Figure 1: PrePre sensor prototype.

PrePre: Presence and Pressure Sensing

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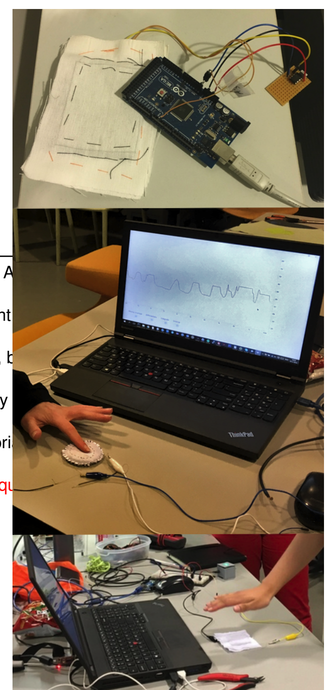

Abstract
Designing with properties such as touch sensing, distance sensing and digital control enables new dimensions within fashion and design. A range of new possibilities for sensing, tactility and functionality. Resistive pressure sensing and capacitive presence sensing are not new in wearable technology. However, there is still limited insight into the potential of soft materials capable of performing multiple functions at the same time. Adding multiple functionalities is fundamental to the exploitation of new e-textile properties. Development of multifunctional textiles may pro- vide greater use possibilities for e-textiles where separate components for each sensor were 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
PrePre demonstrates a method to add presence sensing to pressure sensors, allowing to detect the presence of humans before they touch the pressure sensor. This allows for novel interfaces that guide users even before they de-

liberately 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 of how design research into wearable technology together with the engineering expertise on in this case capacitive sensing can create a new smart textiles with multi-functional capabilities like presence and pressure. PrePre presents a design collaboration between /d.search labs and Wearable Senses lab at TU/e Industrial Design to create an e-textile and its supporting code to sense pressure and presence on as many as four sensors simultaneously.

This collaborative process was selected for a pair of workshops at the Ultra Personalized Smart Textiles (UPST) project at the University of Technology at Eindhoven in part as an ambassador action of the ArcInTexETN Horizon 2020 project[1]. These workshops explored iterations of touch and presence technologies with interaction designers where new frontiers of sensing and actuating were explored.

Design

The capability of sensing doesn?t need to be reduced to pressing against a textile. Knowing about when someone is approaching a textile can add new possibilities on how to interact with it and new dimensions to the design of those interactions. A sensor made with conductive, resistive and insulating materials intended for ?on the body? uses could also be applied for ?near the body? uses where softness and tactility are highly valued product features.

Design Concept

Touch is important in interaction, but vicinity is often revealing of behavior and motivations. Not only can vicinity detect hesitation or reluctance in touching, but vicinity can also reveal choosing not to touch. This becomes very interesting when deployed in a garment worn on the body but it is not easily to achieve. An optional shielding layer allows for the use of PrePre on the body, making?it only sensitive to one side. Following an iterative design process, and several workshops at the TU/e Wearable Senses Lab (see figure 2) not only choices of textiles were perfected, but the technique of capacitative sensing was tailored as well to on-the-body and close-to-the-body applications. At the same time the aesthetic qualities were considered as the PrePre is intended for fashion. The PrePre sample is novel in its dual nature of sensing pressure and presence at the same time. Since it requires no extra hardware or fabric layers, garments can be thinner, more flexible and breathable as well as lower in cost and with lower impact on environment.

Relevancy

PrePre could be integrated into garments, accessories, furniture, automotive and other places were human computer interaction could be of additional value. The sensor is designed to the human body and the scale of the human hand. The soft and flexible nature of the e-textile sensor allows for its implementation on a multitude of surfaces that the hand interacts with, including clothing and accessories.

Textiles

The construction of PrePre consisted of a series of conductive, resistive and insulating layers. A low density ESD Foam[2] was chosen for the resistive layer for its spacer fabric qualities. The low density aspect causes the foam to lift back up quickly after releasing which helps mitigate hysteresis. A conductive silver coated e- textile knit Dorlastan was chosen for the electrode layers due to its soft yet highly

[1] http://www.ArcInTexETN.eu

[2] http://nl.farnell.com/multicomp/039-0050/low-density-foam-305x305x6mm/dp/1687866

conductive feature. The stretch version was chosen to once again aid in resiliency which helps the sensor return to its original state. A hydrophobic polyester was chosen for the insulating layers to protect the conductive layers and prevent influence from humidity. A conductive ripstop nylon was selected for the shielding layer for its conductive conformity. An overview of the stackup of the different materials is shown in Figure 3.

