Demonstrating TwinSpin: A Virtual Ball in a VR Controller Enabling In-Hand 3DoF Rotation

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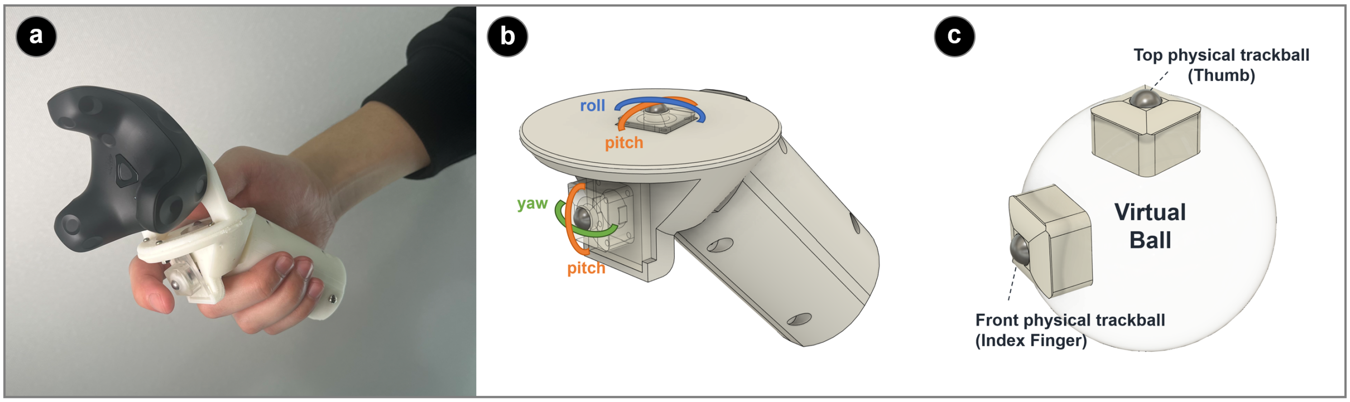

Figure 1: TwinSpin is a VR controller that enables in-hand 3DoF rotation using a virtual ball metaphor within a power-grip form factor. (a) The appearance of TwinSpin prototype. (b) Mapping of pitch, roll, and yaw to the two trackballs in TwinSpin for enabling full 3DoF in-hand rotation. (c) Metaphor of TwinSpin: rolling a ball between the thumb and index finger.

Abstract

In-hand rotation is a natural component of human motor skills; however, most commercial VR controllers rely on a "wrist-arm rotation" technique, in which users rotate virtual objects by physically rotating their wrists and arms. Its repetitive nature and dependence on large movements of the wrist and arm can lead to physical fatigue. To address this problem, we propose TwinSpin, a VR controller that enables in-hand 3DoF rotation by leveraging finger dexterity, inspired by the metaphor of rolling a ball in hand. It combines two trackballs, each providing 2DoF rotation and positioned under the thumb and index finger, to form a single virtual ball that supports full 3DoF rotation. This design allows users to perform rotation tasks efficiently while maintaining a stable power grip on the controller. In our demonstration, participants play the *Puzzle Key* game from *The Legend of Zelda: Skyward Sword* in a VR environment using the TwinSpin controller, allowing hands-on exploration of the effectiveness of our approach.

CCS Concepts

• **Human-centered computing → Interaction techniques**; **Virtual reality**.

Keywords

3D manipulation, interaction design, virtual reality

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1 Introduction

Human hands are inherently skilled at performing fine-grained, in-hand manipulations—such as spinning a dial or fitting together small objects—which rely on precise finger movements. Despite this natural capability, most commercial VR products (Meta, PICO, HTC VIVE, etc.) today use the "wrist-arm rotation" technique for object rotation, which requires the user to rotate their wrist and arm while grabbing the object. This method relies heavily on the involvement of large muscle groups, such as those in the wrist, arm, and shoulder, which can cause physical strain during extended use. Furthermore, due to the limited range of motion of the joints, repeated grabbing and releasing of the object (i.e., clutching [7]) becomes necessary for performing large rotations, requiring extensive and repetitive

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Figure 2: We developed a VR version of the *Puzzle Key* game, inspired by *The Legend of Zelda: Skyward Sword* [6]. In this version, players use the TwinSpin controller to rotate the key. (a) The overall game view of *Puzzle Key*. (b) When the key's orientation matches the key slot, the key starts to glow.

movements of the wrist and arm that contribute to cumulative fatigue and potentially increase task completion time.

Zhai et al. [7] provided empirical evidence that employing small muscle groups, such as those in the fingers, can be more effective for 6DoF manipulation compared to large muscle groups (e.g., wrist, arm, shoulder). Building on this insight, prior research has explored spherical controllers that utilize finger dexterity for object rotation [1, 2, 4]. However, incorporating such finger control into mainstream power-grip VR controllers (e.g., Meta, Pico, VIVE)—where users firmly grasp a handle—remains challenging, as it often conflicts with the existing input space and controller design.

