Instant Instrument Anywhere: A Self-Contained Capacitive Synthesizer

David B. Gerhard
University of Regina
3737 Wascana Parkway
Regina, Saskatchewan, Canada
gerhard@cs.uregina.ca

Brett Park
University of Regina
3737 Wascana Parkway
Regina, Saskatchewan, Canada
park111b@uregina.ca

ABSTRACT

The Instant Instrument Anywhere (IIA) is a small device which can be attached to any metal object to create an electronic instrument. The device uses capacitive sensing to detect proximity of the player's body to the metal object, and sound is generated through a surface transducer which can be attached to any flat surface. Because the capacitive sensor can be any shape or size, absolute capacitive thresholding is not possible since the baseline capacitance will change. Instead, we use a differential-based moving sum threshold which can rapidly adjust to changes in the environment or be re-calibrated to a new metal object. We show that this dynamic threshold is effective in rejecting environmental noise and rapidly adapting to new objects. We also present details for constructing Instant Instruments Anywhere, including using smartphone as the synthesis engine and power supply.

Keywords

Capacitive Sensing, Arduino

1. INTRODUCTION

Instant Instrument Anywhere (IIA) is a small electronic device which can be connected to almost any metal object and attached to any surface, turning that object into an electronic musical instrument with the surface as the speaker. IIA is inspired by the "LED throwie" [3], a small, low-cost, battery-powered magnetic LED used for graffiti and street art. The idea of being able to augment any surface with coloured light is taken one step further with the IIA, which can augment any surface it is attached to in order to create music. IIA is also inspired by the youtube video entitled "Homemade Synthesizer - KITCHEN MUSIC[1]", (Fig. 1a) where a composer seems to construct a synthesizer out of standard household objects and repurposed electronics. The video author admitted that the video was fake, but many of the objects he uses are plausible. Based on his video, we first constructed a simple capacitive-sensing paper-cup instrument[2] (Fig. 1b) and after experimenting with different materials and different ways of processing the signals and turning them into music, we settled on a small Arduino-based system using a surface transducer, with alligator clips to attach capacitive sensing probes to nearby metal objects.

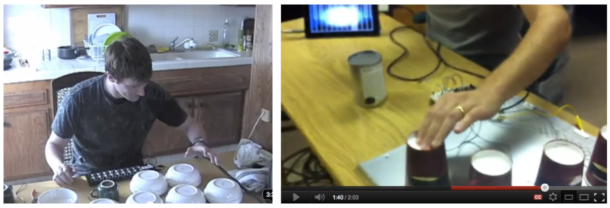

Figure 1: (a) Kitchen music; and (b) our first IIA

The result is a musical instrument which is attached to a flat surface (which becomes the resonator for the transducer), with probes from the instrument attached to a nearby metal object (which becomes the capacitive sensor). Figure 2 shows the exterior of the prototype IIA device.

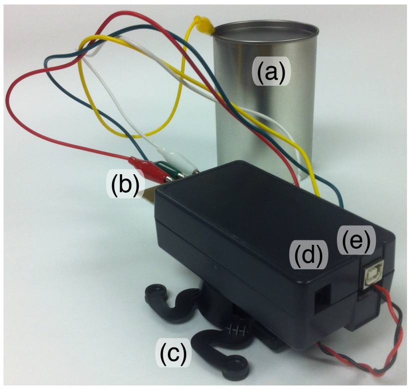

Figure 2: Prototype IIA device. (a) random metal object; (b) Additional unused probes; (c) Surface transducer; (d) power supply jack; (e) USB port for programming.

2. BACKGROUND

The Arduino has become a staple of the hacker/maker community, enabling the integration of embedded processing into many standalone music projects over the last five years. Many opportunities exist for locally manipulating MIDI [1] and OSC data, and building new interfaces. Recently, the Arduino platform has started using an ATmega8u2 (16u2 in the Uno R3 version) as the USB interface. This advancement has opened up many new opportunities for MIDI connectivity (see Section 4).

[1] http://www.youtube.com/watch?v=tCeYMpu3oXg
[2] http://www.youtube.com/watch?v=dLHrn5v772E

NIME'12, May 21 – 23, 2012, University of Michigan, Ann Arbor.

