An acoustic position sensing system for large scale interactive displays

Matthew Reynolds
School of Interactive Computing
Georgia Institute of Technology
Atlanta, Georgia 30332
email: *msr@gatech.edu*

Alexandra Mazalek
School of Literature, Communication, and Culture
Georgia Institute of Technology
Atlanta, Georgia 30332
email: *mazalek@gatech.edu*

Glorianna Davenport
Media Laboratory
Massachusetts Institute of Technology
Cambridge, MA 02139
email: *gid@media.mit.edu*

***Abstract*—We present a hybrid positioning and communication system for tracking interaction objects called 'pucks' on the surface of a large LCD or plasma display. Pucks are smart sensor packages consisting of a microcontroller as well as a contact-type acoustic receiving transducer and an infrared or radio data link. A puck may take the form of a standalone interaction object, or the puck circuitry may be integrated into an existing object, such as a digital camera, cellphone, PDA, or other device. In this work we take advantage of the glass surface atop an LCD or plasma display as a communication and sensing medium, and launch 200KHz Gaussian-shaped acoustic ranging pulses into that medium from transmitting transducers adhered to the corners of the glass. We present experimental results demonstrating millimeter-scale puck positioning accuracy over the entire surface of a 32-inch LCD, at an update rate of 100Hz. We also demonstrate the scalability of this approach to much larger displays. In our first implementation, power consumption of each puck is 3V at 12mA during data transmission, 5mA during positioning, and 50μA when idle, yielding 6-8 hours of continuous tracking from a 90mAH prismatic lithium polymer battery.**

***Index Terms*—position sensing, transparent sensing medium, acoustic positioning, smart surfaces, interactive displays**

Fig. 1: Interaction objects ("pucks") on the display surface

I. Introduction

Motivated by the recent availability of large LCD and plasma displays at affordable prices, we consider a world in which many surfaces in homes, offices, and public spaces are covered with large, interactive displays. These 'smart surfaces' may one day cover the walls of a building as well as being embedded in tables or other furniture [1]. While there are many techniques for sensing the position of a user's finger when in contact with a display surface, including a wide variety of touch-screen technologies that have been developed over the years, there are currently very few options for sensing the interaction of physical objects with display surfaces.

Applications for this type of object-to-display interaction include geographical visualization, interaction with scientific data, navigation of virtual architectural models, and urban planning simulations where physical interaction objects ("tokens" or "phicons") have meaning within the context of the human-computer interface. A photograph of the object interaction system incorporating acoustic position sensing is shown in Figure 1.

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II. Acoustic positioning in display surfaces

Searching for a way to overcome the limitations of existing object-to-display interaction systems including optical [2], [3], free-air acoustic [4], and capacitive [5], [6] techniques, we realized that the most common direct-view displays employ LCD or plasma technologies consisting of several layers (see Figure 2) including a backplane, the display medium itself (liquid crystal or plasma cells), and a thin, top glass surface that seals in the display medium. When employed in a table or wall surface, a thick protective glass surface is usually employed to protect the display from the weight or impact of objects or people leaning or pressing on the display.

Glass surfaces present a relatively uniform, rigid medium that is well known to support acoustic wave propagation. For example, the Tap Window is an acoustic system for tracking knocks on large panes of glass [7] as a way of interacting with a window display. In contrast to the Tap Window's passive knock tracking, we decided to use the glass surface of the

