The SwissBall: A Wireless Spherical Physical Controller for Dynamic Control

Anonymous Author(s)

ABSTRACT

As computing expands beyond the desktop into more aspects of our everyday lives, physical controls are being left behind, despite their advantages over their touchscreen counterparts. We set out to show that physical controllers can be versatile for everyday life. Therefore we present the SwissBall, a wireless spherical physical controller suitable for different everyday uses. The SwissBall functions as a discrete and continuous controller. We create an interaction framework for the SwissBall to define present and future possible interactions. Finally, we demonstrate the SwissBall's everyday use through various applications and scenarios.

KEYWORDS

SwissBall, physical controllers, input devices, spherical, tangible, input techniques

1 INTRODUCTION

We are surrounded by physical controls in our everyday lives. From the brightness of a light, settings on home appliances, to the volume of a speaker, we use controls such as buttons and knobs to interact with parameters in many interfaces. Their simple operation, natural affordances, eyes-free interaction, and haptic feedback make for intuitive and useful physical controllers.

The digitalization of our controls has led to more parameters and means to control them [45]. But physical controls have conventionally been fixed in their number, type, shape, and function [21]. As computing expands beyond the desktop into more aspects of our everyday lives, physical controls are being left behind and replaced by touchscreens. Automakers are replacing car dashboards with large touchscreens. The brightness and color of smart lights can be controlled through an app. Appliance manufacturers are embedding tablets into fridges. Touchscreens provide the flexibility to support a dynamic set of parameters in our increasingly digital surroundings, but lack the tangible advantages of physical controls. With their ease of manipulation and lower demand for visual attention, physical controllers have the potential to be useful in broader contexts if they can adopt some of the flexibility of their touchscreen counterparts.

We set out to show that physical controllers can be versatile in everyday life. Therefore we present the SwissBall, a wireless spherical physical controller suitable for different everyday uses. The SwissBall functions as a discrete and continuous controller. It utilizes Touché [34], a novel capacitive touch sensing technology, for touch interactions based on force and grip configuration. Combined with movement sensing, the SwissBall uses gesture-based interactions to distinguish control in a portable and handheld spherical form factor. Its deformable shell and simple haptic feedback provide tactile information to the user. We create an interaction framework for the SwissBall to enable flexible, multi-functional control for different applications. We use this framework to define present and future interactions. Finally, we demonstrate the SwissBall's everyday use in four applications and scenarios. The contributions of this paper are 1) the SwissBall prototype: a wireless spherical physical controller and 2) its interaction framework.

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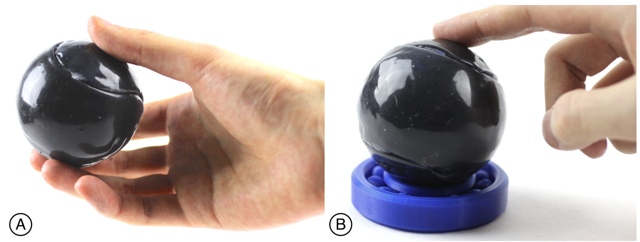

Figure 1: The SwissBall in its A) handheld and B) grounded mode.

2 RELATED WORK

We explore how physical controllers adapt their form and function for different applications. The SwissBall shares the idea of a single controller for multiple applications from the vision of the universal remote control [24, 29, 33, 46, 47]. We present various approaches for dynamic control with physical controllers and survey spherical input devices.

2.1 Dynamic Control

In the past, the function of a physical control was fixed (e.g. light switch, volume, power button). Through digitalization, controls and their functions can be dynamic [14]. As a result, the relationship between a control and its functionality has become weaker [40]. A single control can serve multiple functions. New commercial physical controllers illustrate this multi-functionality [4–6, 10]. For instance, the single dial of Microsoft's *Surface Dial* can control actions such as scroll, zoom, or select which maps to parameters like position, size, or color within different applications.

Controls can also be versatile in their form. Researchers have incorporated dynamic force feedback and shape-changing properties into common physical controls such as knobs/sliders [23, 40], buttons [26, 37], or combination [42]. These properties can also extend to controllers to fit more and different types of controls in the same space. This has been achieved through re-configurable controls [15, 17], built-in mechanisms [28], and material properties [12, 31, 35] of physical controllers.

