

Haptic Interface Using "Estimation of Box Contents" Metaphor

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Abstract

We propose a new haptic interface for handheld devices using the "estimation of box contents" metaphor. This metaphor refers to a situation in which a person shakes a box to determine what is contained in it. In this interface, a handheld device is compared to a box, and the information contained in the device is compared to an object contained in the box. The user can determine if information is present by shaking the device. With this type of interaction, the user can use handheld devices in the same way that he or she uses non-information tools. This is an approach to equalizing information device operation and non-information tool operation by using haptic interactions. We construct a prototype device to examine the applicability of this interface. The experimental result reveals there is a possibility of simplifying the structure of the system by leveraging the periodicity of shaking.

Key words: haptic interface, handheld device, impulse generation, shaking behavior, estimation

1. Introduction

In recent years, the miniaturization of information devices has generated widespread use of handheld computing devices such as palm-size digital assistants (PDAs) and multifunctional mobile phones. This widespread use of handheld devices will change the usage of information devices. Currently, users have sat on a chair and faced the display to operate a desktop computer. In the not-so-distant future, a user will have several handheld devices on his or her table and use them simultaneously. Moreover, he or she would use such devices in several situations such as during walking. In these applications, any display of devices cannot occupy the user's whole visual attention. This is a difficult condition for conventional GUI, because the GUI concept presumes that the user's visual attention is kept on the display. Furthermore, the limited display size of handheld devices is also a disadvantage using conventional GUI in handheld devices.

We believe that a haptic interface for handheld devices provide a solution for this problem. Haptic interaction offers three merits for the interface of handheld device. First, it does not require any visual attention, and hence it is available during walking. Second, haptic interaction is very popular in daily life. Almost all non-information tools are manipulated via haptic interaction, and hence it can be said to be intuitive. Finally, when using a handheld device, the user is required to hold the device in his or her palm. This makes it easy to give a haptic stimulus to the user.

However, haptic sense is closely related to specific actions and is not good at importing objective information. For example firm pressure easily lead to the sense of heaviness, but it does not relate to the thought that "you have a meeting just now". To avoid this demerit, the method employing a metaphor from popular operation and assign significant information to haptic sensations is available. For example, firm pressure can be related to the thought "there is many information in this device." Because we feel firm pressure on palm when having a box contains many objects.

In this study, we employ the "estimation of box contents" metaphor and assign the information about the amount of data to the estimation operation. The "estimation of box contents" metaphor refers to the shaking of a box to determine what is inside the box. The user can determine information contained in the device by shaking it, similar to estimating the contents of a box from the reactive sensation of shaking it.

2. Concept

2.1 Estimation of box contents metaphor

We propose a new haptic interface from which a user can obtain important information by a simple shaking action. For example, to determine if a handheld device has new e-mail, all the user has to do is only shake the device. And if there are two new e-mails, the user feels he or she is shaking a box containing two objects. However, in the case of popular PDA interfaces, the user must look at the display and read the text "two mails



Fig. 1. Concept of the interface

messages" or "no new mail" to know status of the mail arrival. This requires two actions, pick up and look at the device, and perhaps requires more complex operation than only one shaking.

Our interface uses "estimation of box contents" metaphor. Whereby a person shakes a box to determine what kind of object is contained in it. We compare the handheld device to a box containing something, and the information held in the device to an object in the box. The user knows information is contained by the haptic sensation generated when the device is shaken, similar to the case that a person can determine there is an object inside the box by the reaction generated when the box is shaken.

2.2 Representation of "estimation of box contents" metaphor

In this interface, we use a haptic device that has the ability to generate impulse sensation and the simulation of a model that consists of a box and objects contained in it. The abilities reconstruct the characteristics of "estimation of box inside." described below.

When one shakes an empty box, one perceives the inertial force caused by box movement. However, if the box contains some object, one would also perceive the rhythmic impact caused by the collisions between the contained objects and the inner surfaces of the box. And the user estimates the nature of the contained object on the basis of the characteristics of the impulse sensation. The characteristics are divided into three main elements. First is the relationship between the shaking movements and impulse timings. In normal cases, impulse timings are synchronized with shaking timings of the box. If the impulse timing is delayed from the shaking timing, the user finds it strange. The second is the impact strength. Impact strength is a cue for estimating the weight and material of the contained object. For example, a steel ball generates a strong impulse and a rubber ball generates a weak impulse. Last is the number of impulses generated by one shaking motion. If two impulses happened in one shaking movement, one may

assume that there are two objects inside the box.

