SIGCHI Extended Abstracts Sample File: Note Initial Caps

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Abstract

UPDATED—June 11, 2016. Designing with properties such as touch and intimate distance sensing in electronics and digital control enables new dimensions within art and design, and a range of new possibilities for sensing, tactility and functionality. Resistive pressure sensing and capacitive presence sensing are nothing new in wearable technology. However, there is still limited insight into the potential of soft materials capabilities of performing multiple functions at the same time. Adding multiple functionalities is fundamental to the exploitation of e-textile properties. Development of multifunctional textiles may provide greater use possibilities for e-textiles where separate components for each sensor were required. This submission to the ISWC Fiber arts design competition demonstrates describes a method to add presence sensing to pressure sensors, thereby allowing to detect the presence of humans before they touch the pressure sensor. This allows for novel interfaces that guide users even before they deliberately use and interact with the object. In principle, the method only requires a software modification so there are no additional costs for materials and the feature could be made available to existing products with a software update. This textile is a prime example the design research into wearable technology of Troy Nachtigall coming together with the particular capacitive engineering expertise of Admar Schoonen. Together they create a new smart textile with multi functionalities that

sense presence and Pressure.

Author Keywords

Authors' choice; of terms; separated; by semicolons; include commas, within terms only; required.

ACM Classification Keywords

H.5.2.Information Interfaces and Presentation, I.4.8 Sensor Fusion [

Author Keywords

]: Sensor; Sensing; Presence; Pressure; Capacitive; Resistive; Textile; E-textile

Introduction

Troy Nachtigall is a Wearable Technology expert currently exploring programming materials as a Marie Sladowska Curie research fellow in the ArcInTexETN Horizon 2020 project where he explores the relationship of adaptive and responsive wearables between the scales of the individual, the room and architecture. Engineer Admar Schoonen is an expert in capacitive technologies with many past projects in capacitive touch sensing. He is a member of the TU/Eindhoven Industrial Design /dSearch labs exploring design research from an engineering perspective. PrePre presents a design collaboration between Troy and Admar that created an e-textile and code that can sense pressure and intimate presence on as many as four sensors simutaniously. This collaborative process was selected for a pair of workshops for the Ultra Personalized Smart Textiles (UPST) project at the University of Technology at Eindhoven in part as an ambasodor action of the ArcInTexETN Horizon 2020 project (www.ArcInTexETN.eu). These workshops allowed the exploration of touch and presence technologies with interaction designers where new frontiers of sensing and actuating were explored.

PrePre 2015

Novelty

Relevancy

Technical Aspects

Resistive Pressure Sensors

Low cost pressure sensors are often made of a sandwich of flexible electrodes with a layer of flexible moderately conductive material in between. The moderately conductive material is usually made of a carbon impregnated polymer with a specific structure that allows it to be squeezed together. The material can be considered as having many parallel resistors. When the material is compressed some of the resistors will be partially short-circuited due to nonlinear elastic deformations. The partial short-circuits result in a lower overall resistance of the sandwitch structure. This is visualized in Figure 1.

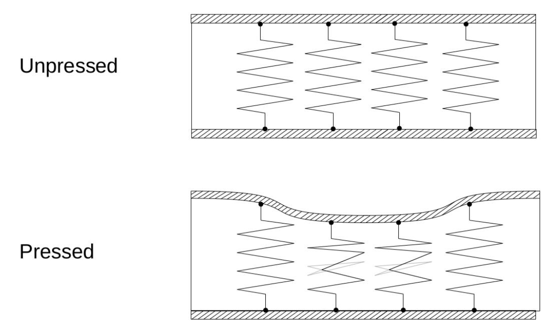

Figure 1: Conceptual model of a pressure sensor. Compressing the sensor causes partial short-circuits which lowers the overall resistance of the structure.

This type of sensor is used in commercial products (FIXME: ADD REFERENCES TO COMMERCIAL PRESSURE SEN-

SORS?) and is also popular in electronic textile products (FIXME: ADD REFERENCES TO VELOSTAT SENSORS?) since it is easy to fabricate and integrates well in textile products.

In these products, the sensor is often used in a resistor divider setup where one electrode is connected directly to an analog input of a microcontroller and the other electrode is connected directly to ground. To complete the circuit, a reference resistor is connected to the analog input and supply voltage.