Rather than on a physical level, the SwissBall achieves dynamic control with its interaction framework based on touch and movement gestures. Its spherical shape enables both continuous and discrete control in a portable form factor. This is important to *"'be usable on the go' and in the field"* [12] for everyday uses.

2.2 Spherical Input Devices

The aforementioned controllers do not share the SwissBall's spherical form, which has unique affordances and technical considerations. Spherical input devices in HCI research are limited, but have a range of applications.

A sphere's generality is useful for the representation and manipulation of virtual 3D objects. Spherical Digital Foam [36] is a wireless, malleable spherical input device that supports clay-like sculpting and modeling operations. It uses 162 evenly spaced sensors to track the location and pressure of touches. Buttonball [13] is a tethered pair of spherical isotonic 7-DOF controller for 3D positional input and scaling of virtual 3D objects. The Tango [30] is also tethered, and uses a pressure sensitive touch shell to manipulate virtual 3D objects. It can sense movement, pressure, and complex touch configurations like the SwissBall, but also orientation and touch location. The SwissBall differs from these controllers it can be used on a tabletop surface but is not constrained to it.

Spheres with deformable properties are a useful combination for the control and creation of music [11]. This makes the device expressive, simple to use, and durable. Researchers have created various deformable spherical instruments with simple but expressive squeeze interactions [18, 22, 39, 43, 44]. Touch is detected through embedded pressure-sensitive sensors often made of conductive fabric/thread. The SwissBall takes inspiration from the deformablity of these instruments but for broader everyday applications.

Most similar to the SwissBall in form and function are Soap [9], PALLA [41], and iOrb [32]. Soap is a mid-air pointing device. The user moves an outer hull with pressure, independently from an inner optical sensor for control in different everyday uses. The SwissBall uses fundamentally different sensing technology and method of interaction to Soap's mouse-based control. Similar to the SwissBall, PALLA uses a combination of touch and movement to detect gestures, as well as simple vibration feedback. It uses an internal inertial measurement unit (IMU) with sensor fusion algorithms to detect single and double taps, orientation, and altitude. It has a hard transparent shell with LED visual feedback. PALLA differs from the SwissBall in its use of an embedded light sensor to detect both touch and hand proximity. The SwissBall can be used in variable lighting conditions while PALLA's sensor is not pressure sensitive and influenced by ambient light. iOrb functions as a discrete and continuous controller like the SwissBall. It is composed of two half hemispheres which can be squeezed together like a button. It uses 3D rotations for the selection and navigation of 2D interfaces. However, its single 1D button restricts the controller to a small range of parameters compared to the SwissBall.

3 THE SWISSBALL

3.1 Motivation

To show that physical controllers can be versatile in everyday life, we designed the SwissBall. The device's name refers to the term *Swiss Army Knife* as a multi-functional physical tool carried throughout the day for a variety of applications. Rather than focusing on a specific use case, our approach was to prioritize portability and flexibility in the number and type of controls, and everyday uses for the SwissBall. Therefore, we used a handheld deformable spherical design. The shape of the sphere has a large uniform interaction surface in relation to its volume. It can be held naturally in the palm and is symmetrical at any orientation. These unique affordances make it a useful shape for a versatile controller.

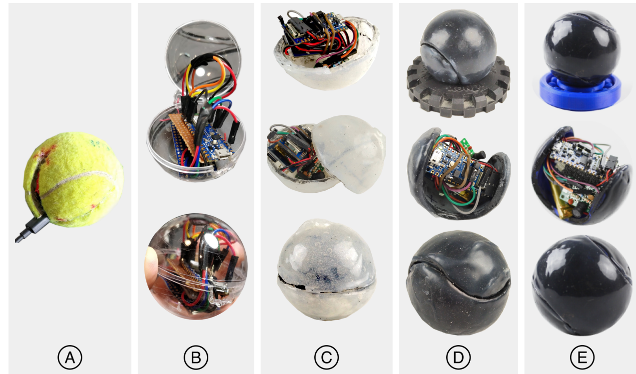

Figure 2: The evolution of the SwissBall through iterative prototyping from left to right. The first iteration A) A tethered tennis ball embedded with simple IMU sensing. B) A transparent plastic shell wrapped with conductive thread for touch sensing and the IMU for movement gestures. C) A deformable silicone shell from exploring different modeling techniques. Implements Touché and wireless communication. D) Uses conductive ink for touch sensing in a 3D printed shell, has a grounded mode. E) Current iteration of the SwissBall, with fabrication and usability refinements.

