motion rendering system within a safe and controlled seated VR environment.
- Ethical and safety feasibility - compliance with participant safety and research ethics requirements during VR motion testing, including informed consent, safe motion limits, and participant withdrawal rights.

2. Problem Statement

Most seated Virtual Reality (VR) navigation systems rely mainly on visual simulation while providing little or no synchronized physical motion feedback. Users can visually experience acceleration, turning, and aerial movement inside the virtual environment, but their bodies remain physically stationary. This sensory mismatch reduces immersion, weakens embodied interaction, and can contribute to discomfort and cybersickness during VR experiences.

Existing VR motion platforms capable of generating physical motion cues are often expensive, mechanically complex, and inaccessible for small-scale immersive entertainment and research applications. In many low-cost VR systems, motion feedback is limited to simple vibration effects that do not meaningfully represent virtual navigation behavior such as acceleration, directional movement, tilt, or flight transitions.

Although motion simulation and haptic feedback technologies have shown strong potential for improving realism and user perception in immersive environments, limited research has explored motion rendering specifically for broom-based seated VR aerial navigation. There is currently no affordable and modular VR motion rendering framework that translates aerial navigation parameters into synchronized actuator-driven motion cues designed to improve realism, immersion, and embodied interaction in seated VR experiences.

3. Project Description

3.1 Proposed Solution

The proposed solution is a motion rendering and control framework for a seated VR aerial navigation system integrated with a motion-seat platform. The system converts VR navigation parameters such as acceleration, directional movement, and tilt into synchronized actuator-driven motion cues.

Unity is used to monitor VR flight behavior and generate real-time control signals, while microcontroller-based hardware executes the corresponding physical seat movements. The component is designed to improve realism, immersion, and embodied interaction during broom-based VR navigation through synchronized physical motion feedback.

3.2 Key Features

- **Scenario-Specific Motion Cueing for Broom-Flight**: Generates synchronized physical motion cues optimized specifically for the Nimbus-based aerial navigation experience.
- **Dynamic Data-to-Actuator Mapping**: Converts real-time VR navigation parameters including position, velocity, and acceleration into precise actuator control signals.
- **Adaptive Motion Rendering Models**: Supports the implementation and comparative evaluation of position-based, velocity-based, and acceleration-based rendering strategies.
- **Multi-Axis Physical Feedback**: Controls actuation to simulate authentic tilt and directional cues during virtual flight maneuvers.
- **Synchronized Real-Time Interface**: Features a low-latency serial communication link between the Unity VR engine and the microcontroller-based (Arduino) hardware interface.
- **Embedded Safety Logic**: Integrates motion control constraints and adaptive intensity limits within the rendering model to ensure user safety and structural stability.
- **Performance & Perceptual Logging**: Captures detailed system metrics and synchronization data for quantitative research and evaluation of motion realism.

3.3 Methodology

The project follows a Design Science Research (DSR) methodology with a focus on iterative development and experimental validation. The system is developed through the iterative design of a motion rendering framework for a modular VR motion seat platform. Evaluation is conducted as a controlled comparison of different motion rendering strategies specifically position-based, velocity-based, and acceleration-based models to identify which approach most effectively improves realism and embodied interaction. Performance is measured through quantitative system metrics such as actuator response time and synchronization accuracy, alongside qualitative user testing involving questionnaires and experimental trials to assess perceived motion realism and immersion.

3.4 System Overview

The system consists of three primary layers. The Virtual Environment Layer is the Unity-based system that manages the VR scene logic, extracts navigation parameters, and dispatches virtual events. The Synchronization Layer serves as the core processing engine, providing signal synchronization, latency monitoring, and the conversion of VR flight data into adaptive actuator control signals. The Physical Feedback Layer is the modular mechanical rig that executes the motion through a microcontroller-based interface, producing real-time seat tilt and directional actuation to the user.

4. Feasibility Analysis

4.1 Technical Feasibility

The technical foundation of the project rests on mature, well-supported, and widely accessible development tools. Unity is utilized as the primary 3D engine for extracting navigation parameters and managing VR scene logic. Motion rendering is executed through a microcontroller-based interface, specifically utilizing Arduino board for real-time actuator command execution. For precision motion response and synchronization evaluation, IMU (Inertial Measurement Unit) sensors provide the necessary support.

A key technical accelerator for this component is the implementation of specialized motion rendering strategies position-based, velocity-based, and acceleration-based to convert navigation data into physical feedback. These models are refined through iterative Design Science Research (DSR), ensuring stable and realistic motion cues. The reliance on high-speed serial communication between Unity and hardware ensures that the system meets the low-latency requirements essential for a coherent VR experience.

The required expertise spans VR locomotion, motion cueing, embedded systems, and Human-Computer Interaction (HCI). The development is structured around iterative milestones, moving from initial parameter extraction to the integration of a fully functional motion seat vertical slice.

4.2 Market Feasibility

The primary target market for this technology is location-based immersive VR attractions, including arcades, immersive venues, and event spaces. The value proposition centers on providing a high-end, multisensory VR flight experience that offers stronger realism and embodiment than traditional seated VR. The target audience includes fantasy and adventure fans, young gamers, and groups seeking unique immersive experiences.

Market demand is supported by the specific niche for scenario-based motion rendering for broom-flight navigation, which is currently underserved by generic seated VR systems. Potential commercial partners include VR arcades, gaming cafés, and immersive entertainment providers. The nature of the ride design allows the platform to be scaled and reused for multiple themes beyond the initial broom-flight, such as dragon-riding or other fantasy flight scenarios.

Evidence of demand is also linked to the growing interest in embodied interaction within the global VR industry. By offering a synchronized motion seat platform that reduces cyber sickness through improved sensory alignment, the system addresses a critical usability barrier in the current VR market.

4.3 Financial Feasibility

The estimated total cost of development for this component is summarized in the table below:

Item	Description	Estimated Cost (LKR)
Hardware	Actuators, Microcontrollers (Arduino), Pressure Sensors	5,000
Fabrication	Metal frame fabrication and actuator mounting mechanisms	35,000
Software Licenses	Unity (Student License), CAD modeling tools (Free/Academic)	0
Mechanical Parts	Seating, structural supports, and safety constraints	20,000
Miscellaneous	Transport, high-speed serial cables, and contingency	10,000
Total Estimated Cost		**70,000**

The total estimated cost is aligned with the requirements of a high-end mechanical VR research project. While the hardware and fabrication represent a higher cash outlay than software-only components, the use of open-source microcontrollers and student software licenses helps contain costs. Revenue potential in a post-research commercial phase would be driven by per-session pricing at venues, institutional equipment packages, and modular IP licensing.

4.4 Operational Feasibility

The system is designed for high reliability and repeatable operation within public or research environments. The modular mechanical architecture allows the frame and seat to be easily transported or adjusted for different users. Stability under dynamic motion is a core design principle, with load distribution and stress analysis conducted to ensure the rig remains secure during intense navigation.

A core operational principle is the synchronization of virtual events with physical feedback. The system includes a dedicated latency measurement module to quantify timing delays between the VR event and actuator response, ensuring the experience remains believable. Maintenance is simplified through the use of standardized electronic components and a modular design that allows for the independent servicing of actuators or sensors.

Scalability is a key feature of the mechanical design. Once the core motion rendering framework is established, the platform can be adapted for new flight themes by updating the Unity scene logic and adjusting the motion cue generation without requiring a complete redesign of the hardware.

4.5 Ethical Feasibility

Because the research involves human participants interacting with a motorized motion platform, strict ethical and safety compliance is required. The study follows the SLIIT Research Ethics Committee guidelines, ensuring informed consent is obtained from all participants. Participants are fully informed of their right to withdraw at any time, especially if they experience discomfort or fatigue during the motion trials.

Safety is technically integrated into the motion rendering model through predefined mechanical limits and adaptive intensity constraints. User data, including performance metrics and questionnaire responses, is fully anonymized to protect participant privacy. All collected logs are stored securely and used exclusively for academic evaluation, ensuring the project meets all professional research standards.

5. Risk Analysis

The following table summarizes identified risks, their likelihood and potential impact, and the planned mitigation strategy for each:

Risk	Likelihood	Impact	Mitigation Strategy
System latency exceeding perceptual thresholds	Medium	High	Implement real-time latency monitoring and optimize the serial communication pipeline between Unity and the microcontroller.
Mechanical instability during dynamic motion	Low	High	Conduct structural stress analysis and enforce predefined mechanical safety limits within the control logic.
Actuator response timing inconsistencies	Medium	Medium	Use high-precision IMU sensors to track physical response and refine motion cueing algorithms based on synchronization logs.
Participant discomfort or motion sickness	Medium	High	Compare position, velocity, and acceleration-based models to identify the rendering strategy that minimizes sensory mismatch.
Hardware-software synchronization drift	Medium	Medium	Integrate a dedicated latency measurement module to capture timestamps and maintain temporal alignment across the interaction pipeline.
Complexity in mapping flight physics to seat tilt	High	Medium	Focus on a single controlled broom-flight scenario to reduce complexity and allow for deep evaluation of specific motion rendering strategies.
Scope creep adding multiple ride scenarios	High	Medium	Lock the project identity as "Herald" with the supervisor and defer additional fantasy themes to a Phase 2 development list.

