

Touch and the Apple iPhone

by Geoff Walker

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A little less than a month ago, Steve Jobs announced the long-awaited Apple iPhone. It was the hit of CES – even though it was announced at MacWorld in San Francisco, 400 miles northwest of CES in Las Vegas. The media and the blogosphere have been buzzing with endless questions and commentary ever since. Will anyone buy it at \$500 and \$600? Why only Cingular? Will it support Skype over WiFi, and if so, won't Cingular object? Why does it have a non-removable battery? When will it support 3G rather than just EDGE? Will Apple win the trademark battle with Cisco? And so on... it's endless. And I actually don't care about any of those questions.

What I do care about is the use of touch in the iPhone. When I saw it at MacWorld, it blew me away. I found it to be an exceptionally well-thought-out implementation of touch. Every gesture and every finger motion seemed natural, intuitive and obvious. In fact, it's the best implementation of touch I think I've ever seen. And that's really saying something.

Before I dive into the details, I'd like to point out that this is an article about a product that won't be available for at least five months (June 2007 is the announced availability date). There's very little concrete information available about the product, so a fair bit of what you're about to read is based on conjecture, rumor and personal opinion. *Caveat lector!* Before you dive into the rest of this article, consider taking a look at the iPhone website (<http://www.apple.com/iphone>). For even more detail and an extensive list of media references, take a look at the iPhone page on <http://www.wikipedia.org>.

How touch is used in the iPhone: There are six fundamental touch-vocabulary elements (call them gestures if you want) in the iPhone user interface (UI), as follows:

- Single tap to select or activate something
- Double-tap to change the display format
- Drag and drop to move something
- A stroke (“swipe” or “flick”) up/down/left/right to scroll
- “Pinching” two fingers together to shrink something
- “Spreading” two fingers apart to enlarge something

These elements work consistently everywhere throughout the iPhone's UI. For example, if you have a photo on the screen, spreading two fingers apart zooms in on the photo. If you have an email message on the screen, spreading two fingers apart enlarges the email.

The scrolling stroke is particularly interesting in that the stroke speed controls the scrolling speed. Stroke faster, scroll faster. But in a typical Apple touch (so to speak), scrolling doesn't simply stop instantly like it does in Windows; it keeps going for a moment and then decelerates to a smooth stop (for example, in the address book). It's a minor detail, but it's illustrative of the incredible level of detailed thought that's gone into the iPhone's UI.

Of the six touch-vocabulary elements, double-tapping is probably the least intuitive. Its function is to change the display format – but what that means is very context-sensitive. If you're watching a video, double-tapping changes between full-screen and letterbox modes. If you're viewing a web page, double-tapping changes from a full-page view to a single-item or single-image view. If you're in a Google map, double-tapping zooms in by one step (equivalent to doing a small “spread” gesture).

Pinching and spreading are the only touch-vocabulary elements that make use of multi-touch (multiple simultaneous touches). Apple certainly didn't invent the idea of multi-touch; it's been around for about 25 years. In one recent example, IRTouch demonstrated multi-touch in a CAD application on a large monitor at SID 2006. Just like on the iPhone, touching the screen with two fingers and spreading them apart zoomed up the CAD image.

Of course there's no physical keyboard on the iPhone; text entry is done via on an on-screen keyboard (OSK). The OSK is backed up by automatic spell-checking and predictive (word-completion) software. Based on watching Steve Jobs enter text during his keynote, the OSK seems to be reasonably useable. (Needless to say, I haven't been able to get anywhere near a prototype to try it myself!) However, the lack of tactile feedback that's inherent in any OSK is likely to be a significant problem for many users.

Steve Jobs' reality distortion field: Steve Jobs has been well known for his "reality distortion field" (originally a term from Star Trek) since 1981. Here's a small portion of what Steve said in his MacWorld keynote:

"The iPhone uses the best pointing device in the world -- our fingers. We invented a new technology called multi-touch, which is phenomenal. It works like magic. It's far more accurate than any touch display that's ever been shipped. It ignores unintended touches -- it's super-smart. You can do multi-finger gestures on it. And boy have we patented it!"

The majority of this is in fact a distortion of reality. It's certainly arguable whether human fingers are in fact the best pointing devices in the world -- most computer users would probably disagree. Apple definitely didn't invent multi-touch. And they definitely didn't invent a new touch screen technology -- although they have applied for a patent on what they developed. The Apple technology is known as "projected capacitive" by Touch International, TouchKO, Zytronic and Elo TouchSystems -- four significant suppliers of the same underlying technology. The MicroTouch division of 3M is probably the original inventor of projected-capacitive touch technology; they called it "near field imaging". While it does have very good accuracy, projected capacitive definitely isn't far more accurate than any other touch screen. And finally, Apple's touch screen doesn't know intended touches from unintended touches; that's the province of the application software. Whew!

