Tilt and Feel: Scrolling with Vibrotactile Display

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Abstract. As mobile computers become more sophisticated, highly graphical stylus driven interaction techniques are becoming overloaded. The combination of movement based input and vibrotactile haptic output offers a promising alternative. To this end we have developed a hardware platform with these sensing and affecting capabilities and have begun to consider them in the specific scenario of scrolling. In general terms, we describe the methods by which movement, in the form of tilting, can be used to control scroll position, and by which a dynamic vibrotactile display can be used to present information relating to a scrolling operation. Two mobile applications are then explored in depth: an address book, and a map viewer. A number of specific interaction techniques are described for each application, and a qualitative assessment of each is provided. This work leads us to believe that movement based input coupled with vibrotactile display can yield satisfying and effective interfaces.

1 Introduction

The advent of mobile computing is demanding the development of new interaction techniques. As devices become more and more sophisticated, the desk-based metaphors underlying modern GUIs are becoming less and less appropriate as a control interface. The small screen and pen-based cursor prevalent in PDAs is not an ideal interface for mobile interaction [1]. Typically a user must stop, and focus entirely on the device in order to perform a task. In this regard, many mobile interfaces resemble transportable desktop interfaces, and not interfaces designed specifically for mobile scenarios. They represent an adaptation of an established interaction paradigm to a new situation, and not a solution designed to fit its particular constraints. Indeed there is a growing sense that a requirement in the field of handheld devices is the development of new interaction techniques specifically for mobile scenarios [2].

Reflecting this observation, there is a growing research interest in the addition of novel sensing functionality to handheld computers in order to support new forms of interaction. One area that shows specific promise is input derived from movements of the handheld device. As Rekimoto [3] points out there are many advantages to using movement as input in a handheld situation, not least that it supports single handed interaction (as a user is already holding the device) and that it offers a rich input channel composed of three Degrees Of Freedom (DOF) translation and three DOF rotation, sufficient to support complex input such as gesture recognition. These qualities have led a number of researchers to design movement-based input techniques [e.g. 4-6]. However, one significant disadvantage of using motion as input in a handheld scenario is that it limits the usefulness of the visual display for the duration of the input; as the user is moving the device, they are unable to clearly see its screen.

Consequently, we believe that non-visual feedback will be an essential component of movement-based interaction techniques. Vibrotactile feedback in particular seems suitable for this role as it can be discretely presented directly to a user's hand, and is already prevalent in mobile devices.

One of the simplest interactions supported by movement is scrolling, and it has been discussed a number of times in the literature. Reikimoto [3] introduced a variety of interaction techniques facilitated by the addition of gyroscopic tilt sensors to a PDA. Perhaps the most compelling was navigating around a large 2D space (a map) by titling the device in the desired direction of movement. Harrison *et al*. [4] examined how tilt input might be used to control position in a list, and found that users had problems monitoring their progress. They tended to overshoot their intended locations, and experienced difficultly making small adjustments to their position, such as moving to adjacent items. Hinckley *et al*. [5] discuss how tilt might be used for scrolling, and consider some practical issues such as the fact that screen brightness can be severely diminished at non-optimal viewing angles, and the potential benefits of restricting the dimensionality of the input to facilitate better control. They also report that users reacted positively on the idea of controlling scrolling with tilt, preferring it to button based alternatives. Finally, Poupyrev *et al.* [6] describe a study of tilt based scrolling in a list. Two conditions are compared, one featuring vibrotactile feedback on the transition between list items, the other without such feedback. Even with this very simple display, the results indicate that improvements in objective performance can be achieved.

This paper extends this work by considering the design of tilt scrolling interfaces in two different scenarios. In each scenario the scrolling is supported by tightly coupled interactive vibrotactile feedback. The goal of this work is to design the scrolling interactions such that they can be monitored non-visually; such that the combination of proprioceptive feedback (inherent in motion interfaces) and dynamic vibrotactile display is sufficient to represent the state of the interface. The goal of our designs is that users should be able to gauge the state of their scrolling operation by feel alone.