Of these risks, the most significant in terms of project delivery is system latency, as a timing mismatch directly breaks user immersion and can lead to cyber sickness. This is mitigated by establishing strict perceptual latency thresholds and utilizing a synchronization layer for real-time monitoring. The second most significant risk is mechanical instability during dynamic motion, which is being aggressively mitigated by integrating safety-constrained motion limits and conducting load distribution analysis on the modular rig.

6. Recommendations

6.1 Feasibility Summary

Aspect	Verdict	Summary
Technical Feasibility	**Feasible**	Core technologies (Unity, Arduino/ESP32) are industry-standard and widely documented. The specialized motion rendering strategies (position, velocity, acceleration-based) provide a clear path for technical implementation.
Market Feasibility	**Feasible**	There is a documented gap in scenario-specific motion rendering for broom-flight VR. The platform has high commercial potential for location-based VR attractions and arcades.
Financial Feasibility	**Feasible**	The total estimated cost is manageable within an undergraduate research budget. Most software tools are accessible via free or student licenses.
Operational Feasibility	**Feasible**	The system is designed with a modular mechanical frame and real-time latency monitoring to ensure repeatable, stable, and safe operation.
Ethical Feasibility	**Feasible**	The project includes strict safety constraints and informed consent procedures that comply with SLIIT Research Ethics Committee guidelines.

6.2 Overall Conclusion on Feasibility

Based on the analysis across all five dimensions, the Motion Rendering and Control for Embodied VR Navigation component is feasible and is recommended to proceed to full development. The technical foundation is solid, supported by specialized cueing models and high-speed communication interfaces. The target market in immersive entertainment is genuine and offers strong commercialization potential. While hardware fabrication requires more capital than software-only components, the costs are manageable, and the operational design ensures a safe, scalable interaction platform. The identified risks regarding latency and stability are real, but each has a clear and practical mitigation strategy.

6.3 Suggested Next Steps

- Lock final VR motion parameters with supervisor approval to ensure the rendering model accurately extracts required navigation data from the Unity environment.
- Begin development of the communication pipeline between Unity and the microcontroller to establish a stable, low-latency serial interface.
- Fabricate the initial actuator mounting mechanisms and integrate them with the structural frame to validate mechanical stability early.
- Develop the first complete motion rendering model (position-based recommended) as a working "vertical slice" to test end-to-end feedback from the broom-flight scenario.
- Integrate real-time latency measurement modules from the start to quantify timing delays and ensure perceptual coherence during the development phase.
- Draft experimental trial protocols in parallel with technical development so that user studies can begin as soon as the motion seat is stable.
- Submit the ethics application to the SLIIT Research Ethics Committee at the earliest opportunity to avoid delays before the participant-based validation phase.

7. Conclusion

This feasibility study has examined the proposed Motion Rendering and Control for Embodied VR Navigation (Component 1) across technical, market, financial, operational, and ethical dimensions. The study finds that the project is feasible on all five dimensions and that the identified risks, such as system latency and mechanical stability, are manageable with the proposed mitigation strategies in place.

The importance of this project lies in the meaningful gap it addresses in high-fidelity VR locomotion. Existing seated VR systems often lack scenario-specific motion rendering, particularly for specialized interactions like broom-flight navigation. The proposed Herald (Nimbus-based) rig directly addresses this through a synchronized, multi-sensory feedback system that aligns virtual movement with physical motion cues, thereby reducing cybersickness and enhancing embodiment.

If successful, this component has the potential to advance the field of VR navigation by providing a modular and scalable motion-seat platform. It offers a blueprint for realistic aerial navigation in location-based entertainment, contributes empirical data on the effectiveness of different motion rendering models, and establishes clear timing thresholds for coherent virtual-physical interaction.

The recommendation of this feasibility study is to proceed with full development, beginning immediately with the optimization of the synchronization layer and the execution of the first motion rendering vertical slice.

8. References

[1] J. Friedman et al., "Embodied virtual reality for the study of real-world motor learning," PMC, 2021.

[2] M. O'Malley, "Revolutionizing touch: Researchers explore the future of wearable multi-sensory haptic technology," EurekAlert!, 2025.

[3] R. Islam et al., "RelaxVR: Cybersickness Reduction in Immersive Virtual Reality Through Explainable AI and Large Language Models," ResearchGate, 2026.

[4] Microsoft Research, "Measuring System Visual Latency through Cognitive Latency on Video See-Through AR devices," in Proc. IEEE VR, 2020.

[5] "Understanding the Effect of Latency on User Performance of Target Selection in Virtual Reality," ResearchGate, 2024.

[6] Souchet et al., "Design guidelines for limiting and eliminating virtual reality-induced symptoms and effects at work: a comprehensive, factor-oriented review," PMC, 2023.

[7] "AI-Powered Multisensory Feedback Systems for Virtual Collaboration: Enhancing Remote Communication with Haptic, Auditory, and Thermal Cues," IJFMR, vol. 6, no. 2, 2024.

9. Appendices

Appendix A - Confirmed Motion Control Focus Areas

The motion rendering and control strategies for the **Nimbus-based VR system** (Component 1) are developed based on established flight physics and human-perception principles, as validated against the research objectives in the proposal deck:

- **Position-Based Motion Rendering**: Maps virtual spatial coordinates directly to actuator positions to simulate static orientation and constant tilt angles during flight.
- **Velocity-Based Motion Rendering**: Utilizes real-time speed parameters to generate continuous motion cues, simulating the feeling of persistent travel through virtual space.
- **Acceleration-Based Motion Rendering**: Focuses on the rate of change in flight data to produce high-impact physical feedback for take-offs, rapid maneuvers, and sudden stops.
- **Real-Time Actuator Command Mapping**: Converts raw VR navigation data into synchronized control signals for the microcontroller-based physical seat interface.
- **Perceptual Latency Threshold Analysis**: Investigates the temporal alignment required between virtual navigation events and physical seat motion to ensure believable interaction.
- **Safety-Constrained Adaptive Control**: Implements software-level motion limits and mechanical constraints to maintain structural stability and user safety during dynamic operation.

Project ID: R26-IM-004

FEASIBILITY STUDY REPORT

Individual Research Component

Feasibility Study for the Environmental Interaction and Immersion Modelling for VR Aerial Navigation

ST ID: IT22119094

ST Name: Botheju W R D

5/13/2026

Executive Summary

This feasibility study evaluates the development and implementation of the Environmental Interaction and Immersion Modelling for VR Aerial Navigation component within the broader project, Immersive Multisensory VR Motion System for Full-body Navigation. This component addresses the lack of physical feedback for environmental factors like wind, turbulence, and speed, which currently limits immersion and realism in seated VR. By extracting real-time parameters from Unity, the system converts virtual states into synchronized physical sensations such as airflow and vibration.

The proposed solution introduces an environment-driven model specifically for broom-based flying. It utilizes force-mapping algorithms to trigger airflow fans, vibration motors, and seat tilt based on the user's virtual altitude and velocity. This multisensory approach creates a deliberate link between the virtual atmosphere and the physical rig, improving perceived realism and embodied interaction.

The project is deemed viable across all feasibility dimensions, utilizing mature tools like the Unity 3D engine and scripted event systems for modeling. Financially, the costs are manageable within an undergraduate budget by utilizing affordable sensors and existing software licenses. While risks include turbulence modeling complexity and synchronization delays, they are mitigated through iterative Design Science Research and controlled experimental testing. Development is recommended to proceed immediately with the environmental parameter extraction layer.

Table of Contents

1.Introduction....1
1.1 Background....1
1.2 Objective....1
1.3 Scope....2
2. Problem Statement....3
3. Project Description....4
3.1 Proposed Solution....4
3.2 Key Features....4
3.3 Methodology....4
3.4 System Overview....5
4. Feasibility Analysis....6
4.1 Technical Feasibility....6
4.2 Market Feasibility....6
4.3 Financial Feasibility....7
4.4 Operational Feasibility....7
4.5 Ethical Feasibility....8
5. Risk Analysis....9
6. Recommendations....10
6.1 Feasibility Summary....10
6.2 Overall Conclusion on Feasibility....10
6.3 Suggested Next Steps....10
7. Conclusion....12
8. References....13
9. Appendices....14

1.Introduction

1.1 Background

Modern Virtual Reality (VR) systems provide strong visual immersion, yet many seated VR experiences lack synchronized physical feedback for environmental states such as wind, turbulence, and speed. Users visually encounter atmospheric changes and virtual resistance, but the absence of tactile environmental cues creates a sensory mismatch that limits the sense of presence and realism. While motion rendering focuses on the body's movement, the lack of environmental haptics specifically the sensation of air and turbulence hitting the body makes aerial experiences feel physically incomplete. Traditional VR navigation often neglects this multisensory coherence, leaving the virtual atmosphere feeling physically "absent" despite high visual fidelity.

Environmental modelling technologies have the potential to bridge this gap, yet current solutions often prioritize visual effects over physical environmental interaction. There is a lack of scenario-focused research into how virtual wind, turbulence, and speed can be converted into synchronized haptic feedback delivered through wearable systems. This necessitates an environment-driven interaction model that turns virtual atmospheric data into tangible physical responses specifically through a haptic jacket to improve immersion and perceived realism.

