Haptics in Touch Screen Hand-Held Devices

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1   Introduction

Haptic technologies enable consumers to perceive touch sensations when using electronic devices. The touch sensation, created by an actuator embedded in the device, makes a virtual experience seem more physical and realistic.

Manufacturers have installed haptics in hundreds of millions of touch-screen consumer devices and the technology is becoming increasingly important in the hand-held market as vendors strive to differentiate their products and win customer loyalty. A broad range of technology options are available. This article summarizes the hardware and software comprising a haptic system and the technical factors that must be considered when selecting an actuator technology for a hand-held device.

2   Designing a Haptic System

Haptic sensations are created by an actuator or motor that is controlled by embedded software and integrated into a device's user interface via control software APIs. Adding an actuator to a device requires a systems-level integration approach to ensure components and software work together to create the best user experience.

A haptic system must integrate the following components:

- ***Actuator –*** In hand-held devices, the actuator is typically mounted in a corner of the device casing to maximize the vibrations felt by the hand holding the device.

- ***Electronics –*** A haptic system in a hand-held device will use a power amplifier to drive the actuator. The power amplifier takes device battery voltage (or a regulated 3V) as the power source. A control signal input modulates the voltage applied across the actuator for a designated time period.

- ***Control Software –*** This is the brains of a haptic system and it should be fine-tuned to the capabilities of the system's actuator. The controller takes an abstract instruction from a software application and runs a control algorithm that will continually adjust the voltage applied across the actuator to create the desired sensation.

- ***Application Software –*** This is the software application that is visible to the device user. It coordinates the playback of touch effects according to prescribed user-interface events. Haptic behavior can be implemented at the application or OS level.

3   Criteria for Selecting an Actuation Technology

Several factors must be considered when selecting an actuator for a hand-held product. While cost and vendor relationships are always critical in purchasing decisions, design criteria determine whether an actuation technology is suitable for a particular device and this frequently influences cost and performance. The most important design criteria include the actuator's size and form factor, durability, its dynamic performance (the actuator's rise time, expressed as the mechanical time constant), and its vibration strength (which depends on the motor used, the mass of the device and device integration).
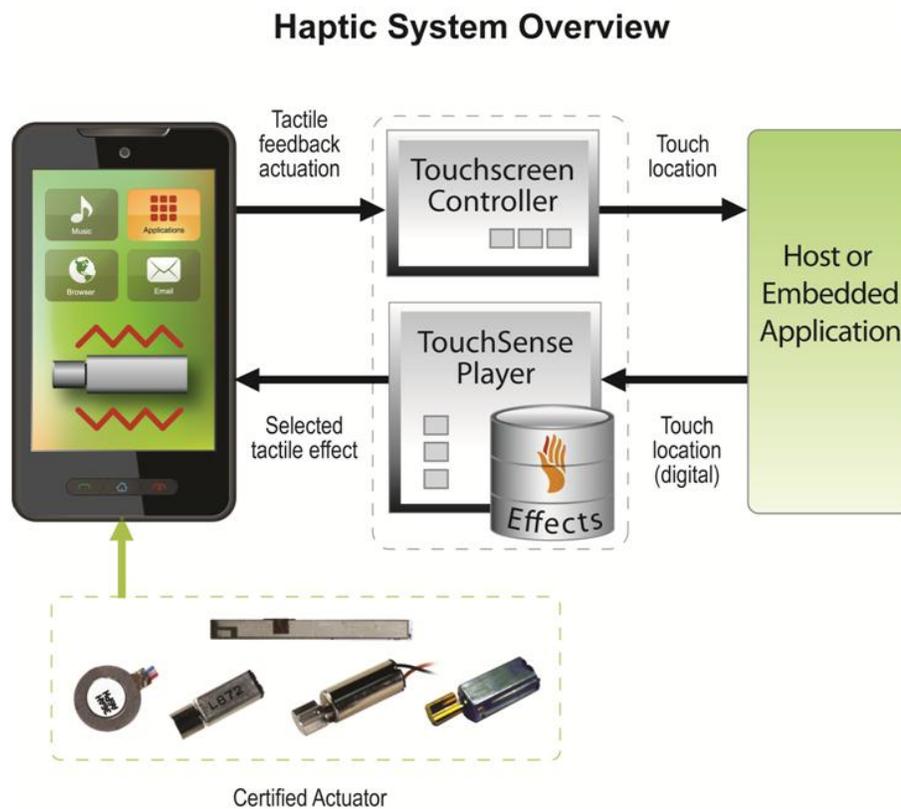
3.1   Types of Actuators

Four types of actuators are used in haptic systems and each has specific functionality and performance characteristics that will influence its suitability for a particular product. Immersion works with companies that support all types of actuators and, upon request, can provide a list of vendors it has certified for use with its haptic solutions.