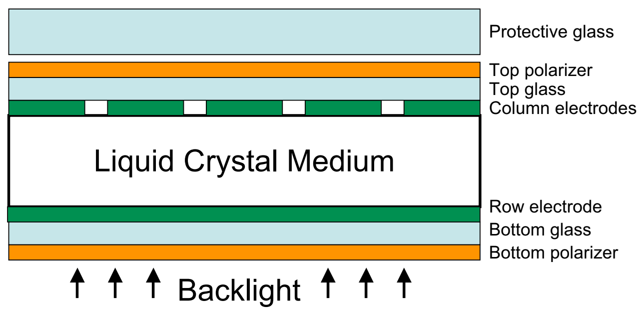

Fig. 2: Simplified LCD structure and protective glass layer

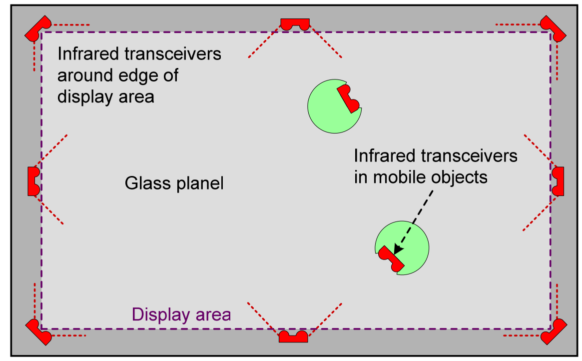

Fig. 4: Infrared data communication subsystem

display itself as an "ether" through which we would broadcast acoustic positioning signals that would be audible to any object placed atop the surface. Because the interaction objects are passive listeners to the "ether", there is no limit to the number of objects that can be simultaneously tracked.

Our positioning system consists of two subsystems. First, a 200KHz pulsed acoustic transmitting transducer is fitted to each of the four corners of the display glass, while an acoustic receiver is fitted to each interaction object (Figure 3). The acoustic system provides object ranging using time of first arrival using a time reference and synchronization from the second subsystem, an infrared communication system complying with the IRDA 1.1 physical layer specification (Figure 4). Eight IRDA transceivers are located around the periphery of the display area to ensure redundant IR communication even in the presence of occluding hands and objects. Our next generation system will replace the IR communication system with a radio frequency system which will improve system throughput and eliminate the need for redundant IR transceivers.

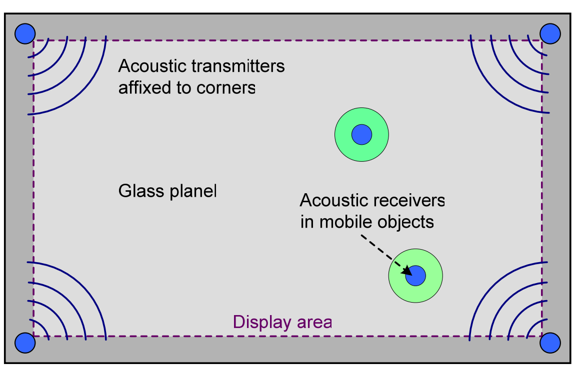

Fig. 3: Acoustic transmitting and receiving subsystem

Using propagation of acoustic waves in the display glass to provide position tracking has several important advantages over the prior art. First, the display glass is a uniform, rigid medium for the transduction of acoustic signals. Second, the display glass is already present, so it does not add cost to the system. Third, the display glass is transparent, so the positioning system allows for the use of a rear mounted display. Finally, the acoustic waves are largely confined to the surface of the glass and do not radiate appreciably into the surrounding air because of the enormous impedance mismatch between the glass and the surrounding air, so display and sensing systems do not interfere with each other when they are located in close proximity.

A. Characterization of acoustic propagation in protective glass

An initial set of experiments were performed to characterize acoustic wave propagation in a piece of thick protective display glass previously used atop a 32 inch (82cm) diagonal Samsung LCD display panel, model number LT-P326W. The protective glass, measuring 687mm x 412mm x 6.3mm, was suspended above the LCD display panel itself with four, 5mm x 5mm x 3mm pieces of hard rubber located in each corner.

A 20mm piezoceramic disc transducer, part number CEB-20D64 made by CUI Inc. of Tualatin, OR was bonded using cyanoacrylate adhesive to one corner of the glass. This transducer was used as the transmitting element in these experiments. An Agilent Technologies model 33120A function generator was configured to produce bursts of 3 cycles of 10V pk-pk sine wave excitation at frequencies ranging from 150KHz to 250KHz, a range chosen to avoid interactions with common ultrasonic systems operating in the 40KHz band, as well as the noise spectrum of jingling keys, predominantly below 100KHz.