Since some microcontrollers (such as the Atmel ATmega328P in the popular Arduino UNO board) have internal pull up resistors on the analog inputs, an external reference resistor is in some cases not even needed. However, the pull up resistors are fixed value (10 - 50 $\mathrm{k\Omega}$) so the sensor must be matched to this resistor value. Additionally, these pull up resistors have a higher tolerance so the gain of the sensor can vary from product to product.

Capacitive Touch / Distance Sensors
Capacitive sensors are popular sensors in embedded computing due to their low cost and capabilities of detecting approaching human body parts, which allows the object to give feedback to the user even before the user is physically touching the object. The physics behind sensors that meaure self-capacitance is that one plate of the capacitor is formed by the sensor and the other plate is formed by nearby grounded objects. The capacitance is a function of area and distance, as shown by the well-known parallel plate model

$$C = \frac{\varepsilon A}{d} \tag{1}$$

where C is the capacitance, ε is the permittivity of the material between the plates (approximately $8.85418{\cdot}10^{-12}\ \mathrm{F/m}$ for air), A is the overlapping area of the plates and d is the distance between the plates.

For many use cases of capacitive touch, the permittivity and area do not change significantly and thus the capacitiance is a measure for the distance between the sensor and the body part.

There are many different methods to measure self-capacitance (FIXME: ADD REFERENCE TO RC-DISCHARGE, CVD, RELAXATION OSCILLATOR, OTHERS?).

R-C Charge Method
A very popular method in the Do It Yourself (DIY) community is the R-C charge method. In this method, the sensor is connected to a digital input pin of a microcontroller and a resistor is connected to the sensor and a digital output pin of the microcontroller. Toggling the output pin causes the capacitive sensor to charge or discharge. These charge and discharge times depend on the value of the resistor and the value of the capacitor formed by the sensor plate and the human body and the microcontroller determines the capacitance by measuring these charge and discharge times.

The R-C charge method is very simple and low cost as it requires only an additional resistor and two General Purpose Input Output pins (GPIO pins) of a microcontroller, which makes it very attractive to the DIY community. However, since it is based on measuring charge and discharge times it is also relatively slow.

An intrinsic feature of capacitive touch sensors is that the electric field needs to fringe out of the object to be able to sense the human body and due to this fringing, the electric field is also easily disturbed by other electric fields or nearby grounded objects such as 110 / 230 V wires or devices or metal structures. The slow measurement method of the R-C charge method makes it more difficult to filter out these disturbances, leading to poor performance of the sensor and poor experiences of capacitive touch for users of the objects which use this method.

CVD Method
Another well-known method for self-capacitance does not rely on R-C charge times but instead relies on a microcontroller with a multiplexed Analog to Digital Converter (ADC), the sample-and-hold capacitor ($\mathrm{C_{S\&H}}$) inside this ADC and the ability of the microcontroller to dynamically reconfigure its analog input pins to digital output pins. This method is called Capacitive Voltage Division (CVD).

In this method, no external resistor is required and the sensor plate is directly connected to an analog input pin. The microcontroller starts a measurement by configuring this pin a digital output and making this output low, thereby discharging the sensor. Next, the microcontroller connects the internal ADC to its supply voltage, which charges $\mathrm{C_{S\&H}}$ to a fixed amount of charge which depends only on the capacitance $\mathrm{C_{S\&H}}$ and the supply voltage.

Afther the sensor pin is discharged and $\mathrm{C_{S\&H}}$ is charged, the sensor pin needs to be reconfigured as analog input and the multiplexer of the ADC needs to be switched to this input. This will redistribute the charge on $\mathrm{C_{S\&H}}$ over both $\mathrm{C_{S\&H}}$ and the capacitance of the sensor. A larger sensor capacitance will result in a lower voltage on the sensor and the last step of this method is to measure this voltage using the usual ADC functions.

Since this method does not rely on R-C discharge times but uses the internal and usually much faster ADC, more filtering can be applied to the signal to remove disturbance of other nearby objects and electronic devices. This results in a superior performance and a better user experience.

Using Resistive Pressure Sensors as Capacitive Distance Sensors
The CVD method connects the sensor directly to analog input of a microcontroller, similar to the resistive sensor setup. The resistive sensor can now be used to also measure capacitance by connecting the other electrode of the sensor to a GPIO pin instead of ground. This setup is shown in Figures 2 and 3.