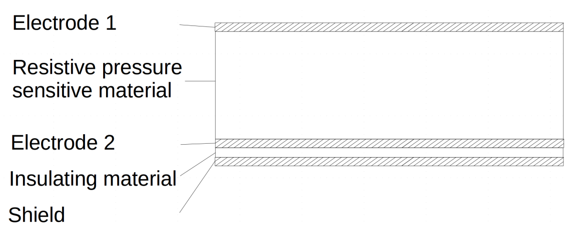

Figure 3: Stackup for pressure and presence sensor with shield

Technical Aspects

Resistive Pressure Sensors

The top three layers in Figure 3 show a typical stackup for low cost pressure sensors made with electrodes and resistive material. The resistive material is usually made of a carbon impregnated polymer with a structure that allows it to be compressed. The material can be conceptualized as having many parallel resistors. When the material is compressed some of the resistors will be partially short-circuited due to non-linear elastic deformations. The partial short-circuits result in a lower overall resistance of the structure. This is visualized in Figure 4.

Capacitive Touch / Distance Sensors

Capacitive sensors are popular sensors in embedded computing due to their low cost and capabilities of detecting

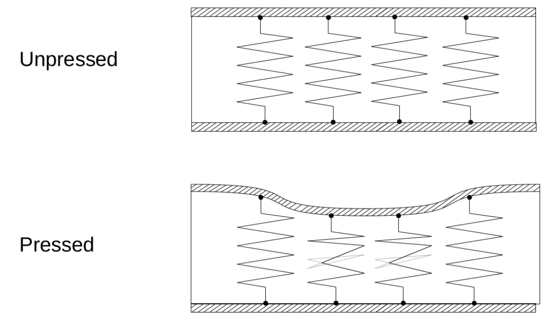

Figure 4: Conceptual model of a pressure sensor. Compression causes partial short-circuits lowering the overall resistance.

approaching human body parts. The parallel plate capacitor model provides a good intuition to the physics behind sensors that measure self-capacitance. In this model one plate of the capacitor is formed by the sensor and the other plate is formed by nearby grounded objects such as a hand or finger. The capacitance is a function of area and distance. There are many different methods to measure self-capacitance, two of those will be briefly discussed and the second one (used in PrePre) will be then described more in detail.

RC Charge Method

A very popular method in the Arduino community is the RC charge method. In this method the charge and discharge times of a resistor-capacitor combination is measured. Since the resistor is fixed value, this is a measure for the value of the capacitor. A detailed description can be found in [**?**].

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. Due to this fringing, the electric field

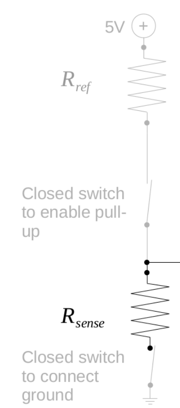

Figure 5: Resistive p
sensor used in capa
resistive setup in res
mode. Grey items ar
the microcontroller.

is also easily disturbed by other electric fields or nearby grounded objects such as power lines, electronic devices or metal structures. The slow measurement method of the RC charge 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.

CVD Method
Capacitive Voltage Division (CVD) is a well-known method for self-capacitance does not rely on RC charge times but instead relies on charge distribution between the sample and hold capacitor of an ADC ($\mathrm{C_{S\&H}}$) and the capacitive sensor. Davison [**?**] gives a good overview of this method.

Here, no external resistor is required and the sensor plate is directly connected to an analog input pin. The microcontroller unit (MCU) starts a measurement by configuring this pin as a digital output and making this output low, thereby discharging the sensor. Next, the MCU connects the ADC to its supply voltage, which charges $\mathrm{C_{S\&H}}$.

Then 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 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 ADC.

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

Resistive Pressure Sensor as Capacitive Distance Sensor
The CVD method connects the sensor directly to the analog input of a MCU, 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 5 and 6.

Figure 5 shows the setup in resistive sensing mode, which is a standard resitive divider setup using an internal pull resistor as reference resistor and a digital output pin as ground to complete the circuit.

Figure 6 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 top electrode of the pressure sensor is only connected to the analog input. The bottom electrode is connected to a pin configured as digital input. This way the sensor is floating, which is exactly the setup that is needed for the CVD method.

