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Tagged Handles: Merging Discrete and Continuous Manual Control

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ABSTRACT

Discrete and continuous modes of manual control are fundamentally different: buttons select or change state, while handles persistently modulate an analog parameter. User interfaces for many electronically aided tasks afford only one of these modes when both are needed. We describe an integration of two kinds of physical interfaces (tagged objects and force feedback) that enables seamless execution of such multimodal tasks while applying the benefits of physicality; and demonstrate application scenarios with conceptual and engineering prototypes. Our emphasis is on sharing insights gained in a design case study, including expert user reactions.

Keywords

Discrete, continuous, haptic, force feedback, tagged object, tangible, tool, token, container, design process.

INTRODUCTION

Tagged objects and haptic force feedback are two means of bringing tangibility to user interfaces. Complementary in their control affordances, one facilitates discrete selection and the other enables continuous manipulation. Both allow a user to employ his or her hands, and to manipulate media in ways that can be more intuitive and convenient than a keyboard and screen. However, the most natural functions of these tangible mediators are different, indeed orthogonal. Tagged objects (physical icons marked with electronic ID or memory) are relevant as tangible references to virtual information, representing data or operations. Haptic force-feedback interfaces (actuated robotic devices through which a user feels computer-generated environments) are used to handle, navigate and sculpt virtual terrains.

Many computer-aided tasks have components of both discrete and continuous manual control. Here we describe a new interaction concept that unites the two, placing both discrete and continuous manual control into a single consistent model. We will develop the percept of using physical selectors to change force-feedback behavior, setting context both electronically and physically: tagged objects have specific shape and action, while haptic objects have a general shape and many actions. This approach connects specific shapes to specific actions while maintaining generality, and we believe that the result’s elegance can ease the introduction of continuous control into digital interfaces.

We present several versions of the idea and scenarios for its use, in two primary vehicles:

I. Tagged objects are handles interchangeably plugged into a force-feedback interface, switching the display’s dynamic behavior while simultaneously changing its appearance and grip;

II. Distinctive discrete selectors are permanently integrated into the force-feedback display and can be manually activated to set a particular function mode and dynamic behavior.

We then describe an iterative conceptual and engineering prototyping process pursuing one branch of this concept in a constrained application space, and reflect on our insights from developing these prototypes and sharing them with several expert users.

BACKGROUND

Discrete and Continuous Control

User interfaces relate to discrete or continuous information and control. While these terms really compose a continuum rather than disjoint spaces, they are a helpful way of looking at the world in the sense of manual control.

Buttons, switches and tagged objects are discrete controllers: they trigger something to happen automatically and beyond the user’s immediate sphere of influence. Flipping a light switch causes the light to come on. The information age brings new kinds of discrete controls with complex responses: opening the door of a “smart” apartment might cause lights to come on, music to play and the oven to warm up.

A handle is a continuous controller: you grab it and maintain direct, active authority. Since the handle couples you to the environment, you can quickly adjust your own motion to its physical signals, forming a tightly closed control loop. One does this when penning a curve, drawing the aftertone out of a piano key or steering through a virtual game-world. Force feedback interfaces share these attributes, and earn their keep when constant, two-way engagement with the environment is needed.

Tagged Objects

From wedding rings to ATM cards, physical tokens have always played key roles in our social and information processes. Holmquist offers a useful classification that distinguishes containers (generic data collections), tokens (data representations whose content is physically demonstrated), and tools (objects that set a function or state for operating on data selected in some other way) [6]. Tagged objects live in the margin between electronic and physical worlds, used to turn things on, select, combine, physically move data, change its context or trigger common tasks [1, 3, 18]. They appeal to those who like to touch as part of doing, and enjoy variety in shape and texture and heft. Arbitrary objects can be tagged; they easily broadcast their function. They rely on cheap, mature technology such as bar codes and radio and magnetic sensing.

But tokens and buttons command a repertoire of behavior more limited than that of many other real objects: they are inherently discrete. While computers are binary creations, the natural world is as often composed of and perceived as an infinity of continuums. People who have grown up within it are accustomed to moving and deforming and creating new possibilities from malleable media. In this sense, tagged objects do not ease the language barrier between humans and electronic devices.

