Presented by Group R26-IM-004

A Multisensory Motion-Enabled VR Interaction System

Immersive Multisensory VR Motion System for Full body Navigation

SLIIT
FACULTY OF COMPUTING

Date
20 March 2026



Google Drive Link to the video

Project ID: R26-IM-004

20 March 2026

The Problem We Solve

Lack of Physical Realism and Embodied Interaction in VR Navigation

VR systems provide strong visual immersion, but lack physical feedback

This creates sensory mismatch, in return reducing immersion

To Whom We Solve

Our users and stakeholders



VR users (gamers, trainees, researchers)



VR developers & simulation designers



VR simulation institutions & companies

How the problem affects Today's VR Navigation Experience?

01.

Lack of Synchronized Physical Feedback

- Visual motion is not matched with physical feedback
- Users **see movement but do not feel it**
- Breaks immersion and embodiment

02.

Cyber sickness & Discomfort

- Sensory mismatch leads to motion sickness
- Causes nausea, disorientation, and fatigue
- Limits usability of VR systems

03.

Unrealistic Navigation

- Movement lacks physical grounding
- Interaction feels artificial and disconnected
- Reduces realism in simulation and training

Research papers mentioned in the last slide for the citations

Research Gaps In Today's VR Navigation Experience?

01.

Existing research shows VR locomotion techniques are diverse but lack unified, realistic solutions [4]

02.

Sensory mismatch between visual and physical cues leads to cybersickness and reduced usability [5]

03.

Effective VR navigation requires alignment between physical movement and virtual motion [6]

Research papers mentioned in the last slide for the citations

Existing Solutions and Their Limitations

Controller-Based Navigation [1]

- Uses joystick or teleportation
- Limited physical feedback, purely visual interaction majorly
- Breaks immersion and embodiment

High-End Motion Simulators [2]

- Provide physical motion feedback
- Expensive and complex systems
- Not modular or accessible

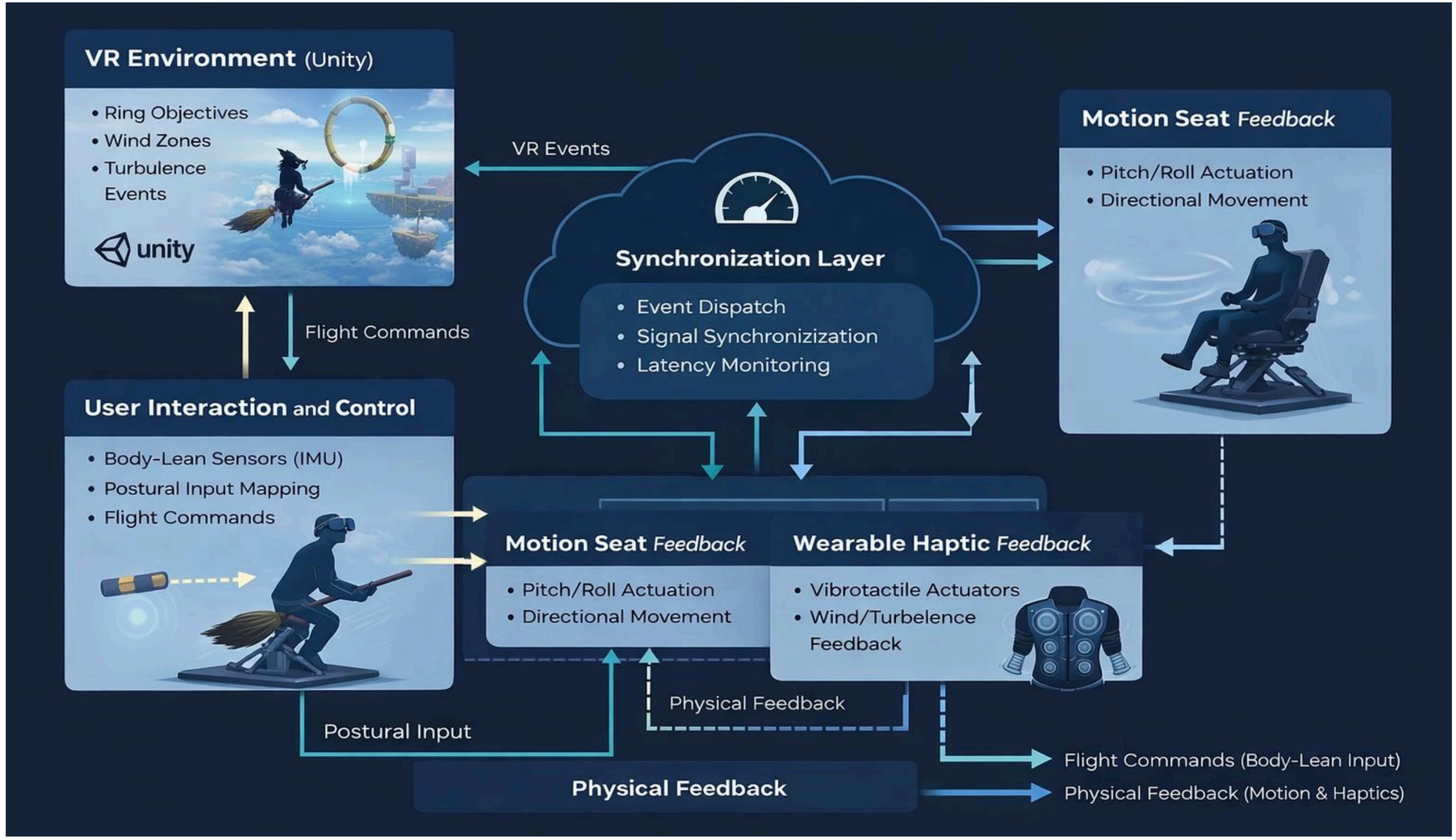
Isolated Haptic Systems [3]

- Provide vibration-based feedback
- Not synchronised with motion or environment precisely
- Limited contribution to realism

Proposed Solution

A synchronized multisensory full-body VR system for realistic and embodied navigation

System Overview



How do we overcome these limitations?



