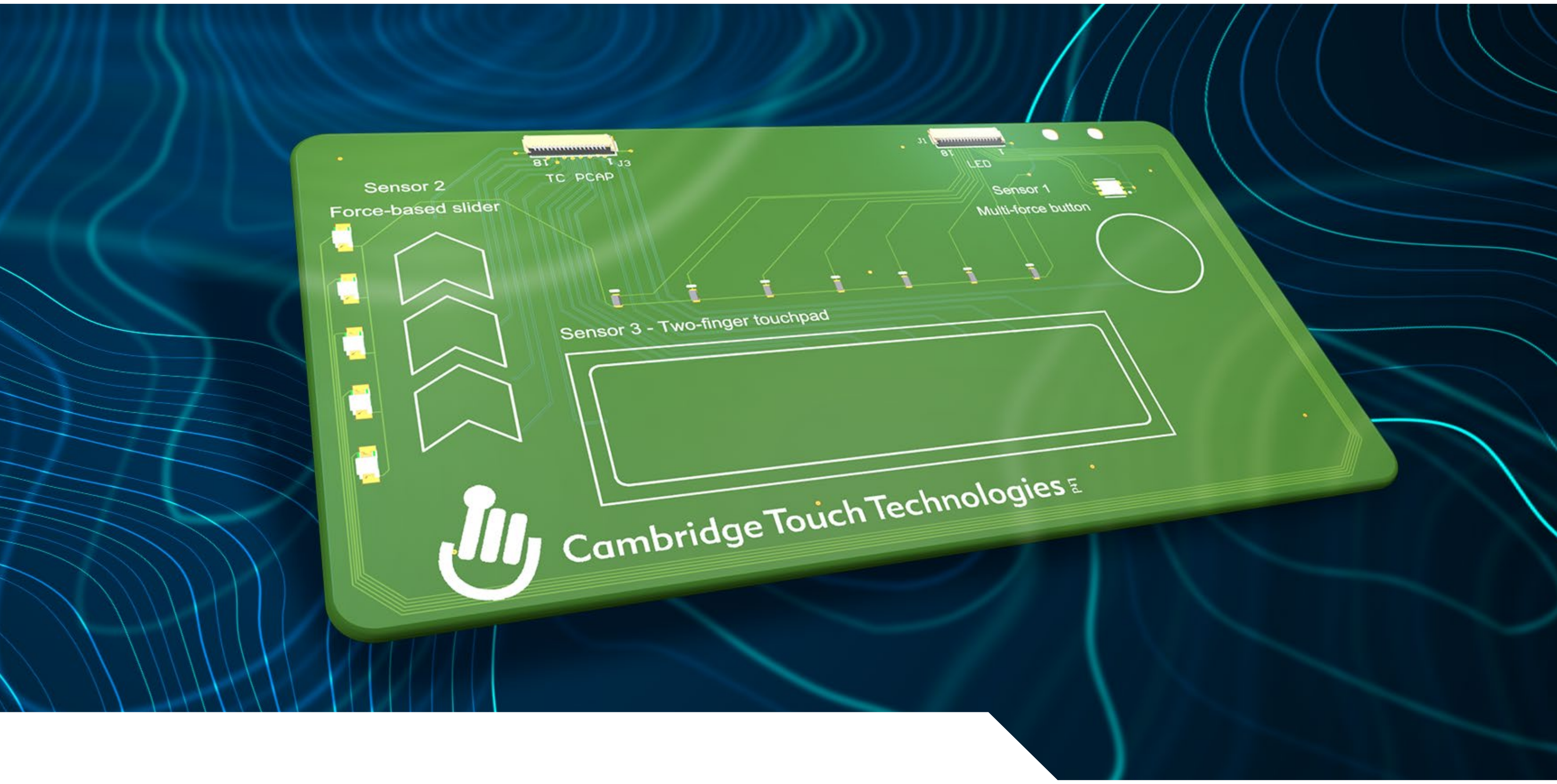


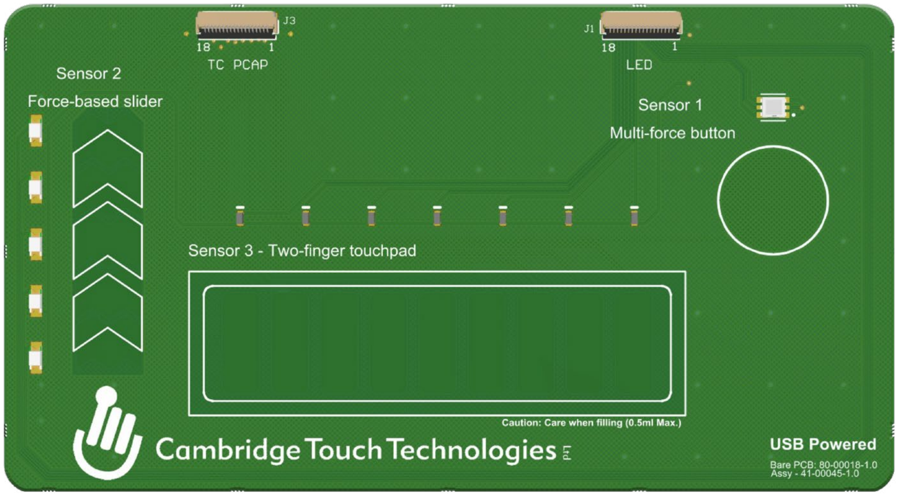
Evaluation Kit Application Note

AI-Powered UltraTouch Technology
for Smart Devices

Cambridge Touch Technologies Ltd

Summary

This application note provides a background on and introduction to touch panel technology, and in particular to the use of embedded piezoelectric films to enable true touch functionality on touch displays and smart surfaces. The basic principles of projected capacitance (PCAP) and piezoelectric sensors are explained along with their relative merits and limitations. The ease of integrating a piezoelectric force and position sensor with PCAP is explained, and the benefits made clear.



The **Cambridge Touch Technologies Evaluation Kit (EVK)** is presented as an example of a smart surface touch panel that combines PCAP with a piezoelectric film force and location sensor. There is a detailed description of the various sensors on the EVK, as well as an explanation of how human needs influence programming for touch response.

Guidance is provided for customising the functioning of the EVK using the optional software interface (UltraTouch Studio), and there are suggestions for possible changes to tailor a touch panel for different application scenarios. Finally, the richness of information that Cambridge Technologies UltraTouch products can gather on human touch is the basis of further innovation in haptics, enabling the human definition of touch to be fully exploited as the 'third sense' in an intuitive two-way human–machine interaction.

Contents

Background

To detect the world around us, we humans are endowed with five discrete senses – sight, hearing, touch, taste and smell – and two combinational senses – vestibular (balance) and proprioception (location of limbs). The electronic miracles of human ingenuity exemplified by the mobile phone and the laptop are only able to interact with humans using two 'senses', namely sight and sound. The ubiquitous 'touch screen' merely responds to the location of our fingers, with the action of touch having to be deduced from things like dwell time or rate of change of finger proximity. This is not always reliable and it confuses our innate instincts, as shown by users stabbing harder on a touch screen when an in-app button fails to respond. In addition, feedback of touch from the machine to human (haptics) is mostly limited to either the vibration produced by a rotating eccentric mass or an audible click, neither of which are true touch senses.

