Rowing Beyond: A Demonstration of Steering Methods for Rowing-based Locomotion in Virtual Environments

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Figure 1: The three steering methods for rowing-based locomotion: (a) head-based steering indicates the direction of movement according to the head's orientation, (b) hands-based steering employs handlebar rotation on a 2D plane and buttons under thumbs to go up and down, and (c) feet-based steering is based on the pressure distribution between left and right feet for steering on a 2D plane and between toes and toes joints for steering in a 3D space.

ABSTRACT

Rowing has great potential in Virtual Reality (VR) exergames as it requires physical effort and uses physical motion to map the locomotion in a virtual space. However, rowing in VR is currently restricted to locomotion along one axis, leaving 2D and 3D locomotion out of the scope. To facilitate rowing-based locomotion, we implemented three steering techniques based on head, hands, and feet movements for 2D and 3D VR environments.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**.

KEYWORDS

virtual reality, rowing, exergame, locomotion, steering

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1 INTRODUCTION

The use of Virtual Reality (VR) for exergames can increase players motivation to exercise through immersive and engaging experiences [5, 8, 11, 20, 24, 31, 35, 36]. Rowing is a form of physical exercise with great potential in VR exergames since it requires physical effort and uses physical motion to map the locomotion in virtual environments [5, 20, 27]. While previous works on rowing in VR have explored one-dimensional locomotion [3, 25, 28, 29, 32], i.e., forward/backward, rowing-based locomotion in 2D and 3D spaces remains underexplored in virtual environments. Given that virtual environments are infinite and have no restriction of natural laws, on a horizontal 2D plane, users can navigate a virtual sea similar, while in a 3D space, the rowing experience can be transformed into a flying vehicle, or a submarine to steer beyond the surface and gravity. As Ivan Sutherland famously stated: "There is no reason why the objects displayed by a computer have to follow the ordinary rules of physical reality" [30]. However, steering while rowing has no obvious mapping for 2D and 3D spaces, and the rowing activity places physical constraints on bodily movements, e.g., the hands should always hold a handlebar, and feet should be placed at specific locations. Therefore, the question is how rowing-based steering can facilitate locomotion in 2D and 3D space and how efficient they will be. Answering both questions will show the most efficient way to fully explore 2D and 3D virtual environments and facilitate users'

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exertion. In this work, we aim to advance rowing-based locomotion on 2D planes and 3D spaces in virtual environments by employing steering methods. For this, we implemented three steering methods based on (1) the physical affordances of a rowing machine, and (2) established steering methods based on head, hands and feet interaction (Figure 1). Head steering facilitates locomotion in the direction of head orientation, hand steering utilizes the rotations of a handlebar, and feet steering employs pressure distribution of toes and big toe joints on feet placeholders. In the following sections we describe our design considerations and implementation details.

2 DESIGN CONSIDERATIONS FOR ROWING-BASED LOCOMOTION

In this section, we introduce design considerations for rowing-based locomotion. These considerations are based on the physical constraints imposed by rowing machines and our aim to facilitate good performance for rowing in an exergame context.

2.1 Metaphor considerations

The locomotion generated by the rowing machine could be mapped to any metaphor in the virtual environment. We opted for a rowing boat metaphor as rowing machines have been substituted for real rowing since their invention [13]. We generally aimed for a realistic "feel" in which users' naive sense of physics helps them understand the interactions [16], e.g., pulling harder increases steering rotation force. However, we also went beyond realism for better ergonomics and efficient locomotion [1]. The virtual locomotion speed was increased compared to a realistic rowing boat since we believe this facilitated a more engaging experience, an important motivational aspect of frequent exergame usage [22]. We also assumed moving forward instead of backward (real rowing is performed backward) would be more engaging and ergonomic in most games. Lastly, 3D "flying" locomotion for boats is unrealistic. Still, we believed it would be easier for users to have the same metaphor and controls in both 2D and 3D instead of introducing a new metaphor, e.g., airplane, helicopter.

2.2 Locomotion considerations

2.2.1 When to provide steering power. According to Bowman, when and how input is triggered is one of three important characteristics of any locomotion technique, together with velocity and direction selection [6]. Although steering power could technically be available as soon as the user provides input, this would feel unrealistic for the user if a rowing motion is not co-occurring. Rowing differs from other vehicle steering methods because it requires the oars in the water. In other words, even if the virtual boat moves forward and the oars are up, steering is impossible. While there are no oars on a rowing machine, we decided to provide steering power when the users were pulling the handlebar towards themselves as it mimics the feeling of putting the oars in the water and pulling.

