Several Sensor Approaches that Retrofit Large Surfaces for Interactivity

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Abstract. Several different techniques are described for turning a large wall into an interactive surface. These include capacitive sensing of arm and body gesture, scanning laser rangefinders for tracking hands above video walls, passive tracking of knocks on large plates of glass with distributed acoustic pickups, and the detection of touch via frustrated total internal reflection.

1) Introduction

Large projection and videowall displays are already common in public spaces such as shopping malls and airports. As the enabling technologies continue to advance and decrease in price, such large displays will become even more ubiquitous. At the moment, however, these displays are mainly noninteractive, and merely play uninterrupted video streams. When they are made interactive, however, they open up entirely new types of group interactions, in contrast with video kiosks, which interact mainly with single users. Participants at interactive walls are part user and part performer – crowds tend to gather around to watch, collaborate, and suggest choices as somebody interacts with a large display wall. In order to be used by the general public, it is important that such interactive walls respond to bare hands and do not require the user to wear any kind of active or passive target. At the moment, there are several sensing and tracking approaches that have been used to make such surfaces interactive, many of which are introduced in [1]. Most do not scale well to large surfaces, however, or involve significant complication or robustness issues, especially in unstructured public or outdoor installations. Accordingly, the Responsive Environments Group at the MIT Media Lab has developed several relatively simple techniques to track activity across large surfaces that are quickly reviewed in this summary. All are essentially retrofits, as they do not require the installation of a custom-designed surface or any significant infrastructure.

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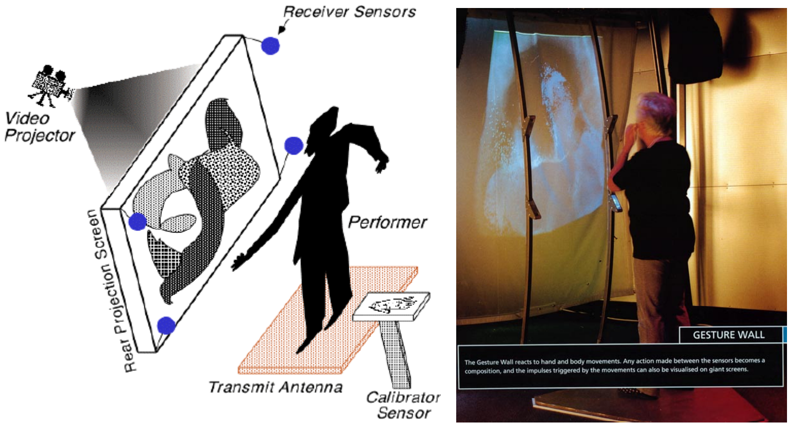

Figure 1: The Gesture Wall; schematic (left) and at House of Music in Vienna (right)

2) Capacitive hand tracking in the Gesture Wall

The first system that we developed to track gesture atop a large projection surface was called the "Gesture Wall", developed in 1996 for a large touring installation that the Media Lab produced called the "Brain Opera". Details are provided in [1] and [2]. This system was based around capacitive "transmit-mode" sensing [3], where a low voltage AC electric field is coupled into the feet (hence into the entire body) of a participant when they step onto a conductive plate mounted atop the floor. As seen in Figure 1, four electric field receivers surround the user that are tuned to receive the emissions radiated at the transmit frequency. These receivers hence each detect their proximity to the body via the measured signal strength; as the capacitive coupling from the body to a receiver increases, its signal also grows correspondingly in strength. If the user's posture is constrained (e.g., body back, one hand forward), this system is able to track the hand's location, albeit with limited accuracy, as the tracking depends on factors like body size and position and shoe impedance (which is mostly compensated by a calibration capacitor that the user touches after stepping on the transmit plate, as shown in the schematic). As this installation was used to drive interactive music and abstract graphics, this device, which responded very well to basic gesture, worked adequately. Several are still in operation at the House of Music in Vienna [4], as seen at right in Figure 1.