Some prior research has special bearing here. Ullmer's slideshow browser [17] illustrates an intriguing use of a media-container as a handle. However, individual slides merge into a stream as their number increases, and overwhelm the browsing capabilities of a passive slider. Gorbet's Triangles [4] have discrete display capability (flashing LEDs), and a magnetic tug between Triangles confirms connection. Yarin has placed multiple tags in a single object to indicate a series of discrete states [19].

Haptic Force-Feedback Interfaces

Force-feedback interfaces are the children of robot technology and biomedical inspiration, and have evolved from the powerful, expensive systems of the 80's [5, 12] to today's commercial desktop and gaming devices [7, 13]. Active force feedback can unload other senses, reduce ergonomic strain, support expressive abstract input, and enable continuous manual control. Interfaces assume many configurations – knob, mouse, joystick, tactile array – and use many mechanisms and actuators. They simultaneously provide input and output, informing the user of a system's state while transmitting her intent.

Current devices have problems with both cost and usability. The technological challenge of generating significant, controllable forces in a small, low-power package maintains a tough tradeoff between expense and quality. Therefore psychophysical illusions that heighten perception of force magnitude, fidelity or excursion can leverage cheaper devices (e.g. [15, 16]).

The point of a force-feedback display is to execute arbitrary functions and feels with the same interface. Unfortunately this means the user might not know what to expect, and the handle might not be the right one. Users may be disoriented and even fearful of "invisible" environments without sufficient context, particularly upon changes in environment or control mode. Additionally, variety in tactile shape and heft of the tool cannot be exploited to overcome limits on environment fidelity imposed by expense and actuator technology. Psychophysical studies as early the '50s [2] substantiate the role of distinctive shape and location of console handles. More recent work (e.g. Rock [11] and Srinivasan [15]) indicates that visual stimuli overpower tactile in most cases, and thus a tool's appearance is central to its function. Nevertheless, economics support the pervasive generic and multi-purpose handle.

TAGGED HANDLES CONCEPT

We feel that physical interfaces are most valuable when customized for a given application at every level –the grasped object, the perceived forces, and in simultaneity and integration with other sensory displays. When both continuous and discrete (modal) control ability are desirable, and where having the right handle matters, use of tagged objects or force feedback alone fails to encompass the whole control task at hand, resulting in user frustration and disorientation. Here we combine bidirectional, continuous manual communication with changeable, appropriate handles and physical context.

Figure 1 demonstrates this schematically with four

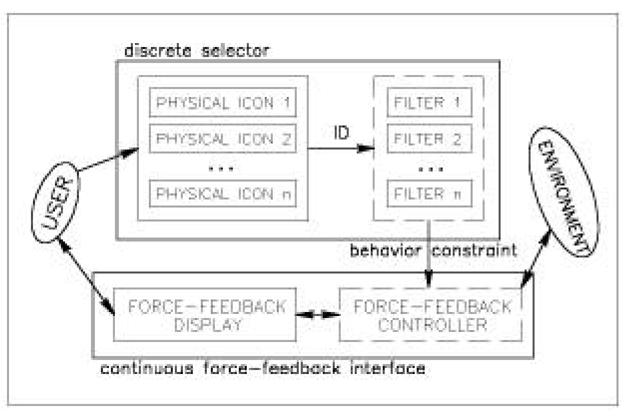

Figure 1: Tagged Handles concept components.

components: user and environment mediated by the Discrete Selector (DS) and the Continuous Force-Feedback Interface (CFFI). A user interacts with the environment by choosing a physical icon, and grasping a force feedback display – usually *through* the physical icon. The computer recognizes the physical handle, and applies its associated behavior filter to the force-feedback controller. The DS thus consists of the set of physical icons and their corresponding filters; the CFFI is the force-feedback display and controller. Of these, the physical icons and force display are tangible, and the filters and the force controller are generally implemented in code. The environment may be a virtual model, a spreadsheet, streaming media such as video or audio, a remote environment or a multitude of other contexts.

By "filter", we mean the system's interpretation of the discrete selector at a given time. It might determine the data the system will operate on, the device that a controller targets, the function executed on an environment, or a user's system setup preferences.

Example Scenarios

The following scenarios are representative contexts where the handle matters and continuous bidirectional control is beneficial; many other applications exist.

