True multi-touch displays: what, how and why

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ABSTRACT

*The characteristic feature of a true multi-touch display is the handling of a large number of interaction points. In this short discussion, we describe **how** these displays work, **why** they are ideally suited for large multi-user systems and **what** kinds of new user-experience they facilitate.*

1. INTRODUCTION

In the past few years, multi-touch displays have become common technology and have proliferated widely, from cell phones and computer displays to picture frames. In parallel with the rise of this ubiquitous technology, a more specific market has emerged for larger displays with greater capabilities. Increased size allows for a larger number of simultaneous users, thereby facilitating a new range of applications such as those oriented towards collaborative productivity, games, *etc.*. Classic edge-based sensing cannot cope with the larger number of touch points required by multi-user interaction, and full-area sensing is required to achieve "true" multi-touch with an unlimited number of touch points.

In the following discussion, we begin by briefly reviewing the differences between edge-based sensing and area sensing. Full-area sensing yields a true multi-touch response, and thus presents a series of new challenges. We conclude the discussion with a number of new interaction schemes made possible by area-sensing.

2. TRUE MULTI-TOUCH AND AREA SENSING

The term edge-sensing describes techniques which infer the positions of touch points using sensors limited to the edges of the screen, *i.e.*, 1D sensor arrays. Common technologies such as Projected Capacitive Touch (PCT) and infrared (IR) barriers belong to this class of sensors. The information to process is limited to L+H data points (see Fig.1a), which makes this technology the standard for smaller, battery powered devices. However, despite its low cost, volume and energy requirements, it has one major limitation: only two touch points can be tracked unambiguously. Software can usually allow a few more points to be tracked by resorting to assumptions such as temporal coherency, but it rarely goes beyond four. Even so, tracking errors become a serious issue as occlusions must be resolved in software (Fig. 1b). PDA devices with small screens cannot physically accommodate more than a few fingers. Consumers have therefore been satisfied with the interpretation of "multi-touch" as simply "more than one touch point". But when more touch points are required edge-sensing reveals its limitations, and for larger sizes, several edge-sensing technologies such as capacitive or resistive masks do not scale well over 30 inches.

With an area-sensing technology, most of these limitations disappear: the data from the sensors consists in a 2D array of L*H data points (Fig. 2) representing the entire display surface and each touch point can be identified unambiguously. The number of touch points is limited only by the computational capacity of the software interpreting the sensor data, and the physical limitations of the device such as the number of fingertips that can fit on the surface, and the number of people who can reach it simultaneously. The term "true" multi-touch is appropriate for this class of devices.

While the achievement of true multi-touch is a blessing, it comes at the cost of four new major challenges for hardware and software developers.

2.1 Number of Touch Points

The fingertip is, in general, the weapon of choice when interacting with a touch screen, and it is therefore natural to assume that one user can contribute a maximum of 10 touch points. Unfortunately this is not true: placing a single hand flat on an area-sensing touch screen can easily result in 20 different contact regions, and a single user can be responsible for about 50 touch points. Multi-user applications and their underlying drivers must therefore be prepared to handle a very large number of touch points, typically more than 200.

2.2 Speed and Latency

Larger screens lead to larger and faster user movements, especially for gaming applications. True multi-touch systems must therefore handle the increased information density of area sensing while also maintaining a high refresh rate. Our experience indicates a bare minimum of 60Hz, and a rate closer to 100Hz for a smooth interactive experience. At this refresh rate, the volume of information that must be processed has increased by several orders of magnitude compared to lower-end edge-sensing systems: L*H/(L+H) = 700 for HD, with a data rate around 100MB/s. Low-latency real-time processing is then a real concern and currently limits the practical implementation of area-sensing for larger high-end systems. This increased volume of information thus comes at a price, but it also reveals a new range of creative possibilities, as will be discussed in Section 3.