Body-Based Navigation

- Replaces joystick-only input with lean-based control
- Makes navigation more embodied and intuitive
- Reduces the disconnect between user action and virtual motion



Motion Feedback Integration

- Motion seat delivers tilt and directional cues
- Simulates acceleration and orientation during flight
- Improves physical realism in seated VR navigation



Synchronized Environmental Haptics

- Wearable haptics simulate wind, turbulence, and speed effects
- Feedback is synchronized with VR events and motion cues
- Improves multisensory coherence and perceived realism



Modular Scenario-Focused Design

- Uses a single controlled broom-flight scenario
- Avoids the complexity and cost of full-scale motion simulators
- Supports evaluation of effective motion rendering strategies

Individual Student Components and Contributions

Component 1

Motion Rendering and Control

- Converts VR navigation data into actuator control signals
- Designs motion cue generation for tilt, direction, and acceleration
- Contributes to realistic and stable seat motion feedback

Component 2

Environmental Interaction and Immersion Modelling

- Models wind resistance, turbulence, and speed-related effects
- Maps environmental events to wearable haptic feedback
- Contributes to perceived realism and environmental immersion

Individual Student Components and Contributions

Component 3

Latency and Synchronization Analysis

- Measures delay across sensing, processing, and feedback stages
- Defines synchronization requirements for coherent multisensory output
- Contributes to perceptual consistency and reduced mismatch

Component 4

Modular Mechanical Design and Stability

- Designs the broom rig structure and motion-seat support system
- Ensures user safety, ergonomic support, and structural stability
- Contributes to reliable and secure physical interaction



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Motion Rendering and Control for Embodied VR Navigation

Motion Rendering and Control for Embodied VR Navigation

Contribution to the Overall Solution

Maps VR parameters to actuator commands

Produces tilt and directional motion feedback

Links virtual events to physical response

Improves realism and embodiment

Motion Rendering and Control for Embodied VR Navigation

Novelty of the Component

- Existing seated VR systems lack scenario-specific motion rendering for broom-flight navigation
- This component converts VR flight data into synchronized actuator commands and vise versa
- It generates perceptually meaningful motion cues
- It supports improved realism and embodied interaction

Motion Rendering and Control for Embodied VR Navigation

Problem Definition

How can VR navigation parameters be translated into synchronized motion cues?

How can motion cueing improve motion realism and embodied interaction?

What control approach supports perceptually coherent motion feedback in a broom-based VR rig?

Motion Rendering and Control for Embodied VR Navigation

Research Objective

To identify and develop motion rendering strategies for a Nimbus broom-based seated VR navigation system

Sub-objectives

- Determine key VR motion parameters for cue generation
- Map navigation data to adaptive actuator control signals
- Generate synchronized and stable motion cues
- Examine how motion cueing influences user perception of realism and embodiment

Motion Rendering and Control for Embodied VR Navigation

Research Methodology

- Design Science Research (DSR) with controlled experimental evaluation
- Iterative design of a motion rendering framework for a modular VR motion seat
- Compares multiple motion rendering strategies to identify those that improve motion realism and embodied interaction

Motion Rendering and Control for Embodied VR Navigation

Knowledge Domain

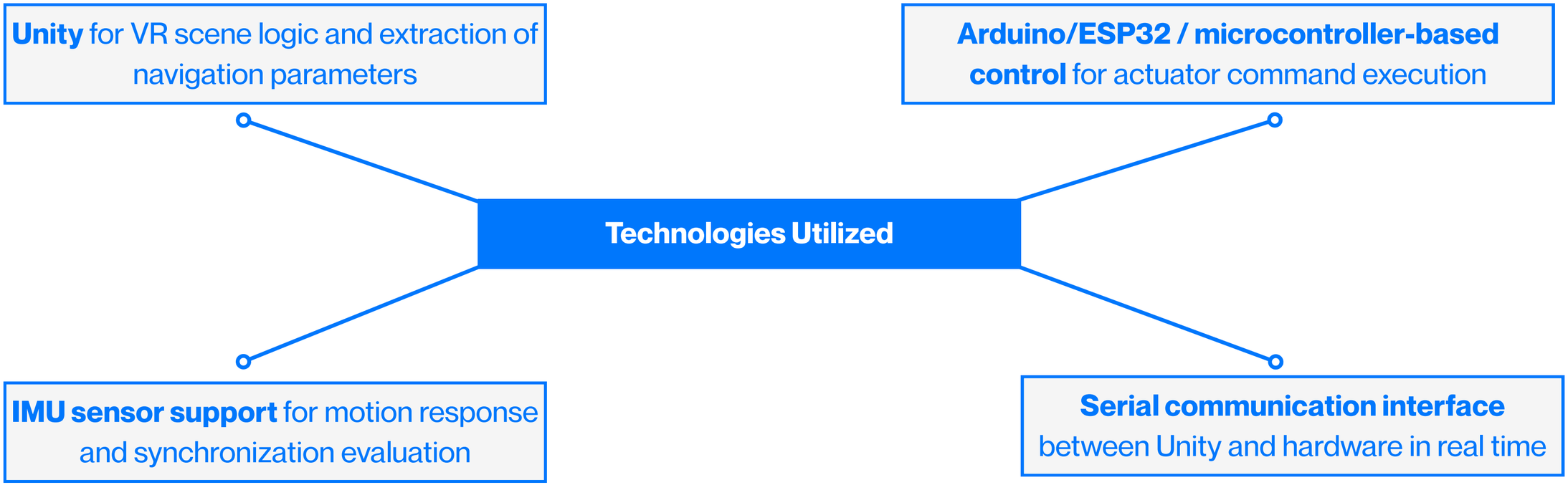
VR locomotion and embodied interaction

Motion cueing and control systems

Embedded systems and actuator interfacing

Human–Computer Interaction and user perception in immersive environments

Motion Rendering and Control for Embodied VR Navigation



Motion Rendering and Control for Embodied VR Navigation

Validation and Evaluation

Controlled comparison of position-based, velocity-based, and acceleration-based motion rendering strategies