2.1 Capacitive Sensing

Electrical field sensing has been a popular topic of investigation in the music interface field for decades [8]. Capacitive sensing works by measuring the influence of the human body on a capacitive plate. A conductive surface or object can be given an electrical charge which can be affected by the air and nonconductive surfaces around it. When a person brings their hand close to the charged object, the storage characteristics of the object change and that change can be measured by an electrical circuit. Most capacitive sensing systems use an additional nonconductive surface surrounding the charged object (like glass on smartphones) that allows the user to touch the surface without discharging the object. For this reason, there is a common misconception that capacitive sensing requires contact, where in fact only proximity is required.

Capacitive touch systems have been used in music synthesis systems in a number of different instances beginning with the Theremin. The Snyderphonics Manta [10] was presented at NIME last year. It uses a touch-based isomorphic hexagonal keyboard [6] similar to the MUSIX iOS software[3]. Traditional instruments, such as a guitar [4] and a piano [7], have been augmented using capacitive sensors to provide additional information such as touch location. New instruments like the T-Stick [5] use capacitive touch sensors as one type of sensor among many to create original experiences and sounds.

2.2 Circuitbending

A significant community has recently emerged around the concept of circuit bending [2]. Circuit bending is the repurposing of electronic toys, instruments, and other devices with the goal of creating new and interesting sounds. In a similar manner, the IIA uses found metallic objects in order to create new and interesting instruments.

3. PROTOTYPE CONSTRUCTION

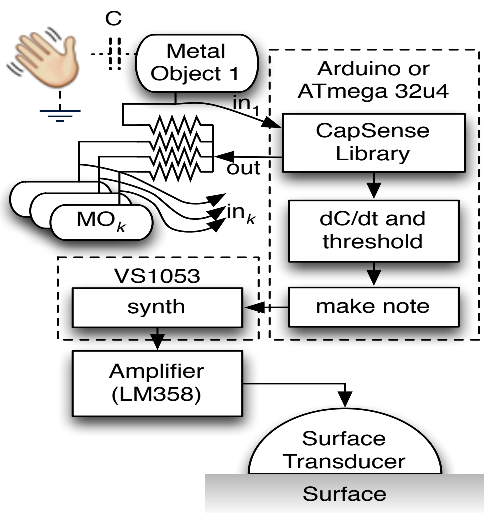

Figure 3: System bock diagram

Figure 3 shows the block diagram of the prototype system as constructed. The core of the system is a microprocessor which is set up to detect changes in capacitance and translate them into note messages. Our prototype uses an Arduino Uno with an ATmega328 microprocessor, but we have also successfully deployed the codebase on a standalone ATmega32u4-based breakout board, which is less expensive and has a smaller footprint than the Arduino Uno.

3.1 Sensor Construction

Because the goal of the IIA is to turn any metal object into a capacitive sensor, a small circuit must be constructed to allow the capacitance to be measured by the CapSense library[4]. A set of alligator clips are attached to I/O pins on the microprocessor through a very large resistor ($\approx 1\text{M}\Omega$). The large resistor means that the RC time constant of the circuit is large, and can be measured in software using pulses expressed through the "output" pin. The "input" pin measures the voltage on the metal object, which is the same as the voltage across the capacitor. The time lag between the voltage changes can be used to measure the RC time constant, and thus the capacitance of the metal object that the circuit is attached to.

3.2 Capacitive Sensing with CapSense

The main use-case for the Instant Instrument Anywhere was to have a person approach a surface, attach the transducer to the surface, clip probes on to a nearby piece of metal, and start to make sounds with no reconfiguration required. Traditional capacitive sensing requires the free-space capacitance of the sensor to be know beforehand and to use a threshold above that free-space capacitance to indicate a trigger event. Because we cannot know what metal the IIA will be attached to, we cannot know the free-space capacitance and are not able to use an absolute threshold to calculate triggers. Instead, we used a relative capacitance measure to detect how fast the capacitance was changing.

Figure 4 shows an example trace of the data coming from the CapSense library on the ATmega328 microprocessor. Note that C is not the measured capacitance of the system, but a time-based value related to RC.

