Force Feedback Double Sliders for Multimodal Data Exploration

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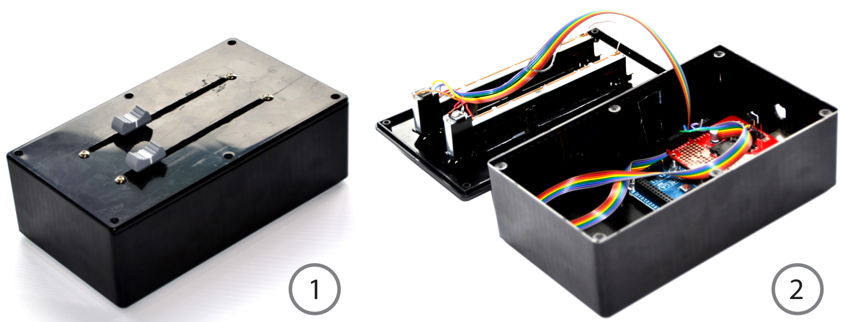

Figure 1: The Force-Feedback Double Slider physical device: (1) desktop version prototype, and (2) opened desktop version showing the two motorized sliders, Arduino board and motor shield.

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Abstract
We explore the use of a novel force-feedback double slider as a physical input device for data visualization applications. Each slider is augmented with a haptic channel for the manipulation and sensing of visualized data. Our goal is to assess the capabilities of this alternative to the mouse and to explore data analysis interactions and applications. Here, we introduce our first prototype and report on our design progress and insights.

Keywords
Force-Feedback slider, Haptic Device, Visual Exploration

ACM Classification Keywords
H.5.2 [**User Interfaces**]: Input devices and strategies.

Introduction
Data exploration with interactive visualization is a common and effective practice for making sense of large datasets. By nature, this practice mainly relies on the analyst's visual channel. Yet, interaction through dynamic queries plays a crucial role in visual exploration [1]. It is typically achieved by manipulating graphical widgets that demand visual attention to be located, reached, and controlled. This attention shift competes with the primary data analysis task that requires focus on the main data representation to mentally maintain connections and relationships.

By using a non-visual channel to control widgets, we can retain visual attention during interaction. Thus, we were motivated to explore if and how a physical haptic device as a combined sensor/actuator can support eyes-free data exploration using tactile and kinesthetic information. Here, we report on our first steps in that direction.

We propose the Force-Feedback Double Slider (FFDS), a two-slider device designed to enrich the data analysis workspace through physical input (see Figure 1). Our device is meant to be simple and specific for the task of data exploration but not tied to a particular data visualization interface. By empowering the controller with force-feedback, we supplement the display channel to convey extra information: FFDS becomes a device for multimodal data exploration.

Design

We were inspired to design a physical device based on the benefits of physical interfaces over their digital counterparts for specific, well-defined tasks [4]. In particular, the following benefits motivated our work:

- *Motor memory:* Our capabilities to sense, control and recall body and limb position and movement and muscular effort allow us to easily acquire, interpret and modify the state of a physical device [6]. The absolute position of the thumb relative to the physical slider is spatial information that is easy to interpret and control, because of this kinestethic awareness.
- *Multi-modality:* Physical devices support both independent as well as joint activities through different sensory channels [2]. For a visual exploration task they are, thus, potentially well suited as the task typically requires full visual attention on the main data display to observe the impact of dynamic queries while manipulating the widgets.

Given the above rationales, we derive the following principles for the design of our physical device to efficiently support the specific application of multimodal data exploration:

- **P1** *Small footprint:* the device should be small and light-weight enough to fit next to a keyboard on an already busy workspace, and facilitate transportability.
- **P2** *Simplicity of interaction:* the interaction device should demand as little learning as possible. Thus, we strive to find a physical design which consists of a small amount of physical widgets that are simple to interact with while maintaining a close natural relationship between the control and its function.
- **P3** *Eyes-free interaction:* motivated by potential benefits of haptic feedback, we want to explore if and how well tactile and kinesthetic sensations through force-feedback can support the visual channel, in addition to eye-free reachability (e. g. can users accurately feel a distribution of the values along one axis, or abstract ticks?).

