overView: Physically-Based Vibrotactile Feedback for Temporal Information Browsing

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ABSTRACT

An approach to providing tangible feedback to users of a mobile device in both highly visual touchscreen-based and eyes-free interaction scenarios and the transition between the two is presented. A rotational dynamical systems metaphor for the provision of feedback is proposed, which provides users with physically based feedback via the audio, tactile and visual senses. By using a consistent metaphor in this way it is possible to support the seamless movement between highly visual touch-based interaction and eyes-free gestural interaction.

Categories and Subject Descriptors

H5.5.2 [**User Interfaces**]: Input devices and strategies

General Terms

Human Factors

Keywords

Eyes-Free, Interaction, Haptic, Vibrotactile, Feedback

1. INTRODUCTION

Quick but informative interaction with a mobile device is beneficial, particularly for users who are on the move or in some other context (e.g. meeting, cinema, etc.) where the eyes or general attention are required for other more important tasks. With the recent explosion of touchscreen devices this kind of rapid semi eyes-free interaction has become more and more difficult since the users visual attention is often demanded by the interface due to the absence of any form of tactile feedback, either naturally occurring feedback from raised mechanical buttons or artificially generated vibrotactile feedback. So how do we facilitate a users interaction with their touch-screen devices, enabling them to take as much information as possible from rapid short interactions without necessarily making use of their visual attention in contexts where this may potentially be hazardous (e.g. on a train, walking down a busy street, etc.)?

The provision of a tangible metaphor for the interaction and feedback design is one way to provide both compelling and informative feedback whilst also helping to compensate for the partial or even total loss of the visual sense during the interaction. The interaction metaphor we propose here uses the simulation of a rotational mechanical dynamic system, similar to that found in a door handle mechanism, driven either by inertial sensor data or touchscreen position data, to facilitate and enrich both touch-based and gesture-based interaction with a mobile device. The intention in using a physical metaphor for this interaction is that users instantly possess a natural intuition for the effects that their movements have with feedback provided via audio and haptic rendering of the internal states of the dynamic system. Allowing users to perceive the changing physical characteristics of the modeled system in this way can be used to convey richer information about the current state of their device or any information they may be interacting with.

Another important issue is the transition between the two forms of interaction. How do we facilitate the transition from complete visual screen-based interaction to eyes-free gestural interaction? One approach is to keep the feedback received from the two forms of interaction consistent. It is proposed here that a suitable metaphor for the interaction, such as the dynamical systems approach described below, can facilitate this kind of modality switching to enable seamless transitions between eyes-based and eyes-free interaction, when necessary.

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2. CHANGING CONTEXTS

With the emergence of powerful mobile touchscreen and internet devices, the kind of tasks users are performing whilst on the move are becoming increasingly complex. Users are now commonly partaking in tasks that previously would have been confined to the desktop environment, such as browsing the internet or watching videos. These changing contexts though are likely to affect user performance and lead to new challenges for mobile interaction design. So is there any way we can alter the interaction mechanism depending on the user's physical context? Hoggan *et al* [3] describe a study where users are presented with different combinations of feedback modality whilst in a disruptive environment finding that performance with the visual modality, even when augmented with audio and vibrotactile feedback, decreases significantly in more disruptive environments. Eyes-free interaction has often been touted as one form of interaction suited to changing mobile context. Pirhonen and Brewster *et al* [6] describe a system used for eyes-free interaction whereby a music player is controlled using sonified 2D gestures on a touch-screen without the need to look at the screen. They found that interaction was better for the gesture/audio display than for the traditional visual/pen display. Similarly Zhao *et al* [11] in their study of an eyes-free menu selection system using reactive auditory feedback found that this was at least as good as the traditional menu selection technique on a mobile touchscreen music player in terms of accuracy of selection and actually performed better in terms of speed of selection.