The value of C relates to the time it takes to charge and discharge the system. Each probe connected to a metal object is in series with a large resistor ($1\text{M}\Omega$) which brings the RC time constant into a measurable range. The output pin provides +5v to the system, which charges the RC circuit. When the input pin associated with the probe crosses the hysteresis input threshold of the ATmega328 (+3v rising, +2v dropping), the CapSense library measures the time for a complete 4-stage charge-discharge cycle to be performed: 1: The circuit is charged past +3v on the input pin; 2: the input pin is set high, pinning the capacitor to +5v; 3: the input pin is disconnected from +5v and the capacitor begins to discharge through the resistor; and 4: the input pin is set low, fully discharging the capacitor to 0v. This complete cycle happens n times (in our case, $n = 30$) and a single measured C value is related to time to complete n charge-discharge cycles. The charge/discharge time is actually measured in number of CPU clock cycles multiplied by a looping factor which is determined empirically.

Referring again to Fig. 4, points a, c, d, and f are interpreted as note-on events, while b and d are note-off events. Note that at point c, the environmental capacitance has changed and a new baseline is present. A standard threshold would fail at this point, but our dynamic threshold continues to accurately detect events and reject the background noise. Additionally, after point g, we can see a significant variation in the background capacitance which is not caused by the player moving in the vicinity of the sensor. This variation is too slow to cause an event, but a strict threshold would likely trigger on these values. The background capac-

[3]`http://www.shiverware.ca/musix.html`

[4]`http://arduino.cc/playground/Main/CapSense`

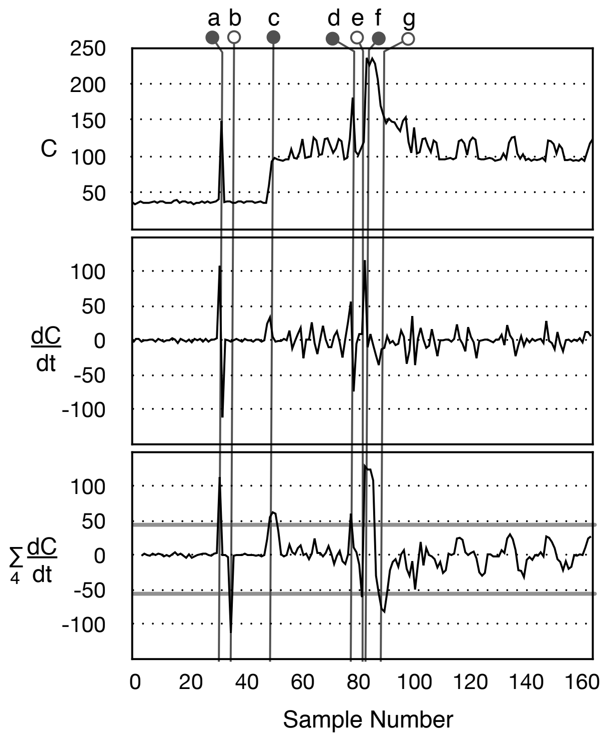

Figure 4: Processing of measured data. C **= Measured values from CapSense;** dC/dt **= differential; and** $\sum_4(dC/dt)$ **= moving four-tap sum of the differential, thresholded at** ± 50**.**

itance can change due to any number of factors including static discharge, humidity, and people in the room.

In a second interaction mode (termed "hold"), a player can start a note by quickly moving their hand toward the metal object, then slowly move their hand away preventing a release. If the player moves their hand slowly enough, the change in capacitance will not surpass the change threshold and the note will be sustained until triggered again.

3.3 Sound Synthesis

The sound synthesis module is the VS1053[5] sound decoder chip. This device, from VLSI solutions, contains decoders for MP3, Ogg, AAC, and WMA as well as a bank of General MIDI instruments for real-time synthesis. Our prototype only makes use of the General MIDI synthesis engine. We decided not to use an analog synthesis engine in order to keep the size and power constrains down. The synthesizer output is routed to a HIAX25C10 8Ω frog transducer.

3.4 Constructed prototype

Figure 5 shows a photograph of the internal construction of the prototype. SparkFun industries makes an Arduino "shield" that breaks out the VS1053 synthesizer chip and contains some prototyping space, so we used that to build the amplifier circuit and attached a resistor for each of four connection probes.

3.4.1 Null Plate

Allowing four connection probes meant that the prototype device could be connected to up to four metal objects. We discovered, however, that when the probes were *not* connected to a metal object, they continued to function as sensors, causing unwanted touch events. In order to mitigate this issue we added a copper plate to the outside of the device, soldered to the output of the circuit pin. When not in use, probes are connected to this "null" plate causing them to instantly charge and discharge, which indicates to the software that they should be ignored without slowing down the sensing algorithm.