2.2.2 How to control steering power. Various possibilities exist for controlling the applied amount of turning force [9]. Other locomotion methods have increased the force based on the input frequency per time unit, e.g., increasing input events during a second increases the amount of force. This works if a user repeats an input action frequently, such as "hammering" a button, which allows a user to easily prevent further input by not acting [6]. In contrast, continuous input directly sets the turn force value from the input source. We decided to provide continuous input so the user could more smoothly set the value, thereby avoiding distracting maneuvers. This means that unintended inputs could be a problem, making the steering feel "wobbly". However, we avoided this by setting continuous input values only during pulling. We amplified the steering input with a power function [9] with pulling speed as an input, causing faster, heavier pulls to increase the turning force exponentially more than slower pulls.

2.2.3 How to move in 3D space. We considered two forms of forces for movement through vertical space: *combined* and *separate*. A combined force would only apply speed power on the forward vector of the virtual rowing boat. This implies that the angle of the virtual boat must be pitched for locomotion to occur. This creates a mismatch between the user's physical and visual orientations in VR, which increases the risk of VR sickness [14]. Roll and yaw maneuvers must also be implemented for a combined force, increasing steering complexity. Instead, we decided on a separate force approach in which up- and downward input creates vertical locomotion directly perpendicular to the forward vector. To avoid an elevator-like experience, we multiplied the vertical force with the handlebar pull force. Thus, to move vertically, forward speed is needed. We did not include gravity to allow users to rest at higher altitudes. To provide a fluent experience we made sure that 2D and 3D steering actions could be performed simultaneously, e.g. moving down and left at the same time.

2.3 Body-specific considerations

We implemented three steering methods based on head, hands, and feet input. Steering techniques are commonly categorized based on which body part controls input [7, 17, 21, 26]. The most frequently used techniques uses input from *head*, *torso* and *hands* [12, 17], with *legs* [4, 37], and *feet* [23, 33, 34] gaining research interest in recent year. A rowing machine restricts users from rotating their torso and repositioning their legs, so we did not implement steering alternatives based on these inputs. The three steering methods we implemented thereby represent the remaining body-specific techniques. Figure 2 illustrates the methods.

2.3.1 Head. For head-based steering, we employed pitch and yaw orientation. We did not consider the headset position as an input because the rowers' motion on the machine would make it unfeasible. Thus, we mapped the left-right steering to the user's yaw orientation, i.e., rotating around the upward axis, and vertical steering to the user's pitch orientation, i.e., looking up and down. An advantage of this method is that it does not require other devices than the VR headset, thus lowering the usage barrier [26].

2.3.2 Hands. Hand-based steering is restricted by the user's occupation of the hands holding the handlebar. Instead, the handlebar can provide input through 3DoF orientation as with head-based steering [26]. In practice, however, only the handlebar roll and yaw orientations are feasible to use, as the chain attached to the handlebar restricts rotation along the pitch axis. Both roll and yaw are intuitive candidates for left-right steering, resembling the steering