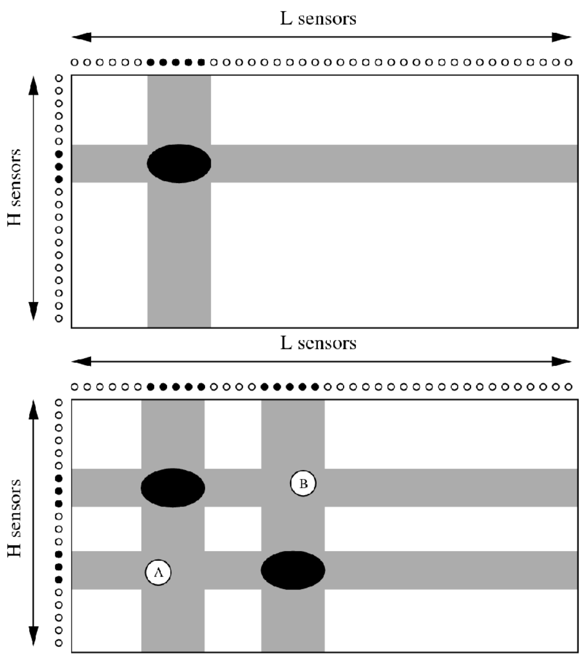


Fig. 1: Edge sensing technology.
Top: L+H edge sensors with a single touch point in black. Black sensor dots indicate activated sensors, sensor shadow is in gray. Bottom: with two touch points. Touching the screen in A or B may result in no points being detected, as both A and B are in the sensor shadow of the two larger black points.

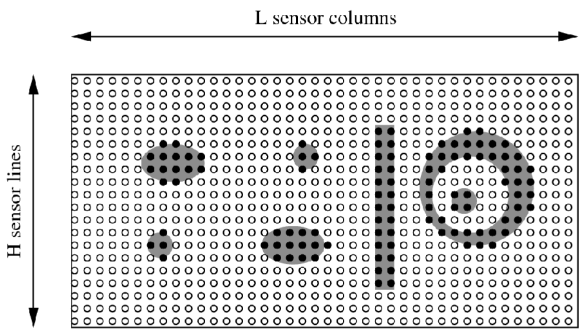


Fig. 2: Area sensing technology with LxH sensors
Black dots indicate activated sensors. All touched areas (in gray) are identified, and there is no shadow, even with large areas. Inclusions can also be properly separated.

2.3 Display Size and Image Quality

The two most common technologies for true multi-touch are machine vision (using cameras) and in-pixel sensing. Both technologies scale well, with cameras being used behind large image walls with a diagonal of several meters. However, an often overlooked issue is that of image quality. As display size increases and the ubiquitous HD resolution remains constant, the pixel size must increase. This is not a concern for an environment such as a home-theater where the viewing distance may be expected to increase with screen size. But with direct interaction, the viewing distance cannot exceed the distance between the eyes and the fingertips, which rarely exceeds one meter. With such short viewing distances, higher resolution displays become necessary for diagonals over about 50”. QuadHD may not be of much interest in the living room, but it definitely has a market in large multi-touch displays.

3. NEXT-LEVEL INTERACTIONS

Bulk, price, power consumption... Is it worth it? Besides their size, multi-user capabilities and accuracy, true multi-touch systems can offer new perspectives due to their unique sensing abilities. While edge-sensing will often yield only point positions, area-sensing systems can provide richer information such as the area and even the exact silhouette of a contact region. This facilitates many interesting new interactions.

Case 1: Virtual keyboard

Touch screen keyboards are typically awkward to use in comparison with a physical keyboard because there are no tactile cues to keep the fingers aligned with the keys. True multi-touch can offer a solution.

Because the silhouette of contact can be observed, the keyboard can be aligned with the placement of the user's hands on the touch screen. The left and right halves may track the hand placements independently (Fig.3), the size and location of each key can even be ergonomically optimized over time based on the frequency and location of typing errors, and many possible variations exist such as only revealing the numerical keypad when a single hand is detected. All this provides a seamless interaction that cannot be achieved with conventional touch screens.

Case 2: Audio/Video mixer

The complexity of audio and video mixing devices makes them a good candidate for touch screen virtualization, especially now that most of the internals of these devices are based on digital technology. Simple touch screens are inadequate because multiple touch points are frequently used, *e.g.*, when moving multiple faders up or down simultaneously. True multi-touch is sufficient, and may also offer improvements to physical devices: controls appearing on-demand, 2D potentiometers, direct video manipulation (for video-jockeys), an “unlimited” number of channels, *etc.*, and since the palms of the hands can be identified, an audio engineer may even rest their hands on the "console" without triggering the controls unintentionally.

