A Haptic Dial System for Multimodal Prototyping

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Abstract

Virtual prototyping (VP) is the efficient tool to evaluate the functions and appearance of the product using its digital model in the early phase of the product development. VP provides realistic visual information of the product, but does not offer physical interaction which is crucial to estimate how people sense and understand physical nature of the product. In this paper, we developed a haptically actuated dial system to emulate tactile and kinesthetic properties of mechanical dial knobs. The haptic dial system is used to evaluate the haptic properties as well as appearance and functionality of the dial knob of a washing machine in the design process. Various haptic behaviors are generated by modulating torque profile along the path and switching physical dial knobs with different shape and material. The haptic dial knob is connected to the virtual dial model and sound effects for multimodal prototyping

1. Introduction

Prototyping plays an important role for the product development. As the product lifecycle shortens, an accurate and quick prototyping is required. Traditional prototyping, however, which uses raw material such as wood or metal and consists of material removal processes, is slow and not suitable to show the physical property of the product. Rapid prototyping (RP), which have advantage of fast prototyping, cannot assure the accuracy and functionality of the prototype [10].

Virtual prototyping (VP) can be a successful alternative since the CAD system broadly used for the design process. A developer can easily share design parameters of the product with the virtual prototype which is precisely produced with 3D graphics. A virtual prototype is classified as a high-fidelity prototype because a virtual prototype has high degree of features and functionality, and it has advantages both of the vertical and horizontal prototype due to its inclusion of all features and fully-implemented functionality.

However, although virtual prototyping is useful in visual design, it does not provide hands-on experiences that are very important to explore physical nature and evaluate affective (emotional) feeling when the user interacts with the real product.

Haptic interface that has recently emerged allows the user to interact with digital models via our sense of touch. Haptic interface device is superior over typical input devices including keyboard and mouse in that it transmits various types of physical information such as force, tactile, moisture and temperature between human and computer bi-directionally.

Haptic interface can be used to not only enhance visual design but also offer physical information source. It allows product designers to estimate and understand physical properties of the product in the early stage of development.

Figure 1: Haptic dial module

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In this paper, we present a haptic prototyping system with a motor-actuated dial knob which is designed to add tactile/haptic feedback to the conventional virtual prototyping (see Figure 1). Haptic profile of the dial knob can be programmed to simulate various haptic behaviors of mechanical dial knobs.

We applied the system to design the dial module of a washing machine by considering the following various parameters of the dial knob.

- Torque profile of the dial along the rotational path
- Number, position, and shape of notch of the dial
- Shape, size, and weight of the dial knob
- Functionality and visual appearance of the dial
- Sound effects corresponding to the situation

By modulating these parameters, we can make and evaluate various dial knob prototypes and then determine appropriate model in the design process. Multimodal interface incorporating haptic, visual, and aural feedbacks enhances the user experience by providing multiple information sources at the same time.

In section 2, we discuss previous work. The haptic dial system is described in section 3. Then, the visual system is described in section 3. An example applied to a front-loading washing machine is presented in section 4. In section 5, we discuss the conclusion and future work.

2. Previous work

Aladdin engineering prototype [4] is a half-door with a haptically active knob to display both torque and thermal haptic outputs and an auditory output. In addition, Authors implemented a set of narratives to situate Aladdin, ranging from the pragmatic to the whimsical. It is used as tool to design and discover haptic experience.

Rob Shaw et al. introduce force-feedback displays (Knobs and slider) for haptically manipulating digital media such as video, audio, and computer graphics [7]. They developed various haptic effects to control, navigate, and annotate media including haptic clutch, haptic fisheye, and haptic foreshadowing.

Force feedback slider (FFS) [1] is a motorized physical slider with position input and force output. It is used to realize to learn system dynamics as part of physics education and to interact with music loops.

H. V. Bjelland and K. Tangeland describe some challenges related to prototyping haptic feedback for the user-centered design process [2]. They present a haptic throttle stick quickly establish a proof of concept as an example of possibilities of prototyping haptic feedback.

A rotary haptic knob [5] is designed to be used for instrument controls in motor vehicles. The haptic knob incorporating brake actuator provides high torque capability in a small volume.

3. Haptic prototyping system

The haptic prototyping system consists of a haptic rotary module to deliver haptic feedback to the user, physical dial knobs to be mounted on the motor shaft, a visual display device to show the virtual 3D model, speakers for the sound effects, and two PCs: visual and haptic PCs. The visual PC is running under MS Windows XP and simulates the virtual model corresponding to the user inputs and sends the images to the visual display. The haptic PC based on a real-time operating system reads the rotational position of the dial knob from the encoder, computes appropriate toque at the current position, and sends control signals to the haptic rotary module

3.1. The hardware

For the haptic rotary module, we use a Maxon DC motor RE25 with a position encoder to directly control the dial knob.

