Haptic Chameleon: A New Concept of Shape-Changing User Interface Controls with Force Feedback

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Abstract
In this paper, we introduce the concept of shape-changing, user interface control devices called "Haptic Chameleon", which refers to computer-controlled user interface devices that convey information to and from the user by altering their shape and feel. The user decides what a Haptic Chameleon control will do by changing its shape, and can immediately recognize the capabilities of the newly shaped device through haptic and tactile channels. By combining the benefits of tangible and haptic user interfaces, this new user interface paradigm has the potential to vastly improve the learning and efficiency of interaction in a wide range of applications. It also represents an appealing alternative to current control devices. We report on our experience with early prototypes based on this concept, discuss open issues, and propose possible directions for future work.

Categories & Subject Descriptors: H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *haptic I/O*, *input devices and strategies*, *interaction styles*, *evaluation/methodology*; H.1.2 [**Models and Principles**]: User/Machine Systems – *human factors*; D.2.2 [**Software Engineering**]: Design Tools and Techniques – *user interfaces*; I.3.6 [**Computer Graphics**]: Methodology and Techniques – *interaction techniques*

General Terms: Human Factors

Keywords: Haptic user interfaces, tangible user interfaces, shape-changing I/O devices.

INTRODUCTION

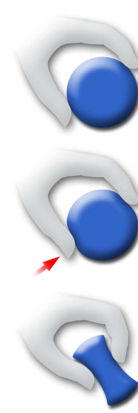
While the concept of dynamic visual displays is well established as a method of interaction with computers, the physical controls, which have interfaced to these dynamic displays, have by and large remained static. A few examples of dynamic controls have been produced which output information via the sense of touch (haptics) ranging from force-feedback mice and joysticks at the low end, to the Phantom device [5] at the high end. However, these devices have either been limited in terms of their ability to produce convincing haptic effects, or have been too unwieldy and expensive to have much impact outside of the laboratory.

There are a number of good arguments however, why haptic and tactile interaction should be pursued as an important means of human-computer interaction. For example, haptic devices can convey information in situations where the ability to see or hear is either difficult or undesirable [1]. This may have the effect of improving safety or simply allowing devices to be operated in ways, which are more convenient. In addition, haptic technology can be beneficial even when the user is perfectly able to see or hear information from the device. The output once provided by traditional mechanical controls (e.g. when a machine is worn or overloaded) offers one example of this.

The Haptic Chameleon concept aims to advance beyond the use of haptic sensations only however, by combining the benefits of haptics with the ability of interface controls to change shape. This allows the dual benefit of being able to physically instantiate control mechanisms made popular by the GUI as well as to draw on the history of instruments and devices which have been made obsolete by the advent of the digital age [7]. As such, the Haptic Chameleon concept bridges the gap between haptic and tangible user interfaces allowing users to literally grasp the meaning of explicit information such as mode, while simultaneously feeling more subtle aspects such as content properties.

The combination of these aspects provides the opportunity for a new user interface paradigm to be created that offers an appealing alternative to current ways of controlling electronic devices.

CONCEPT



Haptic Chameleon controls are real, physical objects, which are able to change both their shape and material feel and consistency. The user can hold the device and squeeze different areas of it with different strengths much as one might do when molding a clay model. Depending on the available options the device will then change its shape while being held, to communicate a particular state.

While the number of applications for which a haptic chameleon could be used is virtually unlimited, we foresee a number of situational requirements where the properties of the Haptic Chameleon will be especially useful. These are:

- Changing to shapes, which mimic real world objects.
- Changing to shapes, which mimic real selection devices (e.g. joystick or wheel).
- Changing to shapes, which represent agreed conventions (e.g. Triangle for play, Square for stop on a VCR).

In these three scenarios, the form of the Haptic Chameleon is likely to be most clearly understood through virtue of a physical resemblance to another device, symbol or control.

RELATED WORK

A number of previous reports have described systems or concepts which partially cover the scope of the haptic chameleon, but fall short of realizing it entirely.

Murakami et al, for example, describe a user interface concept for shaping virtual 3D objects on screen using a deformable input device (DO-IT) [3]. Their approach relies on the close resemblance between the shape of the input device, and the resulting shape of the virtual object on screen, allowing for very intuitive manipulations of such objects. However, their solution does not address the issue of mapping the shape of the input device to denote abstract user interface operations. Their system also lacks force feedback as an important additional communication channel to the user.

The semantics associated with the shape of a user interface control also plays a central role in the tangible user interface paradigm, introduced by Ishii and Ulmer [2]. However, their approach potentially requires the user to deal with many different physical objects in order to perform certain tasks, a disadvantage that our Haptic Chameleon concept promises to overcome.

