Pop Through Button Devices for VE Navigation and Interaction

Robert C. Zeleznik Joseph J. LaViola Jr. Daniel Acevedo Feliz Daniel F. Keefe

Brown University Technology Center
for Advanced Scientific Computing and Visualization
PO Box 1910, Providence, RI, 02912, USA
{bcz,jjl,daf,dfk}@cs.brown.edu

Abstract

We present a novel class of virtual reality input devices that combine pop through buttons with 6 DOF trackers. Compared to similar devices that use conventional buttons, pop through devices double the number of potential discrete interaction modes, since each button has two activation states corresponding to light and firm pressure. This additional state per button provides a foundation to address a range of shortcomings with conventional virtual environment input devices that includes reducing the physical dexterity required to perform interactions, reducing the cognitive complexity of some compound tasks, and enabling the design of less obtrusive devices without sacrificing expressive power. Specifically, we present two novel input devices: the FingerSleeve was designed to be minimally obtrusive physically, whereas the TriggerGun was designed to be physically similar to, yet more functional than a conventional hand-held trigger device. Further, we present a set of novel navigation and interaction techniques that leverage the capabilities of our pop through button devices to improve interaction quality, and may also provide insight for how to harness the potential of pop through buttons for other tasks. Finally, we discuss a case study of how we incorporated one of our devices into a real application.

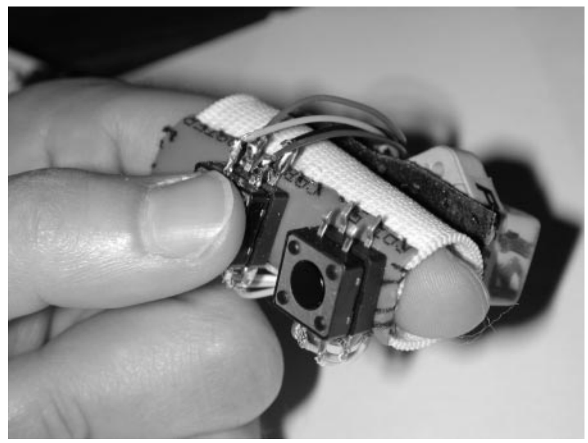

Figure 1. The FingerSleeve device mounts two small pop through buttons on an elastic frame, with the tracker placed on the back of the sleeve.

1 Introduction

A fundamental conflict in virtual environments arises when balancing the requirements for rich application functionality against the need for a physically and cognitively unobtrusive interface. The conventional solution is to decompose application functionality into a set of isolated "interaction modes". These modes are then explicitly invoked by the user through buttons on a hand-held prop, or finger contacts and hand postures on worn gloves. However, this solution introduces a new challenge because, as the number of interaction modes increases, the interaction devices tend to be more complicated and obtrusive, which tends to magnify the user's cognitive and physical burden. Thus, one fundamentally viable approach previously explored by [3][5] is to offload some tasks from the users hands to other physical body channels. Although, this approach can be intuitive and can free the user's hands to perform other tasks, perhaps in parallel, it can also suffer because most tasks such as navigation, selection or manipulation, especially when considered in isolation, can be controlled most efficiently and precisely by hand-centric interaction. Consequently, the complementary alternative to offloading the hands – increasing the number of easily activated hand interaction modes – needs to be considered.

We address the challenge of increasing the number of easily activated hand interaction modes by utilizing the familiar real-world skill of finger pressure, which can extend, in theory without noticeable changes, the functionality of all existing contact-based devices including the popular Pinch^{TM}glove[2] and wand devices. Since we are interested in discrete interaction modes, our research is based on the abstract concept of *pop through* buttons – buttons which have two clearly distinguished activation states corresponding to light and firm finger pressure. Three characteristics of pop through buttons can be exploited to improve virtual environment interaction:

- Twice as many activation states are available in the same physical surface area (and the corollary that only half as much surface area is needed to achieve the same expressive power) as a traditional button device.
- A bare minimum of additional physical activity is required to activate the additional state, less than that required to activate two different traditional buttons.
- The physical action of popping through one button state to another is arguably cognitively more natural for activating inherently sequential or closely related tasks than pressing separate buttons would be.

