The Virtual Tricorder

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Abstract

We describe a new user-interface metaphor for immersive virtual reality — the virtual tricorder (named for the Star Trek device). The virtual tricorder visually duplicates an actual six-degrees-of-freedom input device in the virtual environment. Since we map the input device to the tricorder one-to-one at all times, the user identifies the two. Thus, the resulting interface is visual as well as tactile, programmable, uniform, and based on a tool metaphor.

This new metaphor stimulates user interface research for immersive VR in three ways. First, it makes tactile feedback for user-interface design accessible on inexpensive hardware, second, it unifies existing interaction techniques for immersive VR, and third, it generalizes interaction techniques for use in immersive VR. To demonstrate the tricorder metaphor, we present several immersive interaction techniques.

Keywords: immersive virtual reality, user-interface metaphor, 3D user interface, tactile feedback, interactive systems, information visualization

1 Introduction

Stardate 2715.1.

Captain James T. Kirk, Mr. Spock, Doctor McCoy, and a security officer in a red uniform beam down to a planet's surface. While Mr. Spock uses his tricorder to survey the alien surroundings, e.g., analyzing chemical composition and atomic structure of nearby objects and plant-life, Dr. McCoy monitors their life signs with his medical tricorder. Still glancing at his tricorder, Mr. Spock reports: "Fascinating, Captain: while there are no life-form readings other than our own, I detect rapid movement ahead." "Set your phasers on stun," orders Captain Kirk as he pulls his weapon from his belt . . .

The above illustrates the universal functionality of the Star Trek [12] tricorder. As depicted in Star Trek, the tricorder's functionality encompasses medical, chemical, and structural analysis, determining existence and location of life-forms, location of any kind of geographical feature, and recording data in general; it is a truly amazing and extremely useful tool. Using virtual reality (VR), we can mimic such a device today. We propose the virtual tricorder as a new 3D user interface metaphor for immersive VR.

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1.1 Definition

The virtual tricorder metaphor requires a six-degrees-of-freedom input device, such as the Logitech Flymouse, and an immersive display, such as the FakeSpace Boom. We map the real input device one-to-one to a visual model of the input device, as shown in Figure 1. Since the real device is tracked, the virtual device also reflects all translations and rotations. Users then manipulate and operate the virtual tricorder with their hands within the virtual world. (If tracked gloves are available, we can improve realism by also rendering the user's hands in the virtual world.)

tricorder photo

Figure 1: The virtual tricorder metaphor visually duplicates an actual six-degrees-of-freedom input device in the virtual world. The resulting interface is visual as well as tactile, programmable, uniform, and takes advantage of the user's familiarity with real-world tool use. The metaphor is for immersive VR only: this figure illustrates the device-to-tricorder mapping and not actual use.

This simple setup creates a powerful metaphor with three main advantages. First, the resulting user interface provides direct visual and tactile feedback, since users see and feel the input device in their hands. Second, because the virtual tricorder exists in the virtual world, it is programmable and its appearance can be adapted to the current operation mode. Third and last, users are accustomed to tools, especially when operating in non-natural or abstract environments; thus, a tool metaphor such as the virtual tricorder is attractive for virtual worlds.

1.2 Implications

The new metaphor of using a single tool that is limited only by the possibilities of immersive VR creates a uniform interface. This interface combines previously disparate collections of interaction techniques. Translating these techniques into immersive 3D allows us to refine and improve them, for example, by taking advantage of the tactile feedback (see Section 3). Nonetheless, the virtual tricorder coexists with rather than replaces other immersive user interface metaphors.

1.3 Overview

We compare the virtual tricorder metaphor to other interaction metaphors for immersive virtual reality in Section 2. The advantages and disadvantages of the virtual tricorder are discussed in detail in Section 3. In Section 4 we present a number of interaction techniques that use the virtual tricorder, and in Section 5 we briefly describe our implementation. Section 6 summarizes our contribution and lists possible future work.

