Human Dynamics and Controls Lab
DEPARTMENT OF MECHANICAL SCIENCE AND ENGINEERING
ILLINOIS Mechanical Science & Engineering
GRAINGER COLLEGE OF ENGINEERING
IMMERSE Center for Immersive Computing

Immersive VR-Based Evaluation of Hands-Free Torso-Driven Control for Virtual Robot Navigation

Roberts Ernests Fulss*, Patrick Moore, Linh Dao, Riku Kanzaki, Seung Yun Song, Marshall Tenzer, and Elizabeth T. Hsiao-Wecksler**
Mechanical Science & Engineering, University of Illinois at Urbana-Champaign (UIUC), Urbana, IL.
* [illegible] ** [illegible]

Introduction

Hands-free (HF) torso-control offers an alternative to traditional handheld methods for improving human-robot interaction (HRI). Three embodiments of a Torso-dynamics Estimation System (TES) [1] were developed to estimate seated users torso movements using two translational signals (x, y) and one rotational signal (yaw).

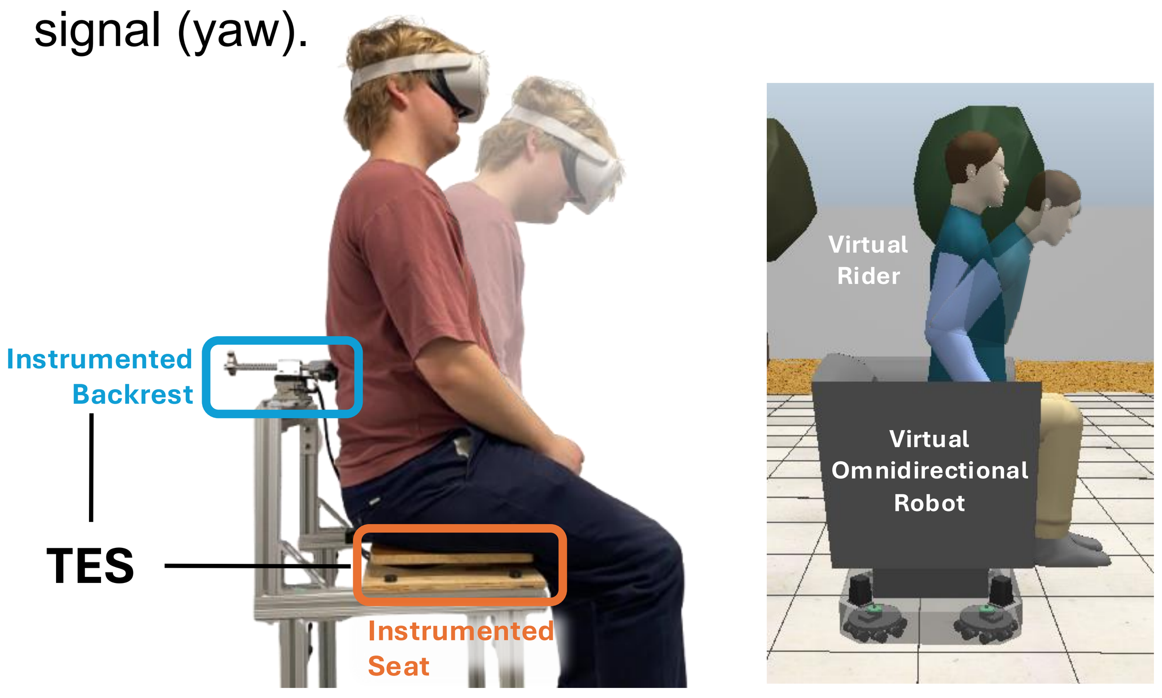


Fig. 1: HF control is used to control a virtual rider on an omni-directional robot using the signals provided by the TES. In this embodiment, the TES consists of an instrumented backrest and an instrumented seat—that measure rotation and translation of the body, respectively.