This feasibility study focuses exclusively on Component 2, Environmental Interaction and Immersion Modelling for VR Aerial Navigation. This component investigates how parameters such as wind resistance, turbulence, and altitude changes can be extracted from a VR environment and mapped to synchronized feedback through a wearable haptic jacket and airflow systems.

1.2 Objective

The objective of this feasibility study is to determine whether the proposed Environmental Interaction and Immersion Modelling component can be successfully designed, developed, and integrated within the technical, financial, and operational constraints of an undergraduate research project. The study aims to evaluate the practicality of turning virtual atmospheric data into synchronized physical feedback using a haptic jacket and airflow fans while identifying potential risks related to multisensory synchronization, model accuracy, and user comfort before full development begins.

1.3 Scope

This feasibility study evaluates the following dimensions of the proposed component:

- **Technical feasibility**: The suitability of the Unity 3D engine and scripted event systems for extracting environmental parameters and mapping them to a haptic jacket and airflow hardware.
- **Market feasibility**: The demand for high-immersion VR attractions and the specific gap for environment-driven feedback in scenario-focused flight simulations.
- **Financial feasibility**: The estimated costs for haptic hardware, vibrotactile actuators, and AI-assisted asset generation within a standard research budget.
- **Operational feasibility**: The practicality of deploying an offline-first multisensory system that functions reliably on accessible hardware in Sri Lankan research environments.
- **Ethical and safety feasibility**: Compliance with research ethics for immersive user studies, including controlled exposure to vibration and wind, informed consent, and participant safety.

2. Problem Statement

Most seated Virtual Reality (VR) navigation systems rely primarily on visual simulation while providing little to no synchronized physical feedback for environmental factors. While users visually experience high-speed flight, wind resistance, and atmospheric changes, the lack of tactile environmental cues creates a sensory mismatch. This mismatch significantly reduces immersion and weakens the user's sense of "presence," as the body does not feel the virtual air it is moving through.

Current haptic solutions in the market often focus on isolated vibration effects that do not represent specific environmental states like wind resistance or localized turbulence. High-end environmental simulators exist but are often too expensive and complex for small-scale research or immersive entertainment venues. There is a distinct absence of a scenario-focused interaction model that translates virtual atmospheric data into tactile sensations delivered through wearable hardware.

Furthermore, while research into VR locomotion is diverse, there is limited exploration of environment-driven interaction models specifically for broom-based aerial navigation. Currently, no affordable framework exists to turn virtual wind, speed, and turbulence into synchronized physical feedback through a haptic jacket. This instructional and experiential gap prevents users from achieving a truly embodied and realistic flight experience within a seated VR platform

3. Project Description

3.1 Proposed Solution

The proposed solution is an environment-driven interaction model that translates virtual atmospheric data into synchronized multisensory physical feedback. The component extracts real-time parameters from the Unity 3D engine—including wind speed, turbulence, and flight velocity and converts them into physical sensations delivered through a wearable haptic jacket and airflow systems. This system is designed to bridge the gap between visual flight simulation and physical presence, allowing the user to "feel" the virtual environment during broom-based aerial navigation.

3.2 Key Features

- **Wearable Haptic Integration**: Utilizes a haptic jacket with vibrotactile actuators to simulate environmental resistance and turbulence directly on the user's body.

- **Dynamic Force-Mapping Algorithms**: Converts virtual environmental states such as wind resistance and altitude changes into synchronized physical feedback intensities.

- **Multisensory Environmental Feedback**: Triggers coordinated airflow from fans and vibration from motors to mimic authentic atmospheric conditions.

- **Environment-Driven Interaction Model**: Introduces a specialized model for broom-based flying that improves realism and immersion beyond standard visual effects.

- **Real-Time Synchronization**: Features a low-latency interaction pipeline to ensure physical feedback is perfectly timed with virtual events.

- **Anonymized Session Logging**: Captures navigation logs and feedback mapping values for research evaluation and performance metrics.

3.3 Methodology

The project follows a Design Science Research (DSR) methodology with a focus on iterative development and controlled experimental validation. The component is developed by creating an environment-driven model that simulates wind, turbulence, speed, and atmospheric openness within the Herald VR world. Evaluation is conducted as a comparative study where user immersion and perceived realism are measured both with and without the environmental haptic feedback. Performance is assessed through structured user-study measures, including immersion questionnaires and consistency checks of multi-sensory event delivery.

3.4 System Overview

The system consists of three primary layers. The VR Environment Engine (Unity) is the software layer that manages the virtual world building, extracts environmental parameters such as wind speed and flight velocity, and identifies turbulence events. The Monumental Interaction Model serves as the synchronization and processing layer, utilizing force-mapping algorithms to convert virtual atmospheric data into coordinated physical feedback signals. The Physical Feedback Layer is the hardware interface consisting of the wearable haptic jacket, airflow fans, and vibration motors that executes the tactile sensations, producing real-time environmental immersion for the user.

4. Feasibility Analysis

4.1 Technical Feasibility

The technical foundation for this component rests on integrating virtual environmental modeling with physical haptic feedback systems. Unity is utilized as the primary 3D engine to extract real-time atmospheric parameters such as wind velocity, altitude, and turbulence—from the virtual flight environment. Physical feedback is executed through a specialized wearable haptic jacket equipped with vibrotactile actuators and a supporting airflow system. These are controlled via a microcontroller-based interface (Arduino or ESP32) for real-time response execution.

A key technical accelerator is the development of force-mapping algorithms that translate Unity's digital wind zones and turbulence scripts into localized haptic patterns. The reliance on high-speed serial communication ensures that environmental sensations, such as a gust of wind or air resistance during high-speed flight, reach the user with minimal latency. The required expertise in Unity scripting, wearable electronics, and multisensory synchronization is well within the scope of an Interactive Media undergraduate specialization at SLIIT.

4.2 Market Feasibility

The primary target market for this technology is the high-end immersive entertainment sector, specifically VR arcades and location-based attractions. The value proposition centers on delivering "physical presence" allowing users to feel the virtual atmosphere, which is a feature currently missing from standard seated VR setups. This addresses a specific demand for premium, multisensory experiences among gamers and adventure enthusiasts.

Market demand is driven by the unique application of environmental haptics for broom-based aerial navigation. While motion seats are becoming more common, wearable environmental feedback systems like haptic jackets represent an underserved niche. The modular nature of the interaction model allows the haptic jacket and airflow systems to be adapted for various scenarios beyond broom-flight, such as skydiving simulations or open-cockpit racing, offering high scalability for commercial partners.

4.3 Financial Feasibility

The estimated total cost of development for this component is summarized in the table below:

Item	Description	Estimated Cost (LKR)
Haptic Hardware	Vibrotactile actuators (ERM/LRA motors) and drivers	25,000
Wearable Materials	Haptic jacket/vest base and wiring integration	15,000
Control Units	Microcontrollers (Arduino) and sensors	8,000
Miscellaneous	Cables, power supplies, and component housing	10,000
Total Estimated Cost		**58,000**

The total estimated cost is well within the budget of an undergraduate research project. By utilizing open-source hardware and student software licenses, the project remains cost-effective. The lower fabrication cost compared to heavy mechanical rigs makes this a financially attractive component for scaling in commercial environments through equipment sales or licensing.

4.4 Operational Feasibility

The system is designed for ease of use and portability, focusing on a wearable interface that can be easily donned and doffed by users. The haptic jacket is designed to be adjustable for various body types, ensuring a consistent experience across a diverse user base. Operationally, the system is "offline-first," meaning the environmental interaction logic is processed locally without the need for constant internet connectivity, ensuring reliability in various deployment settings.

A core operational principle is multisensory synchronization. The system includes a dedicated processing layer to ensure that the haptic sensations (vibration and wind) are perfectly aligned with the visual cues in the VR headset. Maintenance is simplified through the use of modular electronic components, allowing for the quick replacement of individual actuators or fans without disrupting the entire system.

4.5 Ethical Feasibility

Since this component involves wearable electronics and airflow directed at the user, safety and ethical compliance are paramount. The study follows the SLIIT Research Ethics Committee guidelines, ensuring that all participants provide informed consent and are aware of the sensations (vibration and wind) they will experience. The system includes software-level intensity limits to ensure that haptic feedback remains within comfortable and safe thresholds.

Technical safety is ensured by insulating all wearable electronics and utilizing low-voltage power supplies. All participant data, such as immersion scores and feedback preferences, will be fully anonymized. The project adheres to professional research standards, ensuring that the technology is used exclusively for academic evaluation and improving the quality of human-computer interaction.

5. Risk Analysis

The following table summarizes identified risks, their likelihood and potential impact, and the planned mitigation strategy:

Risk	Likelihood	Impact	Mitigation Strategy
Multisensory event delivery inconsistency	Medium	High	Implement force-mapping algorithms and conduct pilot tests to ensure wind, vibration, and tilt triggers align perfectly with the virtual environment.
Inaccurate environmental parameter extraction	Medium	Medium	Use the Unity 3D engine to strictly script event systems for real-time extraction of wind speed, turbulence, and flight velocity.
User discomfort from physical feedback exposure	Medium	High	Integrate safety constraints into the interaction model and allow participants to withdraw immediately if discomfort or fatigue occurs.
Over-complexity in open-world scenario design	High	Medium	Build controlled open-world scenarios with limited environmental variations to focus on core immersion evaluation.
Hardware-driven vibration or airflow lag	Medium	Medium	Profile the physical feedback mapping layer to ensure the control signal generation for fans and motors is near-instantaneous.
Perceived realism mismatch in simulated effects	Medium	Medium	Conduct comparative user studies with and without environment-driven feedback to refine the model based on perception metrics.
Scope creep regarding weather/environmental states	High	Medium	Focus strictly on wind, turbulence, speed, and altitude changes for the single broom-flight scenario.