The haptic PC is implemented by PCM-3370 with Intel Celeron 300/650 and an interval Watchdog timer from Advantech. It is working under a real-time operating system RTLinux [6] to minimize the latency. It reads the current position of the dial knob from the encoder via a Sensory526 AD control board. In order to control the motor, the haptic PC sends the control signal to the rotary module via an EPOS analog controller and the AD control board. The analog controller connected to the motor can maintain stability by tuning PID gain. Haptic prototyping system is shown in Figure 2.

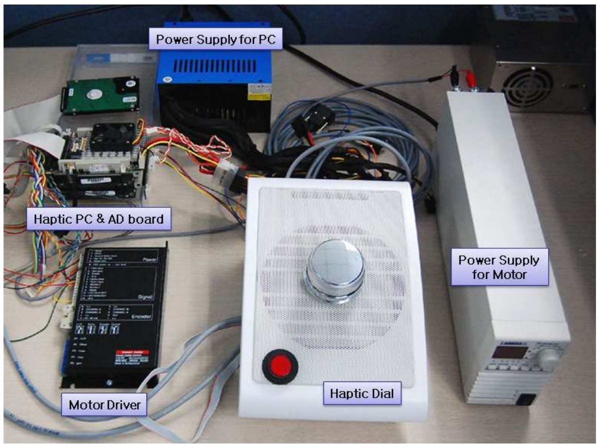

Figure 2: Haptic dial prototyping system

Table 1 describes the specification of the Maxon DC motor and driver and table 2 shows the specification of the haptic dial system.

Figure 3 shows various types of dial knobs for physical prototyping. Physical properties of the dial knob such as shape, texture, and weight are very important factors to affect physical feeling when the user interacts with the knob. Our system allows changing these dial knobs to test various types of knobs.

	DC Motor	*Motor driver*
Model	Maxon DC Motor RE25	Maxon 4Q-DC ADS
Spec.	Power Rate: 20 W	Four operating modes :
	Nominal Voltage: 24.0 V	Speed/current control
	Stall Torque: 243 mNm	PWM power stage
	Max. Continuous Torque: 26.1 mNm	Continuous output current up to 5A
	Torque Constant: 23.4 mNm/A	Max. Operating Frequency: 50kHz

Table 1: Specification of the motor and driver

Part	*Specification*
Body	120 * 120 * 100 (mm)
Dial	ø 70mm
Switch	Power On / Off
Controller	Maxon 4Q-DC via Sensory526 AD board
Power	24DCV Power Supply

Table 2: Specification of the haptic dial

Dial knobs are commercial ones from LG. The bottom face of each dial has a hole with standard diameter and shape to mount on the motor shaft. We make a metal knob guide to fit with the commercial knob.

Figure 3: Various commercial dial knobs

3.2. Haptic display

Haptic output is created with torque applied to the dial's rotational axis. The haptic program running at 1 KHz in the haptic PC controls the rotary module corresponding to the user input. The program makes various haptic behaviors using the following parameters.

- Torque profile of the dial along the rotational path
- Number, position, and shape of notch of the dial
- PID (Proportional, Integrate, and Derivative) gain
- Physical dial knobs with different shape and material

Different torque profile provides different haptic interaction to the user. The PID analog controller is used to control the motor with stability and quickness.

The haptic dial system can emulate several haptic behaviors such as friction, detent, spring, hard stops and combination of these behaviors. For instance, the detent effects physically resist or arrest the rotation of the knob around notches and the spring effect pulls the knob to a set position working like a jog dial. It gives an illusion as if the user manipulates mechanical dials by a hand.

Figure 4 shows the visual interface to select haptic effects and parameters.

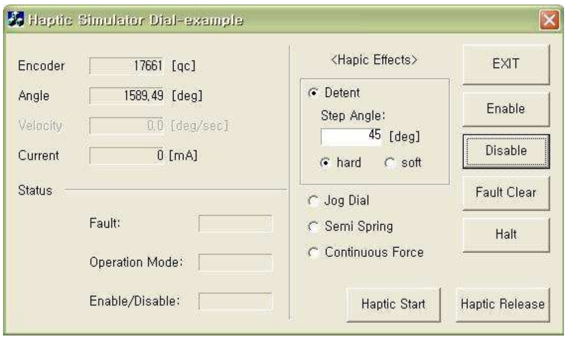

Figure 4: The control interface

3.3. Visual & aural display

In addition to haptic display, we integrate visual and aural display to provide visual and aural information of the dial system to evaluate appearance and functionality. Multimodal interface enhances dramatically the realism.

Visual and aural display is corresponding to the current position of the dial knob and user interactions. The visual system runs under the visual PC based on MS Windows XP.