2 Related Work

2.1 Origins

Work by Angus and Sowizral at Boeing [1] inspired the virtual tricorder. As in our project, the Boeing work displays a visual model of a six-degrees-of-freedom user input device in VR. Their virtual model is augmented with a 2D screen protruding from the front of the device. However, they display and interact with 2D data on the virtual screen only. They thus benefit from the resulting anchored menus (Section 4.1) and the tactile feedback (Section 3.1), but do not take advantage of the full potential of a programmable 3D tool for a 3D world.

2.2 A New Device for Every New Task

Some VR researchers, notably Pausch at the University of Virginia, create for every new task a new hardware input device [9] [16] that is tailored to the requirements of the particular task. Two examples of this strategy are (1) using a flashlight augmented with a six-degrees-of-freedom tracker to operate a virtual flashlight [7], and (2) using a similarly augmented tablet/tennis-ball combination to interact via the "world in miniature" metaphor [16]. The main advantages of this device-per-task technique are its tactile feedback and the sensation of "physical manipulation of tools with mass" [8].

In a sense, our virtual tricorder is a software implementation of the device-per-task philosophy. Instead of creating new hardware, usually a cumbersome process that yields a single-purpose tool, we reprogram the visual representation and behavior of the virtual tricorder. Nonetheless, the tricorder metaphor maintains the advantages mentioned above of tactile feedback and physical tool manipulation. Thus, the tricorder can simulate a wide variety of tools, but due to its generality it cannot outperform input devices tailored to specific tasks (see Section 3.2).

2.3 Glove Gestures and Postures

Perhaps the best-publicized user interface for immersive VR is gesturing and posturing with a glove [20] [18] [4]. The position, orientation, and flex-angles of the fingers of one or two user-worn gloves are tracked and displayed in the virtual world. The user thus controls the environment by gesturing or assuming postures. The interface is considered intuitive, because users typically use their hands to interact with real-life objects.

However, while attractive in principle, glove interfaces are problematic in practice. For example, due to calibration inaccuracies, it is sometimes hard to perform the gesture or posture so that the computer recognizes it. As a result of trying and retrying to issue a command, users become aware of their actions, and the interface loses its intuitive feel. In addition, many actions in the virtual world, for example, flying or changing size, are inherently unnatural, so that no inherently intuitive or natural interface exists for them.

The above reasons, plus the lack of tactile feedback when touching virtual objects, effectively change the glove-interface metaphor from intuitive object manipulation to magic. Like a magician, the user consciously waves her hands in the air to effect changes in the virtual world. However, unlike a magician, the user does not have access to the (usually voluminous) spell-book that lists which posture or gesture corresponds to which command.

The virtual tricorder does not share those drawbacks. In particular, we avoid problems associated with pattern recognition, i.e., inaccuracy and increased lag, by relying on mechanical button-presses to activate commands. Furthermore, the tricorder provides tactile feedback and uses labels and manuals to explain its function. Finally, the tricorder exploits a tool metaphor (see Section 3.3) that applies equally to natural and abstract actions. On the other hand, a tool metaphor and thus all tricorder interaction is inherently indirect (see Section 3.3).

2.4 Floating Menus

Floating menus are text- or icon-menus displayed in the virtual world [5]. Typically, the menu free-floats in space — either absolutely or relative to the user's head position; only when users grab the menu can they change its position. The main disadvantage of floating menus in immersive VR is their foreign look and feel. Furthermore, the added third dimension seems to complicate (rather than simplify) menu selection as compared to 2D environments. We believe that 2D menus are not inherently foreign to immersive VR and describe an inconspicuous integration in Section 4.1.

2.5 3D Widgets

Finally, 3D widgets [6] [14] [15] [17] are graphical direct-manipulation interfaces: they attach directly to the manipulated objects and thus exist in the same 3D world as those objects. Because their graphical design occupies the same space, it must disclose the widget's function without obliterating the manipulated object. However, since widgets do not generally lend themselves to global tasks, such as selecting objects or viewpoint control, or to non-geometric tasks in general, they require other input metaphors to augment them.