Most information visualization exploration tasks (e. g., scrolling, filtering, range-selection) consist of 2-D selections and dynamic queries that are typically performed using slider widgets [1]: sliders represent one data dimension with an upper and a lower bound, and sliders' knobs can be moved to select, highlight, or filter data in this range. We chose to use two force-feedback sliders as they allow us to support single-value selection, range-selection, and a variety of navigation techniques between data widgets. Moreover, by enriching the device with force-feedback, we support haptic display on up to two additional data dimensions.

To keep the physical device small and light-weight, we focused on two sliders although more sliders would allow

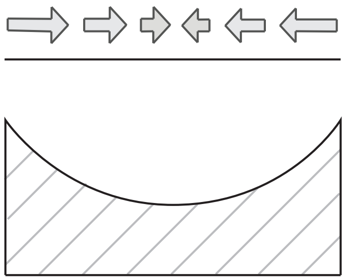

Figure 2: Orthogonal force illusion, created by projecting the slope of a two-dimensional geometric profile (bottom) onto a single axis force profile. Arrows indicate direction and magnitude of displayed force. A user perceives the two-dimensional surface as dip or a hill [8].

us to control more data dimensions at once. However, more sliders would also mean added difficulty during eyes-free control due to added distractors. Our device offers a tradeoff between a highly specialized device (e. g. an audio-mixing console) that is tied to a specific application and all-purpose generic devices (e. g. a mouse and a keyboard) which are constantly attached and detached to various logical devices.

Physical Device

We built the physical device using an Arduino Mega 2560 microcontroller board using a 16 MHz ATmega2560 chip[1] connected to 2 motorized linear potentiometers. The microcontroller reads the position of the potentiometer through two built-in 10-bits analog-to-digital converters (ADC). It controls the force of the motors through two 8-bit pulse-wave-modulation output ports and the direction of the motors through two digital output ports connected to two H-Bridges. All components are mounted in a plastic box (Figure 1) for a total unit cost of under $150 for tethered connections and $170 for wireless connections with batteries.

The physical slider is a standard component with a 10 cm linear potentiometer and a motor attached to it through an elastic string, capable of delivering a force of about 1N[2]. The position is read by the 10-bits ADC—although the two lower bits are not reliable due to physical wobble so the usable resolution is about 0.4mm (256 values).

To provide haptic feedback on a motorized slider we apply a force through the motor in reaction to changes in the position of the slider. This is an approximation of a purely resistive system because it needs displacement to sense a force and react. When the user moves the thumb in a direction, the motor pushes in the opposite direction until the user applies a strong enough force to bypass the resistance. We model force-feedback as an elastic force F applied at each point of the slider. F is described by $F = k \times x$ where k is the stiffness constant, and x is the displacement from the rest position. We implemented varying force by varying the stiffness k.

Since force-feedback should be applied at each position of the thumb, the rest position of the system is moved with the thumb when the thumb is kept stationary (i. e. the user has counterbalanced the system's force). Vibrations caused by this harmonic system are removed using a simple viscosity model applying a force $F_v = -s \times d$ where s is the thumb's speed and d the damping ratio. The total force F we send at each position is, thus: $F = k \times x - s \times d$.

We maintain a lookup-table to store the 256 stiffness values that users can sense when operating the sliders. The application can change the values of the table at any time accordingly. The motors also allow for an automatic positioning of the thumbs.

The current device runs at approx. 400 Hz (positions are sent and received near real-time). Stiffness is encoded with 8 bits and uses an adjustable value-to-force mapping which defaults to linear but can be changed.

Haptic Illusion

We implemented force-feedback on the slider as described above to create the illusion of a relief. Applying a force magnitude along one actuated axis creates an illusion of a force on the orthogonal axis, perceived as a two-dimensional surface with dips and hills [8] (Figure 2).