3.1.1   Eccentric Rotating Mass (ERM) Actuators

ERMs are best used for slow, deliberate user-interface applications such as gaming rumble effects. ERMs are produced in tremendous volumes therefore provide one of the most cost-effective actuator alternatives for mass-market devices.

Typically bar-shaped and as small as 11 mm in length with a swing diameter of 4.5 mm, an ERM takes up little footprint on a device. ERMs have a current requirement of 130-160 mA during operation. They vibrate at frequencies within the 90 to 200 Hz range, although they tend to be much weaker at the lower frequencies. They have a relatively high mechanical time constant (around 50 ms), which is not suitable when providing touch sensations for fast typing on a virtual keyboard. Durability is good to excellent, depending on the model.

Coin motors are very inexpensive and very thin (2mm high and 10 mm diameter). However, except for the very best of these products, most coin motors are extremely sluggish, not durable, and unsuitable for haptic applications.

3.1.2   Linear Resonant Actuators (LRAs)

LRAs are well-suited for haptics and are therefore used in many smartphones. LRAs have a hockey puck form factor. They can be as small as 10 mm diameter by 3.6 mm height, and vendors are developing even thinner designs. LRAs require AC input and use the signal to vibrate a mass at a single frequency within the 150-200 Hz range. The devices draw current at around 65-70 mA. They have a mechanical time constant of about 30 ms. LRAs are durable because they have no bearings and the parts are not subjected to friction. They are more costly than ERMs and they require more sophisticated control to prevent resonant ringing.

3.1.3   Piezo Modules

Piezo modules are high-performing actuators and can be used to create high-fidelity haptic effects. They can easily fit into tablet devices and the technology is advancing to allow their integration into new smartphone designs. These modules, currently available in a matchstick form factor, can measure 3.8 x 3.6 x 42 mm.

Piezo modules have many advantages. They have a superior mechanical time constant (less than 5 ms) and can create haptic effects that are as short in duration 2 ms, which makes them suitable for touch typing feedback. They vibrate at a wide range of frequencies (150 to 300 Hz), which provides the flexibility to create a variety of highly nuanced touch sensations.

Piezo modules do come at a cost. They need an amplifier that can drive the capacitive load of roughly 50 nF at up to +/- 70V. The required instantaneous power draw is high—roughly 300 mA at 3V supply—but in practice they consume no more energy than ERM/LRA options. Piezo modules are very durable despite

their inherently brittle ceramic material; they've been engineered to survive the rigorous drop test regimens typical for handheld devices.

3.1.4 Electro-Active Polymer Actuators (EAPs)

Electro-active polymer technology is used in high-end smartphones. An EAP actuator is a wide but very flat panel (45 mm x 38 mm x 0.8 mm) that is affixed to an external movable mass, typically the device's own battery, which is then mounted in a sled that is engineered to resonate anywhere from 90 to 125 Hz. The EAP mechanical time constant is in the low milliseconds.

EAP solutions require electronics that can generate an 800 V signal. The sled can be challenging to integrate into very tight spaces, but the actuator material itself is extremely thin and can have excellent durability. An EAP solution offers similar performance to a Piezo module.

Actuator Types and Characteristics				
	ERM	**LRA**	**Piezo Module**	**EAP**
Form Factor	Bar or hockey puck	Hockey puck	Matchstick	Flat panel
Approximate Size	11 x 4.5 dia. mm	10 x 3.6 mm	3.5 x 3.5 x 42 mm	45 x 38 x 0.8 mm
Power Requirements	130-160 mA RMS @3V	65-70 mA RMS @3V	300 mA RMS @ 3V	Ask vendor
Frequency Range	90-200 Hz (non-uniform strength)	150-200 Hz, single frequency (e.g. 175 Hz)	150 to 300 Hz usable	90 to 125 Hz (resonant peak), 50-200 Hz usable
Mechanical Time Constant	50 ms	30 ms	<5 ms	<5 ms
Durability	Variable	Very durable	Very durable	Excellent
Fidelity of Sensations	Low	Medium	High	High

4   Electronics Requirements for Each Actuation Technology

A haptic system needs appropriate drive electronics to provide the current levels necessary to induce vibration.

For hand-held systems aimed at large-volume production and that have ample processing power on the device's main processor, the electronics are provided by a simple command interface and a power stage. For systems that do not have a lot of onboard computing power, two options are available. One option is to add a small microcontroller to perform the control operations needed to create the desired haptic effects. The other option is to embed the haptic controller as function block included in a multi-purpose microcontroller if one is available in the device and has the horsepower available to perform this added function.

