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Printed embedded transducers including additional on-substrate signal evaluation

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Abstract

In this work, we present a method for the manufacturing and readout of printed strain gauges, as well as capacitive sensors on pre-coated sheet steel substrates. The state of the art for both sensor elements currently is the integration into a given system by gluing pre-fabricated sensors on a foil onto a substrate. This has, however, inherent disadvantages in terms of force coupling within the bent substrate to the glued strain gauge sensor. For capacitive elements, this leads to a disadvantage that not every degree of surface integration is possible. Furthermore, the interface (foil) can lead to delamination problems. The method presented in this work solves these problems by printing the sensor layer directly on top of the pre-applied organic coating and thereby omitting the glue as well as the extra substrate layer from the conventional buildup.

Key words: printed electronics, printed sensors, capacitive sensors, piezoresistive sensors, embedded sensors

Introduction

Capacitive touch sensors are widely used and well known. Every smartphone utilizes capacitive sensors as they provide an easily usable method of interaction with a device via its surface. This advantage can be utilized in different applications. The development of a large number of low temperature curable conductive materials like inks and pastes based on various materials including silver [1], gold [2], nickel [3], copper [4], conductive polymers [5] as well as carbon [6], [7] enables a wide variety of potential applications. Using these developments leads to the next step of integration of various interaction modules, such as integration of capacitive elements into lesser obvious surfaces.

Strain gauges are established for the measurement of force, strain, and torque in components that undergo mechanical stress. Currently strain gauges can be fabricated on various kinds of substrates. Examples are silicon oxide based [8], polyimide [5], polyamide [9], and poly-dimethyl-siloxane (PDMS) [10] based substrates.

One crucial step is common among all current strain gauges as well as capacitive interaction modules. They are commonly pre-fabricated on thin carrier foils and need to be transferred or placed to their point of application via a gluing process afterwards. While this method is straightforward, it has some inherent disadvantages. First, the adhesive layer acts not only as the glue component, but also creates a damping layer. This damping of the measured strain effect affects the signal generated from the strain gauge or the capacitive transducer. The second shortcoming affecting the performance of strain gauges is associated with the polymer carrier foils, which usually feature different elastic moduli than the material to be measured. Therefore, the strain coupling between the substrate and the sample is, similar to the gluing layer, another origin of spurious signal reduction. In this work, we present an alternative approach for applying strain gauges and capacitive buttons on metallic substrates featuring an organic coating. We particularly review the evaluation and read-out of previously reported elements with the use of µ-Controller based readout circuits mounted directly on top of the sensor carrier substrate.

Fabrication

The process of printing the strain gauge sensors as well as capacitive buttons follows the procedure previously presented in [11], [12] and [13]. The samples, on which the sensors are realized using a screen printing technique, are provided in a pre-coated state in terms of steel sheet substrates with organic primer coatings.

Two different primers are used to investigate differences due to variations in the elastic moduli resulting from the coating. Before the printing process is performed, the samples are prepared with the following cleaning routine. First, we rinse with isopropyl alcohol, second with ethyl alcohol and as a last cleaning step the samples are dried with compressed clean room N2. This cleaning procedure is intended to reduce printing errors. The desired strain gauge design is exposed onto a screen print mesh, which has prior been coated with a negative photoresist. Then one of the prepared samples is mounted to the semi-automatic screen print machine RokuPrint SD05. Next, the screen is flooded with ink and the sensor structures and the circuitry is printed through the screen with a rubber squeegee.

The printed sensor elements and circuits are next thermally cured at the recommended temperatures for the ink. Silver (Henkel EDAG PF050) is cured at 140° C for five minutes. This is done in the furnace featuring air circulation. Following that, the printed strain gauges are top coated, where all the areas where components have to be mounted are covered with a protective foil layer. That is done using spin coating at a speed of 2000 rpm for 120 seconds followed by a burn-in at 250°C for 90 seconds to cure the top coat. After the fabrication of the sensor and circuit structure, the electrical components are placed onto the circuit and are attached using the same silver ink that was also used during printing. Following the placement, a last curing step in the hotplate fixates the components as well as enables the electrical conductivity of the ink. Finally, after the hardware fabrication and mounting, the software configuration of the µ-Controller is implemented.