Figure 2 shows the setup in resistive sensing mode, which is a standard resitive divider setup which uses an internal pull resistor as reference resistor and a digital output pin as ground to complete the circuit.

Figure 3 shows the same circuit but with the GPIO pins reconfigured for capacitive sensing. In this setup, the internal pull up resistor is not used and the to electrode of the pressure sensor is only connected to the analog input. The bottom electrode is connected to a pin that is configured as digital input, which effectively means that the sensor is floating. This is exactly the setup that is needed for the CVD method.

Software Features
In many cases both resistive pressure sensing and capacitive presence sensing applications require relative measurements but do not depend on absolute measurements. In such cases, a state machine which tracks any background variations on the signal level is a simple and effective method to reduce noise. In our case, both the resistive sensor signals and the capacitive sensor signals use the following state machine where each signal has its own instance and its own parameter settings.

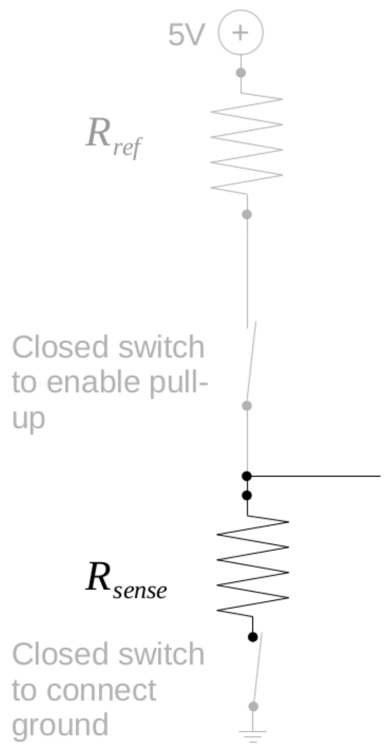

Figure 2: Resistive pressure sensor used in capacitive and resistive setup in resistive sensing mode. Grey items are internal to the microcontroller.

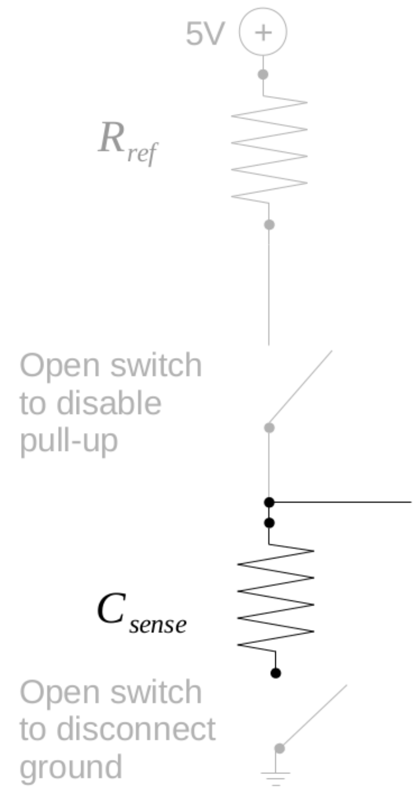

Figure 3: Resistive pressure sensor used in capacitive and resistive setup in capacitive sensing mode. Grey items are internal to the microcontroller.

The state machine for each sensor can be in five states:

- Calibrating
- Released
- Released to Pressed
- Pressed
- Pressed to Released
- Released

This is shown in Figure 4.

In the Calibrating and Released states, the background variations are tracked using an exponential decaying filter and stored in average a. In all other states the background variations are not tracked. In the Released state, if the most recent measurement x is more than P counts below average a, the state is changed to Released to Pressed. If in the next measurement x is less than P counts below the average, the state is changed back to Released. If however the next C measurements are all more than P counts below this average, the state is changed to Pressed.

Similarly the state moves from the Pressed state to the Pressed to Released state and from Pressed to Released to the Released state.

To account for stuck buttons (for example: when the user unintentionally placed a large conductive object very close to the capacitive touch sensor while the sensor was in Released state), there is a maximum time that the sensor can be in the Pressed state. If after this time the sensor is still in the Pressed state, it is changed to the Calibrating state and the sensor will start recalibrating.