3. EXAMPLE APPLICATION

Our example 'overView' application enables the interaction with general temporal information. This information can come from many sources, such as weather patterns, stock exchange data, cardiac rhythm or any data that can be transformed to a temporal intensity pattern. For our example application we take the variation in the crowd noise during a football match. The action from this game is represented as a temporal intensity curve, illustrated in figure 4, with the main events in the match, such as goals, fouls or cards, represented as peaks in the data which can be represented visually on the screen or using vibrotactile feedback. Interaction with the data can take place in a detailed way by interacting directly with the time line on the touch-screen, shown in figure 2 or in a more incidental fashion by physically rotating or twisting the device in situations where use of the touch-screen is not appropriate. The current system, illustrated in figure 1, runs on an iPhone equipped with a C2 tactor connected to the audio port.

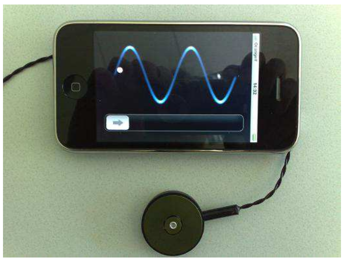

Figure 1: The example application runs on an iPhone with a C2 tactor attached to the audio out port for feedback.

Both the touch-based interaction and the gesture based interaction with this application provide identical feedback using the same metaphor. In the gesture-based interaction a 180° twist of the device is mapped to the full length of the timeline whereas in the touchscreen based interaction the position of the finger is mapped to the same 180° as illustrated in figure 2. When the device is held face up, this corresponds to the beginning of the timeline and when it is face down this corresponds to the end of the timeline. The 180° range was chosen due to the obvious ergonomic constraints when twisting the arm in this fashion.

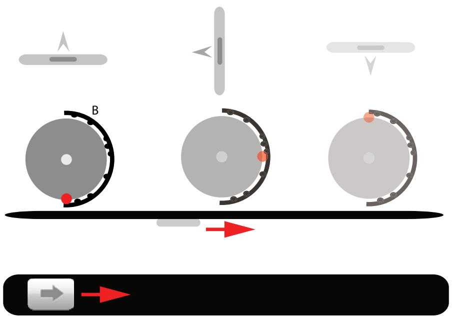

Figure 2: As the mobile device (top) is rotated through 180° the metaphorical disk is also twisted through 180° interacting with the frictional surface (black semi-circle). The 180° twist also corresponds to pushing the arrow from the left to the right of the screen.

4. SCENARIO

1. Dan is meeting a girl at the same time as his team is playing an important match so before he goes out he starts his application. During brief pauses in the meeting he discreetly twists his device to see if there has been any particular incidents in the match. Most of the time he feels only minor spurious vibrations corresponding to fouls, cards or near misses but one time he feels a sharp clear vibration indicating that there has been a goal. Dan then takes the device and sweeps his finger over the timeline until he feels the goal again and focusses on that area feeling more and more detail until he reaches the point just before the goal. He can then view the goal.

2. While on the bus John decides to browse his stocks and shares. He selects a company and gives his device a twist to quickly feel the trend from the last year. He twists to the left and feels strong vibrations corresponding to a good performance at that time then as he twists back to the right the vibration becomes weaker and weaker. He decides to take a more detailed look at the more recent trend so uses his finger on the screen to examine the last few weeks. The vibration feels like it's getting stronger in this time so he decides to buy. Nobody in the bus notices that John is visually impaired.

5. FEEDBACK GENERATION

The feedback generated with this system is based on a tangible physical metaphor similar to that described in [8] and [9] . Shoogle enables the conveying of information via a simple "ball in box" metaphor. Using the simulation of the dynamics of some balls held inside a box and the intuitive effects of the shaking of this box it is possible to convey information to the user such as the battery life of the device or number of unread text messages via the use of auditory impact sounds and haptic rendering. This exploitation of a users natural intuition of an everyday dynamic system is important. Yao and Hayward [10] similarly investigated the simulation of a physical system with audio and vibrotactile feedback, recreating the sensation of a ball rolling down a tube. By simulating the physics involved and providing audio and haptic cues, they found that it was possible for experimental subjects to accurately estimate the position of the ball rolling inside the tube. This was both due to the effective simulation of the system and the participants natural intuition of objects falling under the influence of gravity. Rath and Rochesso [7], likewise, created a convincing sonification of the physical motion of a ball along a beam, finding that subjects were able to perceive the ball motion from the sonification alone. Strachan and Murray-Smith [8] presented the simulation of a rotational mechanical dynamic system, similar to that found in a twisting door knob, to enrich the interaction between two or more users in a geosocial networking context, enabling users to transmit directly the effects of twisting their mobile devices in a meaningful way due to the intuition of the metaphor.