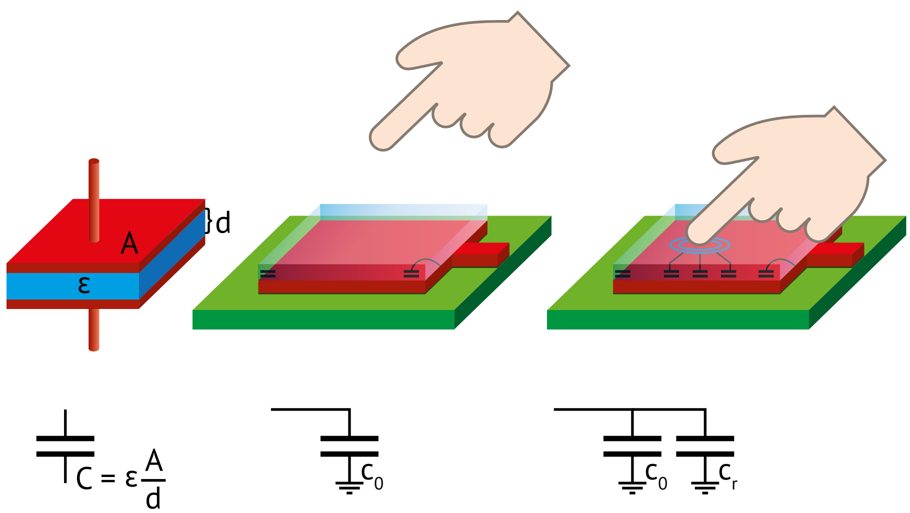
The five discrete senses – sight, sound, touch, taste and smell, and the two combinational senses – vestibular (balance), proprioception (location of limbs)

Clearly, providing a machine with a true touch interface – i.e. one that responds to force, combined with haptics – would extend the scope for interaction with machines to a third sense. By adding touch, human-machine interaction will become more intuitive, richer and ultimately a more satisfying, rewarding and productive experience.

PCAP touch panels

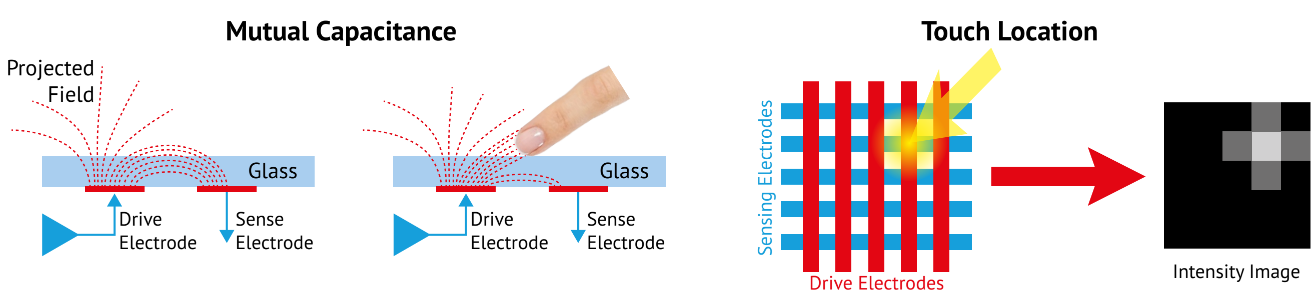
Many engineers will be familiar with projected capacitance (PCAP) touch panels, as they are the current touch technology of choice in virtually all mobile phones, laptops and many other touch screen devices. While PCAP technology exists in many flavours, it is worthwhile reviewing briefly the principles of PCAP, as these help with understanding its merits and limitations as a touch input technology.

In self-capacitance PCAP the sensor can be considered as a capacitor with only one electrode. Close proximity of a finger creates an additional capacitance that can be detected. Self-capacitance PCAP is very susceptible to noise and ghost touches, so has largely been superseded by mutual capacitance.



Self-capacitance PCAP functions by detection of the additional capacitance due to any conductive object in the near vicinity

In mutual capacitance PCAP an array of drive electrodes is used to create an AC field, some of which impinges on the sense electrodes. Proximity of a finger reduces the apparent capacitance between the drive and sense electrodes due to diversion of some of the field. Clever manipulation of the drive electrode waveform is used to improve responsivity, noise immunity and resolution of location.



Mutual capacitance PCAP relies on field leakage to detect the presence and location of fingers

PCAP excels at rapid and accurate determination of finger location, because the array of drive and sense electrodes can be made exceedingly fine. The main limitation of PCAP as a touch interface is that it does not detect what we as humans perceive as 'touch'. In human terms, touch is force, and we can only change the amount of force applied (or determine the amount being applied to us) and its rate of application and removal. A PCAP sensor cannot measure force. It has to use algorithms to deduce these parameters from aspects such as dwell time and change in finger proximity. In the current technology this has not been perfected. On mobile platforms with limited processing power and battery resource the user experience of touch can be quite poor.

The second issue with PCAP is that the sensor relies on the semi-insulative nature of human skin to function. Insulating the finger by wearing gloves means the user cannot operate the touch screen. This might be a mere inconvenience when operating a smartphone, but it has important consequences for the use of touch screens in cars, and in medical and industrial settings where personal protective equipment must be worn at all times. The corollary of an insulator on a touch screen is that the presence of conductive media, notably water on the sensor, can cause the PCAP system to either behave erratically or stop responding altogether. This is why most PCAP touch screens will not work outdoors in wet weather, and certainly not underwater. While this can be improved to some extent through careful design of the PCAP system, it remains the case that a sudden change in temperature or humidity resulting in condensation on a touch screen can temporarily prevent its operation.