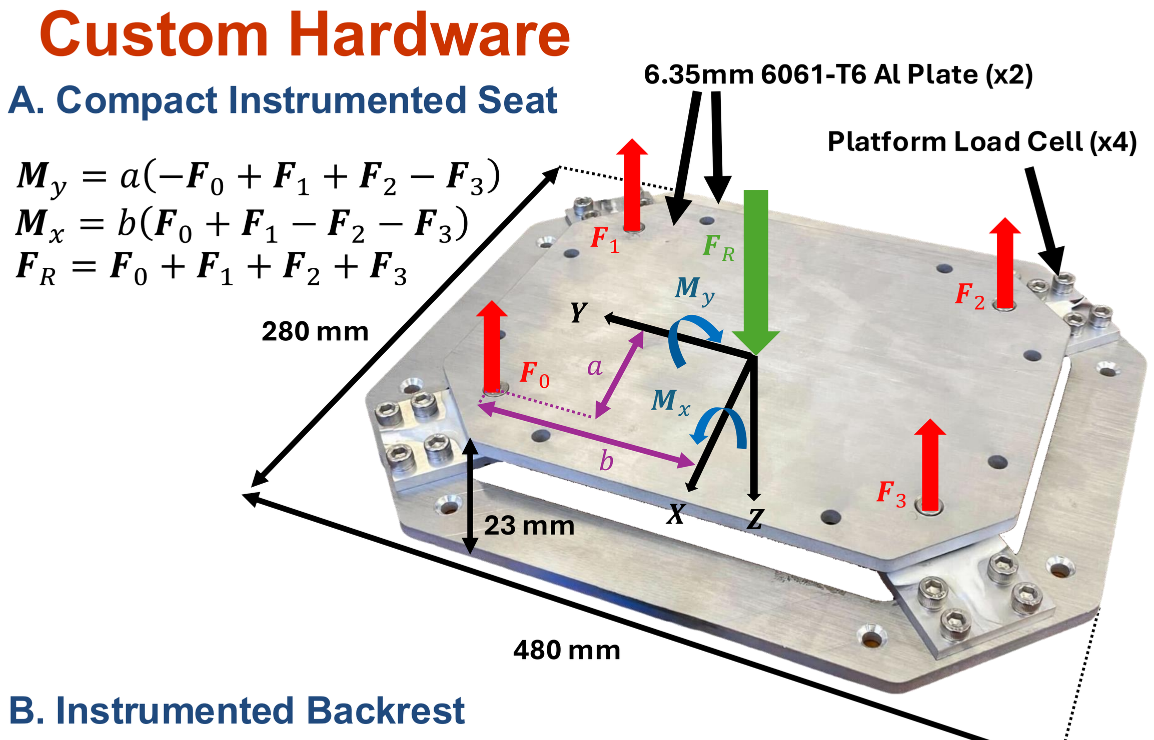
Research Question

How effectively can **torso motion signals**, captured by different sensor configurations, be used to control a virtual robot in a structured VR environment?

Custom Hardware

A. Compact Instrumented Seat

$$M_y = a(-F_0 + F_1 + F_2 - F_3)$$
$$M_x = b(F_0 + F_1 - F_2 - F_3)$$
$$F_R = F_0 + F_1 + F_2 + F_3$$