A: Drawing Implements

To benefit fully from force feedback while using a drawing program (Figure 2), the user selects a drawing implement from a tagged collection of real implements (e.g. paintbrushes, pencils and chalks) and plugs it into the force display. The system recognizes the implement and supplies forces that convey the sense of that tool, while translating the user's motion into an element in a digital drawing. The tool also sets the line's properties and the function used to interpret the controller's motion, creating a fuzzy chalk line or a calligraphic swathe.

Multiple discrete selectors can be used in combination, and a user can generate new interpretations of the objects. Another set of tagged objects (not shown) can indicate the drawing surface – smooth vellum or pebbly handmade paper. Haptic properties of the virtual paper may be automatically extracted from the real sample (e.g [8, 10]) and linked to the sample with a barcode sticker. The chosen surface will be reflected in the haptic interaction between it and the drawing implement, and in the line drawn in the application.

B: Slide Show

A slide presentation is an example of a set of discrete elements that a user must access and manipulate in a many contexts (whiteboard, scanner, printer, projector). As demonstrated by Ullmer [17], a container-type tagged object is a good way to represent and transfer the slide show; but it is cumbersome to browse a large set. Force feedback renders it as a continuous, feature-rich stream.

Figure 3 shows a user scrolling a slideshow by plugging the token into a force-feedback slider and moving it back and forth, feeling detents that mark slide or section edges and annotations. It is easy to step through slides and stop at an intended destination. In this context, a linear, limited range-of-motion slider (shown) has the benefit of clearly demarcating the beginning and end of the slide show – they correspond to the physical endpoints of the input device, and orient the user spatially.

C: Browsing Digital Media

Figure 4 illustrates a means of media navigation and editing. In this scenario, the DS could represent either a set of media-containers (e.g., video clips or shows) or tools (functions to be applied to the media stream, e.g. view, edit, zoom, or feel a set of annotations).

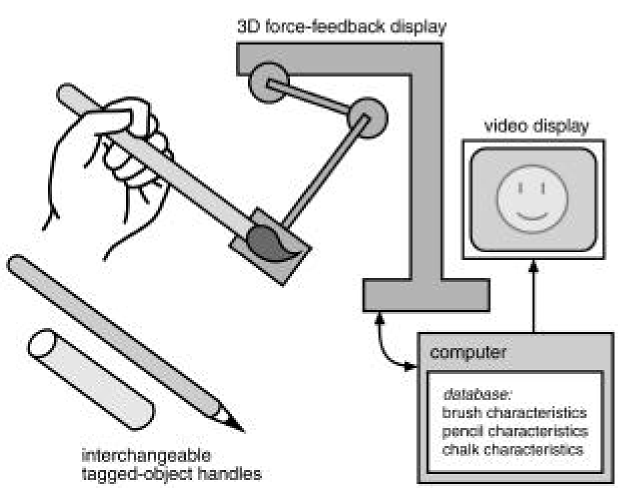

Figure 2: Drawing program. Processor recognizes tagged implement and provides appropriate force-feedback.

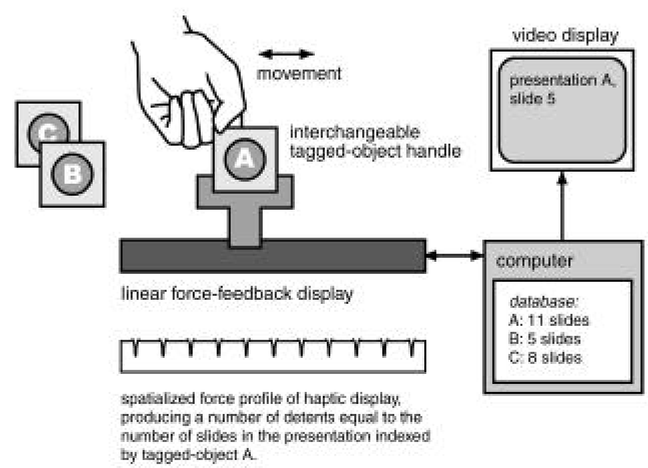

Figure 3: Slideshow browser

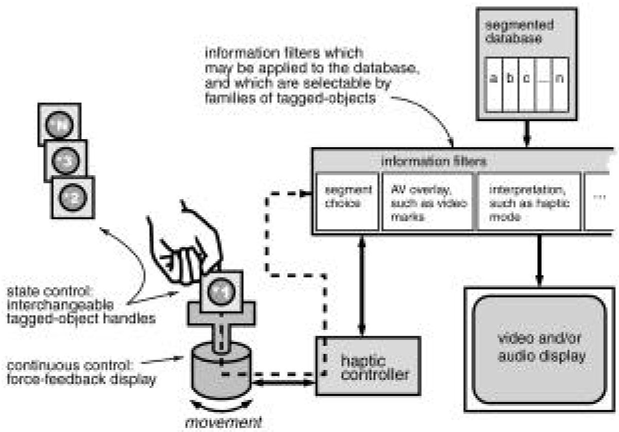

Figure 4: Browsing digital media.