Both haptic feedback and the semantics of shapes in media control have played a major role in the research activities at Interval research as reported in [6] by Snibbe, Maclean, et al. However, in their experiments, the physical object grasped by the user in order to interact with the system could not change its shape, which is central to our approach for a haptic user interface.

APPLICATION SCENARIOS

The flexibility of the Haptic Chameleon concept opens up opportunities for new user interface controls in a wide range of situations. Prime candidates are electronic devices (static or mobile), and devices used in situations where augmenting sight by touch is especially important. One example where the Haptic Chameleon concept could demonstrate its full potential is inside the car. Haptic technology has the big advantage that it provides feedback without sight being necessary. Inside the car a user interface control based on the Haptic Chameleon concept can take on exaggerated shapes to aid the user in carrying out varied and diverse actions, while the eyes of the driver can remain on the road ahead. As well as being novel and appealing, therefore the Haptic Chameleon also has the potential to improve safety (Figure 1).

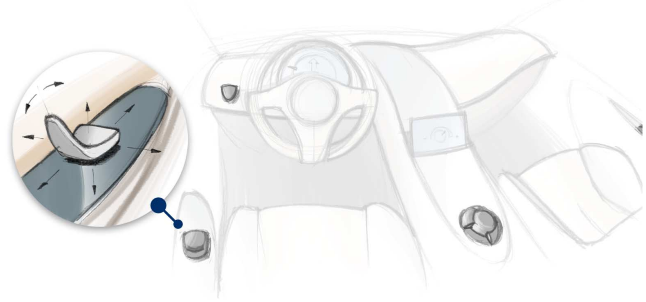


Figure 1. Artist's rendition of a Haptic Chameleon based control in a car interior.

Another important application area is the home. Here, a number of potential applications exist where the need to focus on the control is undesirable. The use of a shape-changing device may also possess a novel appeal in a number of home scenarios. Watching television is one example, which draws on both of these aspects. One could imagine a Haptic Chameleon remote control for this purpose, which would allow controls to materialize by having the user mold parts of the device into particular shapes from which the purpose can be ascertained via touch (Figure 2).

This is already the case to a certain extent where some keys on a remote control take semantically relevant forms such as a triangle pointing up and down to mean volume up and down. A Haptic Chameleon device however would allow the usefulness and applicability of this principle to be greatly expanded as all mutually exclusive functions relating to a single aspect, such as transport speed, could be integrated into a single button or knob.

Figure 2. Artist's rendition of a Haptic Chameleon remote control in a home use scenario.

EARLY PROTOTYPES

In order to verify the theoretical benefits of the Haptic Chameleon concept, we have embarked on the development of a series of prototypes. Since off-the-shelf components are not yet sufficient to build a fully-fledged device, we decided to rely on a two-stage strategy, designing both high-fidelity and low-fidelity prototypes, each of which is better able to reproduce particular aspects of a Haptic Chameleon.

As an application scenario for first experiments we have chosen a new way of controlling video content (compare with [6]). The user interface control takes the form of a dial that the user can rotate for navigation. Depending on the chosen mode of control the user can navigate video content either in a continuous manner (frame-by-frame), in a discrete manner (scene by scene), or in a semantic manner (e.g. jumping from one happy scene to the next one).

The shapes for each mode of the user interface control were chosen to help the user remember its semantics. For the continuous mode we chose a circular shape, where the dial rotates smoothly with a deliberate amount of simulated viscosity applied. The discrete mode is associated with a wedge-shaped variation of the control that also generates a distinct haptic detent when turned. For the semantic modes, the shape of the control was made to resemble either a smiley or a sad face depending on the scene.

High-fidelity

The high-fidelity prototype aims to reproduce the shape changing ability of a future, real Haptic Chameleon device as faithfully as possible. We have chosen a multi-Phantom setup (Figure 3) that combines a high-resolution visualization of a Haptic Chameleon device with the configurable haptic effects made possible by the Phantoms.

The prototype allows the user to feel the surface of the virtual control object as he/she pushes against it. In order to convey this sensation of touching a surface, the Phantom has to oppose the user's hand movement.

This opposing force is compared to a predefined threshold for the virtual control that governs how much pressure needs to be applied in order to start the transformation process. Once that threshold is overcome, the object shrinks by a certain factor, after which the process is repeated until the deformed virtual object is close to its final shape. The object then "snaps" into its final shape. Varying the rate of shrinkage over time is one way to create the illusion of feeling the properties of different materials.