The virtual model is implemented using the CAD file which contains design parameters of the product, and it is able to render accurate 3D model. The 3D model is represented by the X3D and implemented with Xj3D toolkit [9]. The toolkit is fast, platform-independent, royalty-free, and highly standardized.

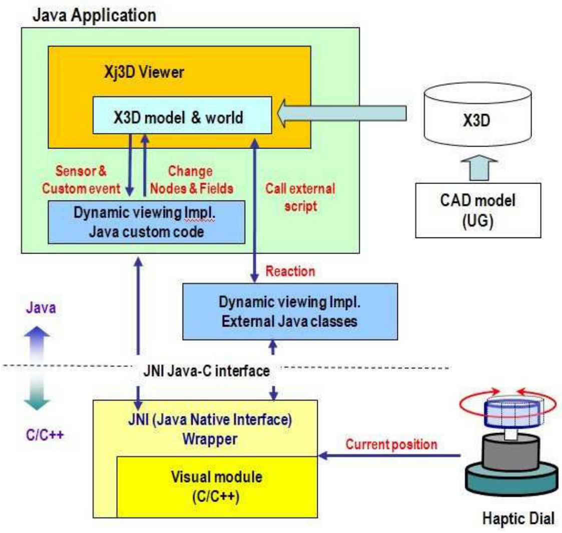

Figure 5: Software architecture of visual system

Figure 5 shows the software architecture of the visual system. An X3D file is converted from a UG CAD model and displayed through the Xj3D viewer. The visual module reads the current position from the haptic dial and updates the virtual model on Xj3D viewer. The visual module written in C++ is wrapped by JNI (Jave Native Interface) [8] to communicate with the java-based viewer

4. Applying to the dial of a washing machine

Modern washing machines typically have simply control modules such as dial knobs, buttons, and a digital display. Among these control modules, the dial is very important and popular since it provides very easy and intuitive user interface. The dial knob is used to select each of modes. The modes the user can select include wash type, dry type, spin speed, washing time, amount of water to be added, and so on.

We apply the haptic dial system to evaluate the dial knob of a washing machine in the design process. The designer can physically experience various dial knobs with different haptic profile, shape, and material. Then, he determines design of the dial module reflecting his experience on the haptic dial.

Figure 6 shows the haptic dial system to prototype the dial knob of a washing machine to be developed. In order to enhance the physical realism, the control panel of a washing machine is mounted on the dial system.

The user explores various types of haptic profiles. For example, torque profile around the notch, intervals between the notches, the number of notches, max and min angle to work, and so on. In addition, he switches the physical dial knobs with different shape and material.

The visual information is updated according to the user input just as the real washing machine does. A LED lamp around the virtual dial knob lights up to indicate the current mode the user selects and the digital display shows relevant information.

The user can hear specific sounds when he operates the dial knob to select one of modes. The system provides various sounds effects to represent each of washing modes.

5. Conclusion

In this paper, we explore possibility to use the haptic dial system incorporating visual and aural interface to estimate and understand physical properties of a product early in the design process.

The haptic dial system allows interaction between virtual and physical dial module. Multimodal interface including visual, aural, and haptic feedback improves the user experience providing multiple information sources at the same time.

The haptic dial system is applied to prototype the dial knob of a washing machine in design. It demonstrated feasibility of haptic prototyping by integrating haptic interface into the conventional virtual prototyping system. This system can be adapted to many applications including automobile control module, control for medical and game.

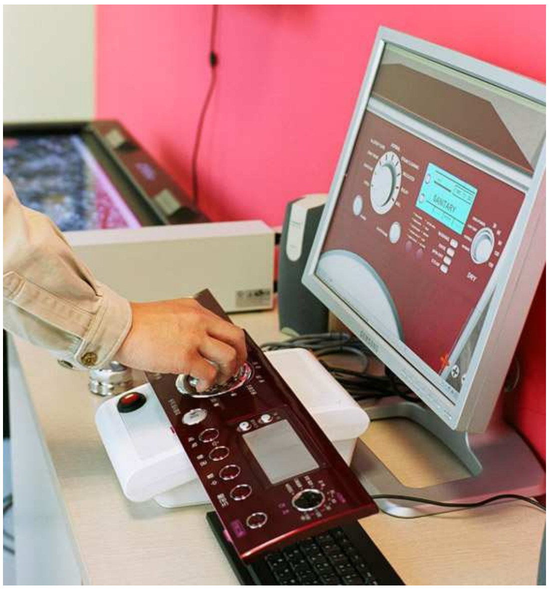

Figure 6: Haptic dial system for prototyping a washing machine

For the future work, we will study the relationship between electrically actuated dial knob and mechanical dial knob. In addition, we will develop a new user interface in which haptic interaction space and visual space are co-located. It provides more intuitive interface to interact with prototype.

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