One interesting tool is the *content filter*, which causes the force feedback to emphasize a particular kind of content. This could be a violence detector for child-safe movie watching, or a person detector that uses signal processing to detect appearances of Grandma in a home video. When the stream is lengthy, innovative interaction techniques may help to navigate it – e.g. the "haptic clutch" metaphor mentioned in [9].

D: Browsing Cartographic Data

Figure 5 demonstrates another variation of a token-type handle, where the tagged object is linked to a parameter in a database (e.g. cartographic) and used with a planar haptic display to explore that parameter.

E: Deep-Parameter Marking in Graphics Applications

Graphics professionals editing images and animations tend to repeatedly modify a small set of parameters, e.g. image brightness or joint position. These parameters are buried in modal dialog boxes and once accessed, difficult to set precisely with a mouse. Here, a user can temporarily associate a deep parameter and a single knob controller using a tagged icon to easily access the parameter and receive specific haptic feedback.

F: Force-Feedback Home Remote with Integral Selectors

The last example demonstrates a different take, wherein the Discrete Selectors remain attached to the force-feedback controller at all times and selection is made by grasping or activating one of them (Figure 6). In the case of our Home Remote prototypes described later, selectors are mapped to control functions such as video selection, play mode and volume control.

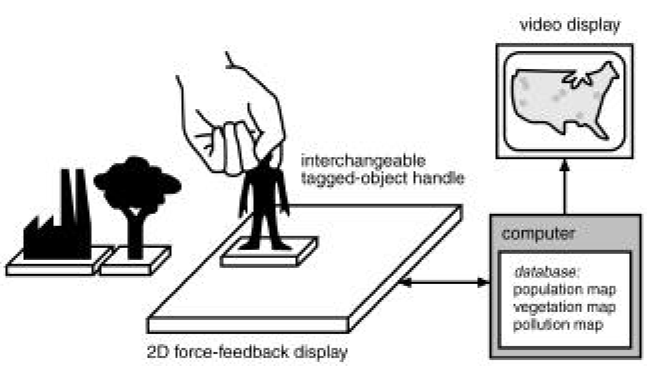

Figure 5: Tagged tokens access cartographic parameters.

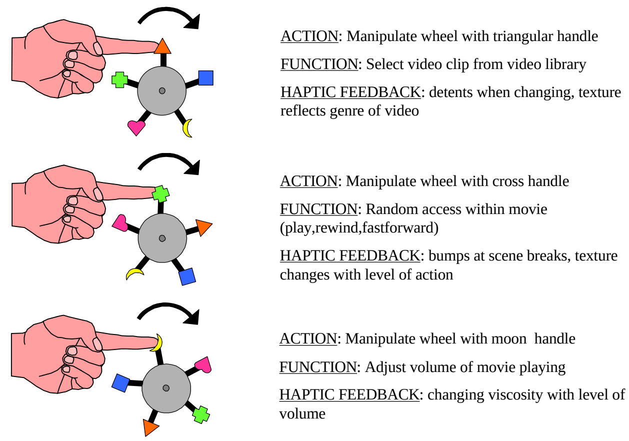

Figure 6: Integral Handles being used for media browsing.

PROTOTYPES

We constructed many conceptual and engineering prototypes to explore two branches of the Tagged Handles concept. The first is the Exchangeable Handles configuration (Examples A-D above), and the second is a series of iterations on the Integral Handles variation described in Example E.

Prototype I: Exchangeable Tagged Handles

Our first prototype was an engineering mockup with no context. Exchangeable knobs (distinguished by abstract shapes) with electronic tags are plugged singly onto a mechanical receptacle on a computer-controlled motor (Figure 7). Object recognition and motor control were implemented locally on a PIC, communicating serially with an audio server on a QNX Pentium.