Specifically, the research we present covers the design of two novel interaction devices, the FingerSleeve and the TriggerGun, that use pop through buttons to explore different interaction trade-offs. We further discuss ZoomBack, a navigation technique that uses pop through buttons to travel temporarily or permanently to a selected location, and we discuss LaserGrab, a direct manipulation technique for navigating to any visible location in an environment. In addition to these navigation techniques, we present SnapShot, a technique for saving and using bookmark images of a virtual environment. Finally, we discuss and evaluate the incorporation of pop through button devices into CavePainting, an existing application for creating and viewing 3D scenes[4].

2 Related Work

Our work derives from research using pop through buttons to augment a conventional desktop mouse[13]. However, that research focused on interactions arising from modifying an existing mouse interaction device, whereas this work focuses on fundamentally new interaction devices. Also, although many of the guidelines presented in that work apply equally to virtual environments, we extend their guidelines to additionally include temporary vs. permanent interactions in which light pressure previews an action and firm pressure commits.

Pegasus Technologies produced a commercial 3 DOF interaction device called a RingMouse[11]. The FingerSleeve device that we present is similar in spirit to the RingMouse, although our device has the advantage of using pop through buttons and a 6 DOF tracker with the disadvantage of being tethered by the wires for the magnetic tracker.

Our LaserGrab navigation technique is similar to the Scaled-World navigation techniques described in [10], but presents fewer perceptual cue conflicts since the user-to-world scale factor remains constant. LaserGrab is also related to Pierce's navigation techniques[8], but is directly applicable to stereo environments, and also orbital and radial movements relative to a target can be controlled separately with a single button. Additionally since the orientation of the user's hand partially determines the selected target, LaserGrab allows users wide latitude in choosing a comfortable arm position, be it by their side or in a range of elevated positions.

3 Pop Through Button Hardware

A pop through button is a tri-state device that has two clearly distinguished activation states activated by pressing lightly or firmly on the button's surface. There are a number of possible implementations of such a button including fully integrated assemblies[1]; however we found that affixing a conventional button on top of another, possibly different, conventional button was the simplest, most flexible way to explore the pop through button design space. Depending on subtle details of both the geometry and force characteristics of each button, we were able to create a range of prototypes that had noticeably different finger travel distances, force thresholds for triggering the first activation state and force differentials for triggering the second activation state.

The paramount design requirement for pop through buttons is that the user must be able to accurately and comfortably control when each of the button activation states is triggered. We found that having a large force differential between the activation of the two buttons and a large finger travel distance between activation states helps users with this task. However, these two characteristics often oppose the goal of making the buttons comfortable for the user. The trade-off that resolves this conflict is highly dependent on the finger with which the user presses the button and the location of the button on the input device.

A desirable nuance of our controllability design requirement is that the activation order of the two buttons composing a pop through button be consistent to avoid the confusion that can arise from inconsistent physical feedback. Thus the triggering order of buttons should ideally not be affected if the user presses slowly or quickly, or if they adjust their finger position on the button. This goal can be particularly hard to achieve if the force thresholds for the two buttons are very similar. In any case, it is not appropriate to propagate inconsistent physical activation order through to an application's behavior. Therefore, the driver software that receives button events must map the first button event generated, regardless of the corresponding physical button, to the first activation state, and the second button event to the second activation state.

With these design considerations in mind, we developed two novel input device prototypes, the *TriggerGun* and the *FingerSleeve*. These devices represent fundamentally different strategies for aggregating pop through buttons with 6 DOF magnetic trackers. We use the Flexible Button system[7], a custom made button control unit capable of handling up to 16 button inputs, to sense the pop through button hardware for both prototypes.

3.1 TriggerGun

The TriggerGun, shown in Figure 2, is physically similar to commercial flight control-based joysticks. However, we chose not to modify an existing input device because we had comparatively little control over the size and physical characteristics of our pop through buttons. On the other hand by prototyping with oven-bake modeling clay, we had considerable latitude to adapt an existing chassis, such as a flight stick, to the properties of our buttons. We find modeling clay to be an inexpensive tool for iteratively designing and tweaking input device variations in response to feedback from users. The TriggerGun, an early result of this design process, has two pop through buttons that are embedded into a clay frame; one button is triggered by the index finger and is characterized by having a relatively long finger travel distance, the other button is more compact and is mounted at a 45 degree angle on top of the frame for thumb activation. A 6 DOF magnetic tracker is mounted on the back of the frame with velcro.