Evaluation based on:

- Actuator response time
- Synchronisation accuracy
- System stability
- Perceived motion realism and immersion

Motion Rendering and Control for Embodied VR Navigation

Data Availability

Primary system data

- Navigation parameters
- Actuator outputs
- Synchronization logs

Experimental data

- Task completion time
- Navigation accuracy
- User questionnaire responses

Data collected through controlled testing and user experiments on the VR motion seat platform

Motion Rendering and Control for Embodied VR Navigation

Security and Ethical Clearance



Informed consent required for all participants



Participants may withdraw at any time



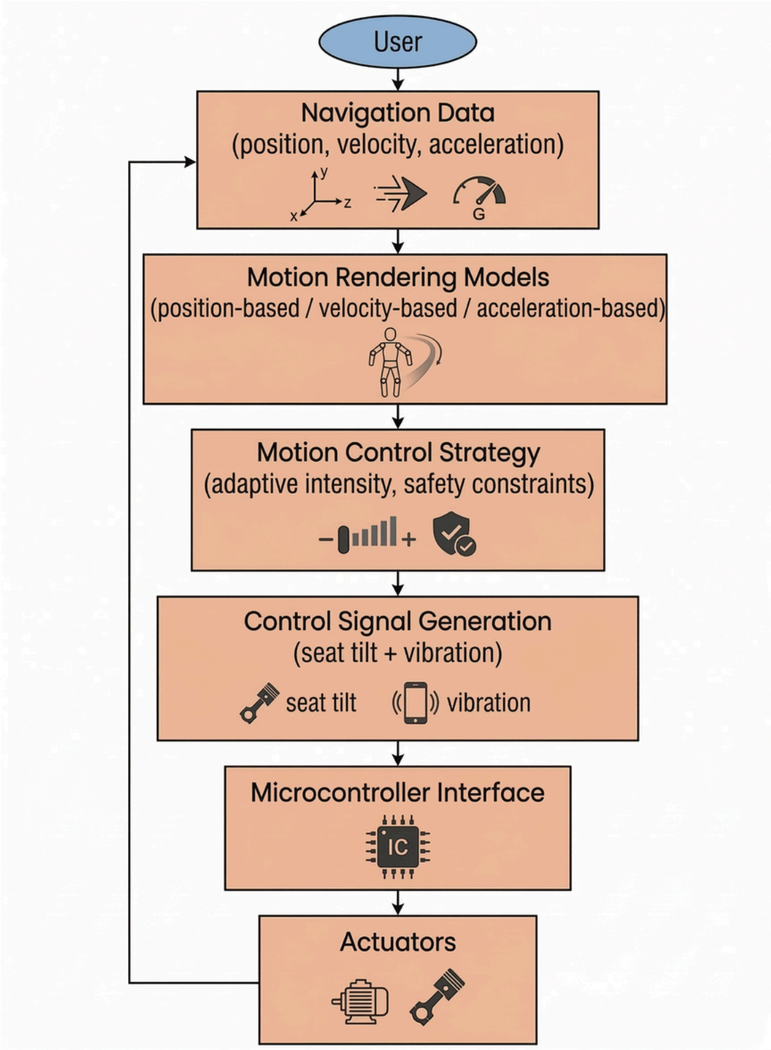
Personal data will be anonymized



Motion control constrained within predefined mechanical safety limits

Motion Rendering and Control for Embodied VR Navigation

System Overview of the Individual Component





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Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Contribution to the Overall Solution

- Converts wind, turbulence, and altitude changes into physical feedback
- Triggers airflow, vibration, and seat tilt based on the VR environment
- Connects environmental simulation with the physical feedback system
- Improves immersion, realism, and embodied interaction in seated VR navigation

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Novelty of the Component

- Existing seated VR systems usually do not turn wind, turbulence, and flight speed into physical feedback
- This component introduces an environment-driven model for broom-based VR flying
- It maps environmental changes to airflow, vibration, and directional feedback
- It improves realism, immersion, and embodied interaction beyond just visual effects

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Problem Definition

How can wind resistance, turbulence, and flight speed be modelled in VR aerial navigation?

How can these environmental states be mapped to synchronized physical feedback?

How can environment-driven feedback improve immersion and perceived realism?

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Research Objective

Design a VR interaction model that turns wind, turbulence, speed, and altitude changes into synchronized physical feedback to improve immersion and realism.