We implemented a variety of scenarios utilizing the handles as audio containers, corresponding for example to a collection of MP3 music tracks or voice mail messages. The user could select a track by plugging in a knob (in this first try, we made no effort to identify the content referred to by each handle). Force feedback was supplied according to a set of rules that were consistent across the different audio types: the user could browse the selection with functions such as a continuous range of scrub speeds in both directions, defaulting to steady play when the handle was released. Mode changes were accomplished using haptic dynamic models previously developed and demonstrated by the lab [14].

Prototype II: Integral Handles

The second prototype family takes on a different theme, integrating a set of Discrete Selectors directly into the force-feedback handle. We moved this way in response to

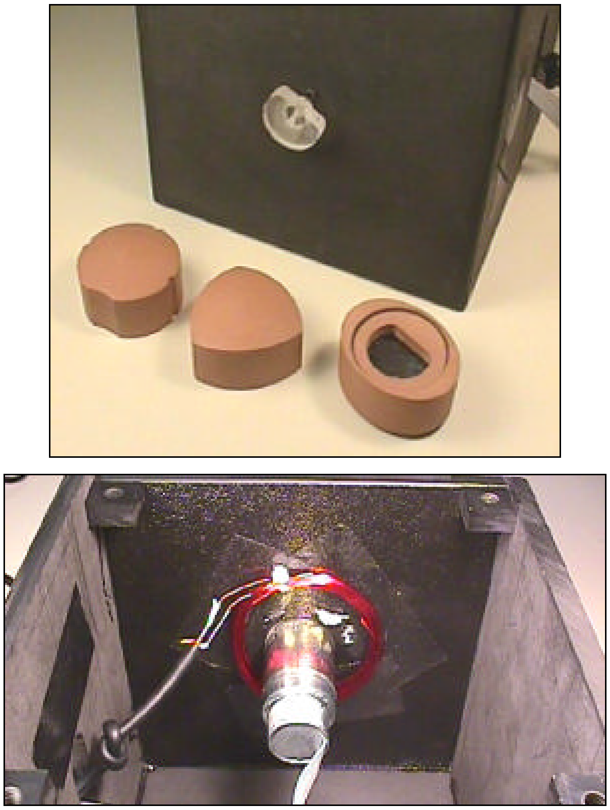

Figure 7: Removable Handle Prototype. (a) Outside: motor adapter and several handles; (b) Inside: inductive tag reader.

the standard tagged-object concerns with losing and organizing the removable handles of the previous prototype, and to streamline the switching process.

The design sequence focussed on a defined application space, a home remote media and environment controller for displays including cable set-top box / digital video, audio, voice mail and lighting/ thermal environment. The universal remote is an interaction challenge nearly as old as the TV, and today's button-plastered clicker may be the most reviled contemporary example of unusability. Some of its intractability derives from protocol inconsistency among manufacturers. Here we focused on the human side of the communication problem, mocking up target systems through a PC network.

With this new interface concept we believed the ancient problem was worth revisiting, aiming eventually to accommodate many devices and functions by developing a tactile language comprising both physical form and haptic feedback. The central goal was to apply a consistent physical language to different target devices, such that the user could browse voice mail with the same gestures as the TV and an audio jukebox. In our scenarios, the target is selected by a means such as pointing the controller, while the integral Discrete Selectors determine the operation – e.g. volume control, channel/message/track browsing, or fast-forward and rewind within a selection.

The concepts shown in Figure 8 are taken from a set of over a dozen; all move but none control anything. Figure 8a whimsically expresses the basic idea of semi-permanently connecting the handles to the controller and selecting by grasping rather than attaching them. However, they are not very graspable and could be dangerous when the knob spins under its own power. In Figure 8b the selectors are flush on the rim, where they are pressed to engage. A mechanism designed but not built would permit only one selector to be depressed at a time, reminiscent of an old car radio. However, we flunked this configuration based on the form mockup – it lost the "handleness" of the basic idea. In Figure 8c, the selectors have moved to the top surface and are rotated

Figure 8: Representative integral-handle concept prototypes, exemplifying force-feedback wheels with a variety of Discrete Selector schemes. (a) Iconic spokes; (b) edge-buttons; (c) top-selectors. (b) and (c) selectors would be physically distinctive.