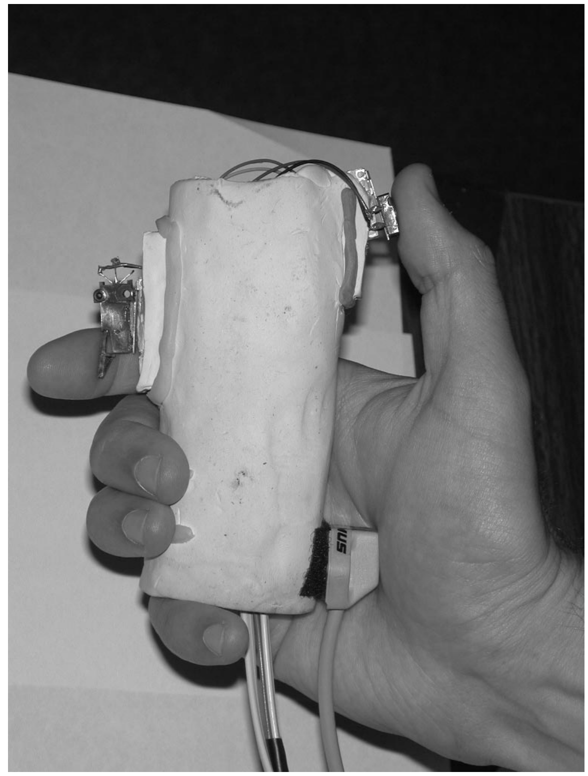

Figure 2. The TriggerGun device houses two pop through buttons mounted on a modeling clay frame. One is placed on the front to be used as a trigger, and the other is placed on top for thumb activation.

The pop through trigger is composed of two flat lever switches, with the exposed button mounted on the lever arm of the base button. The exposed button is of a different configuration and requires more operational force to depress. Because of the way people use their index finger to activate this trigger switch, the relatively large finger travel distance and force differential is not disturbing and makes it particularly easy for users to control activations of the first and second button states. The thumb pop through button consists of a tactile switch mounted on top of a flat lever switch. Because this switch is triggered by the thumb, a relatively high (over 120 gf) force differential can be used without negative consequence, although a smaller finger travel distance is required.

3.2 FingerSleeve

The FingerSleeve, shown in Figure 1, is a device that can be worn on the index finger of either the left or right hand. The frame is made out of an elastic fabric and a small piece of flexible plastic that can be found at any arts and crafts store. The fabric is sewn into a sleeve with a varying diameter that fits snuggly for most users. The plastic is sewn onto the front of the sleeve to provide a solid mount for the pop through buttons. The buttons are glued into place a few millimeters apart on top of the plastic. Finally, a 6 DOF tracker is secured to the back of the sleeve using velcro.

A primary design consideration in creating the FingerSleeve was selecting appropriately sized buttons. If the buttons protrude too far from the sleeve housing, the pressing gestures needed to activate them can be uncomfortable. The buttons we chose are small enough that users can operate the device comfortably. Both pop through buttons are constructed using two tactile switches with the same geometrical layout in width and length, but slightly different heights. The base button's switch is raised slightly above its mount enabling the exposed (top) button to be placed on the raised switch. This configuration has a smaller force differential than our previous pop through designs but is still easily controlled, perhaps because of the extra sensitivity of thumb-index finger interaction.