On a more positive note, it's true that you can do multi-finger gestures on Apple's touch screen (e.g., "pinching"), and Apple has definitely submitted a whole bunch of patent applications on the iPhone. There are more than a dozen of them relating to just the touch screen. The most significant touch-screen-related patent application is #2006-0097991, dated May 11, 2006 and entitled "Multipoint touch screen". Let's take a closer look at it.

Apple's Multipoint Touch screen patent application: The patent describes two different implementations of projected-capacitive touch technology. The first one, which Apple calls "self capacitance," is a simple passive array of 24x36 sensing electrodes in a single plane. This is commonly known as a "matrix" touch panel. It's normally used in applications such as industrial control panels, membrane keyboards and other situations where a limited number of well-defined areas on a surface need to be made touch-sensitive. Since it's basically a low-resolution architecture, it's not commonly applied to displays. However, one recent display application can be found in Whirlpool's Velos SpeedCook series of microwave ovens (see Figure 1).



Figure 1: Matrix touch panel solution on Whirlpool's Velos SpeedCook series of microwave ovens. Photos courtesy of Whirlpool (<http://www.whirlpool.com>) and Quantum (<http://www.qprox.com>)

The second implementation of projected-capacitive touch technology described in Apple's patent is the more traditional structure consisting of two sets of parallel rows of transparent conductors, one on each side of a substrate, perpendicular to each other. Apple calls this implementation "mutual capacitance". From a sensor point of view, it's essentially the same concept as Touch International's ExtremeTouch product (see Gary Barrett's article on ExtremeTouch in this issue for a lot more details).

Figure 2 shows a back-of-the-napkin, oversimplified sketch of Apple's implementation. A single drive line is excited with an AC signal of appropriate amplitude and frequency, then the capacity at each intersection (node) between the driven line and each sense line is measured simultaneously. The measured values are output serially by the multiplexer and then the sequence starts over again with the next drive line.

The key difference between Touch International's implementation and Apple's implementation is in the firmware. Touch International's current firmware only processes and outputs one touch at a time, while Apple's firmware processes and outputs up to 15 simultaneous touches. (Apple describes the 15 points as "ten fingers, two palms and three others".) In essence, Apple's firmware creates an array of touch points (as a serial data stream) and then looks for changes in the array over time. If the user is doing a pinch gesture, the array contains two sets of touch coordinates which are moving towards each other over time.

To my knowledge, the iPhone's UI only makes use of two simultaneous touch points. However, since all the application software is totally under the control of Apple (a key point – it's a closed system!), that means that the application software can process and eliminate any additional "undesired" touch points that are reported by the touch screen. For example, if the user has the address book open, there are a limited number of "active buttons" on the screen that must respond to a static touch. Other static touches, for example, caused by the user's thumb as he holds the device, can easily be ignored. If the application sees a moving touch point of some minimum duration and/or length, then it can interpret the corresponding series of touch points as a scroll stroke and take appropriate action while still ignoring all the "undesirable" touch points. The touch-screen's ability to process up to 15 simultaneous touches makes good sense in this context.

Although I haven't done a patent search on this specific concept, I find it very hard to believe that Apple invented it, since as previously noted, multi-point touch has been around for 25 years. So what exactly did Apple invent? They didn't invent projected-capacitive touch, and they didn't invent multi-point touch. In my opinion, what they did is combine several existing technologies into an amazingly intuitive and easy-to-use touch interface for a mobile phone. Is the combination patentable? I don't think so, because it probably doesn't pass the "something that isn't obvious to someone skilled in the art" test. But I'm certainly not a patent attorney, so I'm just speculating.

Estimated Cost: As one would expect, there's been a lot of speculation in the trade press about the manufacturing cost of the iPhone. iSuppli, a display-industry market research firm, recently published their best guess at a bill-of-materials (BOM) cost (see <http://isuppli.com/news/default.asp?id=7308&m=1&y=2007>). In that analysis, they estimate the cost of the LCD-and-touch-screen assembly at \$33.50. It's fairly easy to determine that a 3.5" 480x320