4.1   ERM Electronics

ERMs can use any of the electronics integration methods described above. For smart phones and tablets, ERM electronics will run control software on the main processor and use either a pulse-width modulated (PWM) or inter-integrated chip (I2C) command to transmit the output control signal, which designates the voltage value that the power amplifier should apply across the actuator leads. The control signal is bidirectional, so positive and negative voltages can be applied. It is updated by the software controller at 5 ms intervals, and at each interval, a new voltage value can be commanded. Immersion's TouchSense 3000 Controller works in this manner.

ERM electronics can also use a microcontroller to store a number of touch effects onboard. In this case, the microcontroller plays the role of the main processor and feeds the control signal to the power amplification component as described above. Immersion's TouchSense 2000 uses this concept in many consumer electronic devices and in some mobile phones.

Alternatively, ERM electronics can embed the haptic controller into a function block of a multi-purpose microcontroller. For example, a microcontroller could include a haptic controller block that is added to the capacitive button sensing functionality on the chip. The microcontroller can then be connected to the power amplification circuit.

4.2   LRA Electronics

LRAs, which are most prevalent in mobile phones, usually run control software on main processor. The controller communicates the drive frequency via a PWM signal or I2C command to the power amplifier. LRAs require an AC drive signal whose frequency corresponds to the actuator's resonant frequency (typically 175 Hz), and the LRA power amplifier provides this capability. A square wave is fine for this. The control signal is updated at 5 ms intervals. The TouchSense 3000 is used to drive LRAs.

LRAs are increasing in popularity and the electronics industry is responding by adding extra functionality to the components. LRA amplifiers that have "auto-tune" functionality are the most important of these new devices. Auto-tune amplifiers can automatically lock on to the LRA's resonant frequency, which optimizes performance and eliminates the experimentation, decision-making and manual programming otherwise needed to integrate these devices. Auto-tune amplifiers can also be used to control the resonant ringing that often occurs in poorly-tuned LRA systems.

4.3 Piezo Module Electronics

Piezo modules employ the main processor in a device to run control software. Piezo modules have more bandwidth to work with than the other actuators and thus their input signal is richer. Piezo module electronics are also slightly more sophisticated than those used for other actuators. The electronics offer a limited amount of data buffering to allow the main processor to send haptics effects data in discrete packets at designated time intervals. The electronics also read the buffer and update the applied voltage level as needed. Immersion's TouchSense 5000 is used with Piezo modules.

Immersion recommends driving these actuators with a signal that is analogous to an 8 kHz 8-bit PCM data stream. The TS5000 produces 80 bytes of data when first launching a haptics effect followed by 40 bytes of data every 5 ms and transmits the data to the electronics via the appropriate bus. First-generation Piezo module electronics solutions use an I2C bus because of its widespread availability in mobile device platforms. The data stream can be sizable, especially on 400 MHz I2C buses, so care must be taken when adding Piezo electronics to make sure other I2C devices do not generate much traffic during touchscreen interactions. Second-generation electronics solutions for Piezo modules will be more tightly integrated than earlier technologies and therefore use fewer components and require less footprint on the device. These are in preproduction and forthcoming from vendors. They should be available in the first half of 2012.

4.4 EAP Electronics

In general, EAP electronics must generate 800 V of output in order to effectively drive the actuator, but EAP components from different vendors can have vastly different electronics needs. Companies planning to use EAP actuators should contact the vendor to determine the electronics drive requirements needed. The TouchSense 5000 can be used with EAP technologies.

5   Embedded and Integration Software

Immersion offers a portfolio of embedded software solutions and development tools for use in designing and implementing haptics effects in mobile devices.

5.1   TouchSense 3000

The TouchSense 3000 is fairly prevalent in the market. It has been deployed in more than 300 million mobile devices worldwide. The solution includes a driver package designed to operate a single ERM or LRA and a haptics application programming interface (API) that programmers can use to create, launch and modulate haptic effects from an application. TS 3000 can be used with a number of mobile operating systems, including Android.

The TS3000 comes with all binaries and documentation needed to successfully integrate the software. The integrator's main task is to link the TS3000 controller's output commands to the communication hardware, typically a PWM unit, or via I2C commands. The TS3000 executes commands at 5 ms intervals during haptics playback, sending a new voltage command signal to the electronics. It produces a single byte of data each time. It is also responsible for shutting down the drive electronics when they're not in use. Developers can use Immersion's Haptic Studio to create more sophisticated effects with the TS3000.