The virtual tricorder is similar to a 3D widget that attaches to the user. As such it may also obscure objects the user operates on. Unlike a 3D widget, the tricorder's functionality and thus design is not limited to a single task. In addition, the tricorder's underlying tool metaphor accommodates geometric and non-geometric global and object-specific actions. However, this metaphor also makes the interface indirect (see Section 3.3). Nonetheless, combining the tricorder with traditional 3D widgets, or any other interaction technique, is probably advantageous.

3 Discussion

3.1 Tactile Feedback

Because the user touches the actual user-input device and because the visual mapping with the virtual tricorder is one-to-one, the user maps the tactile sensation received from the real device to the virtual tricorder. The haptic feedback thus relates to the sense of touch only and in particular does not provide force feedback [3]. Furthermore, the input device's inertia (caused by manipulating a real object with mass) intensifies the tactile sensation.

Even though the tactile feedback provided is basic, it convincingly suggests the reality of the virtual tricorder. Also, mainly due to the inertial effects, the user feels more embodied than with a glove-only interface. Thus, the virtual tricorder amplifies immersion.

This amplified immersion in turn establishes the user's body as the spatial reference to which all actions are relative. As Hinckley *et al.* point out, such a spatial reference point is highly desirable [8].

However, operating such a physical device with mass is also disadvantageous. Prolonged use of it causes fatigue. The tricorder in particular is suspect, because users often operate it close to their eyes, i.e., their arms are in a non-relaxed position. In addition, the tricorder's tool metaphor (see Section 3.3) sometimes induces tiresome ratcheting motions.

3.2 Programmability

The virtual tricorder is multi-purpose: we make it represent several different tools (see Section 4) and let the user choose among those tools while immersed. Each tool communicates its purpose through 3D graphical design as well as button labels. However, to maintain the tactile feedback, all designs must conform to the base-shape of the actual input device.

This conformity and the resulting tactile feedback distinguishes the tricorder from common VR practice. Systems such as [5] give the user a collection of tools, but, since the tools' shapes and designs vary considerably, they provide no continuity and only take minimum advantage of the tactile feedback of the used input device. On the other hand, the device-per-task strategy (see Section 2.2), while providing the same kind of tactile feedback as the tricorder, offers no programmability. Each virtual tool is hard-wired to an actual input device.

The tricorder lets us reuse existing interaction techniques for immersive VR: since it is programmable and thus flexible, we can implement those techniques easily and translate them into the tricorder's metaphor. Therefore, the tricorder quite literally provides a uniform look and feel to the often disparate interaction techniques for immersive VR.

On the other hand, since we so far only translated relatively simple, one verb commands (e.g., "select," "translate," "magnify," etc. in Section 4), it is unclear whether the tricorder also generalizes to complex interaction techniques. Worse, while the tricorder lets us implement and experiment with a variety of simple interaction techniques, it cannot replace task-specific, tailor-made interaction devices such as those in [9] [16]. Thus, its usefulness for specific applications is limited to early prototyping stages that require quick implementations for testing early designs.

3.3 The Tool Metaphor

Direct-manipulation interfaces are considered natural because they mimic human-object interaction in the real world. However, humans also often work with tools (see Figure 2). Accordingly, a tool metaphor, while less direct, is also valid and may in fact be preferable for those virtual operations that have no real-world equivalent (see Figure 3).