[5] http://www.vlsi.fi/en/products/vs1053.html

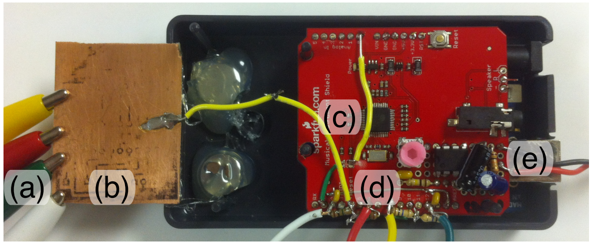

Figure 5: IIA prototype internals. (a) Connection probes; (b) null plate; (c) VS1053 protoboard; (d) Resistors on the receive pins; (e) LM358-based amplifier (wired to transducer) and headphone jack.

3.4.2 Probe Shielding

A second consideration in creating the prototype itself is that the wires used to attach to the metal objects do themselves have capacitance, which can influence the result of the measurement. This was discovered when playing multiple objects which were near to each other: in some instances, if the wires connected to the objects were touching or tangled, multiple instruments would sound at the same time due to crosstalk, or worse, false positives would appear.

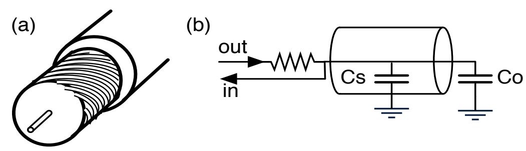

Figure 6: Shielded probe. (a) shielded cable has an inherent capacitance between the core wire and the outer wrapping. (b) Grounding the outer wrapping causes the capacitance of the shield C_S **to be in parallel with the capacitance** C_O **of the metal object.**

By switching to shielded wires (see Fig. 6), the probe wires are no longer reactive to environmental capacitance and will not interact with each other or the player. This was proven by measuring the reaction of the circuit with and without the shielding connected to ground while repeatedly touching the outside of the wire once every two seconds for 12 seconds.

We can see from this figure that without shielding, the wire acts as a sensor and will transmit noise into the system if the user touches the wire. With the shielding, this noise is excluded from the system. The overall capacitance of the system is increased to $C_S + C_O$ with C_S being constant, which increases RC and thus the time it takes to charge or discharge the circuit. Our measurements indicated that it takes about twice as long ($\approx$ 18 ms vs $\approx$ 9 ms) to charge the system with the shielded cables attached to a metal object. The size and dimensions of the metal object will of course affect the overall capacitance of the system, increasing or decreasing the time required to charge the system and receive a measurement.

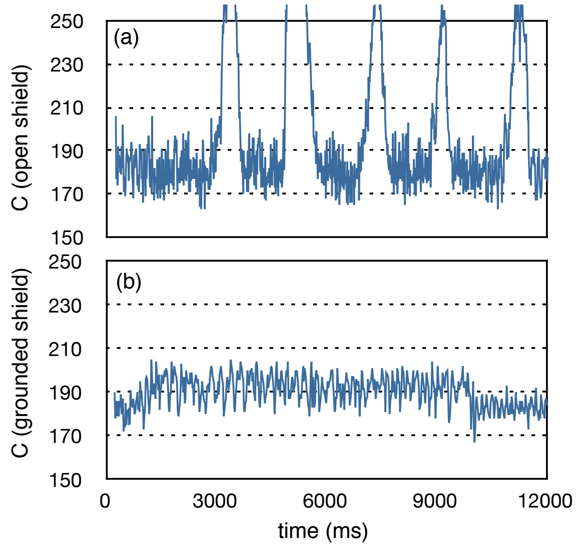

Figure 7: (a) Shield is not grounded and wire capacitance can be affected; (b) shield is grounded and probe is protected from environmental capacitance.

4. SMARTPHONE-BASED IIA

Although the goal of the Instant Instrument Anywhere is to make a standalone device, there is a significant advantage of pairing the capacitive touch sensing module with a smartphone. Modern smartphones are able to run more advanced software synthesizers; they contain a headphone jack to output audio and small speakers which can be augmented acoustically with devices such as the iPhoneAmplifier[6]. Additionally, the phone battery could power all the components for all-day operation. Figure 8 shows an example of a smartphone IIA.