Sub-objectives

- Define environmental parameters for aerial VR navigation
- Build open-world scenarios with controlled environmental variation
- Map virtual environmental states to airflow, vibration, tilt, and directional cues
- Integrate the model with Unity and the motion-feedback platform
- Compare user experience with and without environment-driven feedback

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Research Methodology

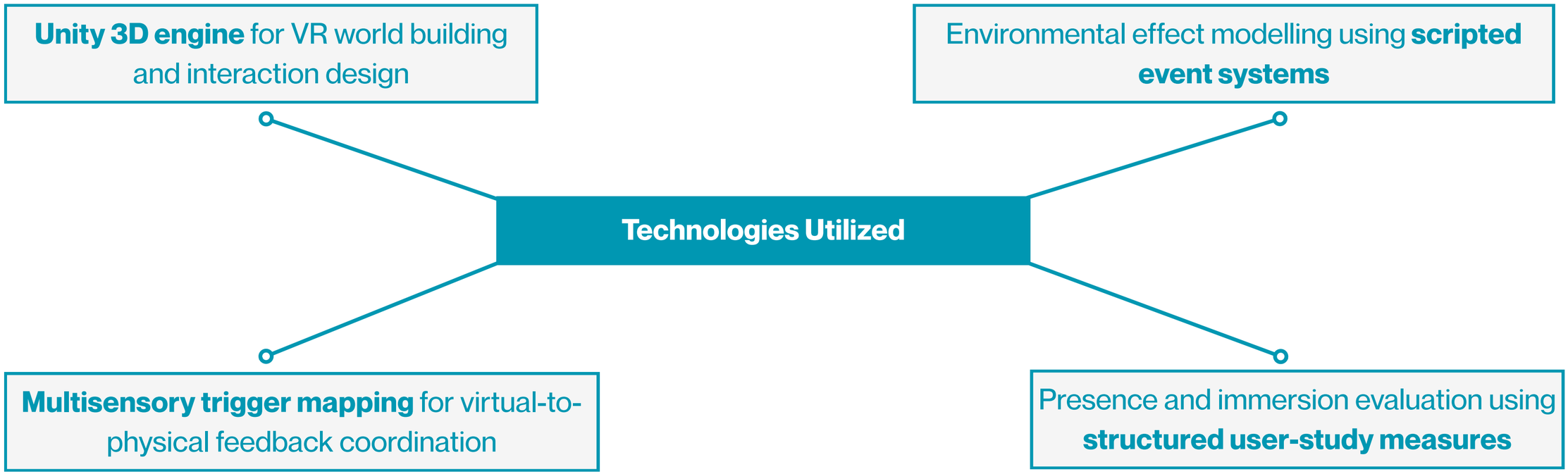
- Uses Design Science Research with controlled experiments
- Develops an environment-driven model for broom-based VR navigation
- Simulates wind, turbulence, speed, and openness
- Converts them into airflow, vibration, tilt, and directional feedback
- Compares user immersion and realism with and without this feedback

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Knowledge Domain

- VR environmental interaction and immersion
- Multisensory feedback design
- Presence and user perception in VR
- Open-world scenario design and interaction mapping

Environmental Interaction and Immersion Modelling for VR Aerial Navigation



Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Validation and Evaluation

User-based evaluation of environmental interaction modelling in a VR aerial navigation scenario

Evaluation based on:

- Perceived realism of environmental effects
- Perceived immersion during navigation
- Consistency of multi-sensory event delivery
- User response to scene-driven interaction cues

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Data Availability

Primary system data	Experimental data
• Environmental parameters • Navigation logs • Feedback mapping values	• Performance metrics • Immersion questionnaire responses • Comparative user-study results

Collected through controlled VR navigation sessions and user experiments on the integrated motion-seat system.

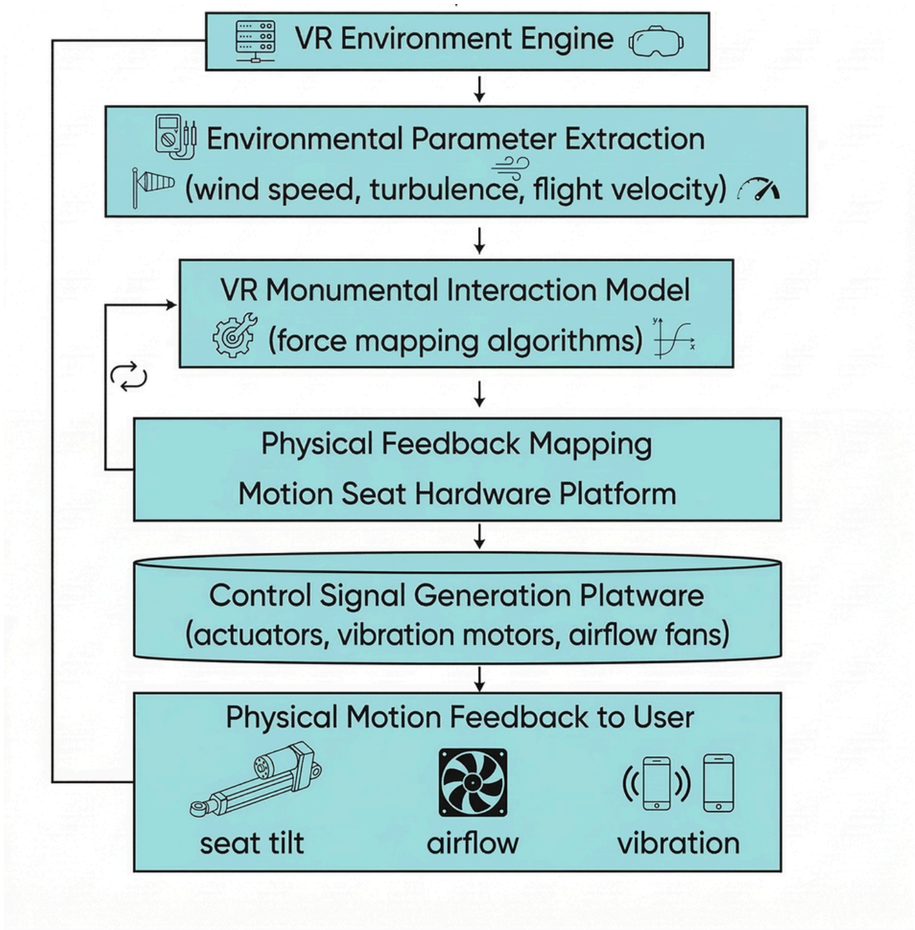
Environmental Interaction and Immersion Modelling for VR Aerial Navigation

