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Invited

A Touchless Interactive Display Technology with Human-body e-Field Detection

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ABSTRACT

A new software-defined sensing technology that detects the human body e-field with higher SNR and sensitivity than found in today's PCap touch controllers is presented. Enhanced capabilities "see" the human body 4-5 feet in front of the display and the hand can be identified up to 2 feet away.

1 Introduction

Interactive digital displays are vital to every aspect of our lives, and interactive displays in public installations are found everywhere from point-of-sale terminals to airport kiosks to meeting rooms. These touchscreens are based on a common technology known as capacitive touch where the electrical capacitance of the touch sensor in front of the display changes when a user touches the display with a finger. This works because the capacitance of the user is directly coupled to the system through touch thereby affecting the total capacitance of the system. But the capacitance changes are actually very small, and a physical touch is needed to produce a change sufficient for detection.

In a post-COVID-19 world, public touchscreens have become a problem for users who are concerned about of virus transmission from bacteria on the touch surface. This is impairing the usefulness of this vital technology.

A true touchless solution is needed that has the same intuitive and operational integrity as touch. Current touch technologies today are wholly inadequate for the task because they require the user to be in physical contact with the display. What is needed is the ability to interact with a display or surface without physically touching it. The system would need to detect a change in the e-field near the surface touch sensor that would be close enough to active capacitive changes in the system, but far enough to clearly avoid physical contact with the system. However, existing capacitive touch systems do not have anywhere near the sensitivity required to detect e-field changes at sufficient distance to avoid accidental touch.

We have developed an entirely new way to do human-body e-field sensing with higher SNR and sensitivity than that found in today's PCap touch controllers. This gives rise to unique high-fidelity data that can be used for analysis not available in any traditional touch system. Our sensing platform is software-defined, not unlike software-defined radio, and we can tune-in any aspect of sensing from proximity to joystick-like hover and direct touch – all in real-time. This capability allows us to "see" the human body 4-5 feet from feet from the display and the hand can be identified up to 3 feet from the display..

2 System Architecture

We use Sigma-delta techniques with advanced digital filtering to overcome the problems of traditional PCap touch sensors. The novel design uses concurrent adaptive sensing transceivers for touch sensor sampling that acquires the mutual touch, self touch and pen signals simultaneously (i.e., no scanning). True continuous and simultaneous sampling of all electrodes using a lower-cost digital architecture provides excellent noise rejection, significantly improves speed, signal-to-noise ratio, and touch sensitivity. Sigma-delta converters are used for high resolution ADC and DAC applications. They also perform noise shaping, filtering, decimation, and are inexpensive to produce. One of the unique characteristics Sigma-delta converters is that the frequency transfer functions for the input signal and quantization noise are different thereby enabling very high-resolution signal creation with a significantly improved Signal to Noise Ratio (SNR). Higher-order Sigma-delta transceivers have increasingly better SNR but usually at the expense of stability problems. We have developed circuits, in silicon, that address the successfully address order-stability issue resulting in the SNR's in excess of 100 dB. The result is that we can detect e-field changes several feet in front of a touch sensor.

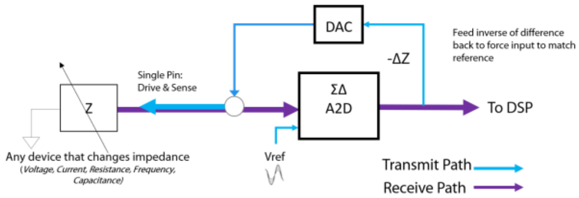

Fig. 1 Concurrent Adaptive Sensing Transceiver

Figure 1 depicts the core idea behind the concurrent adaptive sensing transceiver. In a real-world system that digitizes an analog effect (i.e., temperature, pressure, capacitance, etc.), there is some form of transducer that changes impedance with a change in the analog effect. In the case of a capacitive touch display, the touch sensor is that transducer and a single electrode is depicted as the Z block in Figure 1. Vref is a configurable signal of any frequency and voltage that is driven on to the touch sensor electrode. This signal is purely sinusoidal and consists of one or more frequencies. A unique aspect of this design is that the Vref signal is held constant and is always present on the touch sensor electrode. It is not switched on and off the electrode like typical touch controller. When the electrode is touched, the impedance on the touch sensor changes which would normally change the signal on the touch sensor. However, our circuit holds Vref constant on the sensor through a feedback mechanism that is equivalent to imposing a counter impedance, -ΔZ, back on the sensor to cancel out the change. In other words, the signal on the sensor is always forced to be the Vref signal and all the information about the changes in the sensor impedance is contained in the counter signal. That signal is sent to a DSP where advanced signal processing performs analysis and filtering for strong noise rejection and exceptional SNR resulting in high sensitivity able to detect extremely small impedance changes due to changes in the proximate e-field. This is very different from a system that is looking for a voltage to cross some threshold above the noise. In fact, it is an entirely new way to sense changes in a transducer. Another unique aspect of this architecture is that both the drive signal and the sense mechanism are electrically on the same pin which means that both driving and sensing occur simultaneously on the same pin connected to the electrode. Our architecture is a radical departure from traditional switched capacitive measurement systems and solves many problems in those systems, including parasitic capacitance, loss of signal due to harmonics, RC settling time, and more. An additional benefit of this architecture is the ability to drive high impedance lines for larger interactive displays, or use exotic sensor materials like the optically optimal, flexible, and robust PEDOT:PSS films.