with the non-supporting hand like an old rotary phone

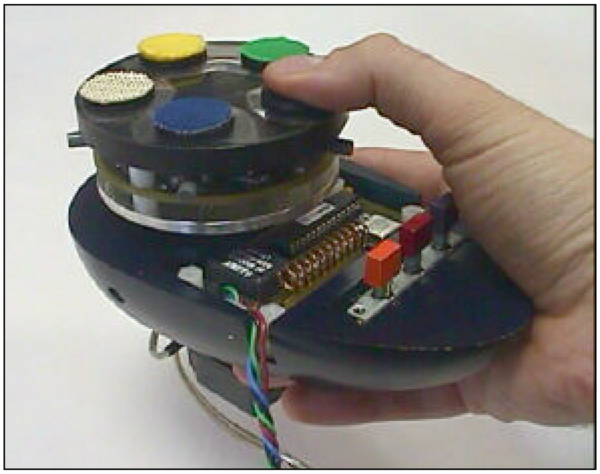

Figure 9: Functional Integral Handles prototype.

Figure 10: Conceptual side-selection prototypes. The force-feedback wheel's mode is chosen by pressing the wheel at a specific position (left and right prototypes) or a position on the wheel's base (center). Since activation location is grounded relative to hand position, the selector is easy to find.

dial, the feel of which delighted us. Concurrent experiments with the basic shape resulted in a hemi-egg form (Figure 8c) that was pleasing to hold while retaining a definite "pointing" direction.

The informal user reactions detailed below were collected while we built a functional prototype of Figure 8c, shown in Figure 9, used only by team members. It employs distinctive fabric swatches to abstractly "label" the selectors (a more semantic mapping is obviously needed eventually), and was programmed to browse digital video and cable TV in realtime. We soon discerned that another iteration was in order: it was hard to find the selectors when they moved relative to the base. This led to the concept series shown in Figure 10, which utilizes muscle memory to find the selectors in locations fixed relative to "ground". At this point the project was terminated for unrelated reasons, and thus a final working prototype was never built and tested.

EARLY-CONCEPT USER REACTIONS

We informally shared our conceptual and engineering prototypes (Figure 7-Figure 8 and others) with several usability-savvy potential users for observation and brainstorms. We feared that these abstract designs would confuse subjects of real usability studies, but we wanted a larger perspective as we produced a version that *would* be suitable for wider exposure. The following comments are distilled from sessions with four colleagues unfamiliar with the project, chosen for diversity in background, aesthetic leaning and attitude towards pervasive technology. Despite obvious usability issues, we used our entire prototype collection to stimulate discussion, and emerged with more ideas and questions.

General Issues and Observations

A few consistent and unsurprising themes surfaced. Perhaps most significantly, our participants unanimously approved of bringing more continuous control to digital interfaces; one observed that those with limited dexterity – e.g. the elderly – might find handles more manageable than buttons. They reinforced our intuition that users will react strongly to a satisfying dynamic feel: multiple subjects preferred nice-feeling prototypes, explaining that their enjoyment came from a combination of the motion and the heft of the object in their hand. One claimed "Make one that feels like this and I'll buy it".

They agreed that removable handles should express what they do and how. The usual concerns with tagged objects came up – losing, organizing and locating them; remembering what they represent; indicating changeable contents. Participants observed that integrating the selectors into the force-feedback handle solved many of the concerns with tagged objects, but introduced other issues of selector usability and findability.

Exchangeable Handles

Reactions to Media-Container Scenarios

The removable media-container scenarios suffered the brunt of general tagged-object criticisms. However, participants perceived the potential of simplification in using physical containers; e.g. they might replace a graphic list display in portable or embedded devices. One questioned the benefit of exchanging a handle if its shape did not markedly change; another predicted confusion in operating a single handle in different modes, but proposed clever means of expressing mode.

There was general agreement on the desirable physical attributes of media-container handles: each must indicate both its contents and how to use them. They should exhibit handleness, stackability and findability (because there are many of them) – a tall order. However, all data containers of a given *type* should share a similar shape, and thus will only need be designed once.

Reactions to Tool-Use Scenarios

Participants responded positively to the idea of choosing (thereby displaying) mode by inserting a physically distinctive handle. Several were taken with the idea of an exchangeable handle as a filter for content selected some other way, as long as the content demanded continuous manipulation; e.g. using a small handle for precise operations and a larger one for powerful movements.