Another important design consideration is the placement of the buttons on the sleeve. We placed the outside (toward

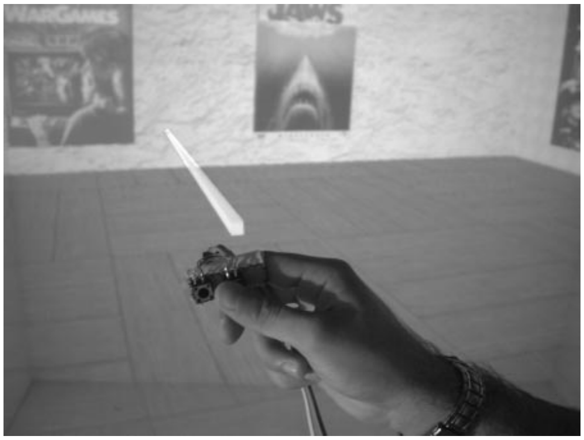

Figure 3. The primary axis for the FingerSleeve tracker is perpendicular to the user's finger orientation. The image shows a virtual laser pointing in that direction.

the tip of the finger) button at the tip of the sleeve housing, and the inner button just a few millimeters away, however some of our users have commented that they would like the buttons to be located even closer together. The optimal placement of the buttons may vary from person to person, particularly because the sleeve may be rotated to different angles on one's finger. Thus, depending on a particular person's preference, the buttons could be located anywhere from the bottom to the side of the finger.

Initially, we expected to be able to point at features while pressing buttons on the FingerSleeve using a virtual laser pointer shooting out of the tip of the user's finger. In practice, we found that this required difficult and uncomfortable hand gestures and that we had limited rotational ability when the pointer was aligned with the device in this way. We now use a pointer that is aligned perpendicular to the user's finger. (See Figure 3) This provides more rotational freedom and is appropriate for the interaction techniques presented here.

4 Pop Through Button Techniques

To explore the impact of pop through interaction devices, we first considered the task of virtual environment navigation because of its general applicability. Although we initially planned to apply our device to known navigation techniques, we felt that none of the published techniques were suitable as-is for use in our building walk-through environments for a variety of reasons. Consequently, we designed two new navigation techniques that bear similarity to existing techniques but are adapted to benefit from the capabilities of pop through buttons. In addition, we designed a novel technique specifically for our pop through devices that addresses the compound task of cropping and taking a snapshot within a virtual environment.

4.1 ZoomBack

A convenient way to facilitate the exploration of an environment is to allow users to quickly inspect a distant location in order to be automatically transported there, and then after arriving, make the decision about whether to stay or return to where they had started. Mine[10] previously explored this inspection navigation style using Head-Butt Zoom; however, pop through buttons, leveraging the naturally sequential nature of this inspection task, enable an alternative that requires significantly less user activity.

The ZoomBack technique allows a user to select a target point on the surface of an object in a virtual environment using a virtual laser pointer that continuously emanates from either the FingerSleeve or the TriggerGun. Then, by pressing a button lightly, the user is translated directly toward that target point such that he ends up two feet in front of the targeted point in approximately two seconds. If the user then releases the button, he is returned to his original location, again in two seconds. Alternatively, if the user presses firmly on the button to pop through, then his location is "locked" so that he can remain where he is after the button is fully released.

We believe the ZoomBack technique exemplifies a generally effective principle for mapping application behavior to buttons: that light pressure performs a temporary action that must be confirmed by firm pressure. This notion was supported by informal testing in a mock-museum environment where users found the device mapping to be natural, and the technique effective for moving about. We are, however, in the midst of an iterative process, inspired by user feedback, concerning second-order ZoomBack design variations such as alternative transition sequences and interactions that might better facilitate stopping short of the target location.

4.2 LaserGrab

The ZoomBack technique was designed for situations in which navigation is based on moving from one object to another. However, the more general walk-through navigation scenario is biased toward moving relative to an object, not just directly to the object. Pierce's image-plane navigation[8], and Mine's Scale-World Grab[10] are both candidates for this task. Instead of using either technique directly, we designed a modified version that we believe is better suited toward navigating dense walk-through environments because the user can keep his hand closer to his side, and head motion is not amplified.

As with the ZoomBack, LaserGrab allows users to select a target point on an object surface with a virtual laser pointer, and press a button lightly to begin navigation. However, instead of being automatically translated toward the object, the relative distance between the user's head and hand is used to proportionately control the user's location relative to the targeted object.[1] Thus, if the user points to an object with his hand outstretched, he will navigate all the way to that object, no matter how far away it is, by moving his hand to the plane of his body. If instead the user moves his hand to be halfway between its initial position and his body plane, then he will navigate half way to the targeted object. In addition, if the user presses harder on the button to pop through, he will then switch to an orbital mode in which he can orbit about the selected target point in direct proportion to the angular change of his arm projected into the plane parallel to the floor, a slight variation of Chung's orbital mode[6].

