Localized HD Haptics for Touch User Interfaces

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Haptic, or tactile, feedback has rapidly become familiar to the vast majority of consumers, mainly through their mobile devices. At the same time touch switches are increasingly replacing mechanical switches in appliance markets. The need for haptic feedback in the mainstream appliance markets is apparent, but implementations are still lagging behind. The main reasons have been the difficulty of implementation, the high cost of available technologies, and touch switch performance issues impacting reliability and quality.

On the technical side there are two obvious obstacles. Firstly, most haptic output solutions are based on shaking the whole device or the whole user interface module, which is hard to implement in larger appliances and cannot convey a quality experience for the user. Second, there is the challenge of reliably adapting a single solution to a wide range of devices or panel overlays in a way that is feasible for high volume production.

This white paper discusses how the revolutionary AitoHapticTouch, based on its software-enhanced piezo (SEP) technology, removes those bottlenecks and enables an energy-efficient user input of unparalleled quality with truly localized haptic feedback that operates through a wide variety of materials, including stainless steel. All in all, this is a compelling haptic touch-switch solution for consumer appliances.

1. Market needs

1.1 Need to feel

The need to feel the button while pressing it is a universal requirement for any button, including touch buttons. Providing correctly designed and timed haptic feedback to the fingertip of the user satisfies this need intuitively, significantly enhancing both the usability and user experience of a touch button interface.

There is also the importance in being able to recognize the location and activation of switches on everyday appliances especially when addressing the accessibility demands of otherwise inanimate touch surfaces.

1.2 Easy applicability and cost efficiency

Adding haptics to a user interface needs to provide a fluent user experience and be easy to accomplish in terms of technical complexity, as well as regarding logistics and manufacturability, including multi-sourcing of every component. The cost of integration also needs to be in line with the benefit achieved by adding haptics to the interface.
To ensure technical compatibility across the wide range of different appliances offered by large manufacturers, easy configurability is essential to readily applying haptic technology. The solution must to be able to provide desired feedback and user experience while using a similar layered mechanical and electrical switch construction regardless of the different overlay materials, their thickness, the integration environment and usage conditions.

1.3 Design freedom

The designer of a product always wants the greatest freedom to determine all aspects of its appearance, behavior and usability, within the potential constraint of maintaining uniformity across a company's product portfolio. Regarding user interfaces, this means a consistent and controlled user experience over different units of the same product, over different product models and possibly even across different product lines.

In an ideal scenario, the designer will design and test a holistic interaction experience once and then apply this to a multitude of devices, only needing to adjust device specific parameters for a given product model.

1.4 Feedback quality

It is one thing for a designer to have a goal in mind for how the different devices in the product range should behave and feel when used but such design freedom is rare. Turning concept into reality and faithfully delivering the desired user experience needs to take account of other factors, such as different usage situations, product aging, and so on. Normally a designer has to take account of all the development stages from the initial design phase through to implementing the low-level actuator driver required by a particular application. In an ideal system the design tools would take care of all these issues leaving the designer confident of being in control and achieving a quality solution.

2. Approach - integrated haptics & touch sensing

To address the needs of both end users and consumer appliance industry, Aito has chosen to expand its market-proven ATB (AitoTouch button) technology by adding a haptic feedback channel, in addition to the existing auditory and visual (LED) feedback channels.
2.1 Standard components, easy integration

All the components used in the solution are standard off-the-shelf components, available from multiple sources, starting with the piezo disc itself.

*Figure 1. Piezo discs typically measure 10-20mm diameter and 200µm thick*

The discs are installed on the back of the user interface in a simple mechanical stack. The material stack adds only 0.3 mm to the height of the printed circuit board (PCB). The stack is easily manufactured and integrated onto the PCB by following Aito design guidelines, which use industry-standard processes.

*Figure 2. Piezo discs are layered into a mechanical stack between the PCB and panel overlay*
All the other mechanical and electrical elements required in the construction of this touch panel stack are standard components, including the AitoChip, which provides the interface between the haptic piezo keys and the equipment’s host processor. Design guidelines provide all necessary technical details for component selection as well as their integration into the target application.

2.2 Tight integration with touch sensing in many levels

The unique feature of Aito haptics is that it builds on the existing AitoTouch software-enhanced piezo (SEP) technology, creating haptic feedback using the very same piezo ceramic sensor used to detect user input. This results in a minimalist solution using a single physical element behind the touch surface to provide both input and output, enabling haptic feedback with “feather touch switching” seamlessly through any material.

Figure 3. The interconnected elements of an SEP haptic touch design

Haptic touch control solutions need to be tightly coupled to ensure ‘real time’ feedback in response to user inputs. This coupling, or control loop, must operate in under a millisecond, to provide a consistent and effective user experience. In Aito’s solution this is inherently provided by the AitoChip, which reads inputs and directly controls the generation of feedback.