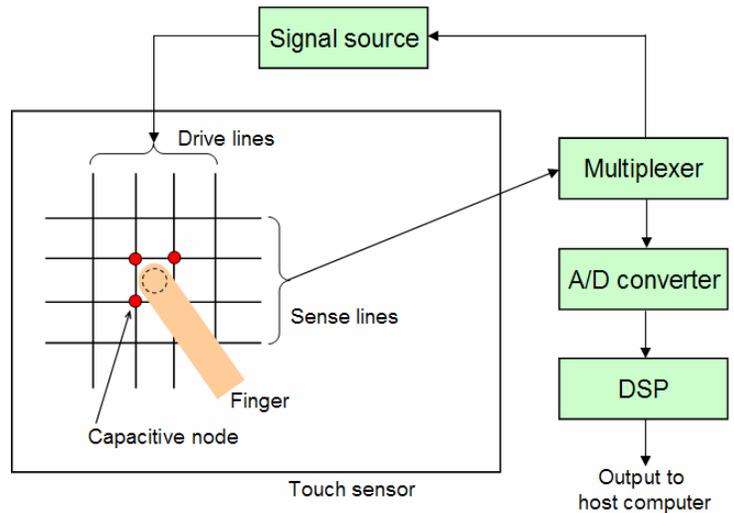


Figure 2: Simplified view of the iPhone's multi-touch implementation

LTPS TFT-LCD should cost around \$30, so that leaves \$3.50 for the touch screen. That's probably a reasonable guess for just the touch sensor, which is assumed to be a single PET substrate with patterned ITO on each side – very similar to Touch International's sensor.

However, the actual BOM for the iPhone probably includes some additional touch-screen related costs that aren't in iSuppli's estimate. In fact, DisplaySearch, a competitive display-industry market research firm, recently stated in an article in *EE Times* that they believe the total touch-screen cost is around \$30. Since they won't break down their estimate, I'll do it for them (note that the breakdown estimates are entirely mine and may be completely wrong!):

iPhone Touch Screen Component	Estimated Cost
Sensor (as above)	\$3.50
Integration (optically bonding the sensor to the LCD and to the polycarbonate touch surface)	\$10.00
Electronics (multiplexer, A/D, DSP, etc.)	\$3.00
Polycarbonate touch surface ("screen cover")	\$0.50
Amortized development cost passed on by the touch-screen manufacturer (remainder of \$30)	\$13.00
TOTAL	\$30.00

There are certainly some optical performance-enhancement coatings on the screen cover, probably anti-glare and anti-reflection, but I consider those to be part of the housing cost so they're not included in the above table.

A guess at the suppliers: There's a fairly substantial rumor in circulation that suggests the manufacturer of the sensor is a joint venture between Optera (<http://www.optera.com>), a well-known Taiwanese display component manufacturer with extensive ITO-coating experience, and TPK Solutions (<http://www.tpkolutions.com.tw>), a custom mobile-device touch-screen design firm actually located in mainland China. The joint venture itself is announced on Optera's home page.

The joint venture will be co-located with Balda AG (<http://www.balda.de>), Optera's German plastics partner. There is therefore some basis for speculating that Balda is involved in some part of the iPhone assembly, perhaps doing the optical bonding and/or integrating the LCD-and-touch-screen assembly into the iPhone's housing.

Apple has previously used both Cypress (<http://www.cypress.com>) and Synaptics (<http://www.synaptics.com>) – and probably others – as a source of capacitive touch controller IP; it's a guess on my part but I think that Synaptics is a more likely partner for Apple as the source of at least part of Apple's custom-ASIC multi-touch controller.

iPhone competitors: In the news section of this issue, we report on one potential competitor to the iPhone, Meizu (<http://www.meizu.com>). Another potential competitor is NeoNode in Sweden (<http://www.neonode.com>). Take a look at the "chief designer's private blog" linked on the NeoNode website; it's an exceptionally weird example of viral marketing. Interestingly, NeoNode has had a similar product (the N1) on the market in Europe for quite a while; a review can be found at <http://www.pencomputing.com/Wince/neonode-n1-review.html>. Yet another competitor is OpenMoko; *Gizmodo* has reported on this entrant several times (go to <http://www.gizmodo.com> and search for "openmoko"). A final competitor is LG's Prada phone (go to *Gizmodo* and search for "lg prada").

How does the touch UI of these four competitive products compare with that of the iPhone? As my college textbooks used to say, "that's left as an exercise for the reader". Actually, I'm copping out – I haven't studied the subject enough yet to have an opinion. Readers, what do you think?

Conclusion: Is Apple's use of touch in the iPhone significant? I think the answer is yes. Certainly Strategy Analytics (<http://www.strategyanalytics.net>), a market research and consulting firm, thinks so. They recently issued

a report entitled “Apple iPhone: Catalyst for Capacitive Touchscreen-Only Phones to Balloon to 115 Million Units within Two Years”. Yikes! That’s an incredibly aggressive forecast.

Actually I think Apple’s use of touch in the iPhone is significant on several fronts, as follows:

- It’s a major gamble in user-interface design. If it succeeds, it’s likely to drive touch into more segments of the CE industry and into even broader adoption generally.
- As I said earlier, I think it’s the best implementation of a touch UI that I’ve ever seen. It sets the bar very high for all present and future competitors.
- It’s a highly visible, high-volume application of projected-capacitive touch technology. As such, it may give the companies already participating in that market a substantial boost.
- Finally, it will undoubtedly be entertaining to watch any patent battles that develop as a result of Apple’s attempt to patent their multipoint touch screen.