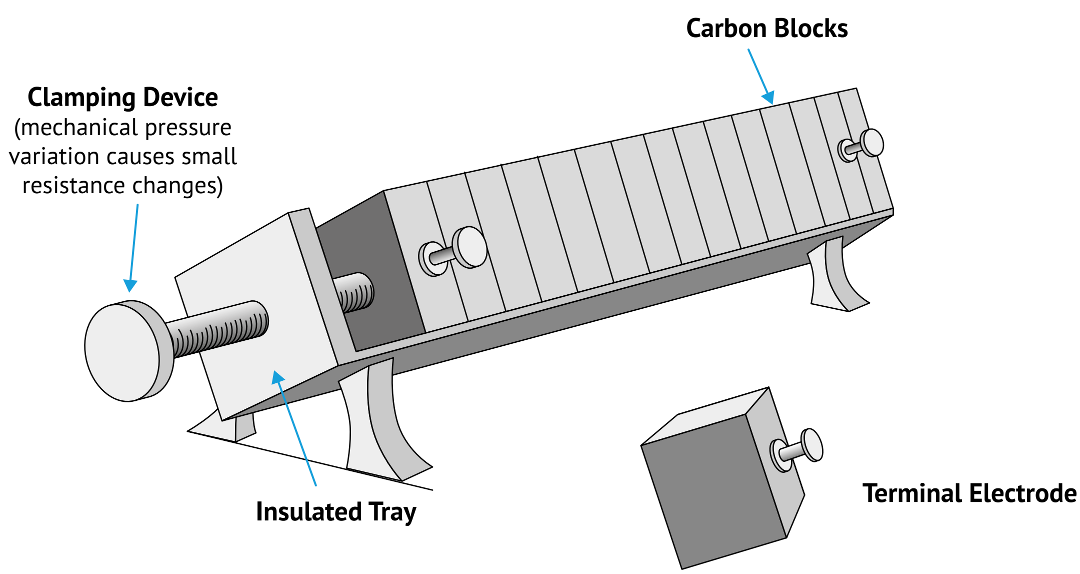
Touch displays are not the only market for touch panels – there is increasing interest in smart surfaces. These are opaque, being made of wood, metal or polymer, yet are still required to detect the location of fingers and the force applied, while remaining immune to ghost touches. Very few PCAP systems are able to function satisfactorily as a smart surface, and innovation in this area is keenly sought.

Concept example of a smart surface with wood finish.
Photo source: The IBT Group; http://www.itbgroup.com/smart-surfaces-potential/

Detection of touch

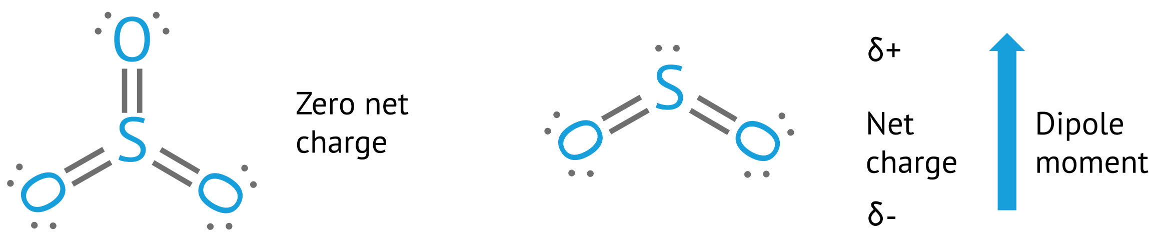
Human touch is essentially force, so it can be detected using a force sensor. While there are many different types of force sensor, only two have achieved the combination of compatibility with displays and commercial adoption. These are resistive touch screens and piezoelectric film touch screens.

Resistive touch screens can trace their origins back to carbon pile resistors. Two flexible sheets are coated with a resistive material and held in close proximity. Touch causes the sheets to contact each other, with the resistance roughly in inverse proportion to force. A resistive touch screen can also give location information for multiple fingers. In recent years, however, resistive touch screens have fallen out of favour. Despite being true touch responsive, low cost and compatible with all screen sizes, perceived or genuine problems with durability, ageing and the need for calibration, coupled with advances in PCAP technology, mean resistive touch screens are now largely confined to niche markets where operation by force is required.



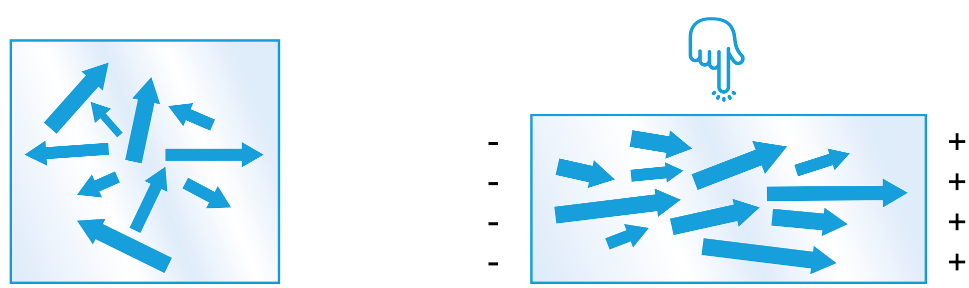
Carbon pile resistor – the applied force changes the contact area and thereby the resistance between adjacent carbon blocks

The piezoelectric effect is conversion, by a solid material, of dimensional change to electrical potential and vice versa. The conversion is linearly proportional. It occurs because many molecules have a slight electrical orientation, called the dipole moment. This is due to a spatial imbalance in the unused valence electrons. For example, compare SiO_3 with SiO_2.



The location of unused valence electrons on molecules means SiO_3 has no dipole moment whereas SiO_2 has a small net charge

In a normal solid material the molecules are randomly arranged at all times and so are all the dipole moments, so there is no net charge on any axis. In a piezoelectric material the application of force changes the dimensions of the solid. To better fill the new volume shape the dipoles align (i.e. polarise), so developing a net electric charge between two faces of the cuboid. This charge is readily detected by an electronic circuit.

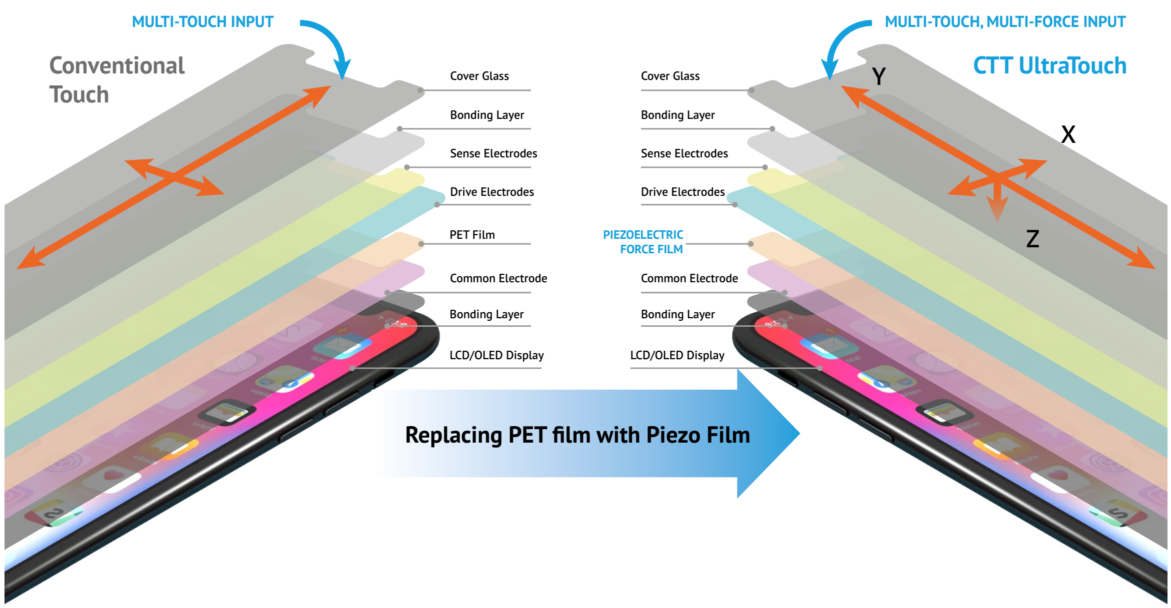


Application of force to a piezoelectric material changes the volume. Alignment of the molecules fills the new volume more efficiently, resulting in a net charge across the material.

