HapticSteer: A 2-DoF Haptic Game Controller

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***Abstract*— In this project, a 2-degree-of-freedom haptic controller was designed from the ground up to govern the movement of a ball in a Unity3D based game. The controller renders the forces acting on the virtual ball to the user, enhancing the immersive experience for users by imparting a sense of the terrain they are engaging with.**

I. INTRODUCTION

The world of gaming and VR beckons exploration and interaction, and haptics can enhance the user experience in these aspects. This project aims to develop a force-feedback platform, HapticSteer that guides users to move objects in a complex virtual environment by rendering the forces applied on the object. Our motivation for this project stems from a two-fold desire:

1) To build the platform from the ground up and design a virtual environment that can show the full range of features of our system.
2) To gain experience in designing in such multi-faceted systems.

Current virtual interaction often relies solely on visual cues. This project introduces haptic feedback as a collaborative partner in guiding users toward their intended destinations. Central to this collaboration is a physics-based guidance system that dynamically analyzes the state of virtual objects in real-time.

II. BACKGROUND

A. Force Feedback Joystick Control of Powered Wheelchair (Fattouh et al., 2004)[2]

Summary: This preliminary study investigates the use of a force feedback joystick to control a powered wheelchair. The study assesses the impact on driving performance for individuals with severe disabilities. Utilizing a Microsoft Sidewinder Force Feedback joystick and a MATLAB simulation system, the force feedback algorithm, based on sixteen virtual sensors measuring obstacle distances, demonstrates reduced collisions for individuals without disabilities.

B. Multi-rate Control Architectures for Dextrous Haptic Rendering (Fotoohi et al., 2006)[3]

Summary: This paper introduces multi-rate control architectures for haptic interfaces in cooperative virtual environments. Employing a strategy where local feedback loops operate at higher rates than data packet transmission, the study is relevant to our project's control architecture. Furthermore, the use of MATLAB's virtual reality toolbox for graphics rendering presents a beneficial reference for our work.

C. Interactive and Immersive 3D Game Simulation with Force Feedback (De Paolis et al., 2008)[4]

Summary: An interactive 3D game simulation controlled by a Phantom Omni device is presented in this paper. Leveraging the Open Dynamics Engine (ODE) for rigid body dynamics simulation, the study inspires our intention to use ODE for collision detection and facilitating object movement in our project. The immersive nature of the virtual billiards game aligns with our project's goals.

D. Haptic Feedback Enhances Force Skill Learning (Morris et al., 2007)[5]

Summary: Investigating the use of haptics in teaching abstract motor skills, this study explores force skill learning through haptic, visual, and combined training paradigms. The findings emphasize the unique cues provided by haptic feedback, aligning closely with our project's objective of users applying contrary forces to control the virtual ball.

E. Using Game Engines for Visuo-Haptic Learning Simulations (Escobar-Castillejos et al., 2020)[6]

Summary: This paper explores the integration of game engines, particularly Unity, for creating visuo-haptic learning simulations. The presented architecture integrates tactile and kinesthetic sensations with visual elements. Inspired by this approach, our project aims to utilize Unity and the HADIU haptic plugin for developing a comprehensive virtual environment.

III. DESIGN

For the mechanical design, the robust frame was made of aluminum 80-20 sections. The system has two degrees of freedom, the pitch axis and the roll axis. The rotating shafts were lathed using a 15mm aluminum shaft. Both axes are capable of giving force feedback. To ensure smooth back drivability, we went for non-geared DC motors. The motors were mounted on the 80-20 frame using a 3D-printed mount. For power transmission, GT2 timing belts and pulleys were

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used. Both the axes had an 80T timing pulley, and the motor had a 16T pulley giving us a total gear ratio of 5. This mount itself acted as the belt tensioning mechanism by sliding on the 80-20 section. For the position sensing, two optical rotary encoders were used. The encoders were mounted on the motor mount itself. The shaft of the encoders was directly coupled to the motor shaft using a 1:1 3D printed gear. All the electronics were cleanly mounted on an acrylic board and attached to the frame. External Lab power supplies were used to power and monitor the power drawn by the motors.

A. Why a Flat Control Surface

A flat surface was used as an input surface instead of a conventional joystick approach used in controllers. A stick input leads to a higher fidelity control in general, and we also wanted to know how the force feedback affects the control ability of the user. Using a flat surface leads to a reduced fidelity of control by the user. This, in fact, will highlight the effect of how force feedback assists in the control of the ball over the terrain even more.

B. CAD Model

The model is displayed in Figures 1 and 2 respectively.