Reactions to some specific tool-use scenarios (e.g. for drawing and surgical applications) were evenly mixed. Half applauded; the rest wondered if the additional functionality of a switched handle justified the effort.

Integral Handles

Interaction

All participants found a set of attributes among the remote control prototypes that pleased them enough to "buy". The whimsical spokes were admired but rejected as awkward because grasp changes with wheel position; but none thought them dangerous. Recessed selectors distinguished by texture (velvet, leather, velcro) were easier to manipulate, but too abstract.

Participants confirmed the need for spatial grounding of the rotating selectors noted earlier, and approved of sketches of the prototypes shown in Figure 10.

Task Allocation, Apparency and Flow

Participants arrived at similar optimums of simplicity and direct access: employ selectable handles to determine an operation, and pointing or a small set of nearby buttons to choose the active device from a set. Operational rules can be consistent if the set shares attributes, such as the need for volume and rate control.

One was willing to learn abstract associations; the rest felt the form should clearly indicate its function, through label or shape. No one felt this would be hard to do.

Random access will sometimes be desirable: "If you know what you want, you should be able to go straight there." That is, it must be easy to modify and configure what is accessible in that continuous range. E.g., if one "function" is a collection of preset channels, it must be easy to add and subtract channels from that set. Otherwise, the ease of traversing the set will be countered by the annoyance of the set being too large.

DISCUSSION

Our insights are a mix of personal intuition and experience, outsider reactions, and awareness of application contexts. Despite prototype usability problems, the process converged towards an interesting solution. Of greatest importance are the notion's value and most useful contexts. The configuration and design parameters we have come to consider significant include:

- Selectors exchanged, or integrated and chosen by holding or touching.
- Force feedback received directly through the selector, or through a separate physical connection. The former may be best for tool use, the latter for containers.
- The user must be able to locate and understand the selector via shape/texture and location.

What Price Physicality and Continuity?

As usual, users want it all. Touch, continuous control, low complexity and intuitive appearance are valued, but cannot replace random access. They prefer the austere elegance of a single lovely knob; but it should have all the capability of a fifty-button universal remote. Functions should be apparent, as long as none are lost.

Some of our scenarios traded too much pushbutton convenience for physical handle affordance. A good compromise for the Home Remote (Example F) may be an ergonomic Integral Handle for function selection and continuous browsing, combined with a few buttons on the base to choose a device.

In other cases a physical content selector may truly simplify an interface by eliminating the need for an on-screen interface. This will be most true when there is no inherent visual content in the media (e.g. an audio application) or when a visual interface would intrude on a principally visual content (e.g. video browsing).

Exchangeable Handles

The Exchangeable Handles concept may be better suited to choosing functions than media targets, because of the difficulty and redundancy of physically distinguishing media-container tagged objects while shaping them as good handles. The container notion shares many drawbacks of simple tagged objects, while the related continuous-control requirements do not seem urgent.

For tool-type Exchangeable applications, having the right handle is valuable; but switching must be no harder than mouse-clicking a screen icon. Handles as media filters that highlight or obscure garnered enthusiasm, perhaps because of philosophic consistency with viewing *through* a visual filter. In such situations, it must be desirable to control and handle the media as well as observe it.

Integral Handles

The Integral Handles concepts make selecting handles easier (you don't have to dig them out of the couch or plug them in) but loses them locally. We think we can make Integral Handles easy to find *and* easy to turn. Textural distinction will not suffice for blind-use handle detection because it requires serial exploration; but shape and texture confounded with static positional cues should.

SUMMARY AND DIRECTIONS

We have described a new interaction percept: the integration of discrete and continuous control capability into a single seamless interface. We believe that designs of this sort are will alleviate stress from forcing inherently continuous tasks into the discrete affordance of prevalent button interfaces, while bringing aesthetic and functional benefits of physicality. Exploration of several application areas helped to trigger the ideas as well as stimulate their development.

We have presented design case studies of two versions of the concept. The process's emphasis on quick iteration in building, trying and discussing, and on relation to promising applications has resulted in satisfying prototype variety and evolution. Informal expert-user responses to these prototypes have validated some of our starting premises – perceived value of physicality, desire for more continuous control and the importance of function apparency. They have pruned others: e.g., the incremental benefit arising from custom handles will not always outweigh inconveniences of organizing and swapping them. Based on this work, the underlying premise appears sufficiently strong enough to continue development in multiple directions.

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