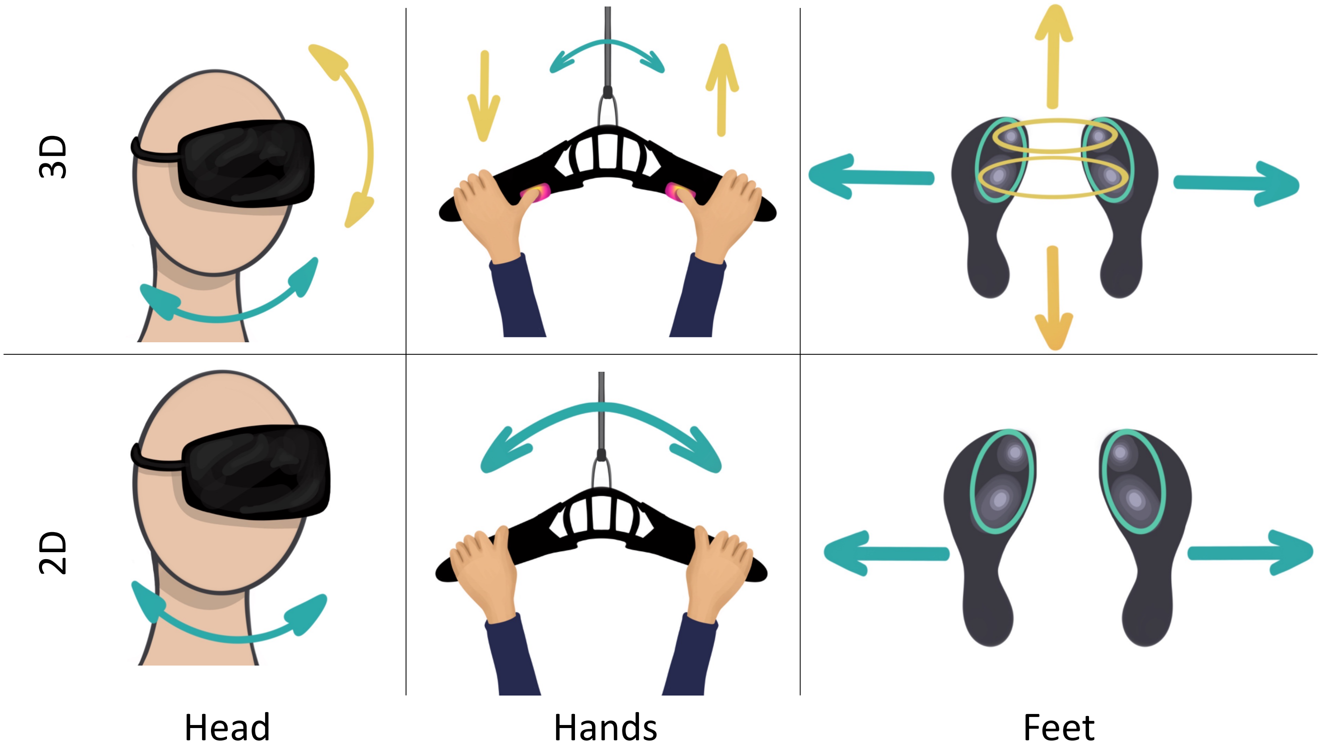

Figure 2: Overview of three steering methods for 2D (lower row) and 3D (upper row) using head, hands, and feet. The head steering facilitates locomotion in the direction of head orientation, hand steering utilizes the rotations of a handlebar, and feet steering employs pressure distribution of toes and big toe joints on feet placeholders.

of a car or bike. While using yaw would cause the users to pull with either the left or right arm mainly, the roll axis affords both arms to be equally involved. This is important for a regular rowing motion, which prevents injuries [32]. We, therefore, used the roll axis of the handlebar for 2D steering. Since the pitch axis is unavailable for 3D steering, other input sources than handlebar orientation had to be used. As the user's fingers are available, buttons can be attached to the handlebar. We decided to add one button for each thumb, right for up and left for down. The logic behind this mapping is based on possible user familiarity with scooters and mopeds, in which acceleration is typically on the right side. This meant fixed discrete input each frame a button was pushed down. The hands method is arguably most akin to steering a vehicle, e.g., bicycle [18, 19], car [26], or scooter, and could therefore feel familiar to users.

2.3.3 Feet. The user's feet need to be strapped on the rowing machine footstances (figure 1) to provide resistance force while pulling, and could therefore not be lifted. This prevents direction from being set by foot orientation or relative foot position [34]. However, the resistance force could be achieved if the heels remained on the footstances. By loosening the straps a little, the user can elevate one foot a bit, thereby easily controlling the amount of pressure on each foot stance. We used this difference in foot pressure between footstances as input for the left or right directions. For 3D steering, the same method can be applied, but the difference must be measured between the front and back of the feet. Since heels must always apply pressure on the foot stance, we used the difference between the big toes and the big toe joints of the feet for up and down input. Pressing with the joints increases the upward force while pressing with the big toes increases the downward force. An inverse mapping could also be feasible. The logic for this mapping was that pressing on one's toes makes one fall forward, i.e., pitching down, and pressing on the joints of one's feet would make one fall backward, i.e., pitching up. By using feet-based steering, hands can be free to perform other actions (e.g. using thumbs for input in some game). The user's head is also decoupled from the travel direction, allowing the user to more easily view the environment while moving.

3 IMPLEMENTATION

Based on our design considerations, we developed a VR rowing environment [1] where users can navigate a virtual ocean and compete on coin collection tracks. The implementation includes a physical rowing machine, external hardware sensors, and a Virtual Reality environment.