6. ROTATIONAL MECHANICAL SYSTEMS

Our feedback generating system uses a similar approach to that presented in [8] but with the simulation of a rotational dynamic system driven either by gesture-like twisting motions or touch-screen interaction on a mobile device to facilitate and enrich interaction in mobile contexts, and the smooth transition between the gesture and touch based modalities. The dynamics of this kind of system, similar to that of turning the key on a clock, represent a tangible metaphor for which most people possess a natural intuition. Enabling users to perceive the changing physical characteristics of the modelled system allows us to convey information about the event that the user is reviewing in a tangible way whilst maintaining a solid theoretical foundation to the underlying interaction.

Figure 3 defines some of the basic notation of this kind of system. θ is the angular displacement, or the twisting angle, of the a disk with respect to some reference and is expressed in radians, ω is the angular velocity of the disk, α (i.e. $\dot{\omega}$) the angular acceleration of the disk, B is the friction between the disk and some surface and τ is the torque present in the system, where the torque is simply the rotational analogue of force in a linear system. Torque is an important characteristic from an interaction design point of view since it provides us with a measure for the amount of force present in the system. This force varies depending on the displacement of the disk or the *friction* in the system at that point and is formally defined as $\tau = B\omega$ [1]. An algebraic relationship between the torque τ and the angular displacement θ exists. For a linear torsional spring or flexible shaft $\tau = K\Delta\theta$ where K is the spring constant and $\Delta\theta$ is the change in θ. Altering the value of K can also have an effect on the overall feel of the system. For example, if the value of K is high the system will feel more stiff. If the user inputs some energy to this system via twisting actions (i.e. changes in the angular displacement) they can achieve a sense of how the system is reacting just by feeling the changes in the resulting torque.

6.1 Two Disk Rotational Mechanical System

The metaphorical mechanism we use to represent the scanning of the timeline involves a single rotational disk attached to a surface with a stiffness shaft. The torque that we feel comes from the movement of this disk and the interaction of this disk with a surface of varying friction via the states of a dynamical system. In order to use the twisting orientation of our device as the input to the dynamic system it is necessary to include another disk attached to the first via an extra stiffness element as illustrated in figure 3. Angle changes in the orientation of the phone, sensed from accelerometers or changes in the position of the finger on the screen act as reference values which drive the rotational system, with the states of the system fed back to the user via vibration, audio or vision depending on the context.

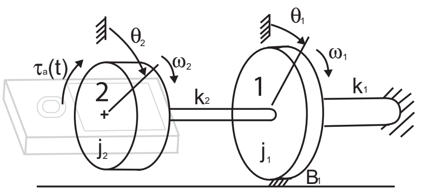

Figure 3: Rotational system to illustrate the laws for reaction torques and angular displacements. Adapted from [1].

We represent this system using a state-space model similar to that described in [2]. We treat the angular displacement θ_2 on disk 2 as an input to the system in order to observe the effects on θ_1 and ω_1 on disk 1. This system is represented as follows:

$$\dot{x} = Ax + Bu \tag{1}$$

$$\begin{bmatrix} \dot{\theta}_1 \\ \dot{\omega}_1 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{(k_2+k_1)}{J_1} & -\frac{B_1}{J_1} \end{bmatrix} \begin{bmatrix} \theta_1 \\ \omega_1 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{k_2}{J_1} \end{bmatrix} \theta_2 \tag{2}$$

where k_1 and k_2 are the stiffness constants in shaft 1 and shaft 2, B_1 is the friction element for disk 1 and J_1 is the moment of inertia for disk 1. If we imagine our mobile device to be represented by disk 2 and we exert some kind of roll-axis rotation on the device, this will induce a reaction in disk 1, the exact nature of which depends on the values chosen for k_1, k_2 and B.