Of these risks, the most significant for project delivery is multisensory event delivery inconsistency, as a mismatch between a visual environmental cue and physical feedback would break user immersion and reduce realism. This is mitigated by refining the multisensory trigger mapping for precise virtual-to-physical coordination. The second most significant risk is user discomfort, which is mitigated by enforcing controlled exposure to wind and motion within safe predefined thresholds during experimental trials.

6. Recommendations

6.1 Feasibility Summary

Aspect	Verdict	Summary
Technical Feasibility	**Feasible**	Unity 3D engine for world-building and scripted event systems provide a mature foundation for modeling complex environmental states.
Market Feasibility	**Feasible**	Addresses a significant gap in scenario-specific motion platforms, particularly for broom-based flying which is underserved by existing systems.
Financial Feasibility	**Feasible**	Development costs for airflow fans, vibration motors, and modeling fit within a realistic undergraduate research budget.
Operational Feasibility	**Feasible**	The model is designed to integrate with the motion-seat hardware to provide real-time interaction feedback in a controlled environment.
Ethical Feasibility	**Feasible**	Research protocols include strict safety constraints, informed consent, and anonymized data collection in line with university guidelines.

6.2 Overall Conclusion on Feasibility

Based on the analysis across all dimensions, the Environmental Interaction and Immersion Modelling component is feasible and recommended for full development. The technical framework for mapping force algorithms to physical feedback is robust and directly addresses the identified research gap in scenario-specific broom-flight navigation. While the integration of multiple sensory outputs (wind, tilt, vibration) increases complexity, the use of iterative Design Science Research (DSR) ensures a manageable development path. The identified risks regarding multisensory consistency and user discomfort are manageable through clear and practical mitigation strategies.

6.3 Suggested Next Steps

- **Finalize the Force-Mapping Matrix**: Define the exact physical hardware output levels for specific virtual wind speeds and turbulence intensities extracted from Unity.

- **Develop the Parameter Extraction Script**: Build the core Unity logic to accurately pull real-time wind speed, turbulence, and flight velocity data.

- **Prototype a Multisensory "Vertical Slice"**: Test a single scenario involving synchronized airflow and vibration to validate the physical feedback mapping layer early.

- **Prepare Immersion Questionnaires**: Draft structured user-study measures to evaluate perceived realism and environmental immersion during the validation phase.

- **Calibrate Safety Thresholds**: Set predefined mechanical and airflow intensity limits to ensure participant comfort and safety during immersive trials.

- **Submit Ethics Application**: Provide the SLIIT Research Ethics Committee with detailed participant protocols to avoid delays before the evaluation phase.

7. Conclusion

This feasibility study has examined Component 2: Environmental Interaction and Immersion Modelling across technical, market, financial, operational, and ethical dimensions. The study finds that the project is feasible on all five dimensions and that the identified risks are manageable with the proposed mitigation strategies in place.

The importance of this project lies in the meaningful gap it addresses in VR realism. Existing seated VR systems rarely translate environmental forces like wind and turbulence into physical feedback, leading to a disconnect between visual and physical cues. The proposed environment-driven model directly addresses this by aligning virtual atmospheric changes with real-world sensory outputs, thereby enhancing immersion and embodied interaction.

If successful, this component has the potential to advance the field of multisensory VR by providing a modular and scalable interaction model for aerial navigation. It offers a blueprint for more realistic environmental storytelling in location-based entertainment and contributes empirical data on how multisensory feedback influences user perception in immersive environments. The recommendation of this study is to proceed with full development, beginning immediately with the extraction scripts and the first force-mapping vertical slice.

8. References

[1] J. Friedman et al., "Embodied virtual reality for the study of real-world motor learning," *PMC*, 2021.

[2] M. O'Malley, "Revolutionizing touch: Researchers explore the future of wearable multi-sensory haptic technology," *EurekAlert!*, 2025.

[3] R. Islam et al., "RelaxVR: Cybersickness Reduction in Immersive Virtual Reality Through Explainable AI and Large Language Models," *ResearchGate*, 2026.

[4] L. Chen and H. Kim, "Ergonomic Design and Safety Constraints for Seated VR Motion Platforms," *Journal of Mechanical Systems*, 2023.

[5] S. R. Gupta, "AI-Powered Multisensory Feedback Systems for Virtual Collaboration: Enhancing Remote Communication with Haptic, Auditory, and Thermal Cues," *IJFMR*, vol. 6, no. 2, 2024.

[6] M. Slater et al., "First person experience of body transfer in virtual reality," *PLOS ONE*, 2010.

[7] L. Rebenitsch and C. Owen, "Review on cybersickness in applications and visual displays," *Virtual Reality Journal*, 2016.

9. Appendices

Appendix A – Confirmed Environmental Modelling Parameters

The atmospheric effects for the **Environmental Interaction and Immersion Modelling** component are drawn from specific virtual variables as defined in the Nimbus-based research objectives:

- **Wind Resistance**: Translation of virtual flight speed into airflow intensity from external fans.
- **Turbulence Modelling**: Mapping of erratic virtual air movements to high-frequency vibrotactile feedback.
- **Altitude Variation**: Use of subtle seat tilt changes to represent changes in virtual pitch and orientation during flight.
- **Speed-Related Vibration**: Gradual increase in vibration intensity as the virtual velocity threshold increases.
- **Open-World Environmental Cues**: Interaction mapping for shifts between closed and open virtual spaces.
- **Safety Intensity Caps**: Predefined limits to airflow and vibration to prevent participant fatigue or discomfort.

Project ID: R26-IM-004

FEASIBILITY STUDY REPORT

Individual Research Component

Feasibility Study for Mechanical Integration and Stability Design for the VR Motion Seat Platform

ST ID: IT22129208

ST Name: Silva H S N

5/13/2026

Executive Summary

This feasibility study evaluates the development and implementation of the Mechanical Integration and Stability Design for the VR Motion Seat Platform (Component 4) of the broader research project titled Immersive Multisensory VR Motion System for Full-body Navigation. The component addresses a critical challenge in the development of low-cost VR motion platforms: ensuring that a modular mechanical structure remains stable and secure under dynamic motion conditions. While high-end motion simulators are often inaccessible due to cost and complexity , this component focuses on providing a reliable, ergonomic, and stable hardware foundation specifically for broom-based seated VR navigation.

The proposed solution is a modular mechanical architecture that integrates the frame, seating, and actuator mounting mechanisms into a single functional platform. The system is designed to facilitate safe and repeatable motion feedback by managing user load, stress, and vibration effectively. By utilizing a constrained motion design, the platform simulates acceleration and tilt cues while maintaining structural integrity during intense virtual maneuvers. This hardware foundation is essential for supporting the multisensory synchronization required for an immersive and embodied experience.

The feasibility assessment finds the project viable across all evaluated dimensions. Technically, the required tools including CAD modeling, metal frame fabrication, and actuator mounting mechanisms are mature and within the expertise of an undergraduate engineering specialization. Operationally, the system is designed for repeatable and safe interaction, with stability verified through load distribution and stress analysis. Financially, the development costs are manageable within a realistic undergraduate research budget by utilizing modular design principles and accessible fabrication methods. Market feasibility is supported by the demand for affordable, scenario-focused VR motion platforms in arcades, immersive venues, and event spaces.

Based on the analysis, the project is feasible and is recommended to proceed. The main risks identified relate to structural stability under peak dynamic loads, mechanical vibration control, and ensuring repeatable motion behavior. Each risk has a clear mitigation strategy involving iterative prototyping, safety-constrained control limits, and rigorous stability testing. The immediate next step is to finalize the CAD structural design and conduct a load distribution analysis before proceeding to the fabrication of the initial metal frame.

Table of Contents

1.Introduction....1
1.1 Background....1
1.2 Objective....1
1.3 Scope....2
2. Problem Statement....3
3. Project Description....4
3.1 Proposed Solution....4
3.2 Key Features....4
3.3 Methodology....4
3.4 System Overview....5
4. Feasibility Analysis....6
4.1 Technical Feasibility....6
4.2 Market Feasibility....6
4.3 Financial Feasibility....7
4.4 Operational Feasibility....7
4.5 Ethical Feasibility....8
5. Risk Analysis....9
6. Recommendations....10
6.1 Feasibility Summary....10
6.2 Overall Conclusion on Feasibility....10
6.3 Suggested Next Steps....10
7. Conclusion....12
8. References....13
9. Appendices....14

1.Introduction

1.1 Background

Modern Virtual Reality (VR) systems provide high visual immersion, yet many seated navigation experiences particularly those involving specialized aerial movement like broom-flight lack synchronized physical grounding. Users visually experience acceleration and directional movement while their bodies remain stationary, leading to a sensory mismatch that causes cybersickness, discomfort, and reduced realism. While high-end simulators exist to provide motion feedback, they are often prohibitively expensive, mechanically complex, and not accessible for modular or small-scale research applications.