Security and Ethical Clearance

- Controlled wind, vibration, and motion feedback exposure
- Informed consent for immersive VR user studies
- Withdrawal allowed if discomfort or fatigue occurs
- Performance and questionnaire data kept confidential

Environmental Interaction and Immersion Modelling for VR Aerial Navigation

System Overview of the Individual Component





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Latency, R onization Ar

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20 March 2026

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Contribution to the Overall Solution

- Quantifies end-to-end latency across the VR–hardware interaction pipeline
- Detects synchronization drift and timing inconsistencies in real-time feedback
- Establishes perceptual latency thresholds for coherent motion experience
- Enhances motion realism and embodied interaction through optimized timing

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Novelty of the Component

Existing VR motion platforms focus on cue generation, but not enough on latency and synchronization analysis.

This component evaluates how timing delays and response consistency affect perceptual coherence in broom-based seated VR navigation.

It helps define timing thresholds for more realistic and embodied motion feedback.

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Problem Definition

How can system latency from virtual navigation events to physical motion output be quantified?

How do response delay and synchronization consistency influence user perception in VR motion systems?

What level of temporal alignment is required for coherent and believable motion feedback?

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Research Objective

To evaluate latency, responsiveness, and synchronization performance in a seated VR motion system for broom-based aerial navigation

Sub-objectives

- Measure end-to-end latency between VR navigation events and physical motion output
- Quantify actuator responsiveness under different motion cue conditions
- Assess synchronization accuracy between virtual events and seat motion response
- Examine how timing performance influences perceived motion realism and embodied interaction

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Research Methodology

- Design Science Research (DSR) with experimental validation
- Implementation of end-to-end latency measurement and logging mechanisms
- Evaluation of synchronization accuracy and timing consistency across VR–hardware interaction
- Controlled user testing to analyze the effect of timing performance on motion realism and embodied interaction
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Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Knowledge Domain

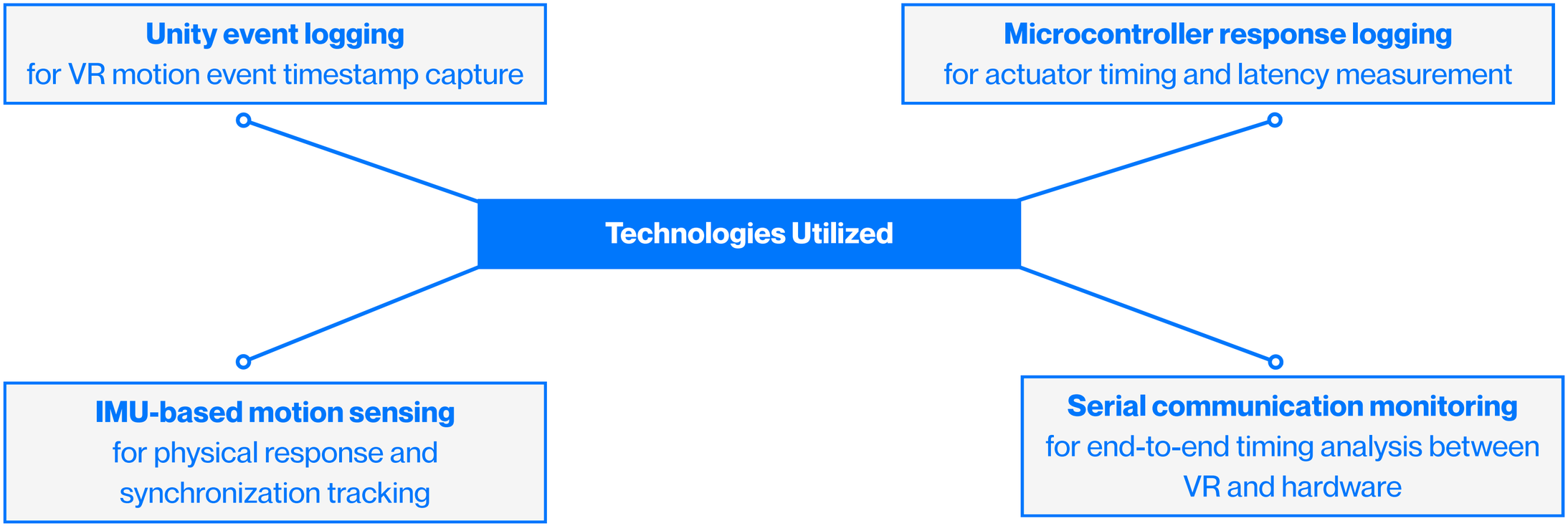
Real-time systems and latency analysis

Embedded communication and response profiling

Synchronization in VR–hardware interaction

Perception of responsiveness in immersive VR

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems



Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Validation and Evaluation

Controlled testing of VR-to-motion response timing and synchronization performance

Evaluation based on:

- Event-to-actuation latency
- Virtual–physical synchronization accuracy
- Response consistency and stability
- User-perceived responsiveness

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Data Availability

Primary system data

- VR event timestamps
- Actuator command logs
- Actuator response logs
- Synchronization records

Experimental data

- Latency measurements
- Synchronization error values
- Repeated-trial consistency results
- Perceived responsiveness ratings

Data obtained through controlled system testing and participant-based evaluation of VR-to-motion timing performance