By treating the parameter B as a non-linear function of θ, $B(\theta)$, we can provide the user with feedback depending on the number and type of events in the timeline. In this case we have elected to represent the presence of an event on the time line as an area of increased friction that can be perceived in the torque of the system in a way similar to the twisting of the knob on a safe, for example. Each tick as the knob is twisted represents an event on the timeline.

One of the main benefits of using a dynamic systems approach to this kind of interaction is the natural kind of variation received in the feedback for varying input speeds. If one were to statically map the intensity curve to vibration or audio there would be no perceived difference between a fast and a slow sweep over the timeline. A dynamic systems approach is speed dependent, which enables a more natural and flexible response. A slow movement of the finger over a rough surface is likely to feel different to a fast movement as we would expect in reality.

Other benefits of using this kind of two disk system include the ability to provide a step response to the system via a single touch of the timeline, which allows the user to feel the entire timeline up to that point as the system is driven to that position facilitating both rapid and informative interaction as illustrated in figure 6. Another complimentary effect of this system is that it also naturally augments the visual display with pseudo-haptic effects [5] as the cursor appears to stick to the areas of the time line with higher friction levels, i.e. the main events on the timeline.

6.2 Example Interactions

Figures 3 and 5 illustrate the dynamic system and show how the torque varies as the device is rotated round 180° for a fast sweep over the timeline (left) and a slow sweep (right). The friction parameter, B, for our model is mapped directly from the example intensity curve shown in figure 4. The user senses a spike in the torque for each event due to the increased friction at that point. The friction value is varied depending on the type of event so for example, a goal in a football match feels sharper and stronger than a foul due simply to the difference in friction between the two events. The torque output from the system shows the response as the finger is swept over the screen until the finger is released then as the cursor naturally decays back to the origin, similar to the way the unlock button works on an iPhone.

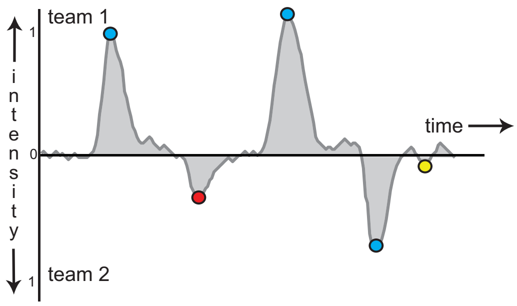

Figure 4: A simplified intensity curve used in our example interactions. The intensity of the game is represented as a temporal curve with peaks corresponding to the main events in the game. The blue circles indicate goals scored and the red and yellow circles indicate cards shown. All the events as well as the general ambiance can be perceived by the user via vibrotactile feedback. This curve is mapped directly to the friction, B, in our dynamic system.

Figure 6 also shows the response of the system from a single touch of the screen at a point further along the time line. The user perceives all the information up to that point as the system evolves then decays back to the origin as soon as the finger is released again. This potentially enables a simple 'one touch' form of rapid informative interaction.

7. CONCLUSIONS AND FUTURE WORK

This paper has introduced a new form of continuous interaction with a mobile device to aid rapid information overview in the constantly changing contexts to which we are subjected when using our mobile devices. We have demonstrated the use of a physically-based metaphor for feedback generation and the potential utility of