First synthesized in the 1930's by DuPont, PVDF (polyvinylidene difluoride) is a fluoropolymer and close cousin of 'non stick' PTFE. It is a piezoelectrically active material that is manufactured in large quantities as a thin film. Other piezoelectrically active polymer films can be produced to optical quality making them eminently suitable for laminating on top of LCD/OLED screens and enabling true touch responsivity.

Piezoelectric touch displays

A PCAP touch screen display comprises multiple layers of materials, each with a different function. One of these is a thin layer of optically transparent polymer film (commonly PET) that acts as an electrical insulator in the PCAP materials stack. Replacing this film with a piezoelectrically active film that is optically and dielectrically equivalent has no effect on the PCAP sensor, but equips the display with true touch sensitivity; that is, both force and location information for essentially no manufacturing cost increment.



PCAP touch screen with PET film replaced by optically identical piezoelectric film to provide true touch functionality

With this changed materials stack a multiplicity of touch operating modes become possible, with seamless transfer between them:

- Location by PCAP, pseudo touch deduction through PCAP algorithms
- Location by PCAP, multi-force detection by piezoelectricity
- Multi-location and multi-force detection by piezoelectricity
- Force detection by piezoelectricity

The beauty of this combinational system is that the precision, speed and responsiveness of PCAP for determination of finger location can be used until it becomes unreliable. Operation through force detection initially increases and then takes over, until it becomes the sole method in service. This covers the entire gamut of desirable use cases of in-app multi-force buttons, gloved hand operation and wet screen environments. In addition, because the piezoelectric effect generates charge from mechanical energy it permits 'wake from sleep' functionality without the power drain of keeping a PCAP system active. As a further benefit, a piezoelectric touch sensor that provides force and location information will operate no matter what the cover material is. This means the cover glass on a display can be replaced by wood, metal, polymer or some other engineered or natural material to create a touch-sensitive smart surface.

Cambridge Touch Technolgies UltraTouch technology

The concept of sandwiching a piezoelectric film in a display or smart surface stack to facilitate touch sensitivity is relatively straightforward. However, analysis of the physics reveals that the electrical charge generated from the touch of one finger is miniscule, and is further masked by noise from the display electronics, PCAP system and other sources. Highly sophisticated electronics and algorithms are required to extract the piezoelectric touch signals and present them to a host controller. How this is accomplished is proprietary to Cambridge Touch Technologies, and some aspects are protected by patent.

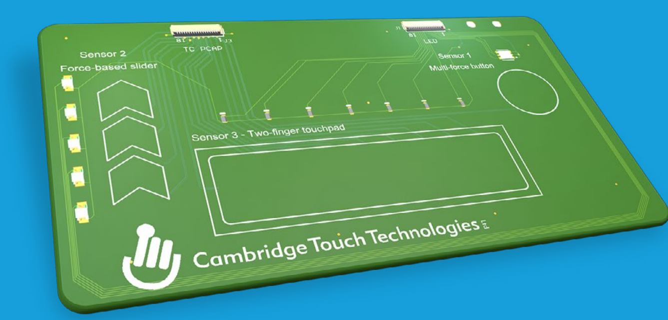
To facilitate easy and widespread adoption of Cambridge Touch Technologies UltraTouch technology, the required analogue electronics and firmware have been integrated into a single application-specific integrated circuit (ASIC). This ASIC has the functionality to communicate with most commercially available PCAP controllers, and an in-built artificial intelligence engine can combine the PCAP and piezoelectric inputs to produce a true multi-force multi-finger touch screen. Furthermore the operating parameters are fully configurable 'on the fly', so different settings can be used if required by the system for each image displayed on the screen. For applications where PCAP cannot be used, such as underwater or smart surfaces, UltraTouch technology provides stand-alone multi-force multi-finger responsivity.

For safety-critical applications a true touch display or smart surface provides a huge benefit in terms of immunity to ghost touches. To trigger a response, not only must the location and applied force be valid, but the signature of the touch must also be correct for a human finger. This provides an additional security measure to ensure touch response is limited solely to deliberate actions.

An example of an UltraTouch smart surface touch panel is provided by the EVK. This is made from two industry-standard FR4 PCBs with a layer of piezoelectric film sandwiched between them, and incorporates electrodes to support full PCAP operation in parallel. The overall structure is essentially the same as for a touch display, but made from opaque FR4 and using standard PCB copper traces as opposed to transparent indium tin oxide (ITO) electrodes.

Cambridge Touch Technologies Evaluation Kit

The Cambridge Touch Technologies Evaluation Kit (EVK) is designed to demonstrate the capabilities of Cambridge Touch Technologies UltraTouch products. It is a fully functional true touch panel right out of the box that is easy and quick to set up. More advanced functions are available by connection to a PC.



Cambridge Touch Technologies Evaluation Kit (computer rendering)

The EVK can detect a very wide range of force, with 255 levels of discrimination. Due to the limits of human dexterity, the firmware is configured to respond to either two or three levels of force, with feedback of detection of touch and position via either the intensity or colour of illuminated LEDs. The maximum force is approximately 10N. For reference, 1N is typical of the force applied by each finger while typing on a low-travel keyboard.

The EVK provides designers and engineers with a platform on which they can experience and configure a true touch-based smart user surface; that is, one where the touch panel sensor is sensitive to force and location of force. This is exemplified by the ability of the EVK to be operated with gloved or bare fingers, and the extreme case of underwater operation in a specially designated test area (available on certain models).

The companion UltraTouch Studio application provides detailed information on the location and force of touch, and permits the user to adjust several operating parameters of the touch panel, such as force thresholds. Communication with the EVK is by standard USB 2.0 protocol, and the drivers are compatible with Windows 10 and above. The application is downloadable from the Cambridge Touch Technologies website.

UltraTouch products can be seamlessly integrated with most PCAP and haptic technologies, to provide a unique and intuitive user experience of smooth scrolling and positive button and slider actuation. Multiple levels of force detection are possible, so a single screen button can be configured to trigger multiple actions. For safety-critical applications, UltraTouch products have two features that provide immunity against ghost touches: setting a minimum force level for touch, and restricting the acknowledgement of touch to the very specific signature of force application and change in fingertip area that a human finger produces. Information on the rate of change of the applied force can also be communicated to the host system, which is a key component in the development of intuitive and natural-feeling haptics.

