SLIIT UNI
THE KNOWLEDGE UNIVERSITY

IT4010 Research Project – 2026 Jan

Topic Assessment Form

V2.1

Project ID:t R26-IM-004

1. Topic (12 words max)

Immersive VR motion seat for full body navigation

2. Research group the project belongs to

MR - Mixed Reality

3. Specialization of the project belongs to

Interactive Media (IM)

4. If a continuation of a previous project:

Project ID	-
Year	-

5. Brief description of the research problem including references (300 – 500 words max) – references not included in word count.

Virtual Reality (VR) has achieved significant advances in visual and auditory immersion; however, it continues to fall short in delivering convincing physical embodiment [1],[2]. Most contemporary VR systems rely on handheld controllers and limited vibrotactile feedback, which restrict the user's ability to physically feel motion, forces, and environmental dynamics [3]. As a result, user interaction remains largely symbolic rather than embodied, reducing presence and limiting the effectiveness of VR experiences across domains such as gaming, simulation, training, rehabilitation, and fitness.

A major limitation within the current VR ecosystem is the absence of accessible, modular, and fully actuated systems that support seated or semi-constrained full-body navigation [4]. Existing motion platforms are typically expensive, highly specialized, and designed for single-purpose simulations, such as flight or driving simulators. These systems are primarily deployed in commercial arcades or high-end training facilities, making them impractical for wider adoption by individual users, researchers, or educational institutions. Additionally, the lack of modularity in such platforms forces organizations to invest in multiple devices to support different interaction paradigms, increasing both economic cost and operational complexity.

While prior research has explored haptic feedback, motion cues, and locomotion techniques in VR, there remains a limited understanding of how modular, seated motion systems can balance physical feedback, immersion, and user comfort across multiple virtual experiences. In particular, the impact of environment-driven physical cues such as simulated wind resistance, acceleration, and directional forces on perceived embodiment has not been sufficiently evaluated within a single, reconfigurable platform.

This gap restricts both academic exploration in HCI and practical innovation in consumer VR hardware.

The consequences of this limitation span technical, economic, and social dimensions. Technically, the absence of synchronized physical feedback reduces the realism of motion representation and interaction. Economically, non-modular systems raise barriers to adoption and experimentation. Socially, users miss opportunities for deeper engagement, experiential learning, and physically active interaction within virtual environments.

Aligned with the Mixed Reality (MR) research cluster and the Simulation, Entertainment, Fitness, and Training verticals, this research aims to address these challenges by investigating a modular, actuated VR motion seat designed to enhance physical embodiment while remaining cost-effective and scalable. The project focuses on evaluating how real-time actuation, sensor-based tracking, and environment-driven feedback can improve user immersion and interaction quality within seated VR experiences.

References:

[1] R. Skarbez, F. Brooks, and M. Whitton, "Immersion and presence in virtual reality systems," IEEE Computer Graphics and Applications, vol. 41, no. 3, pp. 24–38, 2021.

[2] S. Grassini and K. Laumann, "Are modern head-mounted displays sufficient for presence?" Frontiers in Psychology, vol. 11, pp. 1–13, 2020.

[3] J. J. Cummings and J. N. Bailenson, "How immersive is enough? A meta-analysis of the effect of immersive technology on user presence," Psychological Science, vol. 33, no. 2, pp. 157–176, 2022.

[4] J. Jerald, "Human-centered design for virtual reality," IEEE Computer Graphics and Applications, vol. 42, no. 1, pp. 12–21, 2022.

[5] T. Langbehn et al., "Locomotion in virtual reality," IEEE Computer Graphics and Applications, vol. 41, no. 2, pp. 32–46, 2021.

[6] M. Lopes et al., "Haptic interfaces for virtual reality: Challenges and opportunities," IEEE Access, vol. 8, pp. 200124–200140, 2020.

[7] S. Rietzler et al., "Breaking the illusion: perception of motion and force feedback in virtual reality," IEEE Transactions on Visualization and Computer Graphics, vol. 26, no. 5, pp. 2154–2164, 2020.

[8] A. Brunnström et al., "Physical feedback systems for immersive virtual reality navigation," in Proc. IEEE VR, 2024.

[9] C. Boletsis, "VR locomotion techniques: A systematic review," Virtual Reality, vol. 26, pp. 1–22, 2022.

[10] Y. Kim et al., "Multisensory feedback for enhanced immersion in virtual reality," IEEE Access, vol. 11, pp. 45612–45626, 2023.

[11] A. Kitson et al., "The effects of multisensory feedback on user experience in virtual reality," in Proc. ACM CHI, 2021.