By comparison any design that requires a host processor to monitor one circuit for touch sensing, and another circuit for generating a feedback signal, may not be able to provide the necessary timing precision. Here ‘precision’ not only means a very small response time, but also a response that is predictable and consistent.
2.3 Direct drive

Aito’s integrated haptic solution fully utilizes the characteristics of piezo technology. So, rather than the piezo disc generating an electrical signal when pressure is applied to it, it is possible to cause the piezo disc to vibrate in response to an applied electrical waveform. This requires a much higher voltage, which is achieved with a boost converter circuit built around the AitoChip using standard low cost components. This boost converter is directly controlled by the AitoChip and creates all the required voltages and signal timing. This enables some distinctive benefits:

1) Maximum energy conversion efficiency
2) Higher voltages with the converter only active for the duration of the feedback pulse
3) Instantaneous start-up with no delay or lag caused by the actuator or drive electronics
4) The Aito Chip directly controls the shape and timing of the haptic waveforms

2.4 Configurability - scalability

The ability to configure the AitoChip for a multitude of different environments and usage situations has been a driving force behind Aito’s solutions from the very beginning. As with the earlier series of touch sensing products, the haptics enabled chips provide extensive registers that provide the flexibility to cope with various requirements, such as different overlay parameters, adjusting button sensitivity, and configuring how the feedback is felt, heard and seen by the user while operating the keys.

In combination with the benefits of direct drive and having input and output operations controlled by a single dedicated chip, the configurability offered by the AitoChip provides for a truly versatile haptics feedback capability.

3. Benefits

3.1 Design freedom through localized HD haptics

High Definition haptics, or “HD haptics”, is usually defined as haptic feedback that provides a wider range of feedback sensations than first generation rotating motors, which only produce vibrations a limited frequency range. Faster response times are also considered to be a defining characteristic for HD haptics.

In a more holistic sense the measure of a good quality touch user interface should reasonably take account of the following attributes:

1) Localization – localized feedback, just to the user’s fingertip(s)
2) Real time response – a fast (<ms), predictable and controlled response to a user input
3) Wide dynamic range – feedback that provides a range of frequencies and amplitudes
4) Configurability – separate controlled responses that are configurable per key or finger
In many applications, the omission of any of these attributes would diminish the potential user experience and might even limit the effectiveness of haptic feedback by not allowing the user to discriminate different responses. In the worst case, inconsistent feedback could confuse or mislead a user. AitoChip addresses all these points with a production ready solution.

### 3.2 Quality via true localization

The most important point in design freedom is the ability to localize haptic feedback to the user’s fingertips, instead of shaking the whole device, or even the whole user interface. In larger appliances such “mobile phone like” shaking would firstly require significant energy, and secondly would make it very hard to convey the feeling of sophisticated quality. Aside from which, such levels of vibration could lead to mechanical equipment failure over time, even if isolated to just the touch switch module.

Tight mechanical integration of the user interface, along with optimized hardware and the intelligent control methods of Aito’s haptic solution enable the generation of haptic effects just under the fingertip, without shaking or moving any other part of the touch surface. This enables several notable advantages:

- Sophisticated quality feeling for the user
- Minimal energy required, as it is only consumed for moving the required small part of the interface under the fingertip
- Avoids shaking other parts of the equipment and potential mechanical failure with age
- Even avoids having seams on the user interface as the Aito Haptic solution is able to locally actuate even metallic overlays, including stainless steel

![Localized surface bending (exaggerated)](image)

*Figure 4. Haptic feedback can be localized to the user’s fingertip even through a metal overlay*
3.3 Scalability

One of the key values of the AitoHapticTouch solution is the ease with which it can be applied in high volume production across a range of appliance designs i.e. the same control chip with similar mechanical integration can provide a common user experience with many different overlay materials.

And, because the haptic feedback feature builds on established AitoTouch technology, utilizing the same stack integration behind overlays, it is also extremely easy to create user interfaces with and without haptic feedback for different models in a manufacturer’s product line.

4. Benchmarking

Haptic technologies can be mapped in two dimensions to distinguish between simple vibration versus HD haptics and the localization of feedback, from whole body actuation to truly localized.

**Figure 5.** Haptic feedback technologies can be mapped according to the size and weight of a device or appliance and the quality and localization of feedback required

4.1 Eccentric mass and linear actuators

Until now, two of the most commonly used types of haptic actuator are: Eccentric Rotating Mass (ERM) motors, or Linear Resonant Actuator (LRA) modules that use a magnetically actuated
linearly moving mass. Of these the latter typically achieves lower power consumption than an ERM motor because they can be driven at the natural resonant frequency of their internal spring element. Another difference between ERM and LRA is that LRA produces, as the name suggests, linear movement, whereas the ERM’s rotating motion creates vibration in a plane perpendicular to its rotor.