2 MESH Hardware Platform

To enable our research on this topic we have designed a hardware platform we term MESH: Modality Enhancing Sensor-pack for Handhelds. Physically, this comes in the form of an IPAQ expansion jacket, and is fitted with custom sensing and affecting electronics, augmenting the functionality of the mobile computer. It is shown in figure 1, and its capabilities are briefly described below.

2.1 Sensing and Affecting Capabilities

Accelerometers currently form the main sensor input within MESH. There are three accelerometers (ADXL202E), each mounted along orthogonally and in line with the principle axes of the IPAQ. The frequency response of the devices extends to DC, allowing the acceleration due to gravity to be monitored. This supports high-resolution sensing of device orientation. Their bandwidth stretches to 100 Hz, yielding sufficient temporal resolution to capture data to drive gesture recognition algorithms. For the work described in this paper, the data is gathered from the sensors at 100Hz, and transmitted over an RS232 serial link to the IPAQ.

Fig. 2. MESH hardware. Shown next to an IPAQ running a simple tilt-driven maze game

The vibrotactile display within MESH consists of two main elements: a vibrotactile transducer, and a sample playback circuit. The transducer is a VBW32 [7], sold as an aid for hearing impaired people. It is modified (by rewinding the solenoid with a larger gauge wire) to operate at a lower voltage, which enables it to be powered by the IPAQ's battery. To characterise its display capabilities we conducted an informal five user study within our lab. Each user held the MESH hardware as it displayed a 250 Hz sine wave, and adjusted the amplitude until they could no longer feel the vibration. These data were averaged to calculate the perceptual minimum for the MESH hardware. Contrasting these against the maximum amplitude revealed a dynamic range of 54 dB.

The playback circuit is an electronic subsystem within MESH that enables the IPAQ to upload samples, then play them back with short commands transmitted over the RS232 serial link. The hardware supports eight different samples simultaneously. Each sample has a resolution of 8 bits, is a maximum of 256 bytes long and is output at a rate of 1 kHz. This gives each sample a maximum duration of 256 ms. Samples can be looped to provide a continuous vibration. A number of parameters can be adjusted dynamically including the sample amplitude and the start and end position used within each sample. This system allows an application to display a wide range of customised high-fidelity vibrotactile effects for very little processor overhead. Samples can be displayed perceptually instantaneously, and with little impact on the IPAQ's main CPU.

3 Analysis of the Interaction Space

Movement is an extremely rich input channel, and even for the relatively simple task of scrolling, the accelerometers and vibrotactile display within the MESH hardware platform provide us a wide range of potential interaction techniques. We have made several general observations about the kinds of input and output we can support and, to frame the subsequent discussion, these are outlined briefly below.

3.1 Control metaphor

Broadly speaking the accelerometers within the MESH platform support two forms of scrolling input: discrete and continuous control. Discrete control involves monitoring the accelerometer input for specific patterns and mapping them to individual scrolling events. The simplest example of this kind of control is to generate a single scroll event when the acceleration value crosses a certain threshold in only one direction. This transforms the analog input from the accelerometers into a binary input, resulting in button-like behaviour. Harrison *et al*. [4] use accelerometers and discrete control to turn the pages in a handheld book reader, and we speculate that it would be useful for many similar purposes, such as selecting songs on a MP3 player, or specific items from menus.

A number of different metaphors exist for continuous control, but they can be characterized by the use of the full range of the accelerometer input to adjust the scrolling position. We describe three possible metaphors, termed position control, rate control and inertial control. Position control uses the orientation of the handheld device to control the absolute position in a given scrolling space: as the device moves from being face-up to face-down in one axis, the entire range available for scrolling is linearly traversed. One potential advantage of this technique is that it is very direct. It can leverage a user's proprioceptive sense to close the control loop. If a particular scroll location is always available when the device is horizontal, then users can use this physical stimulus to confirm they have reached their desired destination. This input metaphor featured in the miniature text entry system described by Partridge *et al*. [8].