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[1] https://github.com/marthed/vr_rowing

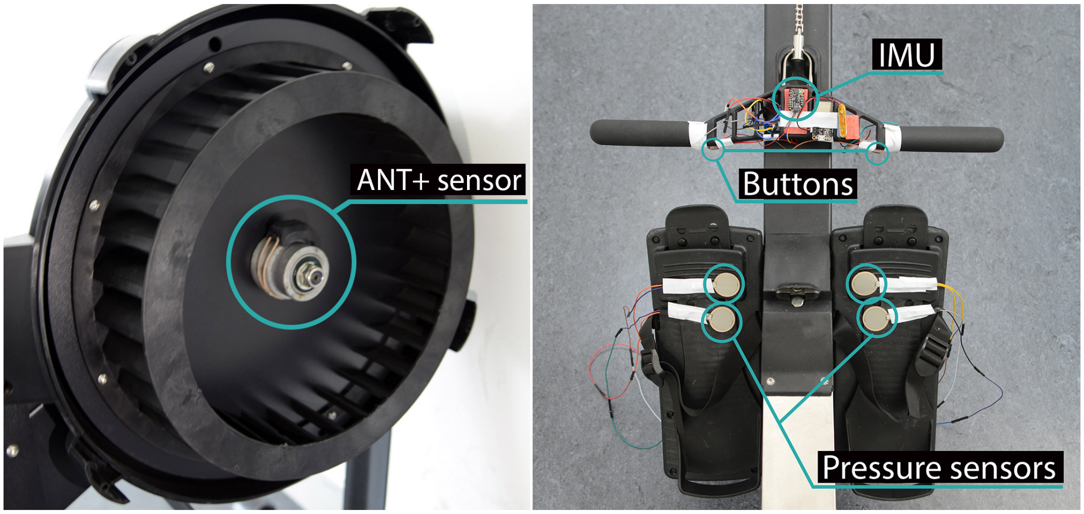

Figure 3: (Left) ANT+ sensor attached to the flywheel for speed input. (Right) Steering sensors for hands (inertial measurement unit, buttons) and feet method (pressure sensors).

3.1 VR Environment

The VR environment was implemented using Unity SDK (2021.1.3) with OculusVR assets and consisted of an ocean with islands. To avoid inconveniences caused by wires, we used the wireless headset Oculus Quest 2. As we later evaluated our steering methods, we designed the virtual environment with minimal distractions, featuring only a flat blue ocean to minimize the impact of VR sickness [2]. Mountains in the distance were added to aid height perception. We also added coin collection tracks for the later user study to compare performance between the steering methods (see study details in [10]).

3.2 Velocity

Force was applied to make the virtual boat move forward by pulling the handlebar of the rowing machine. We used an**Epsilon RX90** [2]) as the physical rowing machine. We fitted the flywheel of the rowing machine with a Garmin Speed Sensor 2, which transmits real-time speed via ANT+ and Bluetooth to the simulation (Figure 3). The continuous value from the speed sensor was applied to the virtual boat's forward direction as a force.

3.3 Direction

To control 2D direction, steering input was applied as a torque rotation force on the virtual boat's yaw-axis. For 3D, we applied an upward/downward force instead of axis rotation to avoid problems described in 2.2.3.

3.3.1 Head-based. The *head-based* method was implemented using the continuous orientation of the Oculus Quest 2 headset (angle tracking error <0.001° [15]) to capture the head's yaw rotation in 2D (sideways), and pitch rotation in 3D (up/down).

3.3.2 Hands-based. For the *hands-based* method, we placed a **LSM6DSOX 6DOF Inertial measurement unit (IMU)** on the handlebar of the rowing machine to continuously measure the roll-axis rotation angle of the handlebar left and right 3. The IMU was connected to a **ESP32-feather** board, which forwarded the IMU signal to the Oculus Headset over a WiFi connection using UDP. A 3.7v 1200mAh ion polymer battery powered the board. Given that turning a handlebar upwards and downwards is difficult and unnatural, as discussed above in the considerations section, we added two buttons (discrete input) on both sides of the handlebar. We aimed to facilitate simultaneous upward-downward and sidewise movement. Pressing the button on the right enables upward movement and the one on the left downwards.

3.3.3 Feet-based. Finally, four **pressure sensors (continuous input, Alpha MF01A-N-221-A01, 0.3-10NF)** on the two footstances enabled the *feet-based* method (see 3. Two sensors were placed under the big toes (toe sensors) and two – under the joints connecting the big toes to the foot (joint sensors). Simultaneous pressure on toe sensors facilitates going downwards, and simultaneous pressure on toe joints – upwards. A pressure on a right toe and/or joint sensor enables turning right, and a pressure on a left toe and/or joint sensor – turning left. We used the same type of board, battery, and communication with the headset for the feet sensors.

4 CONCLUSION

In this paper, we demonstrate our implementation of rowing-based locomotion in virtual environments. For this we introduce three steering methods are based on established interaction techniques using head-, hands- and feet-based interaction. Unlike existing rowing-based locomotion approaches, our implementation goes beyond one-dimensional forward motion, and allow travel in both 2D and 3D, opening new exergame design possibilities.

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