Implement haptics in touch-based user interfaces

Chethan Devaraj, Vairamuthu Ramasamy - June 11, 2014

Capacitive touch interfaces are replacing mechanical switches, knobs, and dials in consumer, automotive, industrial and medical applications. Capacitive touch sensors have gained popularity due to their aesthetic value, increased reliability, and reduced manufacturing/tooling cost. User interfaces with capacitive touch sensing have also been shown to improve the user experience as well as increase a product’s lifespan because there are no mechanical components to fail.

Transitioning from mechanical buttons, knobs, and dials to a capacitive touch interface, however, poses a challenge to designers because there is no tactile feedback present with capacitive touch sensors as exists with mechanical buttons and switches. For example, consider the experience of typing on a keyboard. When a key is pressed and released, it bounces back due to spring action. A person can feel the force of the key bouncing back with his or her finger and thereby confirm the key press. With a capacitive touch interface, there is no inherent mechanical feedback, and users do not have the same experience as that of mechanical keys. The absence of tactile feedback poses a challenge to designers in that their primary goal is to improve user experience. Through haptics technology, developers can provide tactile feedback, improve the user experience, and add value to products.

![Figure 1: An example of haptics technology implemented in mobile phones to provide touch feedback.](image)

Haptics technology is a tactile feedback technology that uses a person’s sense of touch to provide feedback by applying forces, vibrations, or motion to the user. A simple example of haptics technology is the vibration alert used in mobile phones and tablets. When the mobile phone is in vibrate mode, the device is vibrated using an actuator to alert the user of an incoming call or message even when the user is not looking at the screen.
Figure 2 is an example of haptics technology implemented in a capacitive touch system. Here, when the user touches the capacitive touch interface, the actuator is activated to create vibrations. The user finger feels these vibrations and confirms the touch. By controlling the applied voltage and frequency to the actuator, it is possible to generate different touch feedback effects such as single click and double click.

![Figure 2: Principle of working of Haptics Technology](image)

**Implementing haptics in touch user interface:**

Figure 3 shows an example of haptic feedback implemented in a touch user interface. The system consists of the following components:

- Touch Interface
- Touch sensing controller
- Haptics Processor
- Actuator
- Actuator driver
**Touch Interface:** The touch interface is the area where the user interacts with the system. It consists of sensors that are touch sensitive. The touch interface can be a touch screen, a touch button, or both. For example, in applications such as mobile phones, the touch interface is a transparent touch screen placed above the LCD display. In applications such as home appliances, the touch interface will employ a copper pour on a FR4/FPC PCB.

**Touch Sensing controller:** The touch sensing controller detects a finger touch or the location of a finger touch on the touch surface. In the case of a touch screen, the touch controller sends the touch coordinates to the application processor for processing. In the case of touch buttons, the touch controller sends the ON/OFF status to the application processor. An example of touch controllers are Cypress’s TrueTouch and CapSense controllers.

**Haptics processor:** The Haptics processor consists of control software and algorithms that generate the haptics waveforms required to drive an actuator. The Haptics processor can be implemented in the following forms:

- Integrated with application processor/MCU
- Standalone processor
- Integrated with touch controller
- Integrated with actuator driver IC
**Haptics processor integrated with Application processor/MCU:**

In applications where the application processor/MCU has processing bandwidth and hardware resources, the haptics processor can be integrated into it as shown in Figure 3. This method eliminates the need for a dedicated haptics processor, reducing BOM cost and saving board space.

To generate different haptic effects, designers can create custom software or they can license the software from haptics software vendors. Creating custom haptics software can require substantial design effort, time, and added cost. However, the advantage of custom haptics software is that designers can optimize haptics effects to suit their end application.

In order to reduce design effort and time, designers can license haptics software from vendors or they can use a controller, which supports haptics software. An example of an MCU which comes with a built-in haptics software library is the Cypress PSoC1 controller.

**Haptics processor integrated with a standalone processor:**

In applications where the application processor/MCU does not have bandwidth or resources to integrate haptics processing, a standalone processor/MCU can be used as a haptics processor. In most case, this method is not preferred because it increases cost and board space.

Haptics processor integrated with touch controller: There are touch sensing controllers that also integrate a haptics processor. For example, the CapSense has robust capacitive touch sensing hardware and uses Immersion’s TouchSense haptics library to provide haptics feedback. Integrating the haptics processor into the touch controller reduces the load on the application processor/MCU and provides a cost-effective implementation.