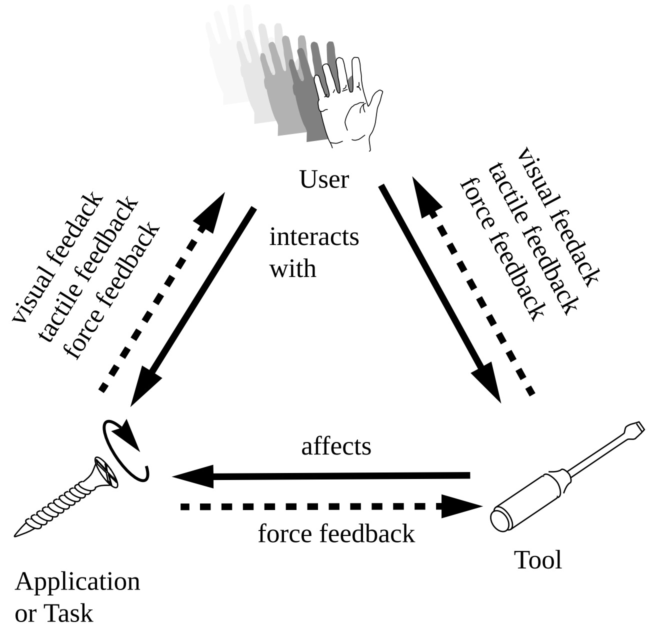

Figure 2: Human beings interact with real objects either via direct manipulation (the left path) or via tools (the right path). In both cases the user receives visual, tactile, and force feedback about the task.

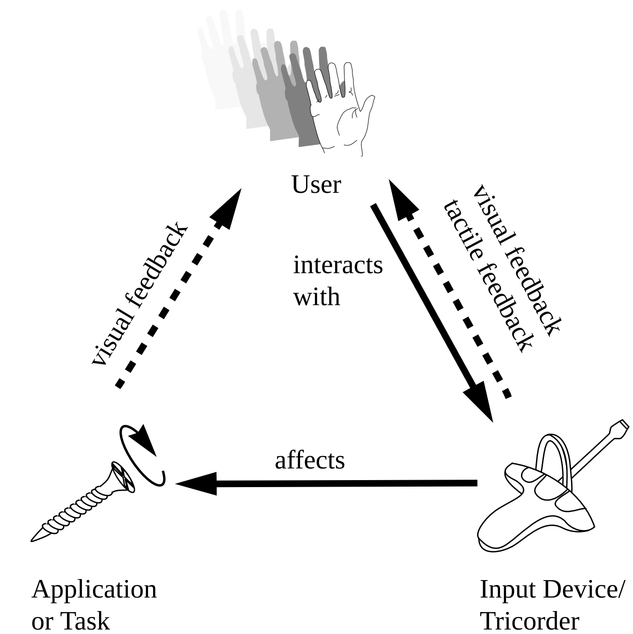

Figure 3: The tricorder metaphor mimics the real world (see Figure 2) closely if we only consider interaction via tools, but it does not provide force feedback.

Tools also obviate the need for hardware clutching mechanisms [8] in which the user presses a designated button (the clutch) to disconnect the tracked input device temporarily from the virtual representation. Clutching is thus crucial for avoiding uncomfortable hand positions, but destroys the user's identification of virtual with real devices, since the clutch suspends the mapping.

The tool metaphor, on the other hand, incorporates two clutches without suspending the real-to-virtual mapping. The first clutch is between the user's hands and the tool: while the non-active hand temporarily holds the tool, the other hand adjusts its grab on the tool to a comfortable position. The second clutch is between the tool and the manipulated object: the user applies and disengages the tool at will. Neither clutch destroys the virtual tricorder metaphor.

Tools have the further advantage that they come with manuals and labels. Thus, a new tool need not rely on the user's intuition to expose how it works; instead, we can label the virtual tricorder to explain its use.

The disadvantage of the tool metaphor is its inherent indirectness. Since the tricorder mediates all interactions, it potentially limits the user to learned, non-intuitive, and indirect actions.

4 Examples

In this section we present a few interaction techniques for immersive VR that exploit the virtual tricorder metaphor. Some are old ideas that are cast into the new metaphor (Section 4.1 and 4.3); some blend known techniques (Section 4.2); and some extend 2D concepts to immersive VR (Section 4.4). Together they cover a variety of disparate tasks, i.e., navigation, object selection, and visualization.