Applicable product range

Cambridge Touch Technologies manufactures a range of EVKs, each having different feature sets in hardware, firmware and software (the UltraTouch Studio app). This application note applies to:

Hardware – 1.0

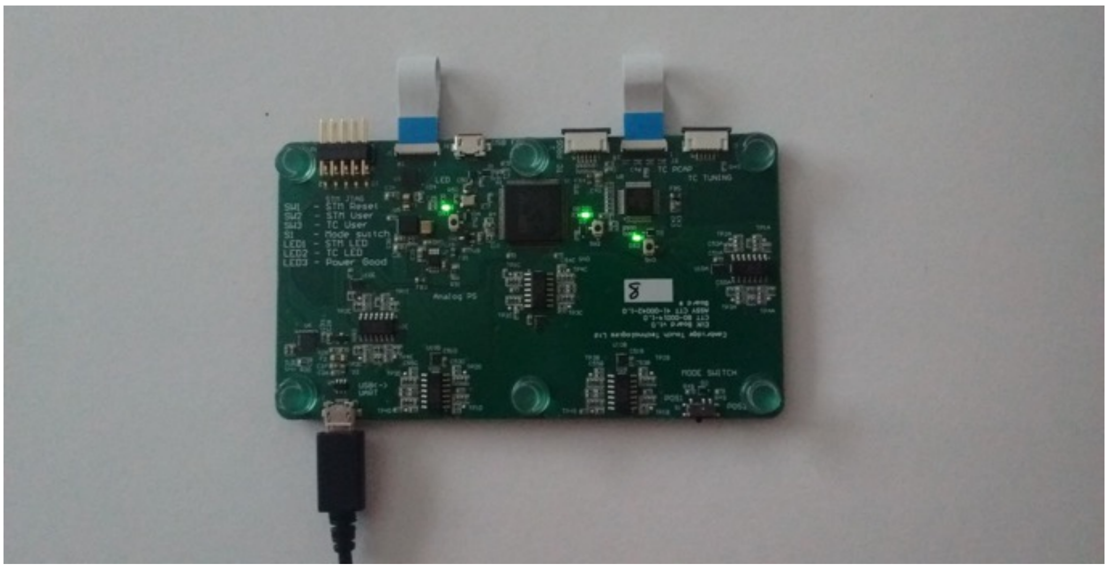
Firmware – 0.4

Software version number 1.1.1

EVK stand-alone operation

The EVK requires a 5 V supply capable of 100 mA peak, 80 mA sustained. Most USB chargers and computer USB sockets should be able to satisfy this requirement.

To operate it, the micro end of the USB cable must be inserted into the socket on the bottom right-hand side of the EVK, and the USB A plug inserted into a suitable device socket. Some, but not all, of the LEDs on the top side of the board will light briefly. On the underside of the EVK the LED marked DS3 will shine green once the power-up sequence has initiated; this indicates that the power supply meets the minimum requirements and there are no hardware faults. This should happen straight away.



Underside of an EVK after successful power-on with LED DS3 – top left, constant green.
LEDs DS1 and DS2 are not used in stand-alone mode and blink green.

During the power-up sequence no touch should occur on the EVK. This is because the boot sequence includes an auto-calibration sequence to 'zero' the no-force level.

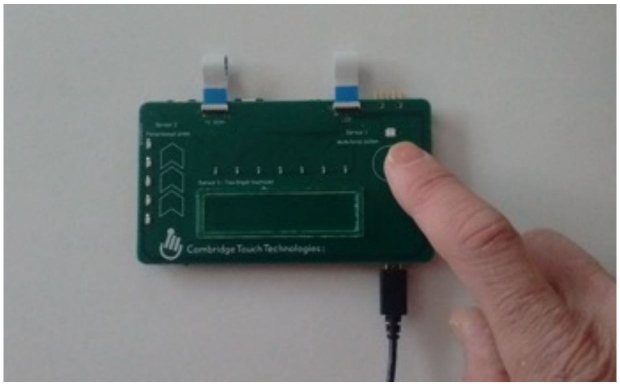
The EVK provides for three types of touch user interface:

- Sensor 1 is a single-finger multi-force button. Three levels of force can be detected, with the colour of the LED changing accordingly.
- Sensor 2 represents a single-finger multi-force slider, and detects the finger location and the force applied. The LED adjacent to the finger location lights dimly or brightly as appropriate.
- Sensor 3 is a two-finger multi-force touch pad. It responds to touch by two fingers simultaneously. Again, the LEDs closest to the two fingers light either dimly or brightly depending on the force applied by each finger.

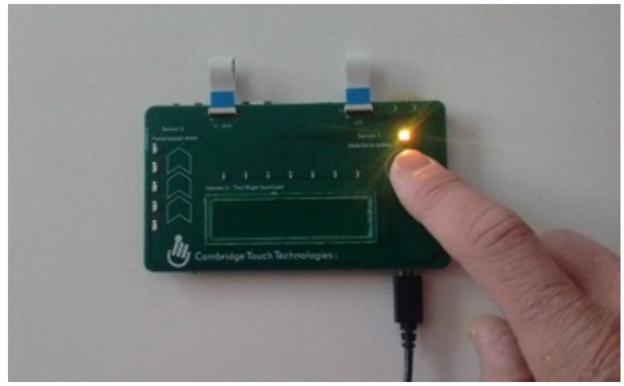
All three sensors will behave identically if the user is wearing thin gloves, such as disposable vinyl, nitrile or latex medical-grade personal protective equipment (PPE). Certain models of EVK can also determine finger location by force alone and so can be operated when wearing leather driving gloves and industrial-thickness PPE.

Some models of EVK are provided with a raised dam surrounding Sensor 3. This can be filled with water using the pipette provided to demonstrate that operation is unchanged when the touch panel is wet or submerged. As supplied, the EVK operates in a hybrid mode where location is primarily deduced by the PCAP controller and force from the piezoelectric sensor. Thus when the dam area contains water Sensor 3 will respond erratically. Using the UltraTouch Studio application the EVK can be switched to force-only mode, where the piezoelectric sensor is the sole sensor used to deduce finger location and force. Sensor 3 will then respond identically when dry and wet.