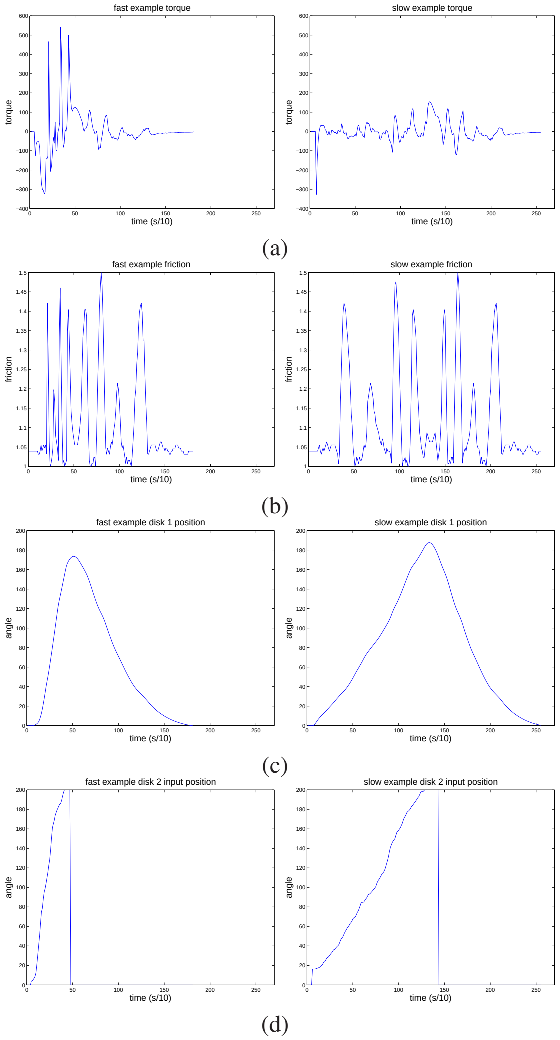

Figure 5: (a) The torque observed from a sweep over the timeline for the fast example (left) and the slow example (right). The main areas of high friction are observed as spikes in the torque, which can be perceived by users. (b) The friction value at each point in the sweep and the recoil back to the origin. (c) The smooth rotation angle of disk 1 as the dynamic system quickly unfolds and then more slowly recoils back to the origin. (d) The input position of disk 2 manipulated directly by the finger of the user. The recoil begins when the position value is released.

this method of generating feedback in a compelling and tangible way for multimodal systems, whilst maintaining a strong theoretical foundation to the overall interaction design. We have demonstrated that the theoretical dynamic systems approach to this kind of interaction design can produce tangible results that more closely represent the interaction with a real physical system.

The seamless movement from highly visual interaction to eyes-free interaction without a total degradation in performance is also desirable when we are on the move, for example, when switching contexts from walking down the street to sitting in a tram and we have demonstrated the design of a consistent feedback mechanism to aid this kind of transition. Future work in this area will also include a user study in order to determine how this kind of 'consistent feedback' can aid the transition between the different modalities aiming to show that consistency in the feedback between touch-based input and gesture-based input can aid smooth transitions between

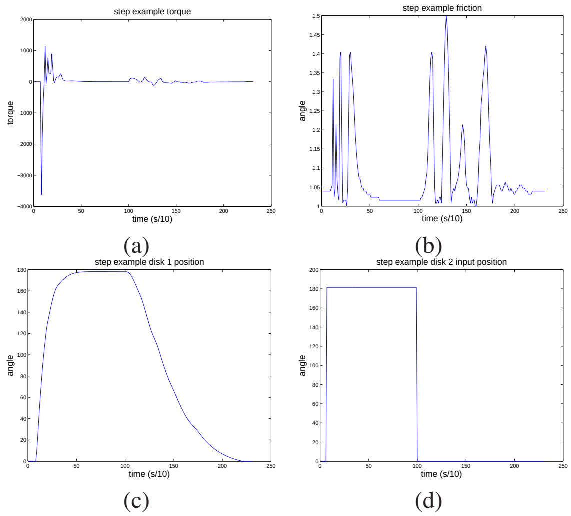

Figure 6: (a) The torque observed from a direct tap one the timeline, equating to a 'step response' for the dynamic system. Again, the main areas of high friction are observed as spikes in the torque, which arise as the system rapidly unfolds to that input value then decays again when the point is released. (b) The friction value at each point in the unfolding of the system and the recoil back to the origin. (c) The smooth rotation angle of disk 1 as the dynamic system rapidly unfolds and recoils. (d) The step input from disk 2. The recoil begins when the position value is released.

the two. Moreover, there is also great potential for the design of this kind of system of visually impared people, as in [4] and more consideration should be given to this in the future.

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