To represent these three characteristics, the device must have two functions of physical model simulation and impulse generation. The simulation function yields a relationship between the shaking timings and impulse timings and the number of impulses in one shaking motion. This simulation consists of one box and some internal objects, and simulating the movement of the box and objects gives the timing of the collision between the box inner surface and the objects in the box. The function of impulse generation gives users several types of impulse sensations. Moreover, functions should be implemented in a palm-sized device. This is because the device is shaken by hand and this interface is for handheld devices.

3. Related Works

The Tangible Bits[1] project aims at connecting the digital information and the physical environment by making digital bits tangible. In this project, a physical cue is given to several graphical user interface elements. In the Bricks system[2], a physical block is used as a handle of a virtual object such as a GUI window or a spline curve of a graphic application. In the metaDesk system[3], several graphical UI widgets are instantiated by tangible UI widgets. For example GUI "window" is instantiated by TUI "lens", and GUI "icon" is by TUI "phicon." These interfaces are similar to our concept of importing a physical sensation of information. However, these give the user only static sensations, such as the sense of shape. We believe haptic sensations are important in designing tangible interfaces.

In the research field on handheld device interfaces, there are some interfaces using physical operations of devices, such as movement, rotation, and so on, as the input channel. Many of them aim to overcome the inconveniences of a handheld device's limited I/O channel, such as small display and small key-space. Harrison et al. proposed a "manipulative user interface" for handheld devices[4]. They use some metaphors of page turning, such as rotating Rolodex and book annotating, to construct the interface. In the page turning metaphor interface, a user pinches the right upper corner of the device and performs a leftward stroke movement to change the displayed content into the next one. This motion is similar to the page turning motion of pinching the right upper corner of a book and turning one page to the left. The "Peephole Displays"[5] is a system used to access a large virtual workspace through the small display of a handheld device. This system tracks the device movement by a position sensor and scrolls display contents according to the movement. For example, when displaying map data, if a user moves the device to the right, then the user sees the right part of the map. In this system, the handheld device's display functions as a hole for peeping into a large virtual workspace. These interfaces apply common



Fig. 2. System Architecture

manipulation metaphors, and this is the same concept used in our interface. However these interfaces apply the metaphor in input operation only, while the output of the interface is only obtained visually.

There are some research studies on mobile haptic devices. These are classified in two types, the bodygrounded type and the gyro effect type. Hirose et al. developed body-grounded haptic device named "Haptic Gear[6]." A user carries this device on his or her back, and feels the force generated from action-reaction effects. Ando et al. constructed a wearable force display based on the gyro effect[7]. This device consists of two rotating wheels, motors and brakes and is attached to the user's arm. By braking the rotating wheel, this device output a torque. Yano et al. construct non-grounded haptic display using the gyro effect[8]. This system generates force by braking a rotating flywheel. The plane of rotation of the flywheel is tilted by two motors, hence this device generates three axis force. These devices are portable, however, they are still too large to implement to handheld devices.

4. Implementation

4.1 System Overview

The total system architecture is illustrated in Fig. 2. According to the facts described in 2.2, the system requires two functions, simulating the physical model and generating impulse sensation. The model simulator consists of physical model simulation and sensing of the position of the device. Hence, this device consists of three major parts, the position sensing part, model simulation part and impulse generation part. The position sensing part senses the acceleration of the device, and this acceleration value is integrated into position data. This position data is sent to the model simulation part. The model simulation part simulates a box containing an object using this position data. In the simulation part, timings of collisions between the box and the object are calculated from the physical model simulation. These timings are used for actuating the impulse generation part to import impact sensation to the user.



Fig. 3. Acceleration data from acceleration sensor and position data given by filtering and integrating ecceleration data

The information flow of the device starts from the position sensing part and through the model simulation part to the impulse generation part. The position sensing part acquires the movement of the device in position data. Then the model simulation part simulates the physical model according to the position data that is transferred from the sensing part. From the simulation result, collision timing data is transferred to the impulse generation part. The impulse generation part imports the impulse sensation to the user according to the collision timing data.

In our prototype model, the model simulation part is implemented in a desktop PC (Pentium4 1.5GHz) and the physical model is simplified to one-axis simulation. Performing the simulation in a PC prevents the portability of the prototype device due to the cable which connects the PC and the prototype device. However we believe this setup is sufficient for demonstrating the efficiency of the device. Simplification of the simulation model to a one-axis one surely limits the reality of the model, but we believe that it is sufficiently realistic to implement "estimation of box contents" metaphor, because most of the users shake the device in one direction.