At a fixed transmitter-receiver spacing of 21cm, the system did not exhibit a high-Q resonant response within the characterized frequency range. Received amplitude increased roughly linearly with increasing frequency. This suggested that the system would exhibit a relatively wide bandwidth and the choice of ranging pulse frequency could be made for convenience of design of the digital and analog processing electronics. A frequency of 200KHz was chosen for convenient derivation from a 20MHz microprocessor clock crystal, and to permit the use of the ultimately selected receiving transducer, part number 200KHF18 made by SensComp Inc. of Livionia, MI.

The varying amplitude response suggested that the system would exhibit dispersive behavior, so two sets of pulse prop-

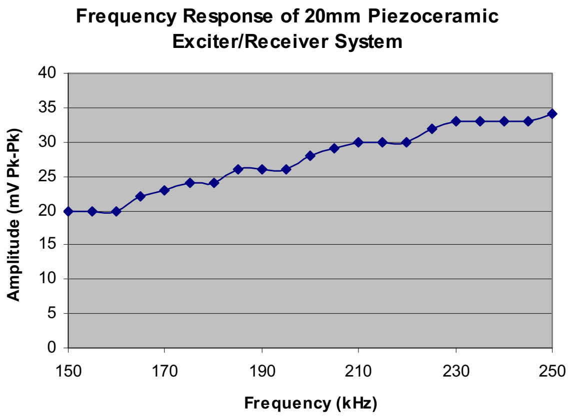

Fig. 5: Frequency response, transmitter-receiver spacing 21cm

agation velocity experiments were performed at 200KHz. In the first experiment, the transmitting and receiving transducers were placed on the same side of the glass, while in the second experiment, the transducers were placed on opposite sides of the glass which is the configuration chosen for the finished system. No substantive difference was observed between same-side and opposite-side excitation. However at room temperature, a propagation velocity of approximately 5500m/s was observed at 200KHz while a subsequent experiment at 160KHz yielded a propagation velocity of approximately 4800m/s, so the glass medium is definitely dispersive.

B. Multipath propagation in the glass surface

Because of the inherent impedance mismatch where the edges of the glass surface meet the air, reflections are expected at the air-glass boundary. Figure 6 shows the reflections arising from a 3-cycle long pulse of 200KHz excitation. The

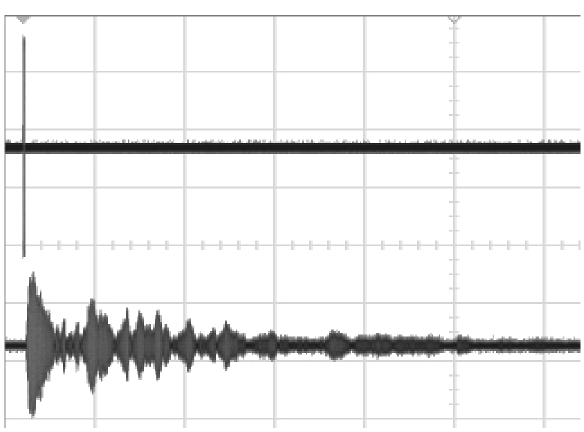

Fig. 6: Multipath propagation in the glass surface. Top trace is excitation pulse, bottom trace is received signal 21cm from the transmitting transducer. Timebase is 1ms/div, top trace is 5V/div and bottom trace is 100mV/div.

top oscilloscope trace shows the excitation pulse while the bottom trace shows the signal at a receiving transducer 21cm away. Many strong reflections, including constructive and destructive interference patterns, arise after the first arrival of the transmitted pulse, but they die down to insignificant levels relative to the amplitude of the first arrival after approximately 5ms. While this effect could be mitigated by bonding a dissipative medium to the edges of the glass, this was deemed unnecessarily complex. We allowed 10ms between successive ranging pulses to ensure that multipath interference did not affect the time of first arrival measurement, which set the 100Hz update rate of the positioning system.