For the purposes of this paper, the main point of the LaserGrab interaction is that orbital and radial translation are separated into two distinct interaction modes activated by light and firm pressure. Even though it may seem arbitrary whether orbital or raidal movement is triggered by light pressure, our informal evaluations in walk-through environments have indicated a general user preference for activating radial translation with light pressure and orbital with firm pressure. However, this is one of a number of important LaserGrab design details that are outside the scope of this paper (others include the gain associated with arm motion and rotation angle, whether and how to support rotation about the user's head, the control function that is applied to arm movement perpendicular to the head-target axis, and how degenerate cases are handled when the user's hand is initially close to his body).

4.3 Snapshot

In addition to addressing conventional navigation problems, we also considered tasks that seem particularly well-suited for pop through buttons, based on the sequential operation guideline[13]. We found that a general class of virtual environment interactions emerged that maps the two activation states of pop through buttons to sequential tasks involving the invocation and manipulation of a widget, followed by either the application or dismissal of the widget.

The Snapshot technique for taking pictures from within a virtual environment is a representative technique from this class of sequential tasks. With the TriggerGun or FingerSleeve, users invoke a simple cropping widget (see Figure 4) by pressing lightly. Pressing harder, the user takes a snapshot of the area seen through the frame of the widget. Since the size of the widget frame is constant, users move the frame closer to or farther from their heads to modify the region of the virtual world that will appear in the snapshot image. These images are stored in a wall-menu. By pointing to a snapshot on this wall-menu, and pressing the same button lightly, users are temporarily transported back to the places where the snapshots were taken. Similar to the ZoomBack technique, releasing this button returns users to their original position; whereas applying additional pressure to the same button to pop through leaves them in the location indicated by the snapshot. In this case, the wall-menu includes an option for returning to the previous location.

Figure 4. With the SnapShot technique, users invoke this cropping widget with a light pressure on the trigger button. A firm pressure takes the snapshot of the area seen through the widget frame.

Taking snapshots with the cropping widget is very similar to taking pictures in the real-world with conventional cameras that have a two-level shutter release mechanism. In informal evaluations, users claimed to have no difficulty controlling the pop through button device for either taking snapshots or controlling the temporary and permanent transitions using the wall-menu of snapshots.

5 CavePainting Case Study

As a study of how one of our devices might function in a real application, we incorporated the FingerSleeve into CavePainting, an artistic tool for creating 3D paintings in a virtual environment (see Figure 5)[4]. The interface for CavePainting consists of several physical props, including a paintbrush. When working with the system, artists typically hold the paintbrush in the dominant hand and access differ-

[1] This interaction is also related to the Go-Go interaction[9], however LaserGrab is designed for navigation, not object-manipulation and the proportional motion control is based on the distance to the target point, instead of being fixed.

Figure 5. A “CavePainter” armed with a paintbrush in one hand and FingerSleeve in the other.

ent modes in the system for changing brush size or color, for example, using a Fakespace Pinch™ glove[2] worn on the non-dominant hand.

The Pinch™ glove interface provided users with four distinct contacts which we mapped to four different painting modes: color picking, resizing the virtual brush, translating the world, and toggling scaling mode on and off. In our redesign of the interface, our goals were to increase the number of modes accessible from the non-dominant hand so we could add new features to the system, to use a simpler device than the Pinch™ glove, and to avoid several problems with the Pinch™ gloves that we observed. After considerable use (almost daily) by artists and researchers, we found several ergonomic problems with the Pinch™ gloves device. For example, the gloves do not fit many people well and are difficult to control for these people, many pinches such as thumb-to-pinkie are uncomfortable to make, and it is hard to grasp other physical props while wearing a glove. In addition, the connections and cloth contacts wear out quickly with the regular use that our application receives.