The overall research project, Immersive Multisensory VR Motion System for Full-body Navigation, addresses these gaps by developing a synchronized, multisensory platform for realistic navigation. This feasibility study focuses exclusively on Component 4: Mechanical Integration and Stability Design for the VR Motion Seat Platform. This component investigates how a modular mechanical structure can be designed to safely support a seated VR navigation system while maintaining structural integrity and repeatable motion behavior under dynamic user loads.

1.2 Objective

The objective of this feasibility study is to determine whether the proposed Mechanical Integration and Stability Design component can be successfully designed, developed, integrated, and evaluated within the technical, financial, and operational constraints of an undergraduate research project. The study aims to assess the practicality of building a modular seat frame that integrates actuators and ergonomic supports, while identifying potential risks related to structural stress, load distribution, and user safety before full-scale fabrication begins.

1.3 Scope

This feasibility study evaluates the following dimensions of the proposed component:

- **Technical feasibility** – The suitability of CAD modeling tools, metal frame fabrication, and actuator mounting mechanisms for a modular VR platform.
- **Market feasibility** – The potential demand for affordable, scenario-focused VR motion platforms in arcades, event spaces, and simulation institutions.
- **Financial feasibility** – The estimated cost of hardware, fabrication materials, and mechanical parts within a realistic undergraduate research budget.
- **Operational feasibility** – The practicality of deploying a stable, safe, and repeatable mechanical system for immersive seated VR use.
- **Ethical and safety feasibility** – Compliance with participant safety requirements, including informed consent and the enforcement of predefined mechanical motion limits to prevent injury.

2. Problem Statement

Current Virtual Reality (VR) motion platforms capable of generating physical feedback are often characterized by high costs and mechanical complexity, making them inaccessible for small-scale research and modular entertainment applications. In many existing systems, navigation remains largely detached from the user's physical state, relying on joysticks or teleportation, which breaks immersion and fails to provide a grounded sense of movement.

Specifically, within the context of a modular VR motion seat, the following critical problems must be addressed:

- **Lack of Structural Stability under Dynamic Loads:** There is a significant challenge in ensuring that a modular mechanical frame remains stable when subjected to the shifting weight of a user and the rapid, multi-axis forces generated by pitch and roll actuation.
- **Safety and Ergonomic Disconnect:** Most experimental rigs focus purely on motion output without adequately addressing the mechanical safety limits, load distribution, and ergonomic support required to prevent user injury or fatigue during intense virtual maneuvers.
- **Mechanical Vibration and Stress:** Repeated, high-frequency motion cues can lead to frame displacement and mechanical wear if the structural integration of the actuators and seat is not optimized for repeatable motion behavior.
- **Accessibility and Modularity Gap:** There is currently no widely documented, affordable mechanical blueprint for a broom-based seated VR rig that can be easily fabricated and scaled while ensuring consistent structural reliability.

This component directly addresses these issues by developing a modular mechanical architecture that serves as the secure and repeatable hardware foundation for the multisensory VR system.

3. Project Description

3.1 Proposed Solution

The proposed solution is a modular mechanical architecture designed for the VR motion seat platform. This hardware foundation integrates the structural frame, seat, and actuator mounting mechanisms to facilitate safe and repeatable motion feedback. The system is specifically engineered to handle dynamic motion conditions by converting virtual navigation data into physical pitch and roll actuation.

3.2 Key Features

- **Modular Mechanical Architecture**: Supports a customizable frame design that can be adapted for multiple interaction modes and ride themes on the same platform.
- **Integrated Actuator Mounting System**: Features specialized mechanisms for stable motion transfer from the hardware actuators to the user's seat.
- **Dynamic Load and Stress Management**: Engineered to remain stable under varying user loads and intense multi-axis motion during virtual flight.
- **Ergonomic Seating Design**: Provides a hardware foundation focused on user comfort and proper postural support during immersive navigation.
- **Safety-Constrained Operation**: Implements predefined mechanical safety limits and structural constraints to ensure the rig remains secure during rapid motion transitions.
- **Repeatable Motion Behavior**: Ensures that physical feedback is consistent and reliable across multiple user sessions for research and commercial use.
- **Optimized Load Distribution**: Conducts real-time and static analysis of weight distribution to prevent structural fatigue or displacement.

3.3 Methodology

The project follows a Design Science Research (DSR) methodology, utilizing an iterative prototype development process. The mechanical platform is developed by integrating the frame, seat, and actuator mounts through a series of design cycles. Evaluation is conducted via controlled testing of the platform's structural stability and safety under dynamic load conditions. Performance is measured through quantitative metrics such as frame displacement, vibration control, and structural balance, alongside comparative studies of modular versus fixed platform designs to ensure repeatable motion behavior.

3.4 System Overview

The system consists of three primary layers that form the mechanical foundation:

- **Structural Layer**: Comprises the **Motion Seat Structural Frame** and ergonomic seating, designed through CAD modeling to handle load and stress.
- **Integration Layer**: Serves as the core assembly point where **Actuator and MCU Integration** occurs, ensuring that mechanical mounting supports stable motion transfer.
- **Stability & Validation Layer**: Acts as the safety engine, involving **Load Distribution Analysis** and safety constraints to produce a final assembly capable of safe and reliable operation.

4. Feasibility Analysis

4.1 Technical Feasibility

The technical foundation of the project rests on mature, industry-standard mechanical design and fabrication tools. CAD modeling tools are utilized for the structural design and integration of the platform, allowing for precise stress and load distribution analysis before physical construction. The fabrication process relies on metal frame construction, a well-documented and widely accessible method that ensures the durability required for dynamic motion.

A key technical accelerator for this component is the use of actuator mounting mechanisms designed for stable motion transfer. These mechanisms are refined through an iterative Design Science Research (DSR) process, ensuring that the integration of the frame, seat, and actuators supports reliable and repeatable motion behavior. The required expertise spans structural engineering, load analysis, and mechanical assembly, which is well within the scope of an undergraduate specialization at SLIIT. The development is structured around clear milestones from initial frame design to the final assembly of the motion-seat platform

4.2 Market Feasibility

The primary target market for this technology includes location-based immersive VR attractions, such as arcades, immersive venues, and public event spaces. The value proposition centers on providing a high-end, multisensory VR flight experience with stronger realism and embodiment than traditional stationary setups. The target audience includes fantasy and adventure fans, young gamers, and groups seeking unique, shared immersive experiences.

Market demand is supported by the specific need for scenario-focused mechanical rigs, such as the broom-flight platform, which are currently underserved by generic or expensive industrial simulators. Potential commercial partners include VR arcades, gaming cafés, and immersive entertainment providers. The modular nature of the design allows the platform to be scaled and reused for multiple themes beyond the initial broom-flight, such as dragon-riding or other fantasy flight scenarios, offering significant commercial flexibility.

4.3 Financial Feasibility

The estimated total cost of development for this component is summarized in the table below:

Item	Description	Estimated Cost (LKR)
Fabrication	Metal frame fabrication and welding materials	35,000
Mechanical Parts	Seating, structural supports, and safety constraints	20,000
Actuator Mounting	Brackets, pivots, and mounting hardware	15,000
Design Tools	CAD modeling software (Student/Academic licenses)	0
Miscellaneous	Transport of materials and contingency	10,000
Total Estimated Cost		**80,000**

The total estimated cost is aligned with the requirements of a mechanical research project and remains within a realistic undergraduate research budget. By utilizing modular design principles and accessible metal fabrication, the project avoids the high costs associated with industrial-grade simulators. Revenue potential in a post-research phase would be driven by per-session pricing at venues and the potential for IP licensing in motion control and modular ride design.

4.4 Operational Feasibility

The system is designed for high reliability and repeatable operation in research and public environments. The modular mechanical architecture allows the frame and seat to be easily transported or adjusted for different interaction modes. Ensuring stability under user load is a core design principle, with load distribution and stress analysis conducted to ensure the rig remains secure during dynamic motion.

A core operational principle is the safety and repeatability of the motion cues. The system includes safety-constrained operation with predefined mechanical limits to ensure user protection. Maintenance is simplified through the use of standardized mechanical parts and a modular assembly that allows for the independent servicing of actuator mounts or seating components. Scalability is built into the design; once the core frame is established, it can be adapted for new themes by modifying the top-level mounting structures without a complete redesign of the base platform.

4.5 Ethical Feasibility

Because the research involves human participants interacting with a motorized mechanical platform, strict ethical and safety compliance is mandatory. The study follows the SLIIT Research Ethics Committee guidelines, ensuring informed consent is obtained from all participants before testing. Participants are fully informed of their right to withdraw at any time, particularly if they experience discomfort during the motion sessions.

Safety is technically integrated into the mechanical design through predefined safety limits and constrained motion ranges. All participant data, including performance metrics and questionnaire responses, will be anonymized to protect privacy. Collected data is stored securely and used exclusively for academic evaluation, ensuring the project meets all professional research and safety standards.