[12] R. Weech et al., "Influence of sensory mismatch on cybersickness in virtual reality," IEEE Transactions on Visualization and Computer Graphics, vol. 26, no. 2, pp. 1086–1097, 2020.

6. Brief description of Existing Research and Systems (300 words max)

Existing VR motion systems can broadly be classified into commercial motion platforms and academic research prototypes. Commercial solutions, such as flight and racing simulators, are capable of delivering high-fidelity motion cues; however, recent studies highlight that these systems are typically expensive, physically large, and designed for narrowly defined use cases, limiting their accessibility and adaptability for broader VR applications [6], [8]. Their fixed-purpose architectures and lack of reconfigurability make them unsuitable for experimental research, consumer deployment, or multi-scenario interaction design.

Contemporary academic research has extensively explored VR embodiment, locomotion, and multisensory feedback. Recent studies emphasize that immersion and presence depend not only on visual fidelity but also on synchronized sensorimotor feedback, including motion, force, and environmental cues [1], [2], [3]. Research on haptic interfaces demonstrates that physical feedback significantly improves realism and user engagement, yet also identifies challenges related to cost, scalability, and integration into consumer-oriented systems [6], [7]. Similarly, recent locomotion research highlights persistent limitations in controller-based and software-only navigation techniques, particularly in balancing realism, comfort, and usability [5], [9].

Despite these advances, existing research predominantly evaluates motion or haptic systems in isolation or within constrained experimental setups. Recent surveys and empirical studies indicate that most systems are designed around single interaction metaphors and lack modular architectures capable of supporting multiple navigation paradigms on a shared actuation platform [5], [9]. Furthermore, while multisensory feedback has been shown to enhance immersion, limited work has systematically investigated how environment-driven physical cues such as resistance, inertia, and motion derived from virtual environmental states affect user comfort and embodiment in seated VR navigation scenarios [10], [11], [12].

These observations reveal a clear research gap: the absence of applied studies evaluating modular, reconfigurable VR motion systems that integrate real-time actuation, multisensory feedback, and environmental interaction within a single platform. Addressing this gap requires research that balances immersion, safety, usability, and scalability under realistic constraints. The proposed research directly targets this gap by investigating a modular VR motion seat designed to support multiple interaction paradigms while enabling systematic evaluation of embodied navigation and user experience.

7. Brief description of the solution's nature, including a conceptual diagram (maximum 500 words).

The proposed solution is an **immersive, motorized VR motion seat designed for full-body navigation**, addressing the limitations identified in existing VR motion systems. Unlike current solutions that are expensive, single-purpose, and rigid in functionality, this system is designed as a **modular and reconfigurable platform** that can support multiple VR experiences using a single actuated base. By combining controlled seat motion, force feedback, vibration, and synchronized VR interaction, the system bridges the gap between visual immersion and physical embodiment.

The motion seat allows users to navigate virtual environments using natural body movements such as leaning, tilting, and directional shifts. These physical actions are captured using embedded sensors and translated into VR navigation commands. In return, the system provides real-time physical feedback through actuators that generate tilt, resistance, and vibration corresponding to virtual events. This bidirectional interaction significantly improves presence, realism, and spatial awareness when compared to controller-based VR navigation.

To address the lack of modularity in existing platforms, the system supports interchangeable interaction modules such as handlebars, broom-style controls, or flight-oriented interfaces. Each module enables a different VR experience while utilizing the same motion seat base, reducing hardware costs and improving scalability. Safety mechanisms, motion limits, and ergonomic considerations are incorporated to ensure user comfort and controlled movement during operation.

From a system perspective, the solution can be described using an **Input–Process–Output** model:

Input:

User body movements (lean, tilt, pressure) module-specific interactions, VR environment events, and sensor data from IMUs, encoders, and pressure sensors.

Process:

Sensory data processed, motion interpretation, haptic mapping algorithms, real-time actuator control, and synchronization with the VR engine.

Output:

Seat tilt and motion, force resistance, vibration feedback, and immersive physical responses aligned with virtual navigation.

The conceptual diagram illustrates the flow of data and control between the user, motion seat, sensors, control system, actuators, and VR environment. By integrating modular hardware design with real-time haptic feedback and VR synchronization, the proposed solution offers a **cost-effective, scalable, and immersive motion platform** suitable for gaming, simulation training, fitness applications, and interactive research environments.