**Haptics processor integrated with actuator driver:**

There are a few actuator driver ICs available with an integrated haptics processor. This method is suited when haptics feedback needs to be implemented in an existing touch user interface. Using an actuator driver IC that has an integrated haptics processor in an existing touch interface minimizes the changes required to the application processor/MCU firmware and board design. The application processor can send the appropriate command to the actuator driver IC to generate haptics waveforms.

**Actuator:**

The actuator is electro-mechanical component used to generate vibrations and provide touch feedback to the user. The haptics processor provides the input to the actuator. The actuator will be integrated with the touch user interface so that it vibrates the device when the input is applied to the actuator.

**A variety of Actuators**

There are various types of actuators used in a haptics system. The most common are:

**Eccentric Rotating Mass (ERM) actuator**

ERM actuator is a DC motor with an offset mass attached to the motor shaft as shown in Figure 4. Because of the offset mass attached to its shaft, when the motor spins, the centripetal force of the offset mass will be non-uniform and results in a net centrifugal force. This centrifugal force causes displacement of the motor. Because the motor is attached to the device, the motor displacement results in the vibration of the entire device. The input to the ERM motor is a DC voltage. The input voltage of an ERM motor ranges from 1 to 10 V, and the operating current ranges from 130 to 160 mA. The frequency of operation ranges from 90 to 200 Hz. ERM motors are inexpensive and provide
strong vibrations. However, they have a very large response times (40-80 ms) and hence are not suitable for high quality haptic feedback. ERM motors are used in mobile phones to provide simple haptics effects such as vibration alerts.

Linear Resonant Actuator (LRA) - The LRA consists of a movable mass, permanent magnet, voice coil, and spring to generate vibrations as shown in Figure 5. When a sinusoidal input is applied to the voice coil, it produces a magnetic field that interacts with the permanent magnet, causing it to move linearly. The permanent magnet pushes the movable mass up and down, resulting in vibrations. The spring attached to the movable mass brings it back to its initial position. The input to LRAs is a sine wave. The operating voltage of LRAs ranges from 2.5 V to 10 V, and the operating current ranges from 65-70 mA. The typical operating frequency (resonant frequency) of an LRA motor is 175 Hz. LRAs have a faster response time (20-30 ms) compared to ERMs and are capable of providing more precise and softer vibrations. LRAs are commonly used in smart phones to provide touch feedback while typing keys on the virtual keypad.

Piezoelectric Actuators:

Piezoelectric actuators work on the principle of the inverse piezoelectric effect in which application of a voltage to the piezoelectric crystal leads to a physical deformation of the crystal. This physical deformation is used to generate vibrations to provide touch feedback. Piezoelectric actuators are made up of ceramic materials. The input voltage to the piezoelectric actuator is a sine wave. The operating voltage of a piezoelectric actuator ranges from 50 -200 Vpp and the instantaneous current...
can be as high as 300 mA. The operating frequency of piezoelectric actuators ranges from 150 to 300 Hz. These actuators are lightweight, have a thin form factor, and provide a fast response time (< 1ms), making them suitable for providing high quality haptics effects in mobile phones and tablets.

Actuator Driver Circuit/IC:
The output voltage/current from the application processor/MCU is usually not sufficient to drive actuators. For example, a typical ERM motor requires a current of 130-160 mA current. To drive an actuator with this current, an external driver circuit is required.

The driver circuit can be designed using one of the following:

Discrete components - The driver circuit can be constructed using discrete components such as a BJT or MOSFET. Many applications use a MOSFET because they are highly efficient when compared to BJTs. A simple high-side motor driver circuit is shown in Figure 7. In this circuit, the MOSFET is operated in the saturation region to act as a switch. Applying a PWM signal to the input of the MOSFET controls the speed of the motor. The advantages of designing a driver circuit with discrete components are increased flexibility and greater design control. The disadvantages are increased design complexity and greater board space.
Dedicated actuator driver IC/ Amplifier IC:

The most common method to drive the actuator in a haptic system is by using a dedicated actuator driver or an amplifier IC. Audio amplifier ICs can be used in applications where simple haptics effects such as vibration alert, single/double click are used. To provide advanced haptic feedback effects, you can use a dedicated actuator driver IC. These actuators are designed to optimize haptics feedback effects by controlling the input voltage/current to the actuator. Also, as explained earlier, there are few actuator drivers with a built-in haptics software library. Designs that cannot implement haptics processing in the application processor can use an integrated haptics driver IC.
References:

Cypress CapSense and TrueTouch Controller - http://www.cypress.com/?id=1932


Cypress TS2000 Haptics User Module Datasheet