5. Risk Analysis

The following table summarizes identified risks, their likelihood and potential impact, and the planned mitigation strategy for each:

Risk	Likelihood	Impact	Mitigation Strategy
Mechanical instability during dynamic motion	Low	High	Conduct structural stress analysis and enforce predefined mechanical safety limits within the control logic.
Structural fatigue from repeated use	Medium	Medium	Use high-quality metal frame fabrication and conduct load distribution testing to ensure repeatable motion behavior.
Actuator mounting failure or misalignment	Low	High	Design specialized mounting mechanisms for stable motion transfer and conduct vibration control tests.
Ergonomic discomfort for different user sizes	Medium	Medium	Develop an adjustable seating design and conduct early usability testing for participant comfort.
Scope creep adding multiple ride themes	High	Medium	Lock the project identity to a single controlled broom-flight scenario early and defer additional themes to a Phase 2 list.
Inaccurate physical response to virtual cues	Medium	Medium	Refine actuator integration through iterative prototyping and stability testing under dynamic loads.
Participant safety risks during rapid transitions	Low	High	Integrate motion-constrained safety features and obtain informed consent before any user trials.

Of these risks, the most significant in terms of project delivery is mechanical instability during dynamic motion, as structural failure would compromise both safety and the validity of the research. This is aggressively mitigated by integrating safety-constrained motion limits and conducting load distribution analysis on the modular rig. The second most significant risk is scope creep, which is mitigated by maintaining a strict focus on a single broom-flight scenario to allow for deep evaluation of the mechanical rendering strategies.

6. Recommendations

6.1 Feasibility Summary

Aspect	Verdict	Summary
Technical Feasibility	**Feasible**	Core technologies (CAD modeling, metal fabrication) are mature and well-documented. Specialized mounting mechanisms provide a clear path for technical implementation.
Market Feasibility	**Feasible**	Addresses a genuine gap in scenario-specific mechanical rigs for VR attractions and immersive venues.
Financial Feasibility	**Feasible**	Total estimated cost is manageable within an undergraduate research budget by utilizing modular design and local fabrication.
Operational Feasibility	**Feasible**	The system is designed with a modular mechanical frame and structural safety analysis to ensure repeatable and stable operation.
Ethical Feasibility	**Feasible**	The project includes strict mechanical safety limits and informed consent procedures that comply with SLIIT guidelines.

6.2 Overall Conclusion on Feasibility

Based on the analysis across all five dimensions, the Mechanical Integration and Stability Design for the VR Motion Seat Platform (Component 4) is feasible and is recommended to proceed to full development. The technical foundation is solid, supported by specialized mounting models and structural integration techniques. The target market in immersive entertainment is genuine and offers strong commercialization potential. While hardware fabrication requires higher initial capital than software-only components, the costs are manageable and the operational design ensures a safe, scalable interaction platform.

6.3 Suggested Next Steps

- **Finalize the CAD structural design** with supervisor approval to ensure the frame accurately supports the required actuator mounting and load requirements.
- **Conduct the initial load distribution and stress analysis** to validate the mechanical integrity of the proposed frame before beginning fabrication.
- **Fabricate the modular metal frame** as the core physical foundation for the motion-seat platform.

- **Integrate the actuators and MCU** into the mechanical structure to test the first vertical slice of motion transfer stability.

- **Implement predefined safety limits** within the mechanical and control structure to ensure all subsequent testing is secure for participants.

- **Draft experimental safety and stability protocols** in parallel with fabrication so that structural testing can begin as soon as the assembly is functional.
- **Submit the ethics application** to the SLIIT Research Ethics Committee to avoid delays before the participant-based validation phase.

7. Conclusion

This feasibility study has examined the proposed Mechanical Integration and Stability Design (Component 4) across technical, market, financial, operational, and ethical dimensions. The study finds that the project is feasible on all five dimensions and that identified risks, such as structural fatigue and mechanical instability, are manageable with the proposed mitigation strategies.

The importance of this project lies in the meaningful gap it addresses in VR hardware accessibility. Existing motion platforms are often expensive and inaccessible; the proposed modular rig directly addresses this by providing an affordable, stable foundation for scenario-specific interactions like broom-flight navigation. This system aligns virtual movement with grounded physical support, enhancing embodiment and ensuring user safety.

If successful, this component has the potential to provide a modular and scalable blueprint for realistic aerial navigation in location-based entertainment. It establishes clear structural standards for safe virtual-physical interaction and contributes a repeatable hardware foundation for multisensory research. The recommendation of this study is to proceed with full development, beginning immediately with CAD finalization and structural load analysis.

8. References

[1] M. Slater, B. Spanlang, M. V. Sanchez-Vives, and O. Blanke, "First person experience of body transfer in virtual reality," *PLOS ONE*, vol. 5, no. 5, May 2010.

[2] J. Friedman et al., "Embodied virtual reality for the study of real-world motor learning," *PMC*, Jan. 2021.

[3] L. Rebenitsch and C. Owen, "Review on cybersickness in applications and visual displays," *Virtual Reality Journal*, vol. 20, no. 2, pp. 101–125, Jun. 2016.

[4] H. Culbertson, J. Unwin, and K. J. Kuchenbecker, "Modeling and rendering realistic textures from unconstrained tool-surface interactions," *IEEE Transactions on Haptics*, vol. 11, no. 1, pp. 31–41, Jan. 2018.

[5] C. Boletsis, "The New Era of Virtual Reality Locomotion: A Systematic Literature Review of Techniques and a Proposed Typology," in Proc. IEEE Int. Conf. on Multimodal Interaction, 2017.

[6] W. Wang et al., "Structural Optimization and Vibration Analysis of a Parallel Motion Simulator for Virtual Reality Applications," *Mechanical Systems and Signal Processing*, vol. 168, Apr. 2022.

[7] L. Chen and H. Kim, "Ergonomic Design and Safety Constraints for Seated VR Motion Platforms," *Journal of Mechanical Systems*, vol. 45, no. 3, pp. 210–225, Sep. 2023.

[8] M. S. Hassan, "Load Distribution and Stress Analysis in Modular Hardware for Immersive Simulators," *International Journal of Mechanical Engineering*, vol. 12, no. 1, Jan. 2024.

[9] S. R. Gupta, "AI-Powered Multisensory Feedback Systems for Virtual Collaboration: Enhancing Remote Communication with Haptic, Auditory, and Thermal Cues," *IJFMR*, vol. 6, no. 2, Mar. 2024.

[10] "Understanding the Effect of Latency on User Performance of Target Selection in Virtual Reality," *ResearchGate*, Feb. 2024.

[11] M. O'Malley, "Revolutionizing touch: Researchers explore the future of wearable multi-sensory haptic technology," *EurekAlert!*, Feb. 2025.

[12] X. Yao, W. Chen, and Z. Liu, "Ethnoscience-enhanced physics virtual simulation and augmented reality with inquiry learning: Impact on students' creativity and motivation," *ScienceDirect*, vol. 115, Jan. 2025.

[13] R. Islam et al., "RelaxVR: Cybersickness Reduction in Immersive Virtual Reality Through Explainable AI and Large Language Models," *IEEE ResearchGate*, Jan. 2026.

9. Appendices

Appendix A – Confirmed Mechanical Design Requirements

The design parameters for the **Modular VR Motion Seat Platform** (Component 4) are developed based on the core structural and interaction objectives of the broader multisensory system:

- **Modular Mechanical Architecture**: Design of a flexible frame structure that supports multiple interaction modes, such as the broom-flight scenario.
- **Actuator Mounting and Integration**: Specialized mechanisms for securing actuators to the frame to ensure stable motion transfer of pitch and roll cues.
- **Structural Stability Analysis**: Development of a rig capable of remaining balanced and secure under dynamic user loads and intense virtual maneuvers.
- **Safety-Constrained Operation**: Implementation of predefined mechanical limits to ensure the motion rig operates within safe ergonomic and structural thresholds.
- **Ergonomic Support**: Provision of a hardware foundation that ensures user comfort and proper postural alignment during seated VR navigation.
- **Repeatable Motion Design**: Engineering the structural components to deliver consistent physical feedback across multiple sessions without frame displacement or fatigue.

Project ID: R26-IM-004

FEASIBILITY STUDY REPORT

Individual Research Component

Synchronized External Visual Feedback System for Spectator Engagement in VR Motion Platforms

ST ID: IT22191724

ST Name: Nimsara L G S K

5/13/2026

Executive Summary

This feasibility study evaluates the development and implementation of the Synchronized External Visual Feedback System for Spectator Engagement (Component 04) of the broader research project titled Immersive Multisensory VR Motion System for Full-body Navigation. The component addresses a significant limitation in current VR motion platforms, where the immersive experience is restricted to the headset user, leaving external spectators disconnected. This "spectator gap" reduces the entertainment value and communicative impact of VR demonstrations, as audiences cannot perceive the intensity or nature of the virtual events the rider is experiencing.

The proposed solution is a synchronized visual feedback framework that translates virtual events into real-world environmental lighting. The system extracts real-time VR parameters such as flight speed, collisions, and environmental triggers and converts them into synchronized LED lighting animations. By utilizing a Unity-to-Arduino communication pipeline, the system generates dynamic visual cues (e.g., red flashes for crashes or blue pulses for aquatic environments) that allow spectators to visually track and understand the user's virtual journey. This shared immersion layer bridges the gap between the invisible digital world and the physical environment.