In this Demos track, we introduce TwinSpin, a VR controller that supports in-hand 3DoF rotation by emulating the experience of rolling a virtual ball in hand. Designed in a power-grip form factor, TwinSpin enables finger-driven input by assigning 2 degrees of freedom (DoF) to each of two trackballs, allowing users to perform intuitive VR object rotations with their thumb and index finger. Through the use of two trackballs, users interact with the system as if manipulating a single *virtual ball* between their fingers. We propose that this approach allows users to perform rotational adjustments efficiently using subtle finger movements. Participants in this demo will have the opportunity to experience this interaction by playing the *Puzzle Key* game from *The Legend of Zelda: Skyward Sword* [6], rotating puzzle keys to unlock dungeon door using the TwinSpin controller.

2 TwinSpin

2.1 Concept

TwinSpin is inspired by the metaphor of rolling a ball between the thumb and index finger. A spherical object can be intuitively rotated in any direction, but directly integrating one large physical ball into a VR controller would be space-inefficient and require substantial modifications to the existing controller's form factor and functionality. Instead, we simulate a large single virtual ball by placing two smaller physical balls—one each under the thumb and index finger—so that the user can manipulate them as if rolling the surface of a larger sphere between their fingers (Figure. 1c). The decision to use two balls arises from challenge of using a small single ball to cover all 3DoF rotations. A VR controller is often moved through various orientations in midair, and the ball must remain securely mounted in the controller without slipping out. However, this limits the exposed surface area of the ball, making some rotations difficult to perform (e.g., the top trackball in Figure. 1b struggles with yaw rotation). Therefore, a single mini trackball is typically limited to 2DoF rotation. To fully support 3DoF rotation, we chose to use two separate trackballs. By mapping complementary axes of rotation to each trackball, we ensure that when one trackball does not cover a certain rotation axis, the other one does. As a result, assigning pitch and roll to the thumb's trackball and pitch and yaw to the index finger's trackball (Figure. 1b). This specific rotation mapping allows users to manipulate multiple axes simultaneously, achieving quick and natural reorientation. Additionally, we still allow wrist-based rotation by rotating the controller itself, so users can combine finger motion with wrist movement as needed.

From a grip perspective, the thumb and index finger are highly mobile even while maintaining a power grip on the controller. Napier et al. [5] note that in a combined grip (a combination of precision and power grips), the inner three digits—redundant when handling a small object—are free to assist in supplementary roles. In practice, these roles parallel how we operate conventional VR controllers, where the index finger often pulls a trigger, and the thumb manipulates a joystick or buttons. Our design thus leverages both the thumb and index finger to maximize dexterity and deliver an intuitive rotation.

2.2 Prototype

We developed a hardware prototype to implement the interaction described above. The controller body was 3D-printed in a form suitable for a power grip and equipped with an HTC VIVE Tracker

3.0 on top for positional and rotational tracking in VR. To provide a tangible sense of rotary feedback during object rotation, we decided to use a physical trackball instead of a finger sensor. A 6 mm diameter carbon steel ball is positioned at the contact point of the user's thumb and index finger, supported by a 5 mm inner-diameter PTFE washer to minimize friction. A 3D-printed resin frame secures the ball in place, allowing it to rotate without slipping out. For high-resolution sensing, we built custom trackball sensors using optical tracking modules (PAT 9125 [3]), which can achieve a resolution of about 630 counts per revolution (on a 1.0 mm diameter surface at a 1.0 mm distance). Each sensor is connected to a microcontroller (Adafruit ItsyBitsy M0 Express) via I2C. The microcontroller reads delta x and delta y values from the two optical sensors and transmits this data to a Unity program over a serial connection. Moreover, each trackball assembly is mounted over an FSR (Force Sensitive Resistor) that detects how hard the user presses. When the pressure exceeds a specified threshold, a built-in LRA (Linear Resonant Actuator) inside the controller vibrates, providing haptic feedback. This mechanism effectively simulates a trigger button, allowing the trigger threshold to be programmable.

3 Demonstration

In the demo, participants will wear a VR head-mounted display (HMD) and use TwinSpin to solve the *Puzzle Key* challenge. Players should rotate a puzzle key to match the orientation of a key slot to unlock a dungeon door. In the original game, players used the Nintendo Wii Remote to rotate the key by holding the *'A'* button to grab it and then physically rotating the controller to perform a one-to-one rotation of the key. Because this puzzle typically requires multiple rotational adjustments, it serves as an excellent use case for testing how effectively TwinSpin can handle VR rotation tasks.

For each Puzzle Key, the player is shown a key slot with only one correct orientation that allows the key to fit through. When players rotate the Puzzle Key to within a specified threshold of the correct orientation, the key lights up. They can then insert the key into the key slot by pushing it forward. Once the key is correctly placed, the next key appears on a pedestal beside the player, and the key slot switches to a new orientation for the subsequent key. After four Puzzle Keys are successfully placed in their respective key slots, the door opens to reveal a room filled with treasure chests, replacing the boss enemy encounter featured in the original game. We summarize the gameplay in four straightforward steps:

Step 1: Grab the Puzzle Key on the pedestal.
Step 2: Rotate the Puzzle Key to fit the Key Slot.
Step 3: Insert the Puzzle Key into the Key Slot.
Step 4: Repeat for all four Puzzle Keys.

Through this demo, participants will intuitively experience TwinSpin's unique mechanism, which utilizes finger dexterity, and gain firsthand insight into how efficiently it supports rotation tasks in VR. We expect that TwinSpin can minimize fatigue and potentially reduce the time required for complex rotational adjustments, offering a new perspective on VR controller design.

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