B. Instrumented Backrest

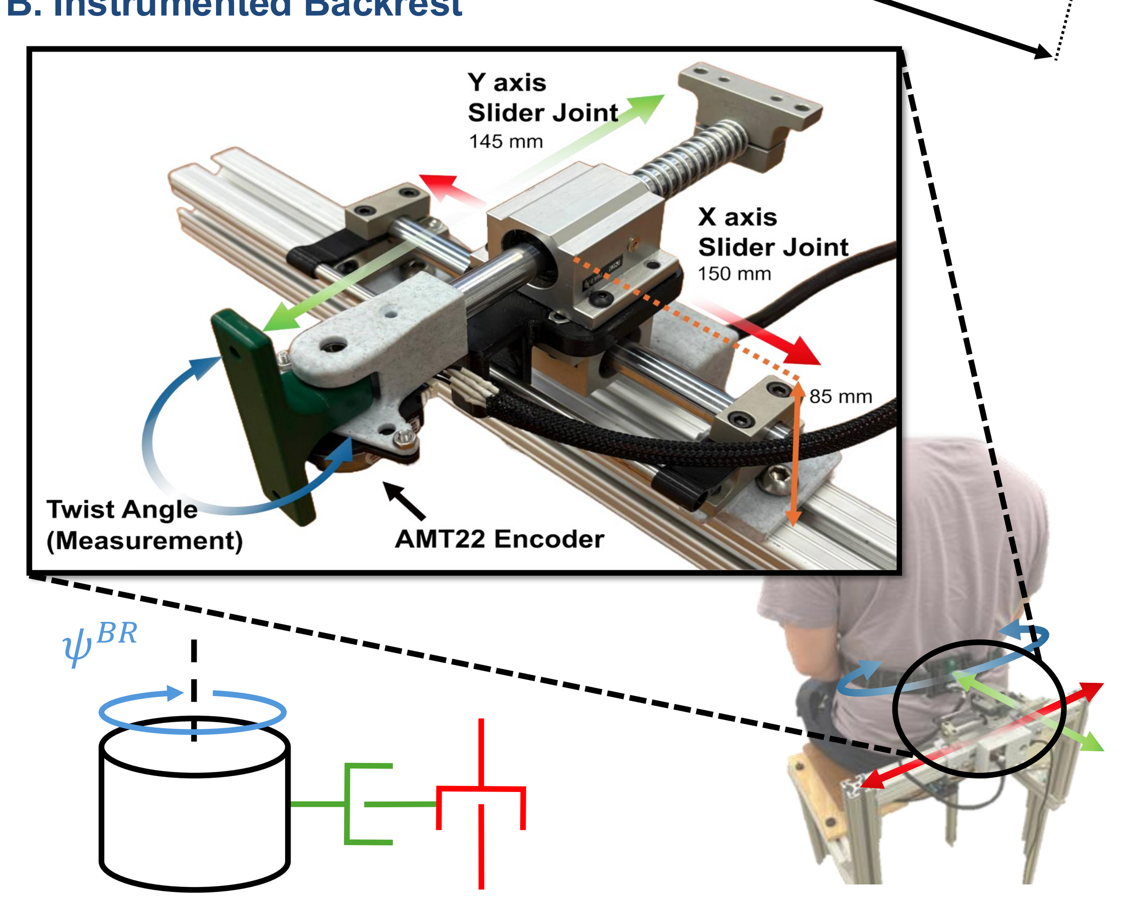


Fig. 2: (A) Four compact uniaxial loadcells (FRC4142_0, Phidgets, Canada) were integrated into the instrumented seat to record reactive moments in sagittal and frontal planes (M_x, M_y), enabling estimation of user torso translations for control input. **(B)** Instrumented backrest system allowing free translational movement in the X and Y directions, while measuring rotational (yaw) angle about the vertical axis using an AMT22 absolute encoder (AMT222A-V, Same Sky Devices, USA).