The feasibility assessment finds the project viable across all evaluated dimensions. Technically, the required components including the Unity Engine, Arduino microcontrollers, and WS2812B programmable LEDs are industry-standard, accessible, and offer the low-latency response times necessary for synchronization. Operationally, the system is designed as a portable, non-intrusive enhancement that can be integrated into various exhibition settings. Financially, the development cost is highly optimized for an undergraduate research budget, relying on affordable hardware and open-source development tools. Market feasibility is supported by the growing need for high-engagement VR showcases in exhibitions, arcades, and educational events where audience interaction is a key performance metric.

Based on the analysis, the project is considered feasible and is recommended to proceed. The primary risks identified include synchronization latency, visibility issues in bright environments, and the complexity of mapping diverse game events to effective lighting patterns. Each risk has practical mitigation strategies involving baud rate optimization, high-intensity LED diffusion, and iterative event-mapping trials. The recommended next step is to develop the core serial communication link and a vertical slice of the "Collision-and-Speed" lighting animations to validate the technical synchronization model.

Table of Contents

1.Introduction....1
1.1 Background....1
1.2 Objective....1
1.3 Scope....2
2. Problem Statement....3
3. Project Description....4
3.1 Proposed Solution....4
3.2 Key Features....4
3.3 Methodology....4
3.4 System Overview....5
4. Feasibility Analysis....5
4.1 Technical Feasibility....5
4.2 Market Feasibility....5
4.3 Financial Feasibility....6
4.4 Operational Feasibility....6
4.5 Ethical Feasibility....7
5. Risk Analysis....8
6. Recommendations....9
6.1 Feasibility Summary....9
6.2 Overall Conclusion on Feasibility....9
6.3 Suggested Next Steps....9
7. Conclusion....11
8. References....12
9. Appendices....13

1.Introduction

1.1 Background

Modern Virtual Reality (VR) systems provide strong visual immersion for the user wearing the headset, yet most seated VR navigation experiences leave external spectators disconnected from the interaction. While the user in the VR environment experiences high-intensity events such as speed, turns, and environmental shifts, those outside the headset can only observe a person sitting on a moving platform. This "spectator gap" creates a sensory disconnect, making it difficult for an audience to understand the emotional intensity or context of the virtual journey. Existing VR demonstrations often lose entertainment value because they fail to communicate the invisible virtual world to the physical room.

While haptic and motion technologies focus on the rider's experience, limited research has explored synchronized environmental feedback systems designed specifically for spectator engagement. There is a need for a framework that translates internal VR data into visible, real-world effects, turning a solo immersive experience into a shared interactive showcase. By using external lighting and visual cues, the gap between the player’s immersion and the audience’s understanding can be bridged.

This feasibility study focuses exclusively on Component 4, Synchronized External Visual Feedback System for Spectator Engagement in VR Motion Platforms. This component investigates how VR gameplay events and motion platform behavior can be translated into synchronized external lighting effects using programmable LEDs.

1.2 Objective

The objective of this feasibility study is to determine whether the proposed Synchronized External Visual Feedback System can be successfully designed, developed, and integrated within the technical, financial, and operational constraints of an undergraduate research project. The study aims to assess the practicality of real-time synchronization between the Unity VR environment and external LED hardware, while identifying risks related to latency, system stability, and spectator engagement before full-scale development begins.

1.3 Scope

This feasibility study evaluates the following dimensions of the proposed component:

- **Technical feasibility** – The suitability of Unity-to-Arduino serial communication and WS2812B LED technology for real-time synchronization.
- **Market feasibility** – The potential demand for high-engagement VR showcases in public exhibitions, gaming events, and research demonstrations.
- **Financial feasibility** – The estimated cost of microcontrollers, programmable lighting, and power components within a standard undergraduate budget.
- **Operational feasibility** – The practicality of integrating a secondary visual layer that functions reliably alongside the main VR motion rig.
- **Ethical and safety feasibility** – Compliance with safety standards for visual stimuli (e.g., avoiding seizure triggers) and ensuring an engaging yet safe environment for spectators.

2. Problem Statement

Most seated Virtual Reality (VR) motion platforms provide high levels of immersion exclusively to the headset user, while providing little to no synchronized feedback to external spectators. While the user in the virtual environment experiences intense events such as high-speed flight, collisions, and atmospheric shifts, those outside the headset see only a rider on a moving rig with no context of the virtual world. This "spectator gap" creates a sensory and emotional disconnect, making public VR demonstrations less engaging and harder for an audience to understand.

Existing methods for spectator engagement are often limited to secondary monitor mirrors, which do not translate the physical intensity or environmental "feeling" of the VR experience into the real world. While some high-end attractions use integrated room lighting, these systems are typically expensive, custom-built, and inaccessible for small-scale research or modular entertainment applications. There is a distinct lack of affordable, real-time synchronization frameworks that can translate specific VR events into visible, environmental visual cues for an external audience.

Although research has focused heavily on the player's immersion, limited exploration has been dedicated to synchronized external visual feedback systems designed specifically for spectator engagement in VR motion platforms. Currently, there is no modular and accessible framework that translates broom-based aerial navigation parameters into synchronized real-world lighting effects. This results in a weak communication of the virtual experience to external viewers, reducing the overall entertainment and educational value of VR exhibitions and public showcases.

3. Project Description

3.1 Proposed Solution

The proposed solution is a synchronized external visual feedback system designed to enhance spectator engagement for the Nimbus-based VR motion platform. The system extracts real-time gameplay events such as flight speed, collisions, and environmental triggers and translates them into physical lighting effects in the external environment. By utilizing a Unity-to-hardware communication pipeline, the system bridges the "spectator gap," allowing an audience to visually perceive the intensity and context of the virtual experience through a programmable LED interface.

3.2 Key Features

- **Real-Time Event-to-Light Synchronization**: Automatically triggers specific lighting animations (e.g., red flashes for collisions, blue pulses for water) based on virtual gameplay events.
- **Dynamic Spectator-Centered Immersion**: Translates invisible VR experiences into visible real-world effects, creating a shared sense of immersion between the player and the audience.
- **Speed-Sensitive Visual Cues**: Generates "chase" lighting patterns and color-shifting animations that correspond to the player's virtual flight velocity.
- **Environmental Storytelling**: Uses ambient RGB lighting to represent changes in the virtual environment, such as day/night cycles or entering high-danger zones.
- **High-Speed Serial Communication Interface**: Utilizes a dedicated low-latency link between the Unity VR engine and Arduino-controlled LED hardware for near-instantaneous feedback.
- **Modular Hardware Architecture**: Designed using affordable WS2812B LED strips and microcontrollers, making the system easy to integrate into various exhibition settings.
- **Anonymized Spectator Engagement Logging**: Captures timing data and system responsiveness metrics to evaluate the effectiveness of synchronized visuals on audience engagement.

3.3 Methodology

The project follows a Design Science Research (DSR) methodology with a focus on iterative development and spectator-based validation. The system is developed through the design of a middleware layer that maps virtual Unity triggers to hardware-executable lighting commands. Evaluation is conducted through an experimental study comparing audience reactions and engagement levels between standard VR demonstrations and those enhanced with

synchronized visual feedback. Technical performance is measured through synchronization latency and system stability, while qualitative metrics are gathered via spectator questionnaires to assess emotional response and understanding of the gameplay.

3.4 System Overview

The system consists of three primary layers. The Virtual Environment Layer is the Unity-based system that manages the VR scene logic, identifies key flight events (such as acceleration, crashes, or environment shifts), and dispatches data triggers in real-time. The Processing & Synchronization Layer acts as the core engine that receives virtual data, applies color-mapping logic, and converts these events into specific animation instructions for the external hardware. The Physical Visual Layer is the hardware array including programmable RGB LED strips and ambient lighting that executes the visual effects for the spectators via a microcontroller-based interface, providing real-time visual representation of the player's experience.

4. Feasibility Analysis

4.1 Technical Feasibility

The technical foundation of the project rests on mature and widely accessible development tools. Unity is utilized as the primary 3D engine for identifying VR gameplay events and managing environmental triggers. The visual feedback is executed through a microcontroller-based interface, utilizing Arduino boards (Uno) to control WS2812B programmable RGB LED strips.

A key technical accelerator for this component is the design of a specialized event-mapping middleware. This logic converts Unity-based data (such as collision triggers or speed variables) into specific lighting protocols. The reliance on high-speed serial communication ensures that external visual cues are synchronized with internal VR events, meeting the low-latency requirements necessary for spectator engagement. The required expertise in Unity scripting, serial data transfer, and circuit design is well within the scope of an undergraduate specialization in Interactive Media at SLIIT.

4.2 Market Feasibility

The primary target market for this technology is location-based immersive VR attractions, including public exhibitions, gaming events, and research showcases. The value proposition centers on bridging the "spectator gap" by making the invisible VR experience visible and engaging for an audience. This enhances the entertainment value for spectators, who traditionally have limited context regarding the rider's experience.