3.2 Material and Fabrication

The SwissBall has a diameter of 66mm and weighs 64.3g. It consists of hardware enclosed in a three layer shell: the inner *structural layer*, middle *conductive layer*, and outer *silicone layer*. Two identical 3D printed U-shaped pieces compose the *structural layer*. They fit and are held together through friction. This tennis ball-like design provides structural integrity to support strong grips but also easy access to hardware. The *conductive layer* enables touch sensing. It is a thin coating of Bare Conductive Electric Paint [2] on the outside of the *structural layer*. The coating turns the sphere's surface into a single electrode, ensuring uniform sensing coverage and distribution on a non-planer surface. The *silicone layer* allows deformation and pressure sensing. It is a 1mm thick coating of fast-drying Ecoflex 00-35 silicone [1]. The fabrication of the SwissBall is DIY-friendly and its components are inexpensive and widely available.

3.3 Hardware

The SwissBall contains a 3V vibration motor and custom Touché circuit, both connected to an Arduino Nano 33 IOT powered by a 500mAh Lithium Ion battery shown in Figure. 3. The Arduino has a 6-axis IMU to sense movement and a WiFi module to send data to a MacOS computer running a custom TouchDesigner program. The vibration motor is attached to the inside of the shell to produce simple haptic feedback.

3.3.1 Touché. The *conductive layer* utilizes Touché, a novel capacitive touch sensing technology that connects to the *conductive layer*.

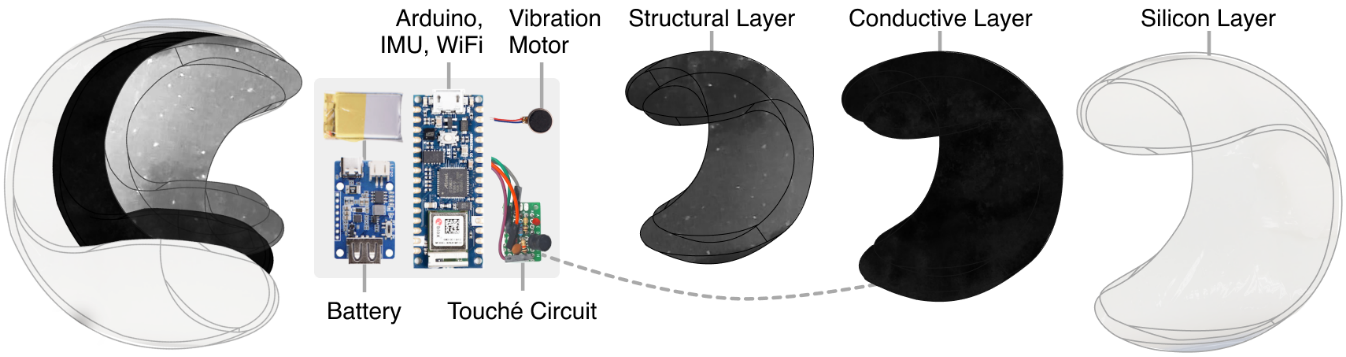

Figure 3: The components of SwissBall: the two half-shells, battery, Arduino, vibration motor, and Touché sensor (which connects to the *conductive layer*).

Because of the deformable *silicone layer*, it can distinguish touch features such as number of fingers and grip type. We built a custom circuit and software to enable Touché sensing for Arduino, using code we adapted from an online guide [38]. Touché captures touch as a *capacitive profile* from which touch features can be extracted, including the SwissBall's mode (handheld or grounded).