Rate control refers to mapping the orientation of the device to the rate of scrolling. As the device is rotated further from a neutral orientation the speed of scrolling increases. Again, this mapping is relatively natural; many everyday controls respond in this way. If you push harder on a car's pedals, the affects on the vehicle's velocity are more extreme. This kind of mapping has been used to control scrolling in canvases such as maps [3, 5].

Finally, inertial control suggests that the orientation of the handheld device could be used to adjust scroll speed through the metaphor of a virtual mass. As the device is tilted the mass gains momentum, and begins to move. This movement is associated with scrolling. To stop scrolling, the momentum of the mass must be overcome. Weburg *et al.* [9] suggests that this technique might be used to control cursor position, but it is unclear what benefits it might offer over rate control.

3.2 Vibrotactile display

Graphical scrolling operations are supported by a number of different visualizations: highlighting is used to indicate the current location and a scroll bar shows the overall position within the scrolling space. Similarly, the vibrotactile modality can support a number of different visualizations. Here, we describe three such visualisations: rate display, position display and contextual display. This discussion does not seek to describe the physiological parameters that can be leveraged to create maximally distinct or effective vibrotactile stimuli (for a good review of this topic, see van Erp [10]), but instead to describe how such a set of stimuli might be meaningfully employed.

Rate display refers to using the vibrotactile output to display the rate of motion. This can come in a number of forms, from generating a brief pop or click on the transition from one list item to the next (as in Poupyrev *et al*. [6]), or when a grid line is crossed on a map, to adjusting the magnitude of a continuous waveform according to the scrolling speed. Both of these mappings result in a similar display; as scrolling speed increases the frequency at which a brief stimuli is felt, or the magnitude at which a continuous stimuli is displayed also increases. This creates a link between stimuli magnitude and scroll rate, and resembles the role of highlighting in graphical scrolling operations. A user is informed of the change in scroll position by the change in highlighting.

Position display, on the other hand, refers to using some dimension of the vibrotactile output to display the absolute position in the scroll space. For example, as a list is traversed from one end to the other, the magnitude of a vibrotactile waveform could be linearly adjusted through the entire range of its scale. In this example, the vibrotactile output functions similarly to a graphical scrollbar: it serves to indicate a user's overall position in the scrolling area, and may be too coarse to register small changes.

Finally, we suggest that vibrotactile feedback could be used to display information relating to the content being browsed. This kind of contextual display could be implemented in many ways. Good examples might be providing distinct vibrotactile feedback on the transitions between items in an address book when a commonly called number is reached, or varying the magnitude of a continuous waveform according to the distance to significant objects on a map. Feedback of this sort is extremely application specific, but has the potential to yield rich and meaningful interactions.

4 Scenarios

We have designed and built vibrotactile-tilt scrolling interfaces for two different scenarios. These represent our current practical explorations of this work and are described below. Currently, they are at the level of prototypes that have undergone informal testing. We intend to move forward to more empirical studies in the near future.

The first scenario we considered was that of an address book. Address books are probably the most commonly used mobile application; they are employed almost every time a call is made or a message sent. Their interfaces are therefore extremely important, and we believe well suited to an interaction comprised of tilt input and vibrotactile display. Essentially, an address book is a list, a one-dimensional scrolling space. Poupyrev et al. [6] describe a study investigating the navigation of such a space using rate control tilt input and rate display vibrotactile output. Tilting the device adjusted the rate at which the list was traversed, and the vibrotactile feedback was used to indicate the transition from one item to the next. They studied whether or not the addition of vibrotactile feedback aided the scrolling operation, and showed that it did; both task completion time and distance scrolled were reduced in the condition incorporating the vibrotactile display. However, they did not contrast performance using the tilt interface to more conventional button or thumb wheel interfaces.