[1] http://arduino.cc/en/Main/Hardware

[2] We use a Bourns PSM series Motorized Slide Potentiometer

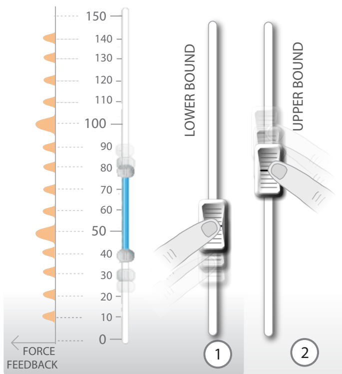

Figure 3: Simulation of a range slider where force-feedback is used to guide navigation through the tactile display of tick marks along the axis.

Applications for Data Exploration

The force-feedback along FFDS can be used to simulate different effects relevant for data visualization scenarios:

A1 *Haptic Rendering of a Data Distribution:* as a direct application of the orthogonal force illusion (Figure 2), each slider supports the haptic display of a data distribution (e. g. a histogram or a timeline) by directly mapping the range of spans to the potentiometer's positions and the range of possible values for each span to the force-feedback control.

A2 *Haptic Rendering of Tick Marks:* the sliders can be restrained to a 2 state model (*resistance* vs. *no resistance*) to indicate the presence of a landmark in the data (e. g. highlighted or annotated items).

A3 *Haptic Rendering of Grid Lines:* the FFDS can also be used for guidance during navigation by providing "snap-to" positions as aids for easier placement of the thumb when it reaches intermediate positions [8].

A4 *Haptic Detents:* as the force feedback model relies on the simulation of an elastic force applied at each point of the slider, we can build a system that increasingly resists to user's pressure as the thumb is pulled away from a stable state, and thus simulate a detents effect as in the catapult application described in [7].

Using the effects described above, the FFDS can support data exploration tasks in multiple ways. The type of support depends on the information mapped to the two possible mapping axes (slider's spatial range and force-feedback display) on each slider. We are currently working on the following types of application scenarios:

Slider Manipulation for Navigation and Filtering

In data exploration interfaces, sliders are typically used for navigating the data along one dimension (timelines are one such example) or for filtering. While filtering data items the sliders are used to select values above, under or, in the case of range sliders, between specific values as indicated by the sliders' thumbs.

Consider an analyst interested in examining countries' life expectancies against global income over time. She can plot the countries according to the two variables and navigate over time using a timeline slider. Assume now that she wants to filter out countries whose life expectancy is above a certain threshold. She then requires a second slider attached to the variable to specify this threshold.

The FFDS can be used as two independent sliders that can be controlled in parallel, as in the above example: one slider to navigate through time, where the force feedback can be used to snap to the different time spans (A3), or prompt dates of interest (A2); a second slider to specify the threshold, where haptic feedback can serve to render the data distribution along the spatial axis (A1).

The FFDS can also be mapped to a virtual range slider where the two thumbs serve as the minimum and maximum bounds (e. g. filter all the countries whose income belongs to an interval). Again, force-feedback can be used to prompt tickmarks as in Figure 3, or the data distribution. Haptic rendering of a distribution can be a useful complementary information when browsing or filtering data on a dimension that is not directly visible (e. g., our user may want to observe the impact of filtering according to the population densities of countries).

Enhanced Scrollbars

Scrollbars, usually used for panning a visualization that does not fit within the available viewing space, are a specific use case of a slider and thus constitutes another natural application for the FFDS. The FFDS can simulate an elastic-controlled scrollbar, for example as implemented

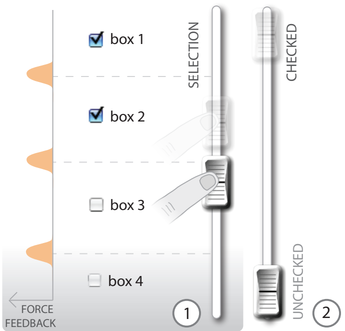

Figure 4: Simulation of checkboxes where the slider (1) allows for selection with a "snap-to" mechanism to disambiguate selection and the slider (2) indicates the state of the current selected checkbox.

in the Picasa software. It's steady-state has a unique stable position of the thumb, located at the mid-point of the scrollbar. Dragging the thumb in one or the other direction scrolls the visualization accordingly, the further from the stable position, the quicker the scroll. Such interaction can be simulated with the haptic detents physical application (A4). This can allow us to navigate in the data space but also filter data without setting a specific upper or lower bounds for a dimension.