C. Overall positioning system architecture

Figure 7 shows the overall system architecture. The system

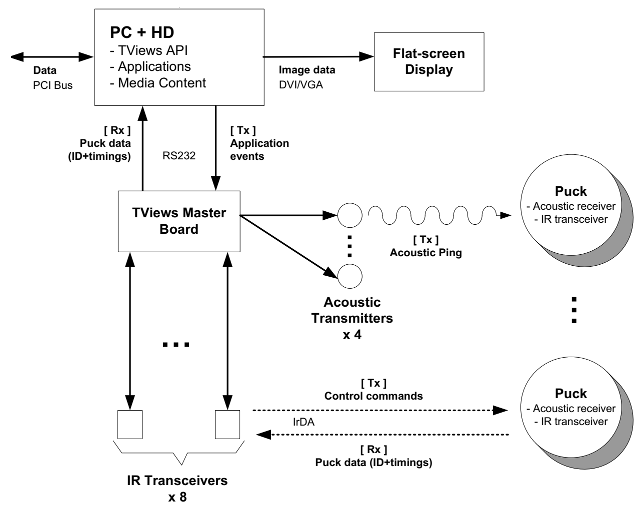

Fig. 7: Block diagram of the object tracking and interaction system.

consists of a real time signal processing system and a PC providing graphical interaction. The real time system consists of a Microchip PIC16F877 microprocessor on a 'master board' running a custom interrupt-driven kernel. The PIC microprocessor handles the real time sequencing of infrared communication messages as well as timing the outgoing ranging pulses. It provides a buffered output stream consisting of interaction object position, as well as control messages to and from the interaction objects, for example to read the state of the user interface button on the pucks as well as to set the state of the puck's LEDs. The use of a separate real time system allows PC software to be written for Microsoft Windows using the Java language and programming environment, which is not real-time capable.

D. Puck receiving system design

Each puck contains a PIC16F628 microcontroller as well as an acoustic receive signal chain shown in Figure 8. The

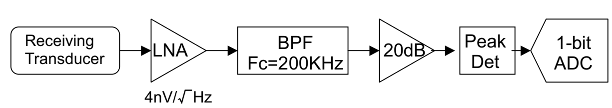

Fig. 8: Puck receive signal chain

piezoceramic receiving transducer is connected to a low noise amplifier with a noise PSD of $4\mathrm{nV}/\sqrt{\mathrm{Hz}}$ and a power gain of 20dB. A second order Butterworth bandpass filter with a 200KHz center frequency and 3dB bandwidth of $\approx$60KHz then passes the ranging pulses while rejecting noise from other sources. After an aggregate power gain of 62dB, the signal is peak detected using a voltage doubling Schottky diode detector and the resulting envelope is digitized by a 1-bit ADC formed from the comparator integral to the puck's PIC microcontroller. The progression of signals through the puck signal processing chain is shown in Figure 9.

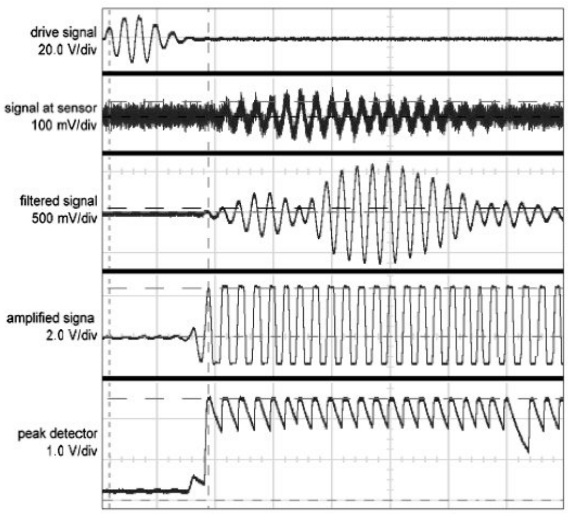

Fig. 9: Puck receive signal progression. Horizontal timebase is 20us/div. Significant multipath is visible approximately 40us after the cursor marking first arrival of the transmitted pulse.