As we explored the specific scenario of an address book, we came to the conclusion that using rate control and display was not the optimal solution. As Poupyrev points out, users experience difficulties in targeting specific items, often overshooting their desired destination and then finding it hard to make small adjustments to position themselves correctly. We suggest that a better solution can be designed using a combination of position control, position display and the key based interfaces commonly used in existing address book applications. The interaction can be described as follows: a user selects a key from a phone style arrangement of 9 keys, 8 of which are associated with the typical groups of 3 or 4 letters (such as abc and def). Holding this key down enables a tilt scrolling interaction with the range available for scrolling restricted to names that begin with the letters associated with the selected key. The scrolling range is mapped to a 90-degree change in orientation such that holding the device horizontally selects the first available item, and holding it vertically selects the last. Users can then select a specific list position by relying on their proprioceptive sense – by simply moving to a specific orientation. Additional vibrotactile feedback supports this interaction in the form of a continuous 250 Hz vibration. As the user moves from one end of the scroll space to the other the amplitude of this waveform is adjusted from a perceptual minimum to the maximum supported by the display hardware. Commonly chosen items are marked by altering the pitch of the vibration to 280 Hz. Releasing the on-screen key causes the currently highlighted address to be selected. Figure 2. illustrates this interaction. Informal testing within our lab leads us to believe this technique shows considerable promise.

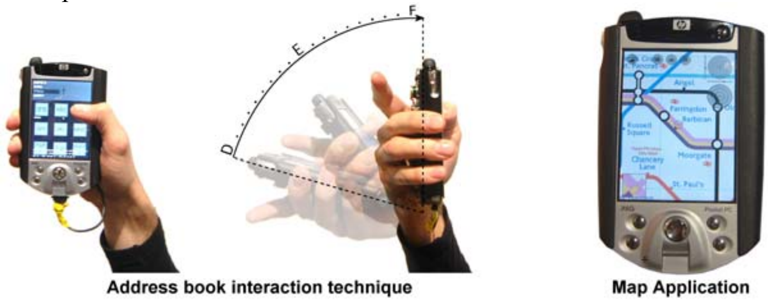

Fig. 2. The left shows the tilt-scrolling interface for address book. The "def" key is selected, enabling position scrolling through this range of names. The right shows the map application.

The second scenario we have considered is that of viewing and navigating maps. This is a uniquely mobile domain: maps are often perused while on the move and in distracting conditions (such as those caused by the weather, or by being engaged in another task). Exacerbating these problems is the fact that maps often represent unfamiliar material. For these reasons, map display software has proven successful in mobile scenarios ranging from in-car navigation systems to tourism applications on PDAs [11].

On small screen devices, it is rare that the entirety of a map can be displayed at a comfortable resolution; due to the density of the information, effective scrolling techniques are an essential part of any map viewing software. Furthermore, viewing a map often takes the form of browsing, of relatively undirected searches of the entire space for specific pieces of information. This kind of search is dependant on a well-designed scrolling mechanism. Tilt input has been suggested as a means to scroll map data by a number of previous authors [e.g. 3, 5], and although no formal evaluations have taken place, qualitative improvements have been reported. We believe that the addition of vibrotactile feedback will provide additional benefits to this interaction.

We have looked at two mechanisms by which we can support tilt-based scrolling with vibrotactile display: using rate display to represent the scroll speed, and using contextual display to highlight specific information that is currently on screen. These explorations were inspired by the observation that it is desirable to navigate around maps using as little visual attention as possible, preferably only tying gaze to the screen when significant objects are already known to be visible.