Market demand is supported by the unique niche for synchronized environmental feedback in scenario-based VR demonstrations, such as broom-flight navigation. Potential partners include event organizers, VR arcades, and educational institutions looking to increase the communicative impact of their immersive displays. The modular nature of the LED system allows it to be scaled or adapted for various themes beyond the initial flight simulation, such as horror or racing scenarios, providing high commercial flexibility.

4.3 Financial Feasibility

The estimated total cost of development for this component is summarized in the table below:

Item	Description	Estimated Cost (LKR)
Microcontrollers	Arduino Uno/Nano and USB communication cables	5,000
Visual Output	WS2812B RGB LED Strips (High-density)	12,000
Power & Wiring	5V Power Supply, jumper wires, and breadboards	8,000
Diffusion Materials	Acrylic panels or diffusion tubes for soft lighting	5,000
Miscellaneous	Mounting hardware, transport, and contingency	4,000
Total Estimated Cost		**34,000**

The total estimated cost is highly optimized for an undergraduate research budget. By utilizing affordable, off-the-shelf electronic components and free development tools (Unity Personal/Arduino IDE), the project maintains low financial risk while offering high experiential value.

4.4 Operational Feasibility

The system is designed for high reliability and ease of deployment within public or research environments. The modular LED architecture allows the lighting array to be easily mounted to the motion rig or placed around the exhibition area. A core operational principle is the synchronization of gameplay events with external visuals; the system includes a dedicated latency monitoring script within Unity to ensure the lighting response remains consistent with the player's actions.

Maintenance is simplified through the use of standardized components and a modular design, allowing for independent replacement of LED segments or microcontrollers. Scalability is a key feature; once the core synchronization framework is established, the system can be updated

with new lighting patterns for different game scenarios by simply adjusting the middleware logic without requiring hardware redesign.

4.5 Ethical Feasibility

As the research involves presenting visual stimuli to spectators, safety and ethical compliance are strictly integrated. The project follows the SLIIT Research Ethics Committee guidelines, ensuring that any lighting effects (such as flashes or pulsing) are designed to avoid triggers for photosensitive epilepsy by staying within safe frequency and intensity thresholds.

Spectators participating in the evaluation phase will be provided with informed consent regarding the nature of the visual display and their right to withdraw. All spectator feedback and engagement data will be fully anonymized to protect participant privacy. The system is designed to be an inclusive enhancement, ensuring that the visual display adds value without causing physical discomfort or safety risks to the audience.

5. Risk Analysis

The following table summarizes identified risks, their likelihood and potential impact, and the planned mitigation strategy for each:

Risk	Likelihood	Impact	Mitigation Strategy
Visual synchronization latency	Medium	High	Optimize serial baud rates and utilize efficient event-handling scripts in Unity to ensure LEDs trigger instantly with in-game events.
Environmental lighting interference	Medium	Medium	Use high-brightness WS2812B LEDs and diffusion materials to ensure visibility even in well-lit exhibition spaces.
Photosensitive safety concerns	Low	High	Design lighting patterns (flashes/pulses) to stay within safe frequency thresholds to prevent discomfort or seizure triggers for spectators.
Hardware power instability	Low	Medium	Utilize dedicated 5V power supplies for LED strips to prevent voltage drops and ensure consistent color reproduction during intense animations.
Complexity in event-to-color mapping	Medium	Low	Develop a standardized "Event-Visual Matrix" and conduct pilot tests to ensure spectators correctly associate colors with virtual events.
Serial communication bottlenecks	Low	Medium	Implement a lightweight data protocol to minimize the amount of information sent per frame, preventing buffer overflows in the Arduino.
Scope creep regarding light quantity	High	Medium	Strictly define the LED placement and density early in the project to avoid over-complicating the power and mounting requirements.

Of these risks, the most significant in terms of project delivery is visual synchronization latency, as a timing mismatch between a visible crash in-game and the external red flash would break the spectator's immersion and understanding. This is mitigated by optimizing the Unity-to-Arduino interaction pipeline. The second most significant risk is photosensitive safety, which is being mitigated by strictly following visual frequency guidelines and conducting safety checks on all pulsing and strobe-based animations before public demonstrations.

6. Recommendations

6.1 Feasibility Summary

Aspect	Verdict	Summary
Technical Feasibility	**Feasible**	Core technologies (Unity, Arduino, WS2812B) are industry-standard and reliable. The serial communication link is a proven method for low-latency hardware control.
Market Feasibility	**Feasible**	Addresses a specific gap in VR exhibitions by improving spectator engagement, which is highly valuable for public events and arcades.
Financial Feasibility	**Feasible**	The estimated development cost is highly optimized for an undergraduate research budget, utilizing affordable electronic components.
Operational Feasibility	**Feasible**	The system is designed as a modular and portable enhancement that does not interfere with the core mechanical operation of the Nimbus-based rig.
Ethical Feasibility	**Feasible**	The project includes safety-first lighting design and follows ethical guidelines regarding visual stimuli and participant evaluation.

6.2 Overall Conclusion on Feasibility

Based on the analysis across all five dimensions, the Synchronized External Visual Feedback System (Component 04) is feasible and is recommended to proceed to full development. The technical foundation is solid, supported by efficient event-mapping logic and high-speed serial communication interfaces. The target market in immersive entertainment is genuine, offering a unique solution to the "spectator gap" during public VR demonstrations. While ensuring low latency between virtual events and physical lighting is a priority, the use of specialized middleware provides a clear and practical path for implementation.

6.3 Suggested Next Steps

- **Finalize the Event-Visual Matrix** with supervisor approval to ensure the lighting patterns (color, frequency, duration) effectively represent the intended flight events.
- **Establish the core communication link** between Unity and the Arduino to validate that data triggers are being received with minimal delay.
- **Prototype a single LED strip vertical slice** to test the "High Speed" and "Collision" animations in a simulated environment.

- **Draft experimental trial protocols** in parallel with technical development so that spectator engagement studies can begin as soon as the system is stable.
- **Conduct a safety calibration session** to measure the intensity and frequency of flashing effects, ensuring they meet ergonomic and ethical standards for public viewing.
- **Submit the ethics application** to the SLIIT Research Ethics Committee at the earliest opportunity to avoid delays before the participant-based validation phase.

7. Conclusion

This feasibility study has examined the proposed Synchronized External Visual Feedback System for Spectator Engagement (Component 04) across technical, market, financial, operational, and ethical dimensions. The study finds that the project is feasible on all five dimensions and that the identified risks, such as synchronization latency and photosensitive safety, are manageable with the proposed mitigation strategies.

The importance of this project lies in the meaningful gap it addresses in public VR exhibitions. Existing systems often focus exclusively on the headset user, leaving spectators disconnected from the experience. The proposed system directly addresses this through a synchronized external lighting layer that aligns virtual events with real-world visual cues, thereby enhancing audience engagement and emotional understanding.

If successful, this component has the potential to advance the field of shared VR experiences by providing a modular and scalable spectator-feedback platform. It offers a blueprint for realistic environmental storytelling in location-based entertainment and contributes empirical data on the effectiveness of external visual cues in bridging the gap between digital and physical immersion.

8. References

[1] J. Friedman *et al.*, "Embodied virtual reality for the study of real-world motor learning," *PMC*, 2021.

[2] M. O'Malley, "Revolutionizing touch: Researchers explore the future of wearable multi-sensory haptic technology," *EurekAlert!*, 2025.

[3] R. Islam *et al.*, "RelaxVR: Cybersickness Reduction in Immersive Virtual Reality Through Explainable AI and Large Language Models," *ResearchGate*, 2026.

[4] Microsoft Research, "Measuring System Visual Latency through Cognitive Latency on Video See-Through AR devices," in *Proc. IEEE VR*, 2020.

[5] "Understanding the Effect of Latency on User Performance of Target Selection in Virtual Reality," *ResearchGate*, 2024.

[6] Souchet *et al.*, "Design guidelines for limiting and eliminating virtual reality-induced symptoms and effects at work: a comprehensive, factor-oriented review," *PMC*, 2023.

[7] "AI-Powered Multisensory Feedback Systems for Virtual Collaboration: Enhancing Remote Communication with Haptic, Auditory, and Thermal Cues," *IJFMR*, vol. 6, no. 2, 2024.

9. Appendices

Appendix A - Confirmed External Visual Synchronisation Areas

The external visual feedback strategies for the **Nimbus-based VR system** (Component 04) are developed based on established environmental storytelling and human-perception principles, as validated against the research objectives in the proposal deck:

- **Collision Detection Feedback**: Triggers high-intensity red flash animations across the LED array to signal impacts or danger events to spectators.
- **Velocity-Based Lighting**: Maps virtual speed parameters to "chase" animations and color shifts, allowing spectators to perceive the rider's flight velocity.
- **Ambient Environmental Cues**: Adjusts the overall room or rig lighting to match virtual environmental states, such as blue hues for night-time or aquatic zones.
- **Directional Motion Indication**: Uses light-movement patterns to visually represent turns and banking maneuvers performed by the rider on the motion platform.
- **Status & Boost Indicators**: Employs specific color cycles (e.g., rainbow "chase") to indicate special gameplay states like boost modes or successful task completions.
- **Safety-Constrained Strobe Control**: Implements software-level frequency limits to ensure all pulsing effects remain within safe thresholds for public viewing.