Other possible interactions include the use of the sliders to navigate at two different levels of details, one slider *S1* allowing for the absolute navigation in the whole dataset, the second slider *S2* allowing for a finer navigation, relative to the position of *S1*.

Checkboxes, Radio buttons and other Lists and Menus
We can further the exploration and extend the FFDS device to support other kinds of dynamic query widgets. A group of checkboxes (or a multiple selection list) can be simulated by breaking down the task into two separate sub-tasks: one slider serves to select the checkbox of interest; the second slider is used as a status indicator to the one box selected. To facilitate the selection of the checkbox, we can force the thumb to snap to stable positions (A3). Figure 4 illustrates this design. Radio buttons and drop-down menus are conceptually similar, the difference is that a single item can be selected at a time, thus, a unique slider for the selection is enough.

Pilot study

Before integrating the above designs in a complex visual exploration tool, we must guarantee that our prototype allows perceiving: 1) the physical position along the slider's length and 2) a number of different force values. We conducted a pilot study with 10 participants on three tasks (T1-3) aiming to evaluate how many levels of pressure feedback coupled with positional information the slider could reliably encode [3]. The tasks and results were:

T1 *Feel the ticks: count the number of tick marks.*
We found that subjects' answers were always close to the real tick count (mean error was -0.69). However, half of the subjects were almost always correct, while others were constantly off. Further investigations are needed to understand this inconsistency.

T2 *Count Force-Feedback Pressure: count the number of distinct pressure levels (possible values were* $\{2, 4, 6\}$*).*
We found that 55 out of 60 trials in total (92%) had an error below 1 level count. While further evaluation is required, this suggests that that future enhanced versions of the device have good chances to reliably display up to 6 levels of pressure.

T3 *Feel a Distribution: select the felt pattern among 12 possible histograms displayed on the screen.*
This task was designed to assess if subjects were able to recognize a force-feedback distribution, at different spatial and dynamic resolution. In this task, we found that patterns with 2–3 levels of pressure were most reliably detected. However, clear landmarks were important to match a shape (such as no pressure, number of blocks, etc).

We learnt from our pilot study that sliders operated using an Arduino chip are limited in force sensitivity but are still usable with 2–3 levels of pressure. The resolution along the slider's axis offered at least 100 values of resolution, as shown by random ticks in (T1) that could be sensed anywhere with a good accuracy. We believe that performance can be improved with further iterations of our physical prototype.

[3] For a matter of space, we only briefly report on the results here. A throurough description of the experimental setup as well as our statistical analysis will be reported in further communication.

Discussion and Future Directions

To date, most data analysis tools rely on graphical dynamic query widgets that require analysts to visually acquire and track controls when they should focus on the data display. To overcome this problem, a wealth of research exists in the area of tangible interfaces as alternatives to graphical controls. A particularly relevant example is the physical mixing board interface [3], related to our approach in that it supports multimodal data exploration. Yet, in contrast to our work, it uses multiple and more specialized components, while we strive for a light-weight (P1) device with a small amount of physical controls (P2).

Our solution consists of a physical device with two physical force-feedback sliders that we use both as sensors and actuators to support eyes-free interaction for data exploration. Whereas force-feedback sliders have been proposed previously for other applications (e.g. [7, 9]), empirical evaluations as well as technical details for our application are still rather lacking. This work is a first step at addressing the gap in the literature. Although other haptic devices can be considered as potential candidates for our purpose (e. g. the Moose [5]), we chose physical sliders because they are widely used in data visualization and because they offer a natural mapping between control and function.

Our further research includes building and evaluating alternative force-feedback sliders. In particular, we are working on a second prototype using a magnetic brake to control the friction in place of the current motor resistance. We also plan to explore ways of enhancing the current device to support a versatile use in our context (e. g. personalized positioning of sliders, or mode switching) while remaining eyes-free, simple to interact with and of a small footprint. Finally, we plan to investigate the use of the FFDS in real data analysis tasks on complex and realistic data sets and during long-term use. In particular, the usefulness of the haptic display will be studied further.

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