4.1 2D Anchored Menus

anchored menus photo

Figure 4: A virtual screen anchored to the tricorder displays 2D menus. The tricorder thus inconspicuously integrates 2D menus into VR without the usual drawbacks of poor readability, foreign feel, or difficult operation.

In tool-selection mode, a virtual screen augments the virtual tricorder (see Figure 4). This virtual screen extends from the front of the tricorder (at a slight angle to improve readability) and displays a selection of menu choices, as well as descriptive labels for the three buttons of the input device (the Flymouse).

We call this interaction style *2D anchored menus*, because the 2D menu is always positioned relative to the tricorder. Anchoring the menu in this way has several advantages. First, it improves readability, since users automatically pull the tricorder and thus the menu to their eyes if they cannot read the text.[1] In addition, users remember the position of choices on often displayed menus. Thus, seeing the outline of the choices at a distance is often enough to confirm a user's memory.

Second, we display the menu in a predictable and convenient position: all menus appear on the tricorder screen. Because of the continuous tactile feedback, tricorder and thus menu position is always known and accessible.

Third and last, interacting with a tricorder menu is similar to interacting with traditional menus. Menus (and even cascading menus) are sometimes operated by the 'up,' 'down,' and 'enter' keys. We map these keys to the three Flymouse buttons. Thus, the virtual tricorder acts as a portable (mouse-less) computer in the virtual world.

The virtual tricorder thus integrates 2D menus into immersive VR without the frustrations typically associated with 2D menus in VR. Furthermore, the virtual 2D screen is not limited to display only menus. For example, it can also display extensive help screens, information about selected objects, or a map of the surrounding environment.

With a slightly more complex input device (as suggested in Section 6.2), for example, one that incorporates a joystick and at least one button, an expanded virtual tricorder could display a 2D user interface and a pointer that is operated by the joystick. Thus the tricorder would allow us to interact with general 2D user interfaces while immersed. This way VR could use this interaction technique to take advantage of two decades of research in 2D user interface design.

4.2 Zero-Gravity Grappling

zero-g grappling photo

Figure 5: Users navigate the virtual environment using a virtual grappling iron. Once they affix the grappling iron to an arbitrary point in space, they pull, push, or throw themselves towards or away from that point. A built-in jet-thruster is used to alter the direction and magnitude of the user's resulting motion.

The *zero-gravity grappling* mode lets the user navigate the virtual environment. The tricorder acts as a grappling iron (see Figure 5) with which users grab an arbitrary point in space and then pull or push themselves towards or away from it. To move a distance greater than arm's length, the user uses either a ratchet mechanism of repeated 'grab-pull-release-reach-grab-. . . ' cycles or a throwing mechanism by which the user releases the grappling iron while in

[1] The tricorder can be moved to the eyes temporarily even while manipulating objects, due to the software clutch described in Section 3.3.

midmotion. In that case, the current motion of the user is maintained until the grappling iron engages again.

The zero-gravity grappling mode of the tricorder also incorporates a jet-thruster that fires both forwards and backwards, accelerating or decelerating the user in the direction the tricorder points. Its main use is to correct the flight path that resulted from the throwing mechanism. Note that engaging the grappling iron in midflight acts as an instantaneous brake.

Zero-gravity grappling combines a translation-only "scene in hand" and the "flying vehicle control" interaction metaphors [19].[2] Combining these two is of advantage because "scene in hand" is well suited for precise short-range navigation, while "flying vehicle control" is good for imprecise but fast long-range navigation [19].

4.3 Selecting and Positioning Objects

tractor beam photo

Figure 6: The cone projecting from the front of the tricorder highlights the object selected when the user presses the select button. To simplify selection the width of the cone is interactively adjustable.

In object selection mode, a semi-transparent cone projects from the front of the tricorder (see Figure 6). The cone determines which object is selected when the user presses the 'select' button, similar to selection in [10]. By incorporating a spotlight at the apex of the cone, we enhance visual feedback by literally highlighting the objects to be selected. In addition, we ease selection by allowing the user to control the width of the cone interactively.