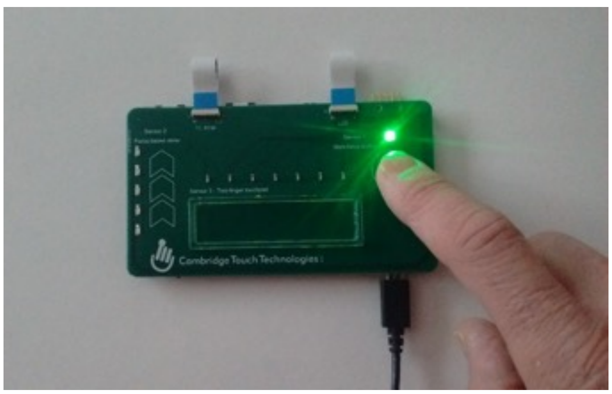
Sensor 1, single-finger multi-force button



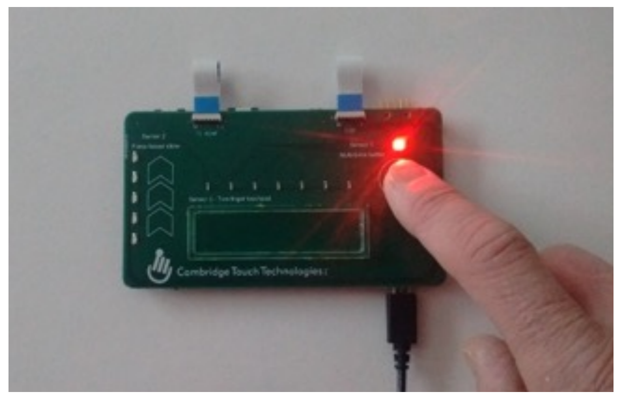
LED off – none or very low force applied



LED orange – medium force



LED green – low force



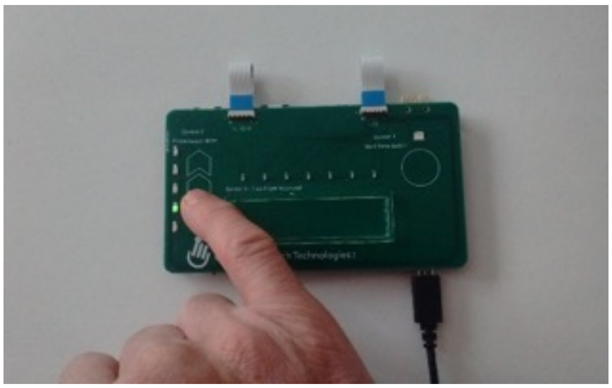
LED red – high force

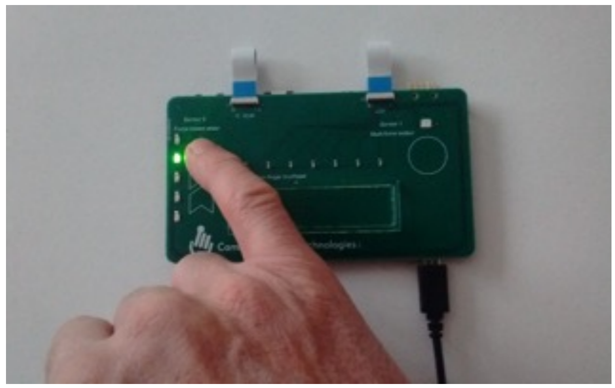
Sensor 1 is a multi-force button. Application of force in the white circled area will result in illumination of the LED immediately above. With no or minimal force applied, the LED is unlit. With increasing force the LED turns green, orange then red as successive force thresholds are exceeded. If the applied force is held steady, the appropriate colour will remain lit. The EVK is programmed only to respond to increasing force, as this is the natural human behavioral instinct. Humans find it very difficult to unload a force in a controlled manner. Thus to go from, say, orange (medium force) back to green (light force) requires the force to be decreased until the LED goes dark and the force is then reapplied. The intuitive method to do this is simply to lift the finger clear from the 'button' between presses.

Sensor 1 will respond to three levels of force. It will be seen that two levels of force, low and high (green and red), are easy to trigger repeatedly. The intermediate force will prove more difficult for most users to achieve consistently. This is not a defect of the EVK, as it has been calibrated by a robot 'finger' to high levels of detection consistency and confidence. Indeed when tested using a robot finger, discrimination between 255 levels of force is possible. The problem is due to inadequacies of human motor control, and demonstrates that a product which relies on application of multiple levels of force to initiate different actions might not be widely accepted.

Sensor 2, single-finger force-based slider

Sensor 2 is a single-finger force-based slider. Applying force to the chevron area will illuminate the corresponding LED to the left; the one closest to the finger. With no appreciable force applied, the LEDs will be off. A low force will light the LED dimly, while at a higher force the LED will shine brightly. The finger can also be slid over the chevron area. In this mode, one LED will be lit corresponding to the finger location and force applied. During the finger slide it is possible to change the force applied. As with the multi-force button described above, the force-based slider will only respond to increasing force. If the force is increased during the slide action, the new force level will be indicated by the next LED to be lit. If the force is decreased during the slide action, no LED will light until the force has decreased below the lower force detection limit and the sensor has effectively reset to zero.



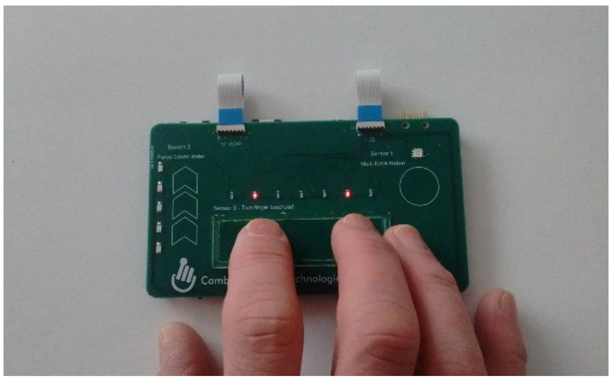


Slider with light force (left) and high force (right)

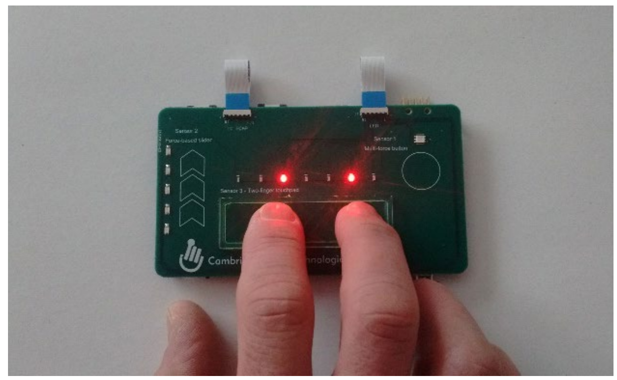
The force-based slider will seemingly respond to touch by two fingers. This occurs because when the second touch is harder than the first, the single point of touch is considered to have jumped to a new site, which is indeed exactly what has happened. The first lit LED will then extinguish and the LED adjacent to the new touch site will light up.

Sensor 3, two-finger multi-force touch pad

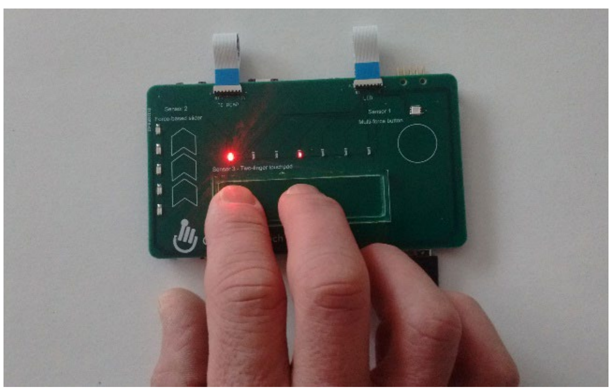
Sensor 3 is configured as a two-finger multi-force touch pad. On some models of EVK this sensor is able to provide the additional functionality of demonstrating touch detection while the panel is covered in water. This sensor behaves in the same manner as the slider, in that each location has two force thresholds. Using a single finger, the sensor behaves as the slider. The difference with Sensor 2 is that on Sensor 3 up to two channels can be active at any one time. This makes it possible to explore multiple gestures, including single slider, dual slider and two-finger pinch.