The disadvantage of this setup is that the user can only feel the device through thimbles attached to the Phantoms (two or three depending on the configuration). The material sensation can therefore be well recreated, however the grasping action cannot.

Figure 3. The high-fidelity prototype.

Low-fidelity

The low-fidelity prototype addresses this issue by accurately reproducing the "grasp-ability" of the device. The shape-changing aspect, however, is limited by the use of a traditional, electro-mechanical design.

The low-fidelity prototype takes the form of a physical dial attached to a servomotor with gearing, and an encoder to measure the rotation of the dial. The servomotor is driven by an external circuit board connected to a PC that implements various force feedback profiles. The user can feel the effects of these force-feedback profiles as haptic detents, viscosity effects, hard stops, and more.

The dark-colored portions on the dial are buttons that the user can depress in order to alter the overall shape of the dial (see figure 4). Status information about the position of these buttons is communicated to the control circuit, and results in the downloading of a different force-feedback profile to match the semantics associated with the new shape. By pushing down on a depressed/latched button again, this button is released and moves to its extended position. As a result, the original shape of the dial is regained along with the matching haptic profile. This simple mechanical solution works well for the limited number of shapes required in the chosen application scenario.

First impressions

Initial, informal feedback from people with engineering, science, and design background who tried out these prototypes can be summarized as follows.

The notion of surprise was common among those who experienced the prototypes for the first time. However, each of them adapted quickly to the operation of the low-fidelity prototype. The multi-Phantom configuration, on the other hand, required some getting used to, due to the lack of true 3D vision, and the fact that interacting with the virtual world via only two or three contact points proved to be a challenge for some.

Very positive feedback was offered by people experienced in the use of video editing tools, who remarked how easy it was to have both course and fine-grained control over the video with a single control, which replaces many different buttons or GUI widgets in the case of traditional user interfaces for commercial video editing tools.

Special haptic effects designed into the prototype systems, such as the inverted damping technique [8], were highly commended, even though their effect was felt only in a very subtle manner. This is additional evidence for us that well designed haptic effects do make a difference in the way user interfaces are perceived by the user.

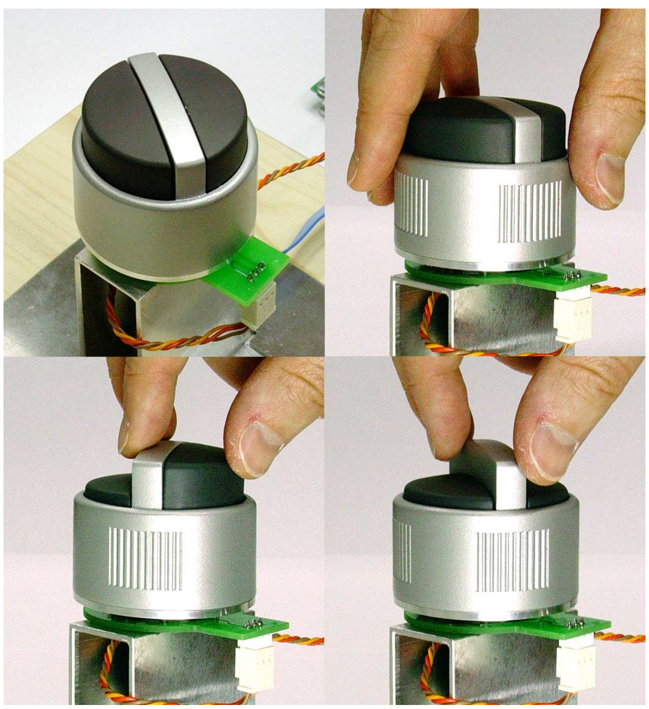


Figure 4. The haptic dial prototype.

SUMMARY AND FUTURE WORK

In this paper, we have described the Haptic Chameleon concept, a new user interface paradigm, which works by varying both control shape and feel. We have described our ultimate vision of the device, and motivated our strategy of pursuing two separate prototypes in parallel – low and high fidelity devices. Early feedback has been encouraging, convincing us of the potential for this new technology.

From the outset, it has been clear to us that a Haptic Chameleon control device should be designed with the user in mind. Our next step will be to augment these initial informal findings with more formal usability studies to determine the most intuitive shapes for given functionalities in our chosen applications. The creation and fine-tuning of the accompanying haptic effects is also an additional goal.

We will also soon be expanding the range of prototypes using input from re-iterative usability evaluations. Furthermore, alternative technologies for the creation of force-feedback effects, such as the use of rheological fluids as reported in [4], will be explored and evaluated for future Haptic Chameleon devices.

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