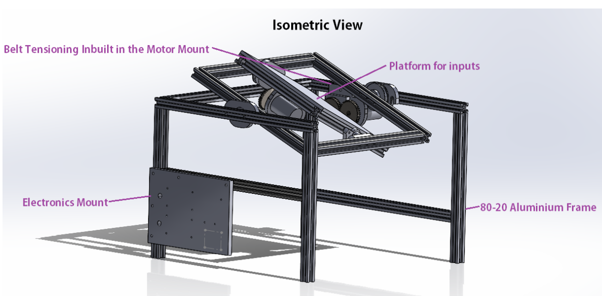

Fig. 1. Isometric view of the Model

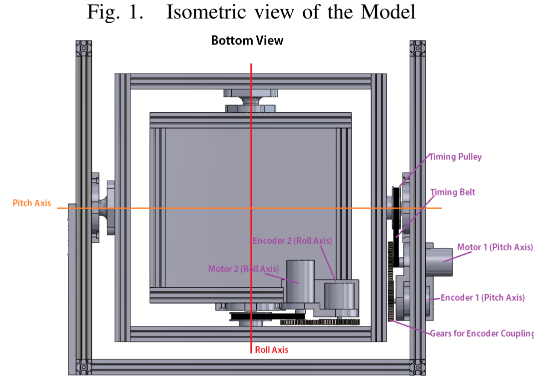

Fig. 2. Bottom view of the Model

C. Experimental Setup

The Experimental setup is shown in Fig 3. The HapticSteer device was placed on four stools, so that the height of the control platform is at an ergonomic height. The Mac Book ran the Unity game engine and was connected to the Arduino for Serial communication. An external monitor was attached to the laptop for better visualization of the Virtual

Fig. 3. Experimental Setup

Environment. Two individual power supplies were used for each motor to keep track of the power usage of the motors to avoid over heating.

D. Unity World Design

- **Ball:** A 3D RigidBody object governed by physics properties, including collisions, falling, and sliding under gravity.
- **Terrain:** A 2000x2000 uneven landscape with mountains, valleys, and plains.

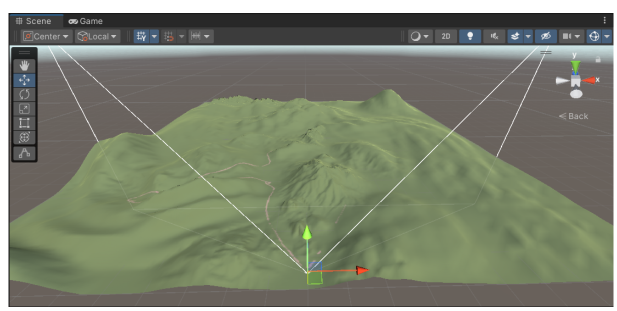

Fig. 4. Aerial view of the virtual world

E. Bidirectional Communication Setup

In our project, we employed Ardity[8], a versatile open-source package specifically designed for seamless communication with Arduino through the serial port. This package

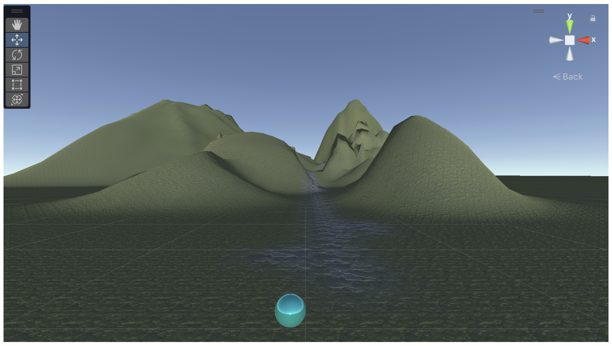

Fig. 5. Game view

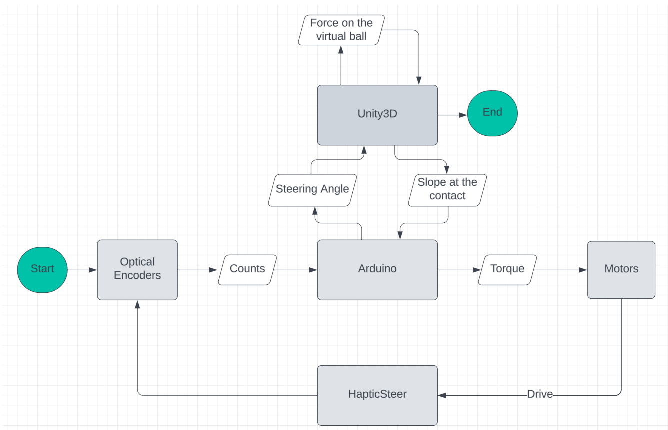

Fig. 6. Architecture of our system

enabled us to send and receive continuous data on different threads and kept the delay as low as possible.

1) Arduino to Unity:

- *Parameters:* Angles of deflection corresponding to longitudinal (forward-backward) and lateral (left-right) movements.
- *Calibration:* Linear curve fitting performed onto the (angle of deflection, encoder count) data which was collected manually moving the steering planks into various angles.
- *Transmission:* Used the Ardity library, to transmit the angles of deflection θ_1 (longitudinal) and θ_2 (lateral) on the Serial monitor.

2) Unity to Arduino:

- *Parameters:* Slope information at the ball's ground contact point.
- *Calibration:* Normal vector computed using Ray casting in unity, with x-component deviation from zero representing lateral slope and y-component deviation indicating longitudinal slope. We chose the sliding force due to gravity is proportional to these components in their respective directions.
- *Transmission:* Sent the 3x1 normal vector over the Serial monitor for Arduino to compute proportionate forces.