3) Tracking hands with a custom laser rangefinder

Wanting a system that was still robust to factors like dynamic lighting, but more accurately tracked hand motion just atop the screen, we devised a system in 1998, shown in Figure 2 (left), that employed a laser rangefinder that scanned a plane above the screen and located hands with a circa 1 cm accuracy out to 4 meters at 30 Hz

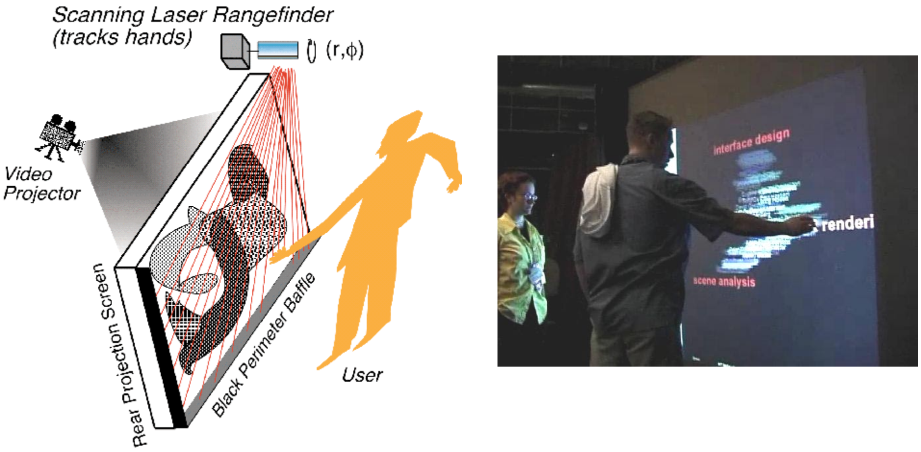

Figure 2: The LaserWall; schematic (left) and with users at SIGGRAPH 2000 (right)

[1,5]. As commercial rangefinders that met our specs were still quite expensive, we designed and built a series of our own simplified continuous phase-shift-measuring scanning laser rangefinder for this purpose. We used this device for several installations, most recently an implementation of Donath's "Visual Who" [6] program, an interactive database browser that let's a user dynamically pull graphical text indices apart to set the distinguishing axes and dynamically observe the interrelation of the database elements. Figure 2 (right) shows this system running at SIGGRAPH 2000 [7]; as the names were all entered by users on the show floor, people became quite engaged at exploring the database to look for colleagues that they recognized. Naturally, they engaged in this interaction in groups, talking with one another as they all explored the database. When the graphic tags were selected and moved about, they also made music [8], which added another level of aesthetic to the experience. The rangefinder system could track multiple hands except in cases where one hand shadowed another (e.g., the hands align with the scanner's beam), in which case the most distant hand wouldn't be any longer detected. For simple cases with few hands, a tracking filter can extrapolate the trajectory of the occluded hand through the shadow, as demonstrated in [9], keeping the interaction intact. Although our system was sensitive enough to use a laser beam of barely visible intensity, we found that users were positive about seeing a red stripe on their hand when they were being tracked, as it provided a very direct indicator that their gesture was being measured.

4) Passive acoustic knock and tap tracking

Although the laser rangefinder could be made to work well and was very robust to lighting changes, hand complexion, etc., it still requires a potentially complex electromechanical system (the rangefinder hardware) to be mounted outside the display. While this may be fine for indoor applications, it is immediately problematic