Once an object is selected, the user can rotate or translate it. Rotations or translations of the object correspond one-to-one to rotations or translations of the virtual tricorder. Figure 7 illustrates how the tricorder transmits its position or rotation to the selected object. The user can change the one-to-one mapping by interactively modifying a scale factor (see Figure 7). If the scale factor is greater than one, movements of the tricorder are amplified in the object's movements. Such amplification is useful, for example, in positioning large, faraway objects approximately and quickly. Conversely, if precise positioning is required, we use a scale factor of less than one: the selected object's movements are a fraction of the tricorder's movements.

[2]The tactile feedback of the tricorder is crucial for this mode to work: without this feedback users might feel that they are moving the scene, i.e. "scene in hand," rather than themselves, i.e. "grappling iron."

transmit photo

Figure 7: Once an object is selected we alter its position or orientation. Position or orientation of the tricorder maps one-to-one to the object's position or orientation. Altering the scale-factor (shown above the button labels) changes the mapping accordingly.

The tricorder thus frees us from operating only within arm's reach. In particular, we address two separate issues. First, we are able to select distant objects, because the selection cone extends infinitely and because its width is adjustable. Second, we can control position and rotation of distant objects accurately, because of our scalable one-to-one mapping.

4.4 3D Magic Lenses

wire-frame photo

Figure 8: The wire-frame lens renders all objects in its view in wire-frame mode. Since the lens attaches to the top of the tricorder, the user positions it easily to view particular objects in a scene. By controlling lens-to-viewpoint distance the user determines how much of the scene is displayed in wire-frame.

magnifying glass photo

Figure 9: The magnifying lens magnifies objects in its view by a user-selected magnification factor. As with the wire-frame lens, the user positions it by moving the tricorder through the scene.

Our final example of VR interaction via the virtual tricorder metaphor generalizes 2D magic lenses [2] into immersive 3D. A magic lens as described in [2] gives the user a different view of the objects underneath (in 2D) or behind it (in 3D).

We currently implement two such lenses: wire-frame and magnify, shown in Figures 8 and 9, respectively. The implementation of the magic lenses rerenders the scene into a rectangular cut-out (representing the lens) with different camera parameters. Thus, we restrict 3D magic lenses to be screen-aligned rectangles.

The wire-frame lens renders all objects in its view in wire-frame mode. The lens attaches to the top of the tricorder and the user manipulates it like a magnifying glass. Such a lens is already implemented in [2], and our contribution lies in porting this tool to immersive VR. The added third dimension allows the user to change the lens-to-viewpoint distance and thus to adjust how much of the viewed scene is shown in wire-frame.

The wire-frame lens suggests other visualization tools, for example, a lens that selectively shows normally hidden pipes or electrical wires in photorealistically rendered rooms.

The magnifying lens, also already mentioned in [2], magnifies objects in its view by a user-selected factor. It is useful for viewing dense information in context and as such relates to other information-visualization work in 3D [11] and 2D environments [13].

5 Implementation

Figure 10 shows our current setup. The virtual tricorder corresponds to a Logitech Flymouse. Its tracking data is processed by a two-processor SGI Onyx whose RealityEngine II renders the scene in stereo. Camera viewpoint and orientation depend partly on the application and partly on the position and orientation of the FakeSpace Boom 2C-M that also displays the stereo scene.

Similar setups with different underlying hardware are possible. However, our current implementation has several drawbacks that should be considered for future systems. First, the base triangle that tracks the Flymouse is stationary at the Boom's base (see Figure 10). Thus, the working volume of the Flymouse is severely restricted.

our setup photo

Figure 10: Our current setup uses a Logitech Flymouse and a FakeSpace Boom 2C-M. Note the stationary base triangle near the middle of the photograph.

In particular, users cannot turn around and look behind their back without losing the tricorder.