III. SYSTEM EVALUATION

Figure 10 summarizes the achieved positioning system accuracy as measured at a 100Hz update rate. One hundred individual ranging measurements are shown at each of nine positions evenly spaced over the display surface. Reported positions are accurate to within 8.2mm of the true position 90% of the time and significantly better (3.4mm) errors can be obtained in 50% of the trials. The major contributor to system error in actual use is false triggering of the pulse arrival timer caused by slip-and-stick noise as the puck is moved on a dirty glass surface. A recursive filter is in development to mitigate this error source. Future work on a non-contact receiving transducer (e.g. an acousto-optical receiving transducer) shows a path to eliminating this error source. In our first implementation, power consumption of each puck is 3V at 12mA during data transmission, 5mA during positioning, and 50μA when idle, yielding 6-8 hours of continuous tracking from a 90mAH prismatic lithium polymer battery.

IV. CONCLUSION

In this work we take advantage of the glass surface atop an LCD or plasma display as a communication and sensing medium, and launch 200KHz Gaussian-shaped acoustic ranging pulses into that medium from transmitting transducers adhered to the corners of the glass. These pulses propagate as longitudinal acoustic waves through the display glass, and are received by any number of pucks that might be present and listening to the surface of the glass. By employing a time of arrival technique to measure propagation delays through the glass, we create a *positioning utility* somewhat akin to GPS, available anywhere on the surface of the display. There is no fundamental limit to the number of pucks that may be simultaneously tracked, pucks are portable from one display surface to another, and we have created a hierarchical identity space for pucks that allow them to take on a rich variety of meanings within a variety of interaction contexts.

Circular Error Probability	Filtered Data - errors in mm		
	Best Data Point	Worst Data Point	Average
90%	3.93	16.90	8.22
70%	2.68	10.26	4.65
50%	1.70	9.36	3.42

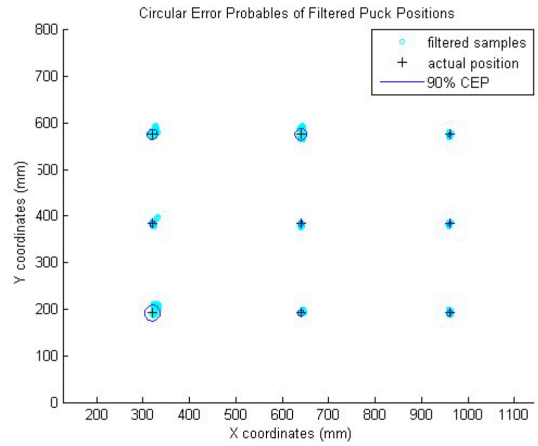

Fig. 10: Positioning system accuracy at 100Hz update rate

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REFERENCES

[1] A. Mazalek, M. Reynolds, and G. Davenport, "TViews: An extensible architecture for developing multi-user digital media tables", in *IEEE Computer Graphics & Applications*, Special Issue on Interacting with Digital Tabletops, vol. 26 no. 5, 2006, pp. 47-55.

[2] J. Underkoffler and H. Ishii, "Urp: A luminous-tangible workbench for urban planning and design" in *Proceedings of CHI 1999*, pp. 386-393.

[3] Microsoft Surface, *http://www.microsoft.com/surface*. Available online.

[4] Mimio interactive whiteboard system, *http://www.mimio.com/*. Available online.

[5] P. Dietz and D. Leigh, "DiamondTouch: A multi-user touch technology" in *Proceedings of UIST 2001*, pp. 219-226.

[6] J. Rekimoto, "SmartSkin: An infrastructure for freehand manipulation on interactive surfaces" in *Proceedings of CHI 2002*, pp. 113-120.

[7] J. Paradiso, C. Leo, N. Checka, and K. Hsiao, "Passive acoustic sensing for tracking knocks atop large interactive displays". IEEE Sensors Journal, vol. 17, pp. 1-7, June 2002.