In our new interface, we use the FingerSleeve device. This device also has four states (from the two multi-level buttons). However, we did not want to map the four original CavePainting modes onto these states directly because we wanted to allow room for more functionality and because combining two states into a multi-level gesture does not always make sense cognitively. We ruled out adding additional buttons to the FingerSleeve because we wanted to maintain the simplicity of the device.

To achieve this extra functionality with the FingerSleeve, we make a logical distinction that did not exist in the previous version of CavePainting, we consider button presses to be different depending on the proximity of the FingerSleeve (worn on the non-dominant hand) to the paintbrush (held in the dominant hand). This distinction provides us with the logical equivalent of eight different button presses. When the FingerSleeve and brush are close to each other, the buttons activate modes that control attributes of the brush. Light pressure on the outer button activates a color picker. Firm pressure locks in the current color and applies it to the brush. Light pressure on the inner button begins to change the size of the virtual brush, and firm pressure locks in the size change. When the FingerSleeve is not held close to the brush, the buttons affect more global operations. Light pressure on the outer button activates a painting scaling widget that provides more accurate and easily accessible scaling functionality than was previously available, while firm pressure on this button activates a translating and rotating mode. This is an example of two actions that often occur in sequence, and our users found it made sense to combine these two navigation modes into a multi-level gesture. Light pressure on the inner button activates an extensible menuing system that was unavailable in the previous version of CavePainting. Firm pressure on this button selects items from the menu.

By using the FingerSleeve device and interface, we avoided many of the ergonomic problems we encountered with the Pinch™ glove. We added more functionality to this portion of the application while moving to a simpler device by approaching our design with the strengths of the device in mind and adding a logical distinction between button presses that makes sense cognitively to our users. Our users are pleased with the ergonomics of the FingerSleeve in contrast to the Pinch™ glove, the additional access to new features that its use has enabled, and the more logical organization of sequential tasks that using pop through buttons has facilitated in this application. We are currently researching even more extensions to CavePainting and anticipate activating these with this simple FingerSleeve device as well.

6 Future Work

Although users have been very positive about our FingerSleeve and TriggerGun prototypes, there are three design possibilities that we believe could provide additional ergonomic and functionality benefits.

First, and most important, we believe there are two clear strategies for making our devices wireless, which would dramatically improve ergonomics. In desktop environments, we expect that either device could be made wireless by complementing a simple RF broadcast of button transitions with optical tracking of colored markers placed on the device’s surface. In fully immersive environments, we don’t expect that externally mounted cameras could readily be used based on line-of-sight and resolution issues. So instead, we propose the use of acoustic tracking, similar to the RingMouse technology, to enable untethered 3 DOF devices. This latter approach necessitates an evaluation of the trade-offs between unencumbered 3 DOF versus wired 6 DOF interaction.

Second, we believe that it would be possible to design pop through buttons in which the user could easily control transitions back from the firm to light pressure activation states, enabling an additional class of compound interaction techniques. With all of our current interaction techniques, the second activation state ends only after both buttons have been released – the release of just one button is ignored.

Third, we believe that a detailed investigation of thickness, size, shape, placement and activation force of the buttons could yield novel device designs that are yet more comfortable than our prototypes. Furthermore, we expect that such an examination, in conjunction with user evaluations, could reveal characteristics such as the maximum number or optimal size of buttons for a given device.

7 Conclusion

We have presented two novel hardware devices, the Finger Sleeve and Trigger Gun. By using pop through buttons, these devices are significant because they make four activation states, equivalent to that of the number of contacts that can be made easily with one hand using a Pinch™ glove, available in form factors that are simpler and less obtrusive. In addition, since each button supports two discrete activation states, triggered by light and firm pressure, some inherently sequential interaction tasks, such as the Zoom-Back and SnapShot techniques, and other compound interaction tasks, such as LaserGrab, can be matched directly to the device, just as focus and shutter release are mapped to a single pop through button on a conventional photographic camera. Finally, we discussed how a real Pinch™ glove-based application, CavePainting, was redesigned, based on user feedback, to use the simpler ergonomic design of the FingerSleeve, while at the same time incorporating additional interactive functionality.

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