Our initial explorations dealt with rate display. We began investigating the simultaneous presentation of two separate streams of rate information, one for motion along each axis. We attempted to achieve this by varying the intensity of two continuously displayed vibrations of different frequencies, but (due to the limitations of both our abilities to sense small differences in vibrotactile pitch and the limitations of our transducer) found they tended to merge into a single stimulus. A second approach involved displaying distinct short haptic pops as map gridlines were crossed. Again, we associated a different stimulus for motion in each axis, but attempted to capitalize on our ability to distinguish overlapping temporal patterns to display the motion, rather than to monitor two simultaneously presented stimuli. We found this technique to be much more effective. However, when scrolling rapidly, the display became somewhat confusing. The density of vibrotactile stimuli led to a masking effect, where the discrete stimuli began to merge into one another. This observation led us to examine rate displays with a lower density of information. We mapped the intensity of two different continuous vibrations (220 and 280 Hz) to acceleration and deceleration in scrolling speed, and overlaid this with a third unchanging low intensity 250 Hz vibration that was displayed whenever scrolling was taking place. Although this system did not attempt to distinguish between motion in the different axes, it did support users as they attempted to control their scrolling speed. Informally testing this technique, we felt that it strongly aided users as they tried to position themselves accurately on a canvas. It provided them with increased levels of control and confidence as they attempted to make small scale targeting movements, addressing a problem that has been consistently reported by other authors investigating tilt scrolling interfaces [e.g. 4, 6].

Maps are very rich information spaces. Contextual display of this information has the potential to support very rich interactions. We experimented with a number of techniques. Initially, we examined the idea of supporting users tracing a specific visually marked route around a map, such as a road or train line. We displayed the range from the path as a continuous vibration that increased in amplitude with increased distance. At the same time we decreased the sensitivity of the tilt scrolling, so movement became more gradual at the same degree of tilt the further one moved from the path. This created the illusion that the vibration represented a friction-like force opposing the scrolling motion, and felt both easy and pleasing to use. We believe that this combination would support path following while demanding relatively little visual attention.

We also considered how to support map browsing. Taking the example of maps augmented with specific meta-information (such as the location of food stores or restaurants) we explored how the vibrotactile channel could be used to display this information without the clutter of continuous visual presentation. In this scenario, as a user scrolls near an area possessing some desired service or object, a vibration is displayed, with its intensity varying with the distance to the object. Staying within the area demarked by the vibration feedback for greater than a certain period of time (in our case half a second) triggers a distinct brief haptic stimuli and a visual highlight containing specific information about the object that has been discovered. This technique enables a kind of simple haptic targeting; it enables a user to select objects using nothing but tilt input and vibrotactile display. Informal experimentation with this technique led us to conclude that even though the vibrotactile feedback is not directional, it is relatively easy to purposefully steer to or from the highlighted areas and engage the selection. The proprioceptive feedback inherent in the scrolling is directional, and consequently the changes in vibration amplitude provide sufficient cues to support the navigation.

5 Future Work and Conclusions

We have described our initial work exploring the potential of a handheld movement based interface featuring a tightly coupled vibrotactile display. We focus on scrolling and after some making some general observations about the kinds of interactions we can support in this domain, we describe in detail our designs for two specific scenarios. Our informal evaluations of these designs suggest that they have considerable promise.

Many avenues exist for future work. To validate this work, empirical study of the techniques we describe is an urgent priority. Furthermore, we are also interested in exploring additional application scenarios. We believe that our approach, consisting of a period of interaction design coupled with informal qualitative assessment, to be an effective one for the generation of novel interaction techniques. It also focuses our work firmly on the qualitative aspects of interaction, which are becoming recognised as critical to overall user experience [12].

Finally, we are also continuing to develop our hardware platform. A new version of the MESH hardware is in development and will feature 2 DOF magnetometers, 3 DOF gyroscopic sensing of device rotation and extended output capabilities in the form of a stereo vibrotactile display consisting of two mechanically isolated transducers. These will allow us to stimulate either side of the device separately and, given the ergonomics of a PDA, enable the display of distinct signals to the fingers and to the palm and thumb. This will provide a considerably richer output channel and support the investigation of more sophisticated vibrotactile interfaces, allowing us to continue our work bringing haptic feedback away from the desktop or workplace and into everyday life.

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