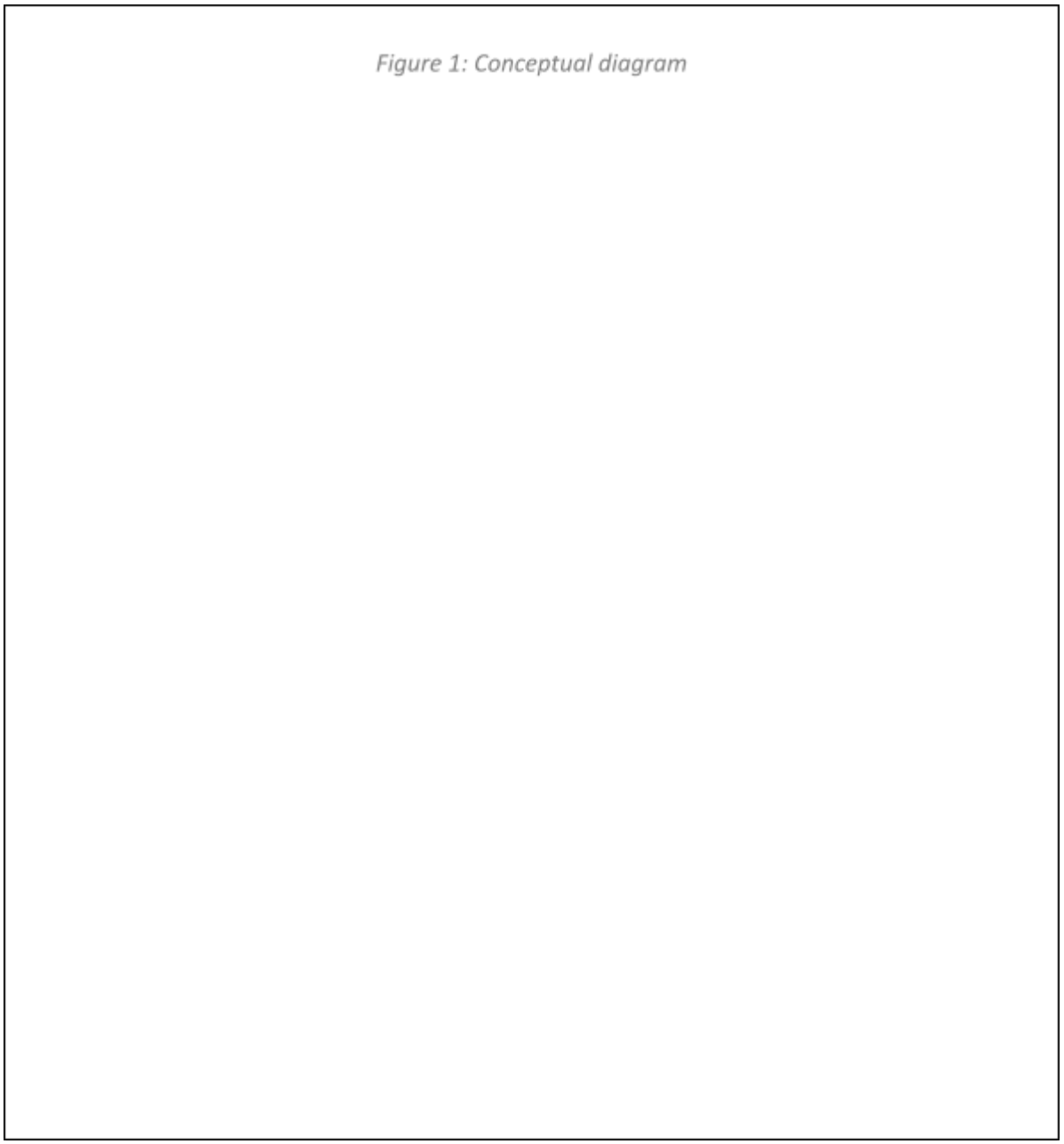


Figure 1: Conceptual diagram

8. Brief overview of the availability of necessary specialized domain expertise, knowledge, and data. (500 words max)

The proposed immersive VR motion seat project requires multidisciplinary expertise spanning mechanical systems, haptics, virtual reality development, and human–computer interaction. The project team can gain essential specialized domain expertise through a combination of academic research, supervisor guidance, practical experimentation, and continuous learning via online resources. Reviewing existing literature on VR motion platforms, haptic feedback systems, embodied interaction, and full-body navigation techniques will provide a strong theoretical foundation. In addition, regular consultations with the supervisor will help align technical decisions with research best practices and safety considerations.

Technical knowledge and skills required for the project include mechanical design and prototyping, actuator selection and control, sensor integration, and VR software development. Team members can acquire these skills through hands-on prototyping, laboratory access, and structured learning using platforms such as Unity or Unreal Engine for VR development. Skills related to embedded systems, motor control, and sensor fusion can be developed incrementally by building small test modules before integrating them into the full system. Knowledge of human–computer interaction principles and user experience design will guide ergonomic decisions and ensure that the motion seat remains comfortable, intuitive, and safe for users.