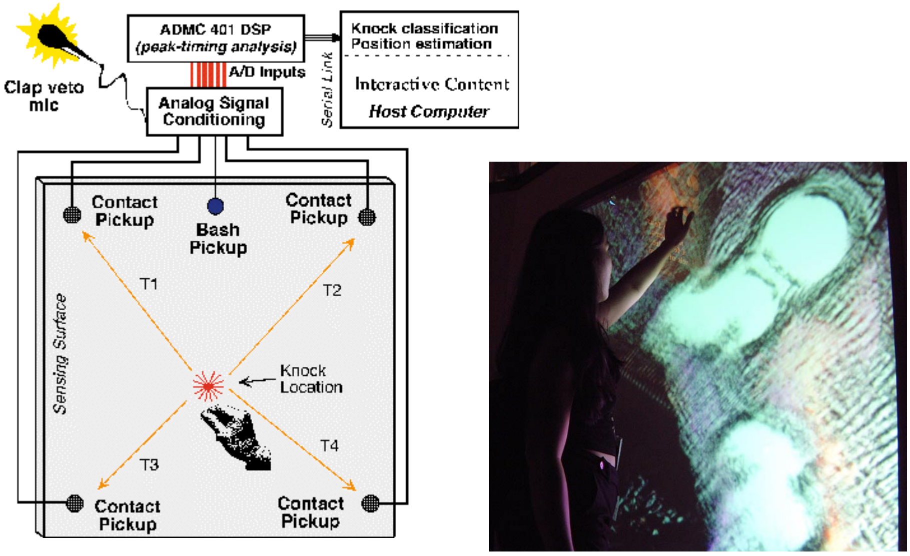

Figure 3: Passive acoustic knock tracker; schematic (left) and in operation at SIGGRAPH 2002 (right)

for outdoor scenarios, where it has to be cabled and withstand the horrors of weather and public prodding. Accordingly, we next developed a system that is extremely simple, based on tracking knocks and taps made by users on a large piece of glass. A simple system from 1999 is described in [1], which we further refined and brought out to various public installations in 2001 [10]. Figure 3 (left) shows a schematic of this device – it is indeed very straightforward. Four piezoelectric pickups mounted on the inside surface of the glass at the 4 corners detect the arrival of bending waves generated by impacts. In measuring the differential time of arrival of these bending waves, one can locate the position of the impact, thereby implementing a tracking interaction where the users "point" through their knocks. We also measure the amplitude of the event (denoting the intensity of the knock) and its frequency characteristics (that determine the type of impact – e.g., knuckle knock, fist bash, metal tap), allowing the interaction to exploit these other characteristics through which various degrees of affect are conventionally expressed. The position resolution ranges from σ = 2-3 cm, depending on the thickness of the glass. As the bending waves can be detected on both sides of the glass, nothing needs to be installed on the active (outside) surface, making this extremely well suited to outdoor venues and retail stores that already have large street-level windows. A recently announced commercial system [11] appears to operate on a similar principal; it seems, however, to exploit the ultrasound component in hard fingernail taps, hence requires a very constrained "fingerflick" gesture. Our device responds to any kind of knock – implementing this feature, however, required considerable effort in compensating for the different kinds of excitation waveforms from the various types of knocks and countering large effects from dispersion in the glass medium. We have used this system in many public installations – Figure 4 shows it at an American Greetings store in Rockefeller Center, where it enabled passers-by to explore store-related

Figure 3: The acoustic knock tracker at an American Greetings Store near Rockefeller Center

content and play interactive games during their peak business seasons (Christmas and Valentine’s Day) running through the winter of 2001-2002. Figure 3 (right) shows it running recently (July 2002) at the SIGGRAPH conference in San Antonio [12]. Here, we ran the system on a large window (2 x 2 meters, ¼” glass), where it drove a complex interactive art visualization [13] that evolved in intricate ways with each knock. This system also used a simple pair of Doppler radars to measure people moving in front of the screen, as schematicized in Figure 5. The radars (Figure 6) are modified versions of those introduced in [2]; they have an onboard processor that extracts three features indicated in Figure 8 (reflecting amount of motion, speed, and direction). The radars are immune to changes in light conditions or optical characteristics of clothing – unlike video imagers, they see directly through noncounductive walls and penetrate clothing, sensing the skin directly. The radars hence open up a degree of noncontact interaction as people approach the wall – in this case, motion in front of the screen generated global, nonspecific behavior (e.g., rolling, scrolling, energy generation) in the graphics in accordance with the motion characteristics. Knocking created more specific and highly localized phenomena. The type of knock also affected the graphics accordingly; hard metallic knocks made more “brittle”, streaming foci than knuckle knocks, and fist bashes created nodes that essentially “exploded”.