Although common, not even the latest versions of such actuators are capable of HD haptic feedback. More importantly both are always constructed to shake either the whole device, or at least the overlay of the user interface, with a mechanically loose (floating) connection to the main body of the device, allowing it to move separately. In theory one actuator per key could be an option to achieve localization, but the cost of components alone would make this a very impractical solution, even ignoring the mechanical integration challenges.

4.2 Piezo modules

Piezo actuators have previously been used for simple haptic feedback, typically within a complete multi-layer module and driven with high-voltage AC signal. This form of construction is somewhat similar to the use of LRAs, i.e. to either shake the whole device, or just the separate user interface module, or its overlay, for example the touch screen of a device. Driving such a module with a suitable piezo driver can deliver HD haptics characteristics in terms of dynamic range but do not fulfill the requirements for localization and the direct relationship of sensing the button being touched. In addition the total cost of implementation would be high, including the very special actuator modules, and separate sensors are still required for each input key.

4.3 Electro-active polymers

Commonly known as EAP (Electro-Active Polymer), this group of polymer materials behaves somewhat similarly to piezoelectric materials when subjected to an electric field, with the difference being an even larger displacement than piezoelectric materials, but also requiring much higher voltage to induce this movement, typically a kilovolt or more. Industrially mature drivers and methods for handling such voltages, as well as the materials for production are under development, but are not yet available in high volume. In addition the touch sensing function still requires separate circuitry, which adds to the complexity of the total solution, as well as cost.

4.4 Industrial maturity

Apart from EAP, all the haptic technologies described above, including AitoHapticTouch, can be considered as industrially mature, available as “off the shelf” solutions in mass volume. EAP is gradually getting there as well, but is not yet at the level of the others. However, as noted already, only with Aito Haptics is the touch sensing and haptic feedback fully integrated with the same piezo element serving both function and with the AitoChip providing a “conflict-free” user interface. With any of the others the touch sensing technology needs to be selected, sourced, integrated, and tuned to fit together with the selected haptic technology.
4.5 Comparison summary

Comparison of industrially mature haptic technologies:

<table>
<thead>
<tr>
<th></th>
<th>Haptic Touch</th>
<th>ERM/LRA</th>
<th>Piezo modules and EAP</th>
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</thead>
<tbody>
<tr>
<td><strong>Response delay</strong></td>
<td>No significant delay from input sensing to feedback delivery (i.e. below &lt;1ms)</td>
<td>Touch sensing processing delay plus 50-100ms actuator start-up delay</td>
<td>Touch sensing processing delay plus 10-20ms start-up delay of piezo/EAP driver</td>
</tr>
<tr>
<td><strong>Averaged power for “settings input”</strong> (1 press / sec) (1)(2)</td>
<td>&lt; 10mW (including input recognition)</td>
<td>~50mW + input recognition</td>
<td>~30mW + input recognition</td>
</tr>
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<td></td>
<td>~14 days w/2xAA</td>
<td>~2.5 days w/2xAA</td>
<td>~5 days w/2xAA</td>
</tr>
<tr>
<td><strong>Averaged power for fast typing</strong> (4 presses per second) (1)(2)</td>
<td>&lt; 20mW (including input recognition)</td>
<td>~200mW + input recognition</td>
<td>~150mW + input recognition</td>
</tr>
<tr>
<td></td>
<td>~7 days w/2xAA</td>
<td>~½ days w/2xAA</td>
<td>&lt; 1 day w/2xAA</td>
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<tr>
<td><strong>Averaged power for continuous “alarm” buzzing</strong></td>
<td>~100mW</td>
<td>~300mW</td>
<td>~250mW</td>
</tr>
<tr>
<td><strong>Integration</strong></td>
<td>A single stack with same piezo elements to read user input and to give localized HD haptic feedback</td>
<td>Mechanical design to enable floating user interface. Overlay material options limited by selected sensing method.</td>
<td>Mechanical design to enable floating user interface. Overlay material options limited by selected sensing method.</td>
</tr>
<tr>
<td><strong>Total cost of user interface</strong></td>
<td>Low</td>
<td>Medium/High</td>
<td>High</td>
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1) Single AAA battery approximated as 1000mAh @ 1.5V
2) Short and strong “click” type of feedback assumed for key presses

5. Conclusions

In the area of non-touchscreen haptic feedback, there is currently no other technology available that provides all the benefits of AitoHapticTouch:

- The same sensor/actuator element to sense touch and produce haptic feedback
- Suitable for industrial applications and cost efficient with multi-source components
- Maintains a quality user experience regardless integration differences or operating environment, allowing for metal overlays, moisture, etc.
- Real-time controlled haptics with practically no delay (sub-ms) from input to feedback
- Truly localized to the fingertip, offering seamless construction with metal overlays
- High energy efficiency, consuming current only when activated