The data required for the project will primarily be collected through controlled system testing and user evaluation studies. Quantitative data will include sensor readings such as tilt angles, acceleration values, actuator response times, and system latency measurements. Qualitative and quantitative user feedback will also be gathered to assess immersion, comfort, usability, and perceived realism. This data will be collected through observation, questionnaires, and standardized evaluation metrics commonly used in VR research, such as presence and comfort scales. All data collection will be conducted in a structured manner to support analysis and iterative system improvement.

Since the project involves human participants interacting with a motorized physical system and immersive VR environments, **ethical clearance is required**. Ethical considerations include ensuring participant safety, minimizing physical and cognitive discomfort, obtaining informed consent, and allowing participants to withdraw at any time. Safety mechanisms, motion limits, and clear testing protocols will be implemented to reduce risk. Obtaining ethical approval ensures that the research adheres to institutional guidelines and promotes responsible and safe experimentation.

9. Objectives and Novelty

Main Objective To design, develop, and evaluate an immersive, modular VR motion seat that enables full-body navigation through real-time actuation, sensor-based tracking, and synchronized haptic feedback, thereby enhancing user embodiment, realism, and immersion in virtual environments.			
Member Name with Registration No	**Sub Objective**	**Tasks**	**Novelty**
Gunawardena L H IT22082992	Motion Rendering and Control Strategy Evaluation	• Design and implement **multiple motion rendering strategies** (e.g., position-based, velocity-based, and acceleration-based motion cueing) for seat tilt, vibration, and resistance. • Develop **adaptive control logic** that dynamically adjusts motion intensity based on user state (speed, direction changes) and environmental context. • Integrate real-time actuator control with VR navigation events using closed-loop feedback from sensors.	• Comparative evaluation of motion control strategies specifically for **seated VR navigation**. • Introduces safety-aware motion rendering tailored to immersive full-body VR experiences.

		• Apply **safety-aware constraints** (motion bounds, jerk limits, emergency damping) to prevent instability, discomfort, or simulator sickness. • Conduct **comparative experiments** to evaluate responsiveness, smoothness, realism, and user comfort across control strategies.	
Botheju WRD IT22119094	Environmental Interaction and Immersion Modelling in Open-World VR	• Define environmental interaction parameters such as wind resistance, speed, turbulence, and spatial openness. • Design **open-world VR scenarios** with controlled variations of environmental conditions. • Map virtual environmental states to physical force feedback (resistance, vibration, directional cues) delivered through the motion seat and attachments. • Implement parameterized force models to simulate perceived environmental resistance during navigation. • Conduct controlled user studies comparing navigation experiences with and without environment-driven physical feedback.	• Evaluates **environment-driven force interaction** in open-world VR navigation. • Links environmental simulation with physical motion feedback to enhance embodied immersion beyond visuals.

Nimsara L G S K IT22191724	Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems	• Measure end-to-end latency between VR events and physical motion feedback. • Log system response times and identify jitter or synchronization inconsistencies. • Conduct controlled navigation tests to assess perceived delay and responsiveness. • Compare system performance under varying update rates and synchronization settings. • Identify acceptable latency thresholds for immersive seated VR navigation.	• Empirical study on **latency and responsiveness thresholds** in seated VR motion systems. • Directly correlates system timing performance with user perception and control confidence.
SILVA H S N IT22129208	Modular Mechanical Design and Stability Analysis of a VR Motion Seat	• Design modular and fixed VR motion seat configurations using CAD tools. • Perform load, stress, and vibration analysis under dynamic motion conditions. • Design ergonomic seating and leg support suitable for extended VR use. • Evaluate structural stability during actuation and force application.	• Proposes a **modular mechanical architecture** for VR motion seats supporting multiple interaction modes. • Balances structural stability with reconfigurability for immersive VR applications.

		• Compare modular versus fixed designs in terms of safety, stability, and usability.	

10. <u>This part is to be filled by the Supervisor and the Co-supervisor of the Project.</u>

a) This research topic possesses a comprehensive scope suitable for a final-year project.

Yes		No	

b) The proposed topic exhibits novelty.

Yes		No	

c) The student group can successfully execute the proposed project.

Yes		No	

d) The proposed sub-objectives reflect the students' areas of specialization.

Yes		No	

e) Any other comments:

	Title	First Name	Last Name	Signature
Supervisor				
Co-Supervisor				
External Supervisor				
Summary of external supervisor's (if any) experience and expertise				