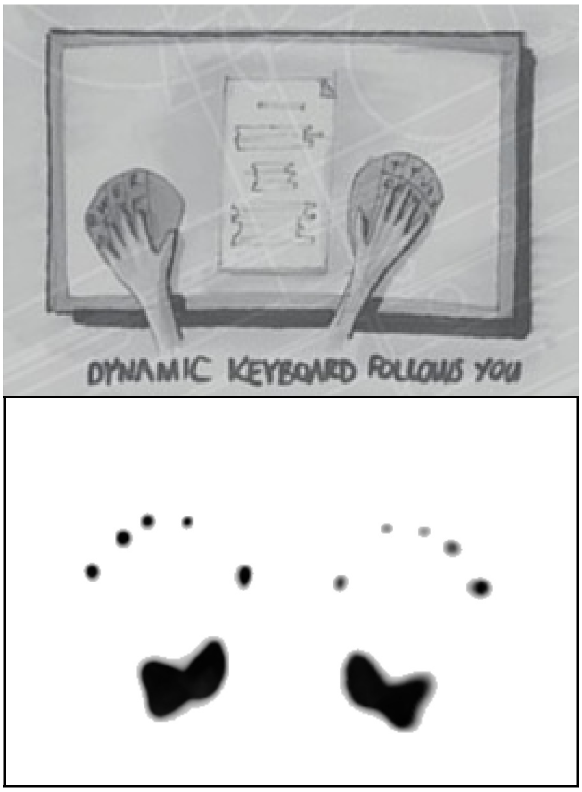
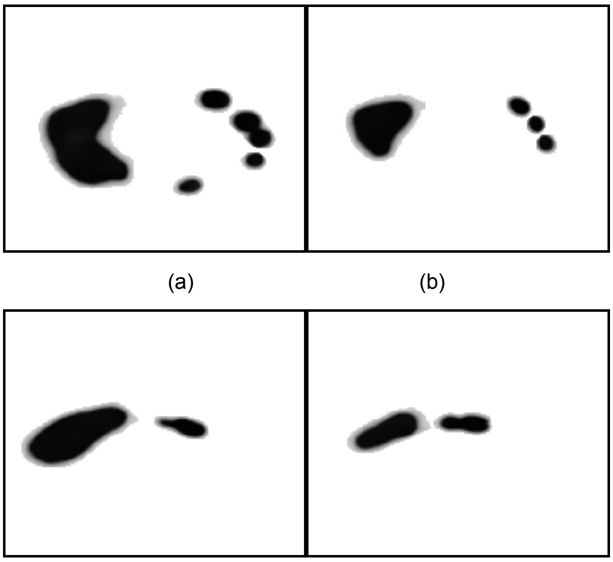


Fig.3: Dynamic virtual keyboard concept
Top: Concept art. Bottom: Area sensor output for two hands in typing position.



(a) (b) (c) (d)

Fig. 4: Sensor response for the hand-on-card gesture
(a) Hand covering the card, (b) Hand lifting up, thumb first, (c-d) Hand forming a vertical wall to hide the card.

Case 3: Card game

Games such as poker and mahjongg rely on opponents not seeing your cards. How can this be achieved on a flat display? Once again, the contact silhouette can be used to reveal game cards or tokens only when a hand is hiding them from the view of other players, for instance by detecting an oblong pattern in front of the tokens (Fig.4d). For card games, a covering and revealing gesture can be exploited, e.g., a hand must first be placed over a face-down card (Fig.4a), and then pulled into a cup shape hiding the card from other players and mimicking the action of gathering up the card (Fig.4c-d). When this successive combination of patterns is detected, the card may be displayed. As soon as the player removes of shifts their hand a sufficient distance, the card is once again displayed face down.

More advanced possibilities also exist, such as user recognition through the imprint of their hand, interaction using other body parts, such as fore-arms, elbows, even the nose for a vertical display and feet on a floor-integrated unit. But it doesn't need to be complex to be useful: the ubiquitous picture sorting application can dramatically speed up the collaborative selection of designs or artwork and the virtual white board also represents a simple yet large market for meeting tables and long-distance learning.

4. CONCLUSIONS

True multi-touch was popularized by Jeff Han in 2005 [1], and is only starting to gain momentum now that several products are on the market. Although the cost of true multi-touch seems to be the biggest barrier to wider adoption, it is software that now needs to catch up before the technology can become ubiquitous. True multi-touch systems need applications that show off their abilities and have the "wow" factor, not necessarily from complexity, but more impressively perhaps, from the simple and intuitive interactions they facilitate. Designers and programmers are beginning to rethink interaction completely in collaboration with pattern analysis specialists. Once a new breed of developers becomes truly multi-touch aware, this technology will certainly achieve a wide audience. The market is waiting...

REFERENCES

[1] J. Han, Low-cost multi-touch sensing through frustrated total internal reflection, in *Proceedings of the 18th annual ACM symposium on User interface software and technology*, 2005.