4.2 Motion sensing

The device shaking motion is required for physical model simulation. Hence the system acquires the device position data by the position sensing part. The position data require a 1kHz sampling rate, because the physical



Fig. 4. Prototyped device



Fig. 5. Model of physical simulation

model is simulated at that frequency. This sampling rate is a standard haptic rate. The measurement range is approximately 300mm for sensing a normal shaking movement.

We decided to employ a simple acceleration sensor and integrated acceleration data to obtain position data. The reason for employing an acceleration sensor is that it is small in size (one chip IC). It is suitable for using in the handheld devices. Popular position sensors, such as laser position sensors or magnetic field sensors take up to a large space compared to handheld devices.

However, integrated data is difficult to use, because of the accumulation of integration error. To avoid this problem, we focus on the characteristics of shaking. When one shakes the box to determine the contents, the shaking operation has a cyclic behavior. Hence, acquiring the typical frequency and amplitude of shaking movement is sufficient for our needs, and the absolute position data is not important. Therefore, we filter out the low-frequency factor of acceleration data, and obtain the cyclic fluctuation of the device position.

Fig. 3 indicates the original acceleration data and the position data obtained by integrating the filtered acceleration data. This graph indicates the elimination of the accumulation of integration noise. We used a LPH filter with a 2Hz cut-off frequency in filtering acceleration data.

4.3 Impulse generation

To represent the collision between the inner surface of



Fig. 6. Cyclic behavior of shaking



Fig. 7. Collision timings in simplified model

the box and the contained object, we employ linear solenoids and strike their cores against the inner surface of the device. Conventional force feedback devices could not create impulse vibration, thus we employed a method of causing a collision between the actuator's core and the wall of the device. Moreover, this actuation mechanism does not require any grounded point. This characteristic is very important for handheld devices to ensure their portability.

The placement of the solenoid is a problem. In our prototype device, we use two solenoids. One is placed on the left, and the other, on the right, with the aim of distinguishing between the collisions on right and left. When a collision occurs on the right as a result of simulation, the right-side solenoid is actuated to generate impulse sensation on the right. The left side collision is achieved similarly. **Fig. 4** shows two implemented solenoids on the left side and right in the device.

Impulse strength generated by a solenoid can be controlled by the applied voltage[8]. However our prototype device employs the two-state (on/off) control to simplify the actuation circuit.

4.4 Physical model simulation

In the simulation part, collision timing is calculated from simple physical simulation. This simulation model is illustrated in **Fig. 5**. This model consists of a box and the contained objects. In the illustration, there is one object but in the simulation, the number of contained object is variable. The equation of motion is as given.

$$ma_{m} = \begin{cases} -\mu N & (v_{m} > v_{b}) \\ +\mu N & (v_{m} < v_{b}) \end{cases}$$
(1)

Here, μ is the coefficient of dynamic friction. In this model, N = mg, because tilting of the box is not taken into account. (g is the constant of gravitation) When the box's wall and the contained object collide with each other, the velocity of the contained object in the next loop is calculated from this equation. α is the reflection coefficient between the contained object and the box's wall.

$$v_{m(t)} = v_b - \alpha (v_{m(t-1)} - v_b)$$
(2)

On the basis of this processing, collision force F is calculated from equation (3).

$$F = m \frac{v_{m(t+1)} - v_{m(t)}}{\Delta t} \tag{3}$$

Here, Δt is sampling time. This simulation is calculated with a 1kHz sampling rate. Hence, the sampling time is 1msec.

This physical model simulation indicates cyclic behavior. As indicated in Fig. 6, collision timings are delayed from the turning points of position data. Noting about this characteristic, we construct a more simplified simulation model that derives collision timing after some delay from the turning point of position data. The delay time is programmable.

5. Experiment

We performed informal testing for two models with this prototype. In many cases, users shook the device in a cyclic motion and recognized the feeling of something being inside the device. The users did not find it strange to use the simplified model. Namely, user did not notice about the any difference between the realistic simulation and the simplified one. We change the delay time from 0 to 100 msec in the simplified model. However, users also did not notice whether or not there was a delay time.

We also tested the difference between right-side impulse and left-side impulse. In normal cases, when a collision occurs on the right in the simulation, the solenoid placed on the right is actuated. We constructed a contrasting version. In this version, when a collision occurs on the right in the simulation, the solenoid placed on the left is actuated. When the user was shaking the device, we switched the left impulse and right impulse without any indication. Using these two versions, we performed a test in which the change normal version was suddenly changed to the contrasting version when the user was shaking the device. We observed whether the user noticed about this change or not. The users who noticed the change constituted approximately one quarter of all users. Moreover, no users noticed the change at the exact moment the change occurred, but noticed after a slight delay.