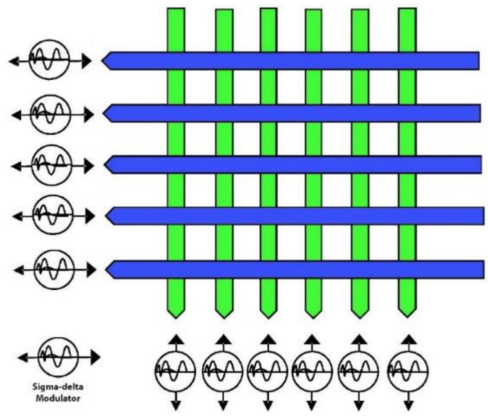

Fig. 2 A touch sensor concurrent adaptive sensors on each row and column

Our architecture is unlike traditional systems that switch and scan. We have a concurrent adaptive sensing transceiver on every row and column of the touch sensor. This architecture allows for multiple frequencies and simultaneous drive-sensing independently on each row and column. Since there is no time wasted on scanning, the sampling can be extremely fast at speeds greater than 1000 Hz. Multiple frequencies on each channel provides concurrent modality which means both self and mutual capacitance detection is performed in the same sample cycle. For this paper, we are interested in the mutual capacitance changes that occur when the sensor e-field is changed. Having a transceiver on each channel allows for the individual channel frequencies to be adapted in real-time to avoid environmental noise. This, along with powerful digital filtering that rejects out-of-band noise and the very high SNR, gives this new approach unrivaled noise immunity and rejects out-of-band noise that is just 50 Hz away from the fundamental drive frequency which improved e-field detection sensitivity and system reliability.

3 Results

Since ultra-high SNR is critical to detecting off-sensor e-field changes, we tested our architecture against a commercially available touch controller to measure the *touch* SNR differences. Note: it was note possible to make this comparison with a *touchless* SNR measurement as not commercially available touch system can perform that function. To create an equivalent measurement, we calculated the measured *SNR* and divided it by the drive voltage *v,* multiplied by t_n , the normalized time required to make the measurement as given in equation (1). This is done because the drive voltage and sampling time will change the SNR measurements (e.g., a higher drive voltage or a slower sampling time, result in higher SNR) and the metric of equation (1) accounts for that.

$$\frac{SNR}{v} * t_n \tag{1}$$

The experiment was performed on a 32” PCap touch sensor and results are shown in Figure 3. The measurements using a typical commercially available switched-capacitive touch sensor are on the left and the measurements from our more sensitive circuit are shown on the right.

The typical controller produced a touch SNR of 15 dB with a drive voltage of 20 V at a sample frequency of 120 Hz. This resulted in a performance metric of 0.2812. Our touch controller produced and touch SNR of 52 dB using just 800 mV and a much faster sample frequency of 300 Hz. The results are significant with our touch controller demonstrating a performance improvement of 2,796 times. This exceptional sensitivity is what is needed to create a usable touchless interface

32” Touch Sensor: 786.2/0.2812 = ***2,796x better SNR/v***	
15dB SNR, using 20.0V @ 120 Hz	52dB SNR, using 0.8V @ 300 Hz
$\frac{10^\wedge(15dB/20)}{20V} = \mathbf{.2812}\ \frac{SNR}{v}$	$\frac{10^\wedge(52dB/20)}{0.8V} = \mathbf{497.6}\ \frac{SNR}{v}$
$Time_{normalized} = \sqrt{(120/120)} = 1$	$Time_{normalized} = \sqrt{(300/120)} = 1.58$
$0.2812 * 1 = \mathbf{0.2812}\ \frac{SNR}{v} * t$	$497.6 * 1.58 = \mathbf{786.2}\ \frac{SNR}{v} * t$

Fig. 3 SNR performance comparisons between a typical switched-capacitive touch controller (left) and our Sigma-delta touch controller

We tested our touch controller on many devices from 6” diagonal to over 100” diagonal. Performance was excellent as expected. In each system we were able to demonstrate the highly sensitive e-field change detection needed to develop a touchless interface. Figure 4 shows one example. The diagnostic software depicts a 3D heatmap (right) and the detected hand blob (left). There is significant SNR at the shown distance – more than what is actually needed. The hand blob signal is very clean and well above the system and environmental noise which is why the 2D graphical depiction is so clear.

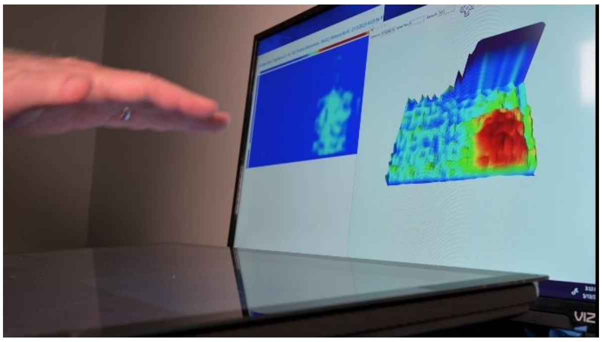

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Fig. 4 Hand detection above a PCap touch sensor.

4 Conclusions

Touchless interfaces are desirable for many applications, but technology hurdles have prevented their development. We developed a novel Sigma-delta architecture that uses concurrent adaptive sensing transceivers for touch sensor sampling. It has the highest SNR in the industry which makes touchless interfaces possible. We introduced a performance metric that can be used to correctly compare the performance of different touch controllers. Our novel architecture compared to a typical commercially available switched-capacitive touch controller showed a substantial improvement in performance of over 2700 times. We showed that high hover is possible and easily detectable. In the future, we will develop a metric to reliably compare *touchless* SNR performance by adding distance to the performance metric of Equation (1).