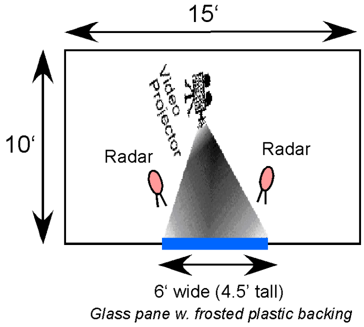

Figure 5: SIGGRAPH 2002 Interactive Window with motion radars

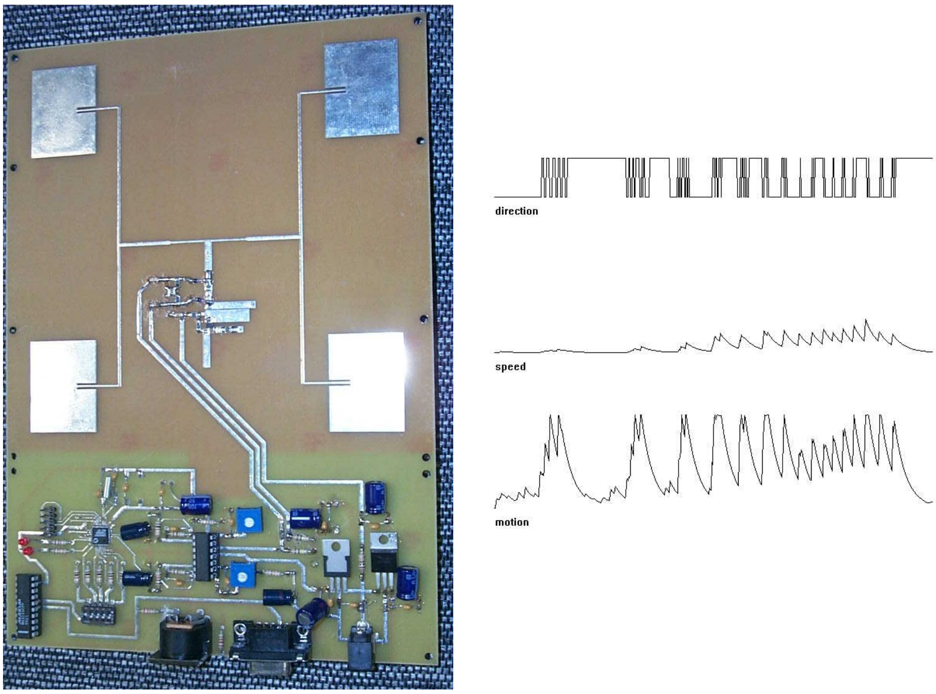

Figure 6: Digital Doppler radar head (left) and sample signals from hand motion (right)

5) Tracking touch with Frustrated Total Internal Reflection

Another technique that we have recently been exploring is to track the position of fingers and objects touching the screen by "Frustrated Total Internal Reflection" [14], where an object in contact with the screen absorbs some of the light injected into the glass. Figure 7 shows an example, where the light from a laser is injected into one side of a piece of plexiglass, and detected by a photodiode mounted on the other side. The drop in intensity is easily seen when the finger touches the glass (the red LED is illuminated when the glass is touched in this test example). Accordingly, a matrix of photodiodes at the window's perimeter and a set of light sources on the opposite side are able to make a large window into a touch screen. Also with this system, there is no need to mount any hardware on the outside (interactive) surface of the glass, making it appropriate for outdoor installations. Unlike the acoustic tap tracker, however, this system does not require the user to tap or knock (not entirely intuitive for interaction and potentially painful after extended sessions) – simple touch works well.

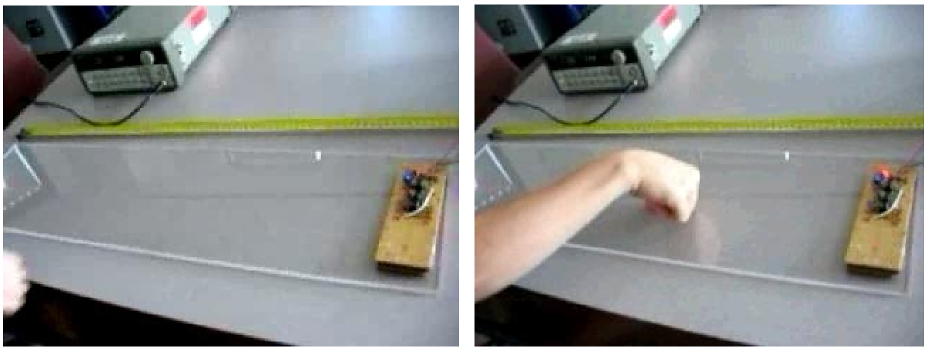

Figure 7: Touch detection by total internal reflection - Before touching (left) and while touching (right) - note red LED at middle right in each photo