Modern MCUs have fast ADCs (typically 1 MHz or more), allowing it to rapidly switch between resistive and capacitive sensing modes, using the same sensor for both resisitive pressure and capacitive presence sensing.

Software Features
In many resistive pressure sensing or capacitive presence sensing applications relative measurements are sufficient. In such cases, a state machine which tracks any background variations on the signal is a simple and effective method to reduce noise. In our case, both the resistive and capacitive signals use the following state machine where each signal has its own instance and parameter settings.

Similar to the state machine described by Bohn [**?**], the state machine for each sensor can be in five states: Cal-

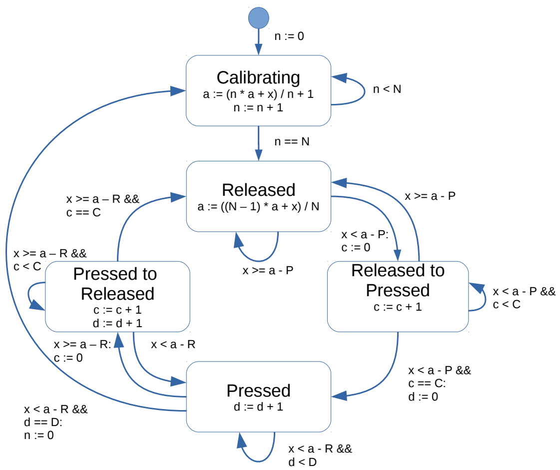

Figure 7: State machine for resistive and capacitive measurements to track background variations.

ibrating, Released, Released to Pressed, Pressed and Pressed to Released. This is shown in Figure 7.

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 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), there is a maximum time that the sensor can be in the Pressed state. After this time the state is changed to the Calibrating state and the sensor will start recalibrating.

By changing parameters N, C, P and R the amount of filtering and speed of detection can be tuned to the application. Once tuned properly, the difference of x and a is a measure for how close a user is to the sensor (in capacitive mode) or for how much pressure a user applies to the sensor (in resistive mode).

Shielding

In capacitive mode, the sensor is also sensitive on the underside. If the distance between the underside of the sensor and the human body is relatively constant, tuning could be sufficient to filter this out and make the sensor only sensitive to large and / or rapid variations.

However, some applications such as lose fitting clothing require more filtering and benefit from 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 to the input of a 1 x opamp and the output of the opamp to the shield, the voltage of the shield is always close to the voltage on the sensor. This is similar to what Davison describes in [**?**]. The electric field underneath the sensor is then virtually zero and no sensitivity is lost. Note that in many applications also the cable to the sensor should be shielded. A schematic diagram is shown in Figure 8.

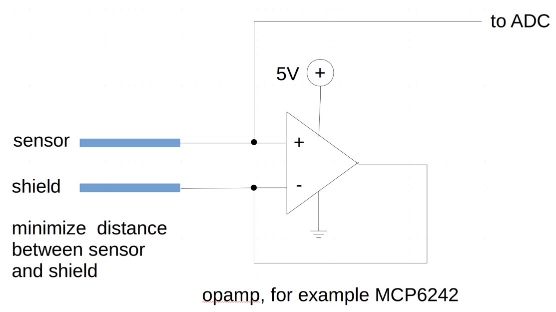

Figure 8: Circuit to shield underside of capacitive sensor.

Conclusion

The possibilities of a reliable, textile, soft presence and pressure sensor are numerous. This reliability was detailed in 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 MCU 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 approaching the button. The choice of textiles increases the reliability and performance of the sensor in their specific contexts. In the use of shoes we measure not only how hard the foot is being pressed, but if and how far the foot is disconnecting from the shoe. In garments we can understand how multiple people approach and touch each other in performance or everyday activities. In the context of an automative steering wheel we can understand not only where someone is touching, but how they move their hands when engaged in an maneuver such as turning a corner. Using multiple sensors for greater movement vector and specific specific touch location sensing is a serious possibility that the authors intend to explore further.

Acknowledgements

The authors would like to thank the Wearable Senses Lab, /dSearch Lab and E-Labs along with the Designing Quality in Interaction group of the Industrial Design department of the Eindhoven University of Technology. Support for this project also comes from the Marie Curie Horizon 2020 Action ArcInTexETN. Special thanks to Dr. Oscar Tomico and Dr. Stephan Wensveen of TU Eindhoven.