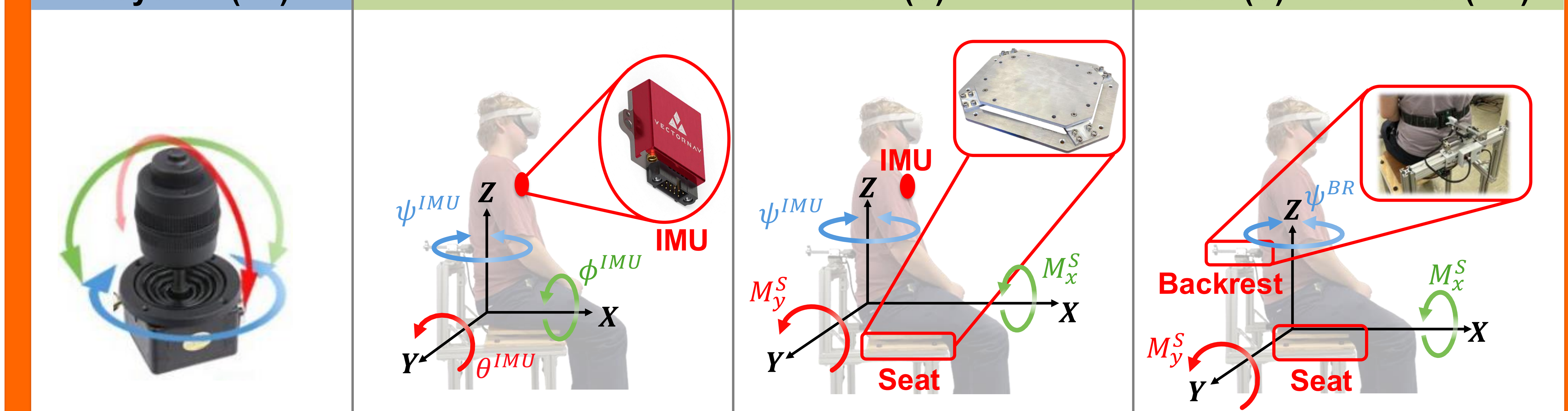
References

[1] S.Y. Song et al., U.S. Patent Pending

Methods – Mapping Between Physical & Virtual Reality

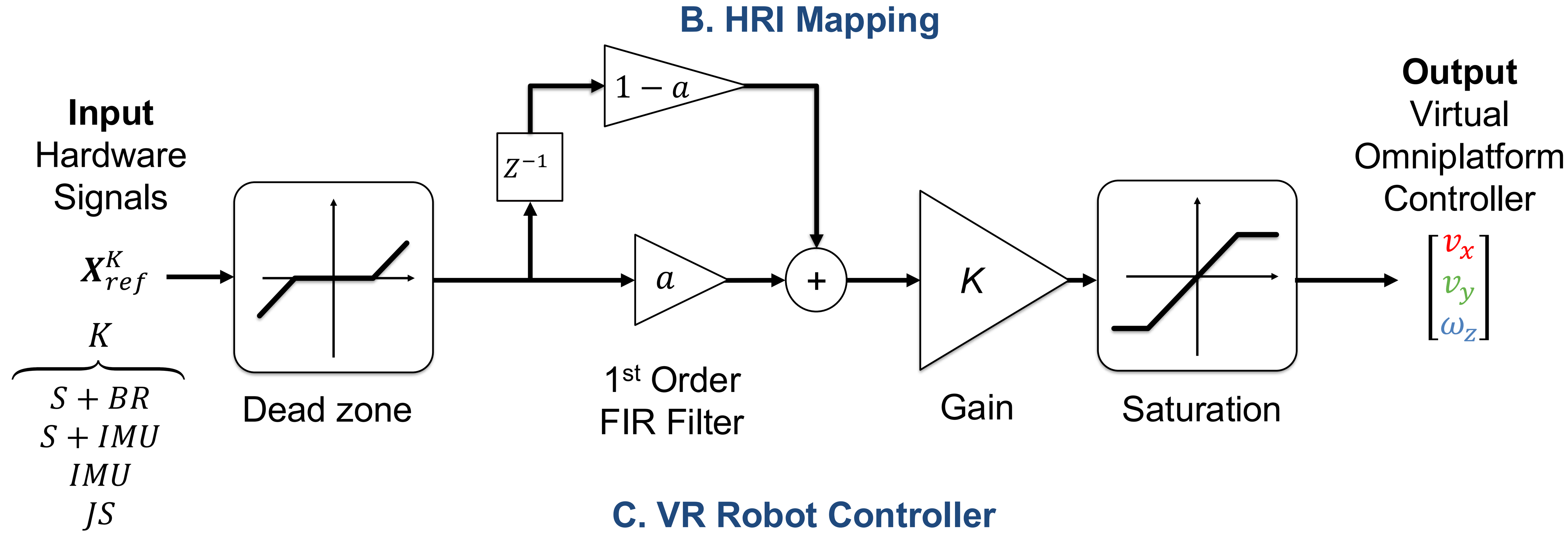
A. HRI Hardware

Hands-on	Hands-Free		
Joystick (JS)	IMU	Seat (S) + IMU	Seat (S) + Backrest (BR)



$X^{JS}_{ref} = [\psi^{JS}, \theta^{JS}, \phi^{JS}]$ | $X^{IMU}_{ref} = [\psi^{IMU}, \theta^{IMU}, \phi^{IMU}]$ | $X^{S+IMU}_{ref} = [\psi^{IMU}, M^S_x, M^S_y]$ | $X^{S+BR}_{ref} = [\psi^{BR}, M^S_x, M^S_y]$

B. HRI Mapping



C. VR Robot Controller

$$\begin{bmatrix}\omega_0\\ \omega_1\\ \omega_2\\ \omega_3\end{bmatrix} = \begin{bmatrix}-1 & 1 & 1\\ 1 & 1 & 1\\ 1 & -1 & 1\\ -1 & -1 & 1\end{bmatrix}\begin{bmatrix}v_x\\ v_y\\ \omega_z\end{bmatrix}$$

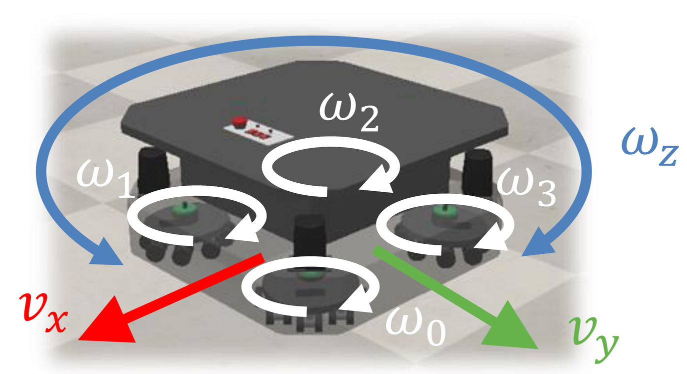
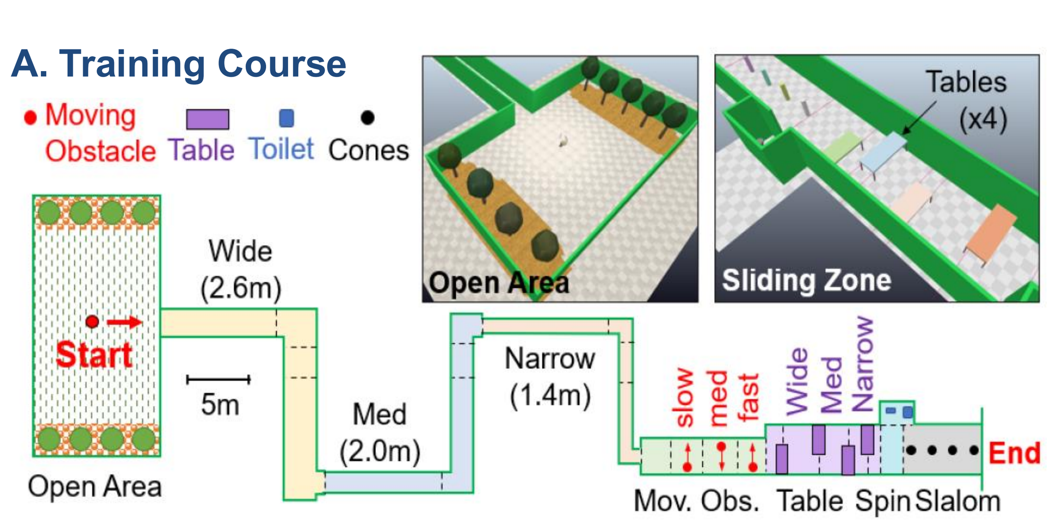