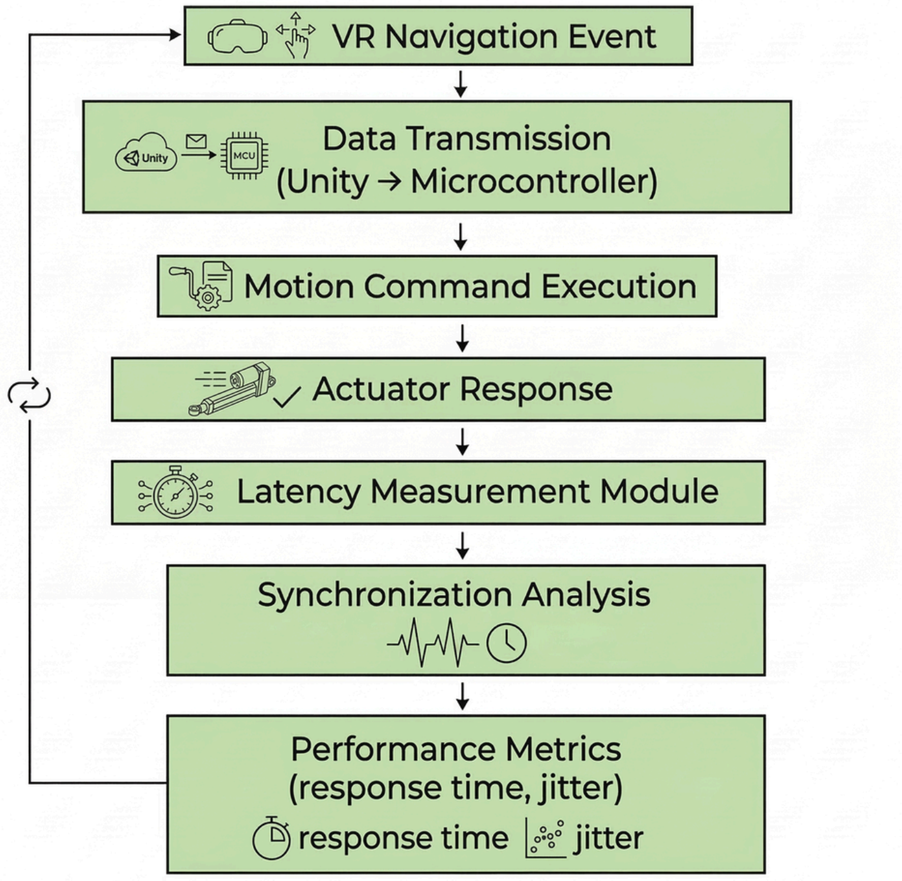
Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

Security and Ethical Clearance

- **Informed consent required before latency and synchronization testing**
- **Participants may withdraw immediately if discomfort occurs**
- **Timing logs and participant responses will be anonymized**
- **All motion trials conducted within predefined system safety limits**

Latency, Responsiveness, and Synchronization Analysis in VR Motion Systems

System Overview of the Individual Component





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Mechanical Integration and Stability Design for the VR Motion Seat Platform

Mechanical Integration and Stability Design for the VR Motion Seat Platform

Contribution to the Overall Solution

- Designs the modular motion-seat structure for safe VR interaction
- Integrates the frame, seat, and actuator mounts into one functional platform
- Ensures stability under user load and dynamic motion conditions
- Provides the mechanical foundation for safe, accurate, and repeatable motion feedback

Mechanical Integration and Stability Design for the VR Motion Seat Platform

Novelty of the Component

- Introduces a modular mechanical architecture for the VR motion seat
- Supports multiple interaction modes on the same seat platform
- Ensures structural stability, safety, and repeatable motion behavior
- Provides an ergonomic hardware foundation for immersive seated VR navigation

Mechanical Integration and Stability Design for the VR Motion Seat Platform

Problem Definition

How can a modular VR motion seat remain stable under dynamic motion conditions?

What mechanical design can manage load, stress, and vibration effectively?

How can the system ensure safe, ergonomic, and repeatable motion during immersive VR use?

Mechanical Integration and Stability Design for the VR Motion Seat Platform

Research Objective

To develop a stable, safe, and modular VR motion seat platform for immersive seated VR navigation.

Sub-objectives

- Design the frame and seat support system
- Integrate actuators into the mechanical structure
- Test stability under load and motion
- Ensure user safety and ergonomic comfort
- Compare modular and fixed platform designs