3.4 Software

The Arduino reads movement and touch data. It detects linear acceleration and rotational velocity from the IMU, and uses the Madgwick AHRS algorithm [3] to calculate orientation. The Arduino reads its touch data from Touché as a set of 120 points that form its *capacitive profile*. This data is sent using the Open Sound Control (OSC) protocol over a local WiFi network to a TouchDesigner program running at 60fps. TouchDesigner enables rapid prototyping for real-time signal processing, gesture detection, and application creation. We detect touch and movement gestures through basic feature extraction and map them to four applications (see Figure 6). We also send OSC commands back to the SwissBall to control its vibration motor for generating force feedback.

4 INTERACTION FRAMEWORK

In this section, we detail the particular gestures used by the SwissBall and how they are combined into *gesture phrases* for discrete and continuous control. We describe a visual system that maps the SwissBall to an application-specific set of parameters. We demonstrate this system using two instances of different applications (see Figure 5).

4.1 Interaction Vocabulary

We describe the gestures and their function and properties that compose the interactions with the SwissBall below. Because Touché can sense rich touch data, we select a small subset of gestures to sense based on the Tangible Gesture Interaction Framework (TGIF) [7] for simplicity of use.

- *Squeeze* (activation and closure): sustained hold with pressure using 2-5 fingers
- *Rotate* (continuous): controlled rotational movement
- *Shake* (discrete): brief linear displacement
- *Twist* (discrete): brief rotational displacement
- *Tap* (discrete): brief touch using 1-2 fingertip(s)
- *Null* (discrete): lack of movement and touch

4.1.1 Modes of Operation. The SwissBall has two modes of operation: *handheld* and *grounded*. In its *handheld* mode, the SwissBall be used in one or both hands. In its *grounded* mode, the SwissBall can be placed on a dock. In our current prototype, a dock is an apparatus that can hold and rotate the SwissBall along a fixed axis (e.g. rolling-element bearing) shown in Figure 1.B, allowing for more stable control. Also, the SwissBall does not have to be constantly held in this mode.

4.2 Gesture Phrases

Gestures in the SwissBall's vocabulary are combined into a grammar to control parameters which we refer to as the GESTURE PHRASE. It is based on the design principles of the *gesture phrase* from Golod et al. defined as *"a sequence of chunks (single gestures) that have one common, logically closed intent"* [16]. We implement the principles of the *gesture phrase* in the SwissBall shown in Table 1.

To interact with the SwissBall, the user first holds a *Squeeze* (ACTIVATION), then performs parameter control gesture(s) (INCREMENTAL ACTIONS), and finally releases the *Squeeze* (CLOSURE). While the activation is sustained, the user can execute incremental actions that correspond to parameter control. Upon release of the activation (CLOSURE), the SwissBall becomes inactive and ignores these incremental actions. This activation-closure method, made possible by force-sensing, mitigates accidental activation issues associated

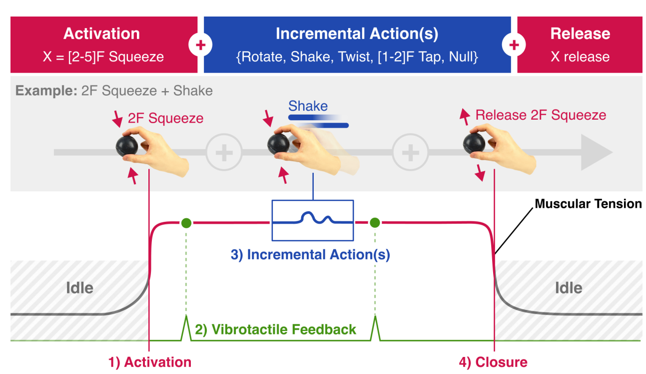

Figure 4: The sequence in which gestures are combined to form a *gesture phrase* shown with an example phrase.

Table 1: The design principles of the gesture phrase, their description and implementation in the SwissBall.