Fig. 3: Overview of the HRI system architecture.
(A) Input hardware configurations for robot control, including hands-on joystick (JS) and three hands-free embodiments using an IMU only (VN-200, VectorNav Technologies, USA), an instrumented seat (S) + IMU (yaw), and a backrest-mounted sensor (BR) (yaw) + instrumented seat.
(B) Signal processing pipeline for mapping input hardware signals to platform control commands, including dead zone filtering, first-order filtering, gain adjustment, and output saturation.
(C) Virtual robot controller structure for converting desired platform velocities (v_x, v_y, ω_z) into individual wheel commands for an omnidirectional mobile robot platform.

Methods – Virtual Course Design

A virtual reality (VR) course was developed to evaluate torso motion navigation performance. The course incorporated elements based on U.S. Building Code standards, including standard hallway widths, doorways, restroom layouts, and static and dynamic obstacles. The aim of the course is to simulate realistic navigation challenges encountered in built environments.

A. Training Course



B. Test Course

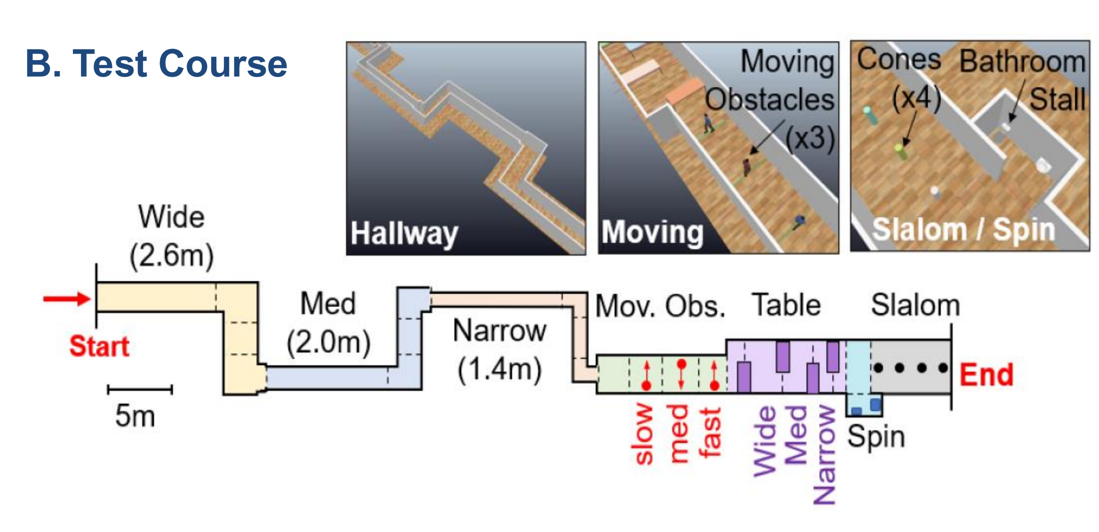


Fig. 4: Virtual training (A) and testing (B) courses

Acknowledgements

This research was supported by NSF NRI Grant #2024905.

We would like to also thank Prof. Joao Ramos and Coach Adam Bleakney for their additional guidance in the development of this work.

Future Work

To further develop this project, an autoencoder-based model is proposed to generate personalized control mappings from user-specific torso motion patterns and translating them into commands for the omni-directional robot. This enables adaptive, user-specific control without manual gain tuning.