Mechanical Integration and Stability Design for the VR Motion Seat Platform

Research Methodology

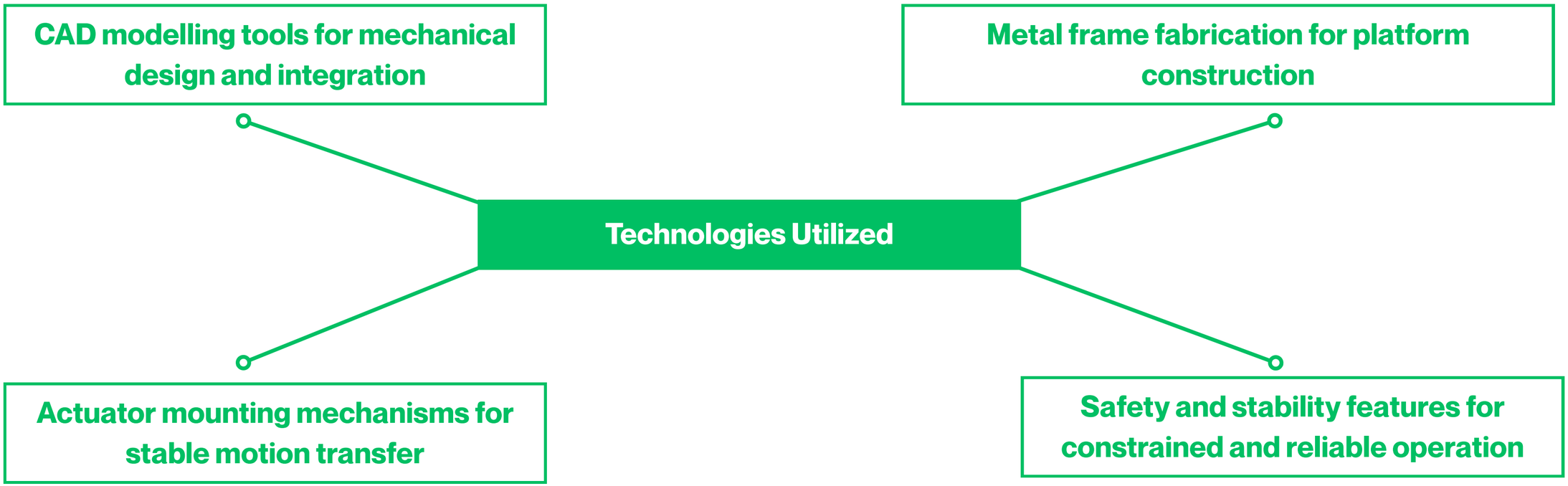
- Design Science Research with prototype development
- Iterative design of the mechanical seat platform
- Integration of frame, seat, and actuator mounts
- Stability testing under user load and motion
- Safety and repeatability evaluation through controlled testing

Mechanical Integration and Stability Design for the VR Motion Seat Platform

Knowledge Domain

- Mechanical design and structural integration
- Load distribution and stability analysis
- Actuator mounting and platform assembly
- Safety, ergonomics, and reliability

Mechanical Integration and Stability Design for the VR Motion Seat Platform



Mechanical Integration and Stability Design for the VR Motion Seat Platform

Validation and Evaluation

Controlled testing of the platform's structural stability and safety under seated VR operation

Evaluation based on:

- Structural stability under user load
- Balance during motion
- Vibration control
- Safe and repeatable operation

Mechanical Integration and Stability Design for the VR Motion Seat Platform

Data Availability

Primary system data

- Structural dimensions
- Material properties
- Load distribution data
- Actuator mounting and motion constraints

Experimental data

- Stability under dynamic load
- Vibration response
- Frame displacement
- Repeatable motion behavior

Data collected through controlled testing and user experiments on the VR motion seat platform

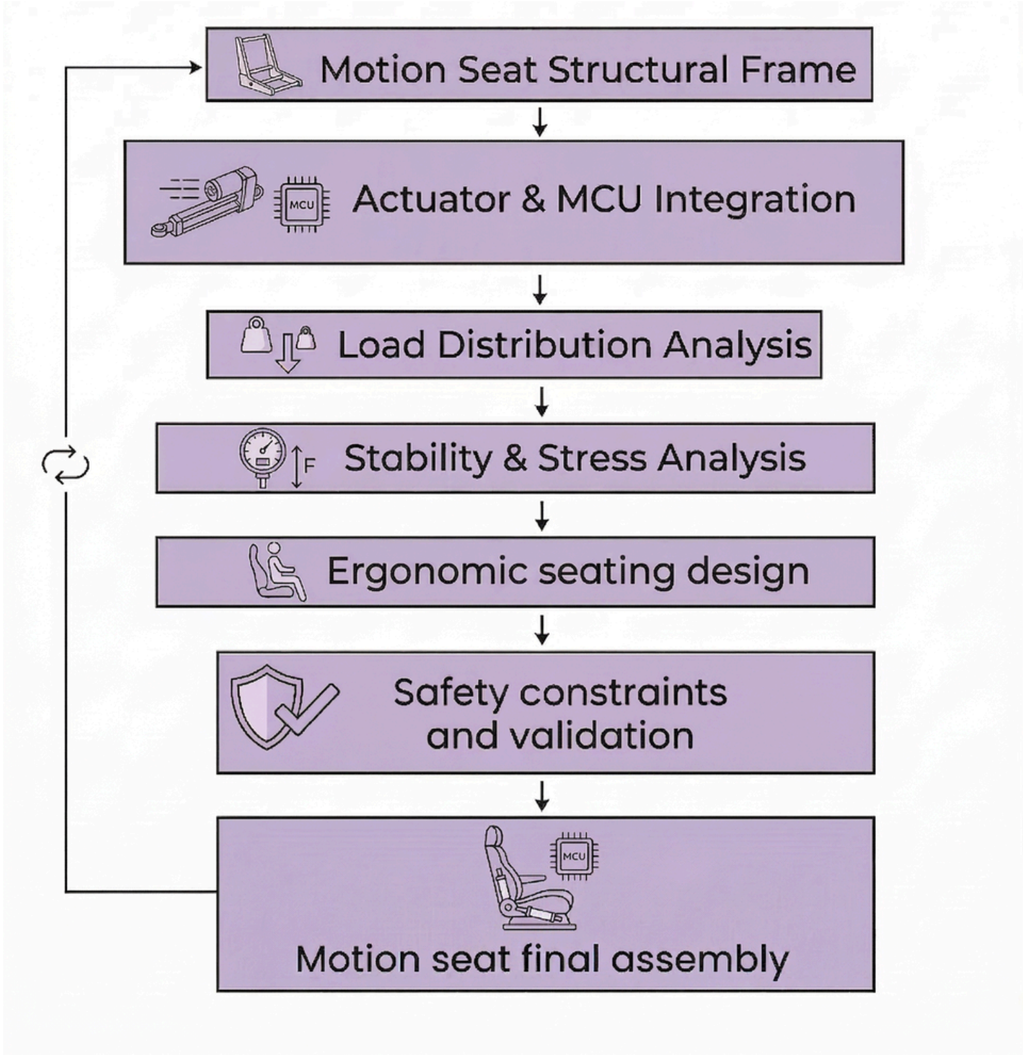
Mechanical Integration and Stability Design for the VR Motion Seat Platform