We demonstrated the prototype device to dozens of participants and asked them their impressions and comments. Many of them commented that they felt as if something was present inside the device. They also commented that the operation of this device is easy to learn. Some of them commented that the collision sound is a very important element of reality. This collision sound is produced by the collision between solenoid core and the device inner surface.

Some advices from the users for this device is listed below.

- It would be an improvement if the interface had the capability of presenting the box containing water.
- This interface is suitable for indicating the remaining money in an IC money card. It is troublesome to insert card to the device each time one wants to find out a remaining amount.

6. Discussion and Future Works

We have developed a new haptic interface using the "estimation of box contents" metaphor. By using haptic sensation as an output, this interface accomplishes intuitive operations.

When shaking prototype device, users feel there is something inside the device, and there is no significant difference in users' feeling between physical model based responses and simplified model based responses. On the basis of this fact, it can be said that the users are not sensitive about the impulse timing. If impulse timings are roughly synchronized with the user's device shaking motion, the user recognizes the feeling of something being present inside the device. This consideration is consistent with the fact the users do not notice the delay between collision timings and the shaking timing. The important point in the "estimation of box contents" metaphor is that impulse response timings are synchronized with the shaking movement.

Many users are not aware of the change between left impulse and right impulse. This indicates that user are not concerned with the impulse point. This suggests that it is also possible to reduce the number of impulse generation solenoids to only one.

This device only expresses the content of a solid object.

Increasing the expressiveness would extend the application range of this interface. If it is possible to express the content of numerous objects or liquids, several types of information can be displayed to users. For example, a collision sensation indicates the presence of mail, while a liquid sensation can independently indicate the remaining memory area.

This prototype cannot control the strength of impulse sensation. This remains one of our next tasks. Additionally the prototype connects to a PC via cables, and we are planning to construct a new wireless device to test it while walking.

7. Conclusion

We have presented a haptic interface using the "estimation of box contents" metaphor. Using this metaphor, a handheld device and information contained in the device are compared to a box and the objects contained in the box. A user checks for the presence of information by shaking the device, in the same way a person checks for the presence of box contents by shaking the box.

We made a prototype device and implemented this interface in it. This prototype device consists of three parts, a position sensing part, a model simulation part, and an impulse generation part. This device simulates a physical model that consists of a box and a contained object, by using position data. In response to physical simulation, this device reconstructs the haptic sensation of collisions between the box and the object. We also constructed a simplified model, which derives collision timing after some delay from the turning point of position data.

We examined the difference between both simulation models and the result revealed that both are effective in reconstructing box and object sensations. Moreover, the change of delay time of the simplified model does not affect the instinctual recognition by the user. This indicates that user is not sensitive to the collision timings.

Further more, changing the impulse point also makes no difference in the recognition. This indicates the possibility of reducing the number of solenoids generating impulse to only one.

References

- 1. H. Ishii, B. Ullmer: "Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms," *Proc. of CHI'97*, pp. 234-241 (1997).
- 2. G. Fitzmaurice, H. Ishii, W. Buxton: "Bricks: Laying the Foundations for Graspable User Interfaces," *Proc. of CHI'95*, pp. 442-449 (1995).

- 3. B. Ullmer, H. Ishii: "The metaDESK: Models and Prototypes for Tangible User Interfaces," *Proc. of UIST'97*, pp. 223-232 (1997).
- B.L. Harrison, K.P. Fishkin, A. Gujar, C. Mochon, W. Roy: "Squeeze Me, Hold Me, Tilt Me~ An Exploration of Manipulative User Interfaces," *Proc. of CHI'98*, pp. 17-24 (1998).
- 5. X. Yee: "Peephole Displays: Pen Interaction on Spatially Aware Handheld Computers," *Proc. of CHI2003*, pp. 1-8 (2003).
- 6. M. Hirose, T. Ogi, H. Yano, N. Kakehi: "Development of Wearable Force Display (Haptic Gear) for Immersive Projection Display," *Proc. of IEEE Virtual Reality '99*, pp. 79 (1999).
- 7. H. Ando, K. Obana, M. Sugimoto, T. Maeda: "A wearable force display based on brake change in angular momentum," *Proc. of ICAT2002*, pp. 16-21 (2002).
- 8. H. Yano, M. Yoshie, H. Iwata: "Development of a Non-grounded Hoptic Interface Using the Gyro Effect," *Proc. of the 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pp. 32-39 (2003).
- 9. S. Matsui, M. Imura, Y. Yasumuro, Y. Manabe, K. Chihara: "Haptic Display for Impulse Force using Linear Solenoid," *Proc. of 8th annual conference of VRSJ*, pp29-32 (2003). (in Japanese)