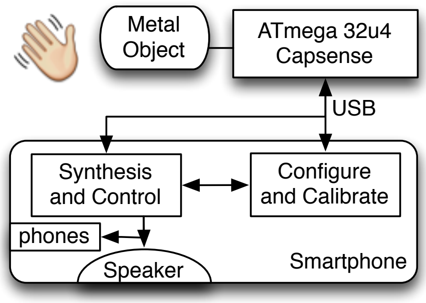

Figure 8: Smartphone-based Instant Instrument Anywhere, with the smartphone fulfilling the role of configuration, synthesis, power source and speaker.

An further advantage of using a smartphone for the IIA is that a custom app can be created to provide access to configuration settings relating to the digital capacitive sensing. For example, the app could allow the user to modify the dC/dt threshold, or route different probe values to different control parameters (aftertouch, bend etc.) or choose different notes or effects for each sensor being played. This increases the utility and reconfigurability of the system.

A smartphone version of the IIA was constructed as a proof of concept. An Arudino Uno was loaded with the CapSense library as well as a USB driver that made the 8u2 chip appear as a General MIDI device. The device was then connected, via USB and the apple camera connection kit, to an iPhone running synthesis software. The result was a peripheral device connected to the iPhone which provides capacitive touch sensing. This is the device shown in our video response to the Kitchen Synthesizer.

[6]http://www.iphoneamplifier.net/

5. FUTURE WORK

Building on the portability and DIY construction of these instruments, we plan to create a single-PCB device that contains all of the circuitry necessary for the IIA. This single board device would contain an ATmega32u4, a sound synthesizer, and an amplifier circuit. It will have connection terminals for a power source, a speaker, probes, and USB for programming and MIDI out. This could be the heart of any new instrument that uses capacitive sensing as the fundamental interface characteristic. It will also serve as a platform for a true acoustic throwie (with a small battery, speaker, and a magnetic probe).

6. REFERENCES

[1] D. Diakopoulos and A. Kapur. HIDUINO: A firmware for building driverless USB-MIDI devices using the Arduino microcontroller. In A. R. Jensenius, A. Tveit, R. I. Godøy, and D. Overholt, editors, *Proceedings of the 11th international conference on New interfaces for musical expression (NIME 2011)*, pages 405–408, Oslo, Norway, 2011.

[2] R. Ghazala. Circuit-Bending: Build your own alien instruments. Wiley, 2005.

[3] Graffiti Lab. LED Throwies. Online, last checked: Febuary 1, 2011, [http://www.graffitiresearchlab.com/blog/projects/led-throwies/].

[4] E. Guaus, T. Ozaslan, E. Palacios, and J. Arcos. A left hand gesture caption system for guitar based on capacitive sensors. *Proceedings of the 10th international conference on New interfaces for musical expression (NIME 2010)*, pages 238–243, 2010.

[5] J. Malloch and M. M. Wanderley. The T-Stick: from musical interface to musical instrument. In *Proceedings of the 7th international conference on New interfaces for musical expression (NIME 2007)*, pages 66–70, New York, NY, USA, 2007. ACM.

[6] S. Maupin, D. Gerhard, and B. Park. Isomorphic Tesselations for Musical Keyboards. In *Proceedings of the 8th Sound and Music Computing Conference (SMC 2011)*, 2011.

[7] A. McPherson and Y. Kim. Design and Applications of a Multi-Touch Musical Keyboard. *Proceedings of the 8th Sound and Music Computing Conference (SMC 2011)*, 2011.

[8] J. Paradiso and N. Gershenfeld. Musical applications of electric field sensing. *Computer Music Journal*, 21(2):69–89, 1997.

[9] G. Roma and A. Xambó. A tabletop waveform editor for live performance. *Proceedings of the 8th international conference on New interfaces for musical expression (NIME 2008)*, 2008.

[10] J. Snyder. The Snyderphonics Manta and a Novel USB Touch Controller. In A. R. Jensenius, A. Tveit, R. I. Godøy, and D. Overholt, editors, *Proceedings of the 11th international conference on New interfaces for musical expression (NIME 2011)*, pages 413–416, Oslo, Norway, 2011.