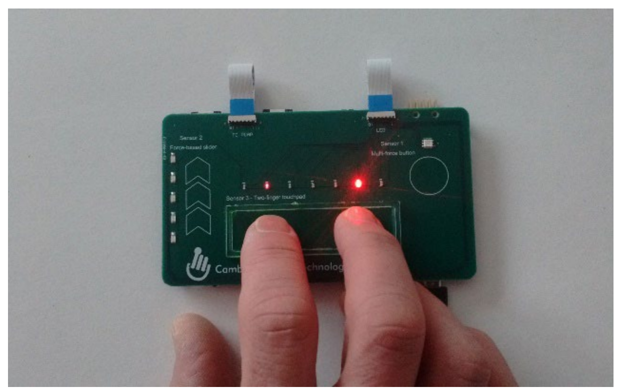
Both fingers low force



Both fingers high force



Left finger high force, right finger low force



Left finger low force, right finger high force

The Cambridge Touch Technologies EVK has been designed to resemble a touch panel display in construction. A typical flat panel display is supported primarily at the edges. This means that a force applied to the centre will result in noticeably more deflection than when the same force is applied close to the edge. Consequently the sensitivity to force also varies over the area of the touch panel. This is true even for a relatively small touch panel like the Sensor 3. The EVK firmware incorporates an ‘auto-tuning’ feature that takes this mechanical attribute into account, so the force thresholds appear constant to the user over the touch panel area.

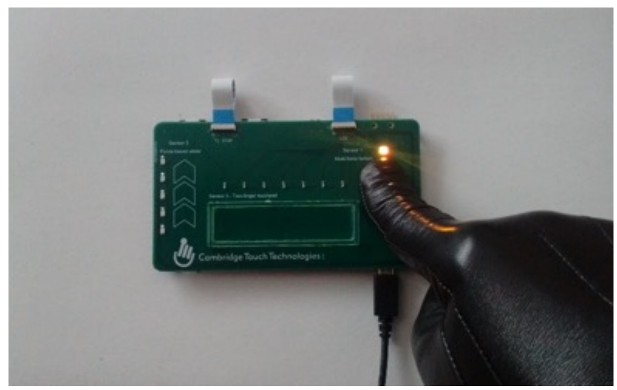
Sensors 1, 2 and 3

The three sensors operate independently, so can all be active simultaneously. The Cambridge Touch Technologies UltraTouch firmware and hardware has sufficient resource to accommodate all dimensions of touch panel, including and beyond 140-inch diagonal displays.

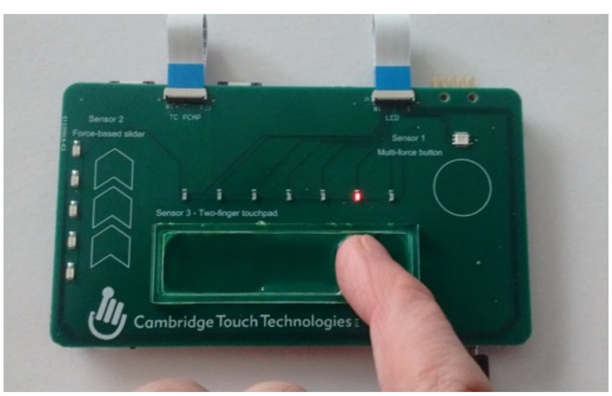
Harsh environments (applies to certain models of EVK only)

Glove mode

PCAP touch controllers fail to respond when the user is wearing gloves (except for the unusual case where the gloves are made of conductive material). Where the gloves are made of material that is highly insulative, the encased finger is unable to cause sufficient perturbation in the electric field to permit detection. Glove materials, such as leather or wool, are relatively thick and prevent the finger from getting sufficiently close to the PCAP sensor to trigger a response. However, Cambridge Touch Technologies touch panels detect force, no matter how it is applied. Thus gloves and gauntlets do not impede operation, and the panel can also be operated with certain styli. The stylus must have similar attributes to a human finger to trigger touch detection, namely an area of at least 11 mm^2 and the correct geometrical relation to force in order to be detected as a finger. Other types of stylus must be enabled in the EVK firmware library to be detected.



Touch panel operation demonstrated while wearing thick leather gloves (EVK hardware 2.0)



EVK operation with water in the dam area

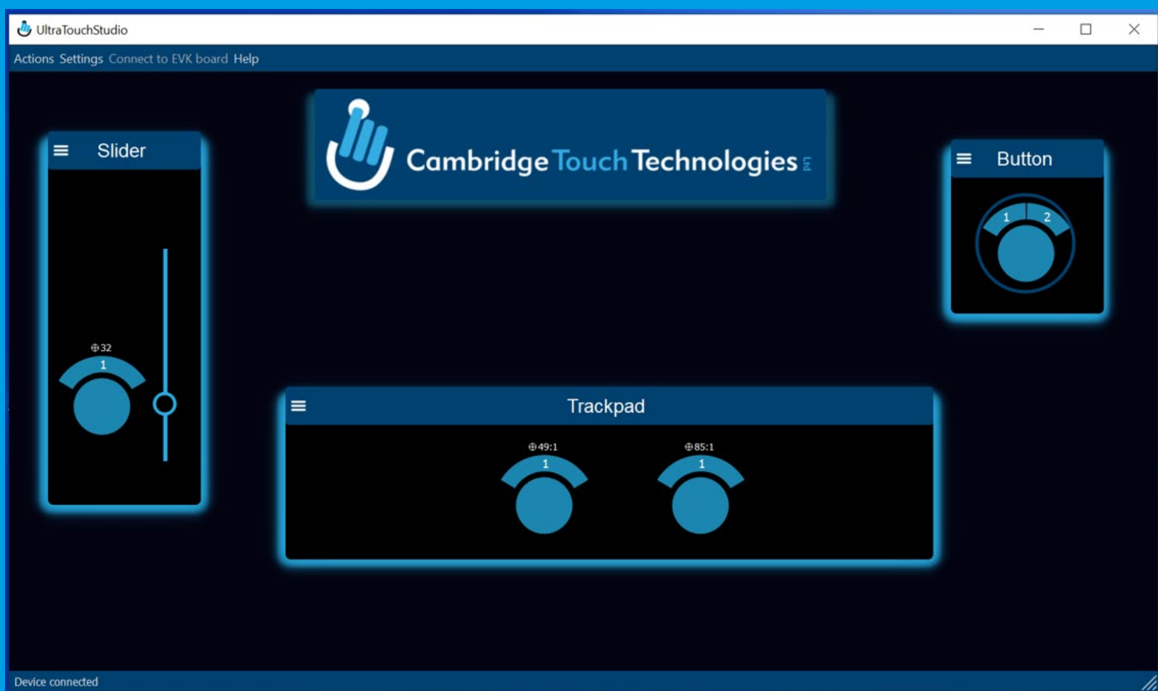
Water mode

PCAP touch sensors become confused by the presence of water droplets on a touch panel, and cease operation entirely when submerged in water. This is because water has sufficient electrical conductivity to effectively 'short' the field lines.