6) Summary

Several systems for tracking activity at a large interactive surface have been introduced. All are essentially perimeter retrofits for a large projection screen or glass window, and do not require any complex modifications or specially treated surfaces. Each has its set of tradeoff advantages – e.g., cost and infrastructure vs. constraint on the interaction, and each is appropriate for different circumstances – e.g, indoor or outdoor operation, fine pointing vs. coarse gesture capture. We have fielded these devices in many public installations, and have been gratified to see them readily accepted and used for the kind of group interaction that spontaneously occurs at large interactive displays.

7) Acknowledgements

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8) References

1) Paradiso, J.A., Hsiao, K., Strickon, J., Lifton, J. and Adler, A., “Sensor Systems for Interactive Surfaces,” *IBM Systems Journal*, Vol. 39, No. 3&4, October 2000, pp. 892-914.
2) Paradiso, J., “The Brain Opera Technology: New Instruments and Gestural Sensors for Musical Interaction and Performance,” *Journal of New Music Research*, Vol. 28, No. 2, 1999, pp. 130-149.
3) Paradiso, J., Gershenfeld, N., “Musical Applications of Electric Field Sensing,” *Computer Music Journal*, 21(3), 69-89.
4) See: *http://www.hdm.at/*
5) Strickon, J., Paradiso, J., “Tracking Hands Above Large Interactive Surfaces with a Low-Cost Scanning Laser Rangefinder,” *CHI ‘98 Conf. on Human Factors in Computing Systems: Summary*, ACM Press, New York, 1998, pp. 231-232.
6) Donath, J., “Visual Who: animating the affinities and activities of an electronic community,” In *Proceedings of the third ACM International Conference on Multimedia (Multimedia ’95)*, Nov 5-9, San Francisco, CA., ACM Press, NY, 1995, pp. 99-107.
7) Donath, J., Paradiso, J., et. al., “LaserWho,” in *SIGGRAPH 2000 Conference Abstracts and Applications*, ACM Press, NY, July 2000, p. 86.
8) Paradiso, J., Hsiao, K, Strickon, J. and Rice, P., "New Sensor and Music Systems for Large Interactive Surfaces," *Proc. of the International Computer Music Conference 2000 (ICMC 2000),* Berlin, Germany, August 2000, pp. 277-280.
9) Yang, C., “New Laser Range Finder Designs For Tracking Hands Atop Large Interactive Surfaces,” M-Eng Thesis, MIT Department of Electrical Engineering and MIT Media Laboratory, March 2001.
10) J. A. Paradiso, C. Leo, N. Checka, K. Hsiao, "Passive Acoustic Sensing for Tracking Knocks Atop Large Interactive Displays," in the *Proceedings of the IEEE Sensors 2002 Conference*, Orlando, Florida, June 11-14, 2002,Vol. 1, pp. 521-527.
11) Pearson, H., “Bus Shelters to Talk Back,” Nature News Service, September 16, 2002, See: *http://www.nature.com/nsu/020909/020909-15.html.*
12) J. A. Paradiso, C. Leo, N. Yu, M. Downie, "The Interactive Window," in *SIGGRAPH 2002, Conference Abstracts and Applications*, ACM Press, 2002, p. 79.
13) Downie, M., Eshkar, S., and Kaiser, P. "'Loops' - A Digital Portrait," ACM SIGGRAPH 2002 Technical sketch. Also: *http://web.media.mit.edu/~marcd/nws/process/npr.html*
14) Bekefi, G. and Barrett, A. H., *Electromagnetic Vibrations, Waves, and Radiation*, Cambridge, MA: MIT Press, pp. 479-483, 1987.
15) Leo, Che King, “Contact and Free-Gesture Tracking for Large Interactive Surfaces,” M-Eng Thesis, MIT Dept. of EECS and MIT Media Lab, May 2002.