Security and Ethical Clearance

- **Informed consent required before all test sessions**
- **Participants may withdraw at any time**
- **Personal data will be anonymized**
- **Motion constrained within safe mechanical limits**

Mechanical Integration and Stability Design for the VR Motion Seat Platform

System Overview of the Individual Component



Immersive Multisensory VR Motion System for Full body Navigation

Ability of Commercialization

- Viable as a location-based immersive VR attraction
- Suitable for arcades, immersive venues, and event spaces

Target Market

- Fantasy/adventure fans, young gamers, and experience-seeking groups
- VR arcades, gaming cafés, and immersive entertainment providers

Value Proposition

- Motion-enabled full-body VR flight with stronger realism and embodiment
- Reusable modular platform for multiple ride themes

Immersive Multisensory VR Motion System for Full body Navigation

Cost and Pricing

- Cost: hardware, fabrication, VR setup, software, and maintenance
- Revenue: per-session pricing, venue packages, and repeated use

Scalability

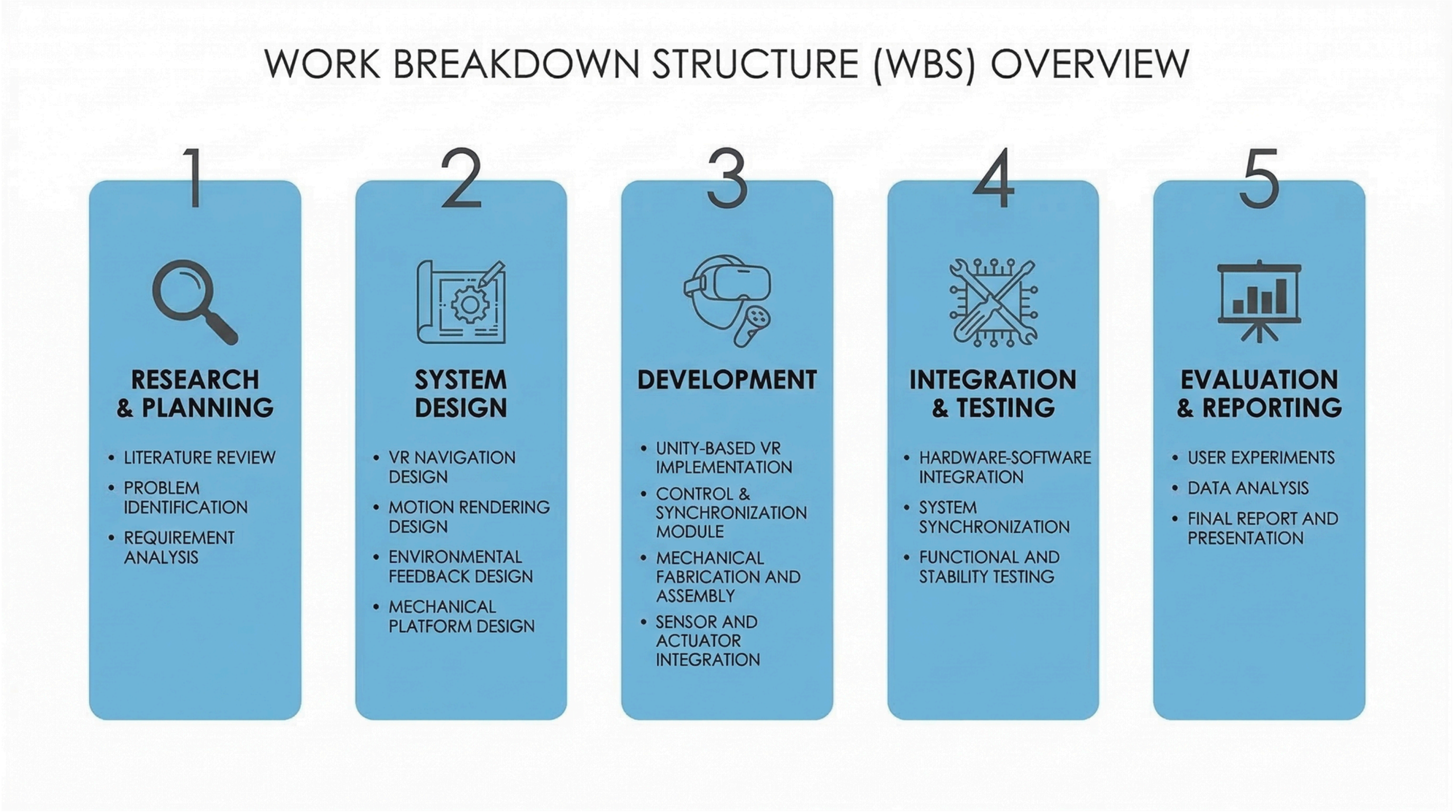
- Starts with broom-riding, expandable to dragon-riding and other fantasy flight themes
- IP potential in motion control, synchronization, and modular ride design

Immersive Multisensory VR Motion System for Full body Navigation

Gant Chart



Immersive Multisensory VR Motion System for Full body Navigation



References

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[3] (Haptic Feedback)

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***[4]** Boletsis, C. (2017). The New Era of Virtual Reality Locomotion: A Systematic Literature Review of Techniques and a Proposed Typology. IEEE*

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Thank you!