IV. User Study

A. Method

For the experiment, for every user the ball starts from the same starting point. In the terrain, there is a grey path marked for reference. The user has to try and keep the ball constrained to this grey marking in the Virtual Environment. For the first run, the force feedback is off and the user can experience the control of the ball in the Virtual environment using the controller. After the user reaches the end of the marked path, the game is restarted. This time the force feedback is on for the user to experience. The user has to again control the ball and follow the grey path to the end.

B. Questions Asked

1) On a scale of one to ten how much would you rate the immersiveness of the Virtual Environment with Force Feedback on?
2) On a scale of one to ten how much did you feel the nature of the Virtual Environment with Force Feedback on?
3) On a scale of one to ten how much would you rate the controllability of the ball in the Virtual Environment with Force Feedback on?
4) On a scale of one to ten how natural did the Force Feedback feel to you?

V. RESULTS AND DISCUSSION

1) *Immersiveness:*
Users were generally positive about the immersiveness of the haptic device. The average rating for the question "Does the device feel immersive?" was 8.6 out of 10. Most users rated it above 8, with some giving it a perfect 10. This suggests that the haptic feedback system contributed to a sense of immersion in the virtual environment.
2) *Perception of Terrain:*
Participants provided positive feedback regarding their perception of the bumpy terrain. The average rating for "How well do you feel the nature of the bumpy terrain?" was 8.4 out of 10. Users generally felt well-connected to the virtual environment and could perceive the terrain features accurately. The majority of users rated it 8 or above, indicating a satisfactory representation of the virtual terrain.
3) *Control Performance:*
The feedback on the control performance of the device was generally positive. Users were asked, "How well were you able to control the ball better with the device?" and the average rating was 8.6 out of 10. Most participants felt they could control the ball effectively using the haptic platform. While there were some variations in ratings, with a few users providing lower scores, the overall trend suggests a positive user experience in terms of control.
4) *Naturalness of Force Feedback:*
Regarding the naturalness of force feedback, opinions

varied more widely. The average rating for "How natural was the force feedback?" was 7.4 out of 10. While some users rated the force feedback as high as 10, indicating a very natural feel, others provided lower scores, with one user giving it a 4. This suggests that there may be room for improvement in terms of making the force feedback more universally perceived as natural.

5) *Overall Impression:*
In summary, the user study indicates a positive reception of the HapticSteer for moving a ball in a virtual environment. Users found the experience immersive, felt connected to the virtual terrain, and generally performed well in controlling the ball. However, there is a need for further refinement to enhance the naturalness of the force feedback, as opinions on this aspect varied among participants.

6) *Stability and Power:*
The stability of HapticSteer was carefully considered during the design phase. Due to the multi-threading implementation of the Ardity library we were able to successfully communicate information with minimum loss at a baud rate of 115200. This helped us maintain minimum delay in the visual and the force rendering. Lot of stress tests were performed on the motors and we didn't face any unstable configurations as long as the hand was on the frame. Motors drew a maximum of 30W when pushed but usually stayed below the 10W limit. This helped to limit the heating on the motormount.

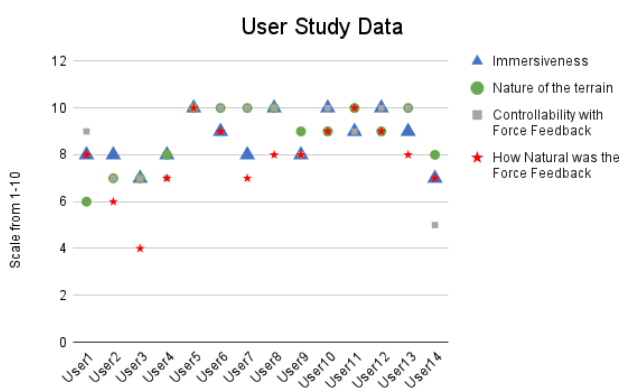

Fig. 7. User Study Data

VI. CONCLUSION

In this project, we developed the HapticSteer, a 2-degree-of-freedom haptic controller designed from scratch to govern the movement of a ball in a Unity3D-based game. The controller successfully rendered forces acting on the virtual ball, heightening users' immersive experiences and connection to the virtual terrain, as revealed in a positive user study. While participants showcased proficient ball control, the study highlighted a need for further refinement, particularly in enhancing the naturalness of the force feedback, given varying opinions among users. Overall, the project's success underscores the efficacy of HapticSteer in virtual environments.

ACKNOWLEDGMENT

We express our sincere gratitude to Professor Tania Morimoto for her invaluable support and guidance throughout the duration of the course. Her timely assistance was pivotal to the success of our project, particularly when our team encountered a critical shortage of motor drivers just before the demonstration. Professor Morimoto's expertise and swift intervention were instrumental in resolving the issue, enabling us to proceed with our project effectively. Additionally, we extend our appreciation to the Teaching Assistant, Anoush Sepehri, for the unwavering support and guidance provided during the completion of assignments and the final project. Anoush's willingness to help greatly contributed to our learning experience and the successful execution of the course requirements.

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