Ultimately, we will mount the Flymouse's base triangle directly on the Boom's display to correct this problem. Figure 11 sketches the proposed installation. This unimplemented scheme is superior to the current solution for two reasons. (1) The Flymouse's working volume always corresponds to the user's working volume, i.e., it is always placed directly in front of the display. (2) No harm is done if the user pulls the tricorder off to the side, out of the tracking range, since at that angle the tricorder is out of the view of the display.

Second, the Logitech system uses ultrasound to track the Flymouse, so that the Flymouse must always be in a clear line of sight from the base triangle. This property is problematic because it prohibits full rotation of the tricorder, and also because the user might accidentally obstruct the line of sight.[3]

Third and finally, the Boom is not a true head-mounted display, i.e., the user has to hold it in one hand. Thus, two-handed user interfaces become impossible.

6 Conclusion

6.1 Contribution

The virtual tricorder is a new user-interface metaphor for immersive VR. Rather than replacing existing user-interface metaphors

[3]Our current environment precludes the use of electromagnetic trackers due to large electromagnetic distortions from nearby power cables. Incidentally, these distortions also prevent us from using data gloves.

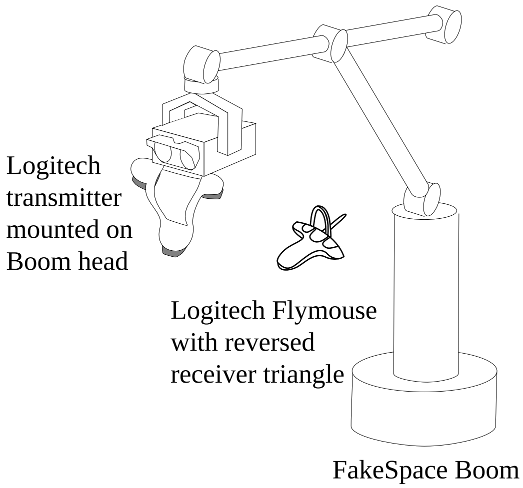

Figure 11: Sketch of a superior setup. Mounting the base triangle directly on the Boom would make the user's work-volume and the Flymouse's tracking volume coincide.

(see Section 2), it combines with them to let users take maximum advantage of the available state of the art.

We present several interaction techniques that translate to the tricorder metaphor (see Section 4). These translations point the way to whole classes of useful future tools for VR, for example, 3D magic lenses. The tricoder combines these techniques into a uniform interface that has three main advantages: tactile feedback, programmability, and the underlying tool metaphor (see Section 3). The tool metaphor in particular is crucial: we believe that equating users of virtual worlds to real people carrying real tools (e.g., computers, phones, etc.) is more fertile for immersive interface design than equating them to magicians who have lost their spell-books.

6.2 Future Work

In general, the interaction techniques of Section 4 could be refined and extended. In particular, investigating the use of other 3D magic lenses for immersive information visualization seems fruitful. Other tricorder-inspired interaction techniques could also be studied; for example, it might be possible to adapt some of the 3D widgets mentioned in [6] [14] to immersive VR via the tricorder metaphor. Extending this idea to combining the tricorder metaphor with other immersive interface metaphors seems intricate but ultimately rewarding.

In the hardware realm, designing an input device that better represents a tricorder has much potential. Such a device should probably be equipped with a six-degrees-of-freedom tracker, a number of buttons, a 2D joystick or track-ball, and a number of sliders, dials, or thumb-wheels. As hinted in Section 4.1, such a more general device opens up a much wider design space for immersive VR interactions.

We also believe that adding tracked gloves to the interface is worthwhile: realism improves and two-handed input becomes possible. Once gloves are incorporated, one might experiment with multiple tricorders, probably permanently attached (for example, via cords) to a user-worn tool-belt.

Finally, user studies should be done to evaluate the tricorder metaphor and its interaction techniques. Questions that require answers are: for which applications is the tricorder metaphor appropriate? In what sense, if at all, is the tricorder metaphor better than other metaphors? Are the interaction techniques presented here more efficient than traditional ones? For what tasks?

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