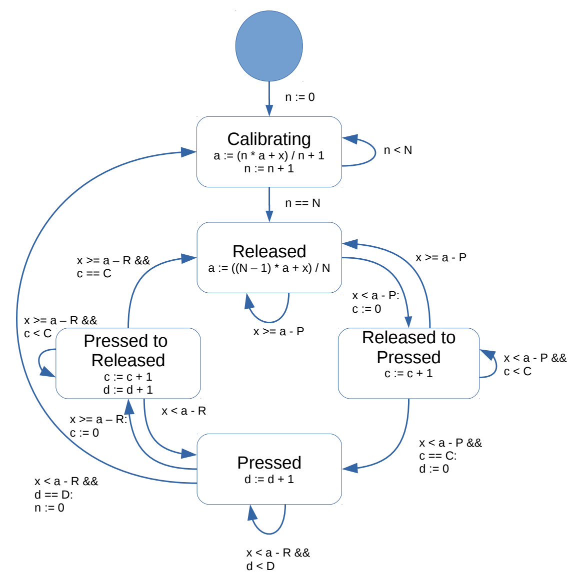

Figure 4: State machine for resistive and capacitive measurements to track background variations.

By changing the parameters N, C, P and R the amount of filtering and speed of detection can be tuned to the application.

FIXME: ADD REFERENCE TO STATE MACHINE

Shielding

In capacitive sensing mode, the bottom electrode of the resistive pressure sensor is floating. In this mode the pressure sensitive resistive material in between can be seen effectively as a conductor and thus the whole sensor can be seen as just a single electrode. The electric field of the sensor will therefore also fringe all around the sensor, including the bottom side. As the electric field is also present at the underside of the sensor, the sensor is not only sensitive for the presence of human body parts above the sensor, but also below. If the capacitance underneath the sensor is relatively constant, tuning of the state machine could be sufficient to filter this out and make the sensor only sensitive to large and / or rapid variations.

However, for some applications such as lose fitting clothing, this might still not be sufficient. In such cases, the sensor can be made less sensitive by adding a shield underneath the sensor. Connecting this shield to ground effectively removes all of the capacitance variation but also reduces the sensitivity of the sensor. By connecting the sensor itself to the input of a 1 x opamp and the output of the opamp to the shield, the voltage of the shield is always very close to the voltage on the sensor itself. As a result, the electric field underneath the sensor is virtually zero and no sensitivity is lost. Note that for proper shielding, also the cable to the sensor should be shielded. A schematic diagram is shown in Figure 5.

FIXME: ADD REFERENCE TO SHIELDING

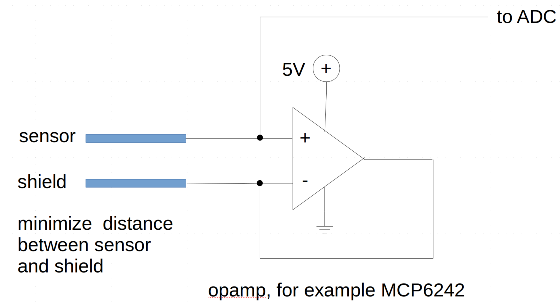

Figure 5: Circuit to shield underside of capacitive sensor.

Mechanical Features

An overview of the stackup of the total sensor is shown in Figure 6. In this figure, the electrode and shield material can be conductive textile, the insulating material can be any non-compressable insulating material (for example cotton) and the pressure sensitive material can be Velostat or ESD foam.

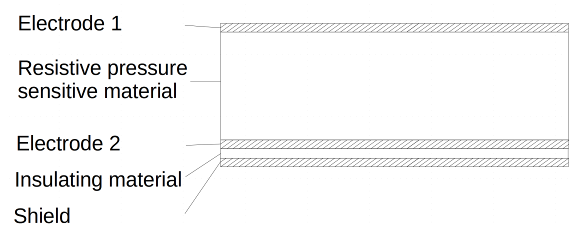

Figure 6: Stackup for pressure and presence sensor with shield

Conclusion

In this paper we have described the combination of capacitive distance sensing using the CVD method for presence sensing with resistive sensing for pressure sensing. The robustness of the CVD method as well as the required circuit and microcontroller features make it ideal to combine with existing resistive pressure sensing applications to enhance the user experience by not only sensing how hard a user presses on a button but already giving feedback to the user when he / she is approaching the button.