To demonstrate operation in the presence of water droplets and even when submerged, certain models of EVK are provided with a dam surrounding Sensor 3. Using the pipette provided, water can be applied to this area. Because the EVK works by true touch alone, the function of Sensor 3 will be completely unperturbed. After evaluation most of the water should be sucked into the pipette to remove it, and a paper towel used to absorb the remainder.

UltraTouch Studio application

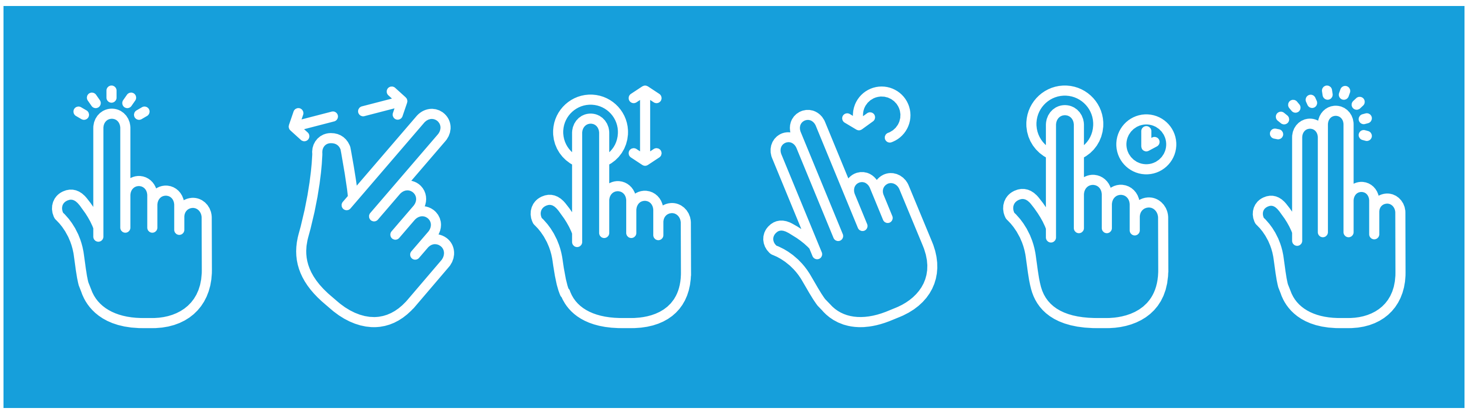
A companion application, UltraTouch Studio, interfaces to the EVK via USB. The application provides engineers with detailed real-time information about touch events on the EVK, such as the XY location of finger(s), current and peak force, and the ability to alter some parameters such as the force thresholds for each sensor.



Screen shot of UltraTouch Studio in operation show simultaneous detection of fingers on the multi-force button, the force-based slider and the two-finger touch pad

Gesture complexity

Centuries of scientific endeavour have led to great understanding of human biology, psychology and the links between them. Some aspects of this work have considerable bearing on touch displays and smart surfaces, as their implementation must ‘feel’ natural. As mentioned previously, most humans cannot reliably reproduce more than two levels of force without some additional tactile feedback. This can be further analysed, and it can be proved for example that for a virtual button a push-and-hold action is more difficult for a human to accomplish than push-to-toggle. Indeed it is possible to rank human touch gestures by relative complexity, and this can provide a useful starting point for designing human–machine interfaces that use finger location and force as inputs.



For virtual button actions, the order of increasing perceived complexity is:

- Push select (any touch launches action)
- Push toggle (touch triggers alternate actions)
- Push hold (something happens only while the button is pressed)
- Push staircase (different actions initiated by different forces, typically a maximum of three)
- Slow tap (akin to a security entry keypad)
- Fast tap (e.g. smartphone keyboard)

Sliders can be linear or rotary, and combined with button actions. Intuitive combinations in order of increasing complexity are:

- Linear position
- Rotary position
- Linear/rotary and push select
- Linear/rotary with push toggle

Finally, touch gestures are defined as multi-finger multi-force inputs. While not an exhaustive list, typical examples include:

- Pinch to zoom
- Two-finger tap (e.g. trackpad)
- Multi-finger tap (e.g. alpha-numeric keyboard/piano keyboard)
- Scroll (finger movement on long axis)
- Swipe (finger movement on short axis)
- Drag (push to select new action then move while force applied)

Haptic feedback

A true touch sensitive display or smart surface represents a step forward in human–machine interaction (HMI). As humans we crave some form of response to touch, otherwise the object feels very inanimate. The response is preferably movement, for example a push-button switch, but in some situations sight and sound are also acceptable. Generally feedback in the form of sight and sound is limited to industrial or medical applications where the feel of the machine is dampened by gloves. Partly for that reason, the human-machine interface tends to be limited to a few widely spaced buttons with limited gesture complexity.

For a richer and more intuitive HMI experience it is necessary for touch detection to be acknowledged by the machine as haptic feedback. On many mobile phones it is possible to engage a setting where the phone vibrates when the keypad is engaged. While this form of touch feedback helps prevent spurious entries like double keystrokes, low-frequency vibration of a surface is an unnatural response and feels alien.

To overcome this problem, some companies now specialise in providing haptic feedback. Through various means, the display or smart surface is manipulated in some way so that the user experiences the expected sensation in response to touch. This means that when a button is touched the display or surface either physically moves, akin to a real mechanical button, or gives the sensation of moving. One means by which this movement or sensation can be created is by using piezoelectric actuators. Due to reasons of physics the piezoelectric film at the heart of Cambridge Touch Technologies UltraTouch products is unsuitable for use as an actuator, so haptic feedback must be provided by a third-party solution. UltraTouch products can provide a trigger signal to a haptic system so that a haptic response can be achieved without the inherent delay of sending the information through the host controller.

Conclusions

Cambridge Touch Technologies UltraTouch EVK is a true touch panel interface able to detect the force applied and location for multiple fingers, simultaneously. It can operate either stand-alone or in combination with PCAP, with an artificial intelligence engine used to present the most likely touch scenario to the host system controller. This mode of operation means the touch panel will continue to operate normally when the user is wearing gloves, or when the touch screen is wet or underwater, and setting minimum force thresholds for touch provides high immunity against ghost touches. In both of these instances touch screen technology, based solely on PCAP, is unreliable. In addition Cambridge Touch Technologies touch panels can report the rate of touch, making it possible to conceive many new ways of interacting with machines using haptic feedback, limited only by the ingenuity of the designer.

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