Name	Description (from Golod et al. [16])	Device Implementation
1. Activation	An unconventional and arduous activation gesture ensures that the system does not start accidentally.	A sustained *Squeeze* with force above a threshold.
2. Feedforward & Feedback	Provide continuous feedforward and feedback (e.g., system attention, from Charade [8]).	Device deformation during a *Squeeze* as feedforward and vibrotactile feedback.
3. Incremental actions	Support (additional) different single gestures within the same gesture phrase (e.g., next/previous song).	Continuous (*Rotate*) & discrete (*Shake*, *Twist*, *Tap*, *Null*) control.
4. Closure	The last phase helps to identify the end of the gesture phrase.	The release of the initial activation *Squeeze*.

with touch-sensing input devices [19]. It allows the user to hold and perform gestures on the same touch-sensitive surface.

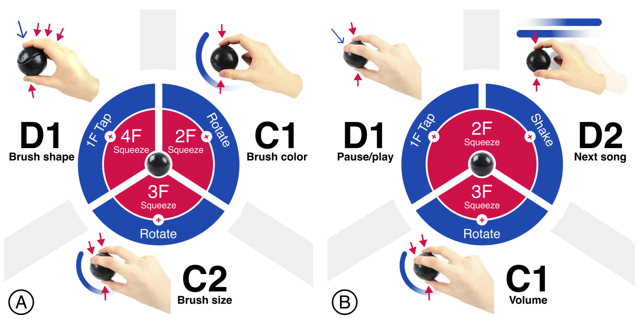

Figure 5: The mapping of two sets of parameters in different applications for discrete (Dx) and continuous (Cx) control. A) refers to the drawing scenario in Figure 6.A and B) for the music scenario on Figure 6.B

4.3 Parameter Mapping

Gesture phrases map to discrete (e.g. select, switch, toggle) and continuous (e.g. zoom, scroll) parameters. The interaction space of the SwissBall is visualized as a wheel composed of concentric rings divided into slices shown in Figure 5. Each ring represents an aspect of the *gesture phrase* (gesture and its property). Each slice corresponds to a single *gesture phrase* which maps to a parameter. The *gesture phrase* sequence starts from the center and proceeds outwards. The gesture phrase and mode determine the mapping. A grounded device can have a different mapping than in its handheld mode. We demonstrate how this mapping visualization can be customized in two application examples in Figure 5. This shows how the number of continuous and discrete controls can be adapted to best fit the application. The mapping of the *gesture phrase* can be assigned to different parameters.

5 APPLICATIONS

We present four applications situated within different everyday scenarios to demonstrate the versatility of the SwissBall and validate our prototype [25]. The applications were chosen to highlight different aspects of the SwissBall's capabilities.

5.1 Drawing: Multimodal Interaction

The SwissBall can be used for supplementary indirect control in multimodal interaction. The drawing scenario in Figure 6.A represents authoring content in a personal workflow. The user uses the SwissBall in its *grounded mode* to modify brush parameters through continuous (brush size and color) and discrete (brush shape) control. This showcases how the SwissBall can be used with existing tools to leverage this multimodal approach [20].

5.2 Music: Eyes-free Interaction

This application demonstrates a user using the SwissBall eyes-free in various positions. The music scenario in Figure 6.B represents a non-visual activity (e.g. listening to music) in variable environmental conditions. The user transitions from standing upright, sitting, to lying down while controlling the music. This shows how the user does not be constrained to fixed position.

5.3 Lights: Environment Control

This application demonstrates how the SwissBall can operate in different situational and environmental conditions. The lights scenario in Figure 6.C represents control of digital parameters in the user's environment with the light as an example of smart home technology. It shows the light's brightness as continuous and its state (on/off, color) as discrete controls being used in variable lighting conditions.

5.4 Slideshow: Dynamic Media Control

This application demonstrates control of different types of media in the same application. The slideshow scenario in Figure 6.D represents a collection of media with a different set of parameters specific to each piece of content. In this case, a 2D image has a different set of parameters than a 3D model (3D rotation and zoom).

6 DISCUSSION

We discuss implications of the SwissBall and possible further applications. Our choice of the SwissBall's use for "everyday life" is broad. This served to highlight and challenge the SwissBall's versatility around the dynamic characteristics of everyday life. For instance, being used *"on the move"* [12] in different situations by a context-switching user.