5.2   TouchSense 4000

The TouchSense 4000 is identical to the TS3000, but it can control up to 16 ERMs and LRAs. It is used to coordinate and control the individual behaviors of multiple actuators in a device to maximize the effectiveness of the haptics experience. This capability is important in mobile gaming applications, for example, which often require multiple actuators to produce effects similar to those experienced on console gamepads.

While the TS4000 API can be used to control multiple actuators, it is otherwise identical to the TS3000 API. Integration is also similar, although the TS4000 expects each actuator to have its own dedicated amplifier and the controller must provide output commands for each actuator used. Developers can use the Haptic Studio with the TS4000 to create advanced effects and to coordinate the vibrations among many actuators.

5.3   TouchSense 5000

TouchSense 5000 is designed to control Piezo modules and EAP solutions. It incorporates all features offered with the TS3000 and TS4000, but offers significant upgrades. For example, it generates a wider variety of output waveforms and it also generates a finer-grained control signal, which allows it to create superior haptics effects.

The TS5000 controller has two features, a synthesis engine and a sampling engine, which give designers a wide variety of approaches and options for creating high-fidelity haptics effects. The synthesis engine takes high-level haptics parameters, which the designer can define through an API or develop in Haptic Studio, and generates the desired haptics effects in real time. The sampling engine takes signal input and applies it to the actuator. Both engines can run concurrently to enhance haptics effects.

TS5000 integration is very similar to that used with the TS3000. The main difference is the greater amount of data produced and transmitted by the TS5000 and its use of a data buffer to improve performance.

5.4 Integrator

Integrator is a tool that developers can use in conjunction with TouchSense controllers to add haptic capabilities to the operating system of Android devices. The current release, v. 1.5, includes a number of modules that can be integrated, as desired, depending on the level of haptic functionality needed.

The *UI Module* available in Integrator can be used to add haptic capabilities to more than 150 UI widgets in Android. The *Themes Manager Module* provides a selection of haptics themes that developers can apply to the Android OS and applications; once installed, end-users can choose among the themes to customize their device. The *Reverb Module* is a software algorithm that creates haptic sensations from the device's audio output. The module can be used for applications, such as games, which do not include haptics code. It can also create a subwoofer effect for music. The *WebKit Module* can be used to add haptic effects to a number of browser-based interactions. The *Ringtone Module* can be used to associate a variety of haptics effects with audio ringtones, to provide a tactile and unique means of identifying a caller when a smartphone is in silent or vibrate mode.

5.5 Haptic SDK

The Haptic SDK is a platform developers can use to optimize haptic effects for all Android devices that have an onboard actuator. The Haptic SDK provides a Universal Haptic Layer (UHL), which can be used to quickly integrate haptic features in applications. The UHL includes an easy-to-use Launcher class that developers can use to call up a predefined haptic effect for playback in an application. The Haptic SDK also provides Haptic Studio, a haptic design tool for developers and haptic designers. Studio is a Windows-based application that allows a developer to connect the mobile device to a PC to conveniently create, preview and tweak haptic effects.

The Haptic SDK is available for download at developer.immersion.com. The site provides documentation, sample code, and an online forum that developers can use to ask questions pertaining to their haptics implementations.

6   Best Practices for Haptics Design

As with any technology that influences the user interface of a device, haptics must be designed thoughtfully in order to achieve the desired effects. Once a software designer has selected a technology for their device, Immersion recommends employing haptics design best practices to ensure a superior user experience. "Enhancing Your Device Design through Tactile Feedback," an Immersion white paper, is one example of design resources available from Immersion. To download a copy of the paper, visit this link: http://www.immersion.com/docs/Enhancing-Device-Design-Through-Tactile-Feedback.pdf. Additional design resources and guidelines are available by contacting Immersion directly.

7   About Immersion

Founded in 1993, Immersion (NASDAQ:IMMR) is the leading innovator in haptics technology; the company's touch feedback solutions deliver a more compelling sense of the digital world. Using Immersion's high-fidelity haptic systems, partners can transform user experiences with unique and customizable touch feedback effects; excite the senses in games, videos and music; restore "mechanical" feel by providing intuitive and unmistakable confirmation; improve safety by overcoming distractions while driving or performing a medical procedure; and expand usability when audio and visual feedback are ineffective. Immersion's TouchSense technology provides haptics in mobile phone, automotive, gaming, medical and consumer electronics products from world-class companies. With more than 1200 issued or pending patents in the U.S. and other countries, Immersion helps bring the digital universe to life.

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