The SwissBall's dock suggests other apparatuses that serve as non-electronic attachments to modify the affordances of the overall device [27]. These could include a sliding axis for controlled linear displacement, button/knob attachments. To explore haptic enchantments, tactile markers of various shapes and sizes can be embedded in the *strucural layer*. The SwissBall's interaction framework could be used for personal, customizable, and context-aware interactions [37]. Users could prescribe gestures they find easiest to perform,

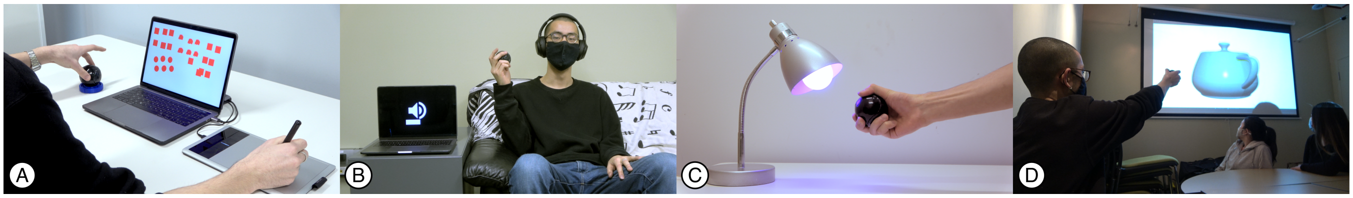

Figure 6: Four applications situated within everyday scenerios to demonstrate the SwissBall's versatility. The scenerios are A) drawing, B) music C) lights, and D) slideshow. The parameter mappings for applications A) and B) are shown in Figure 5.

remember, or attach their own semantic connections between a gesture and particular function. Additionally, the surface of the device itself could be customized through visual or tactile markers (e.g. small colored stickers) for users to construct their own personal systems of interaction.

A control's affordances indicate its function to the user. These affordances can be conveyed through means such as a control's physical properties or the interface it maps to. With the current SwissBall prototype, we convey the function of its controls through vibration feedback and the application interface (e.g. displaying a changing slider corresponding to volume). For multi-functional controllers, how and which affordances should be emphasized is less clear than prior non-digital physical controls. The digitalization of our controls poses a vast new design space around the relationship between a control, its feedback, and function. There exists a balance between versatility and usefulness, generic and specific use, which can be explored through the design of more controllers like the SwissBall.

6.1 Limitations

Our current prototype of the SwissBall has several limitations. The SwissBall remains stationary on a level surface from friction, but can roll on inclines. The shell must be opened to charge or program the device. Since Touché relies on the impedance between the user and device, we connected the internal hardware to the user via a small wire for grounding purposes. We calibrate touch sensitivity threshold based on the user's grip strength.

Because we measure rotational displacement relative to the user, the SwissBall requires an initial calibration to determine the direction of rotation. Our movement software can measure small rotational displacements, but drifts with absolute orientation or rotations over an extended period of time. Further development is needed to improve the reliability and accuracy of movement sensing. Some of these sensing limitations can be overcome in future iterations through modification of the *silicone layer* and software.

7 FUTURE WORK & CONCLUSION

Future work can leverage the wider set of gestures the SwissBall can sense, which its interaction framework can easily support. These include more complex gestures such as a roll, throw, and bounce with properties like repetition and pressure. User evaluation can help determine a balance between this expanded functionality and usability. Further iterations can also leverage prior work [26, 40] to make the SwissBall's vibration feedback dynamic. In general, the fabrication process for the SwissBall allows for similar new shell-like controllers. Most importantly, future work would include evaluation of the SwissBall's overall usability in the different domains it can be used.

In this paper, we set out to show that physical controllers can be versatile for everyday life. We created the SwissBall: a wireless physical controller, made versatile through its deformable spherical form and flexible interaction framework. We demonstrated this versatility in four different everyday applications and scenarios. We hope the SwissBall and its future iterations open up opportunities for more controllers of its kind.

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