Capacitive Sensor

The integration of capacitive sensors into the organic coating of sheet steel was reported by Sell et.al [13], [14]. As part of this work, a standalone demonstrator with sensor readout and response visualization was developed in which the used discrete electronic components were directly mounted on the steel substrate, i.e., that the steel substrate was used as replacement for a printed circuit board. A MSP430G2452 microcontroller from Texas Instruments was chosen for this task. In the demonstrator design, the circuitry for the discrete elements was combined with the capacitive sensor design and printed in one layer. The material used for printing the sensor as well as the integrated circuit leads was Henkel EDAG PF050 silver based screen print ink. The placement of the microchip, resistors, and LEDs was done manually and the screen printing ink was used as conductive adhesive. In a final

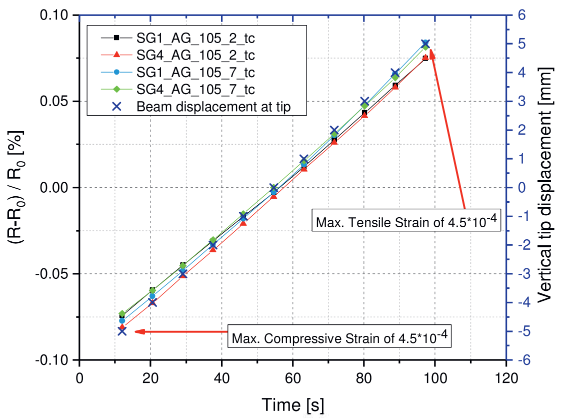

Figure 1 Particle silver screen printed strain gauge. Measurement data from beam number one and four with 100 µm (SG1) and respectively 400µm (SG4) line width and a length of 10.5 mm. Again, samples 2 and 7 are printed on two different base coatings. However, the particle silver based strain gauges show no difference in the gauge factor independent of base and top coating. The resulting GF is approximately 1.85.

processing step, the ink was cured. Figure 2 and Figure 3 demonstrate the detection of a fully (blue LED) and a partially (red LED) covered capacitive touch sensor.

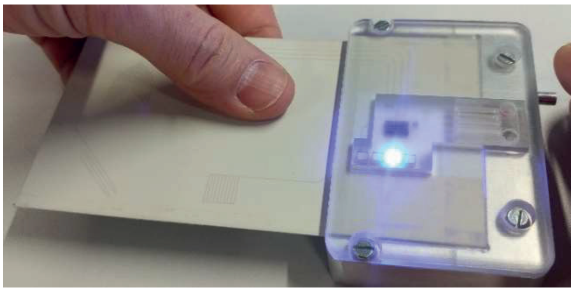

Figure 2 Capacitive touch button fully covered.

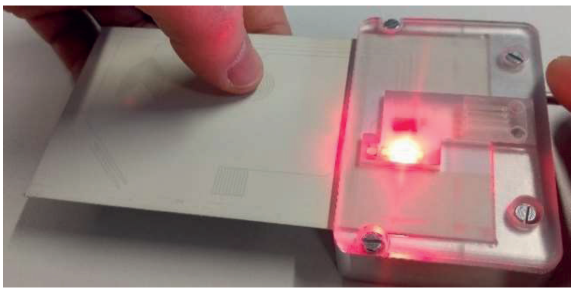

Figure 3 Capacitive touch button partially covered.

Piezoresisitive Sensor

Similar to the capacitive sensors, strain gauges, reported by Enser et.al [11], are implemented using a one-layer print process including the sensor array and the electric circuitry. The used silver-based conductive ink inhibits a gauge factor of ~ 2 as seen in Figure 1. The process for manufacturing the sensor as well as the circuitry is as described above. The electronic components are then mounted onto the printed

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circuit using the same conductive ink as conductive glue followed by a curing step. To enable a simple detection of strain, the strain sensor is implemented in a half Wheatstone bridge setup. This Wheatstone bridge is read out with an ADS1246 chip, which features a 24-Bit ADC and a programmable preamplifier. The evaluation of strain is carried out with a MSP430G2452 microcontroller. In Figure 4 the strain gauge is exposed to tensile strain as indicated by the blue LED signal, while Figure 5 depicts compressive strain also indicated by red LEDs.

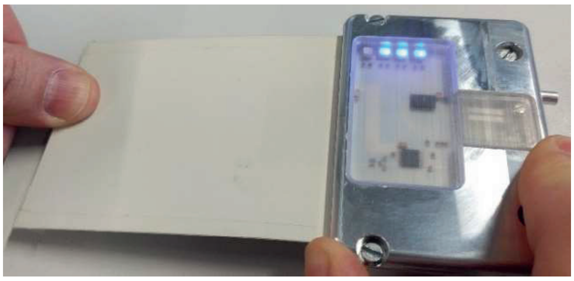

Figure 4 Strain gauge in tensile strain mode.

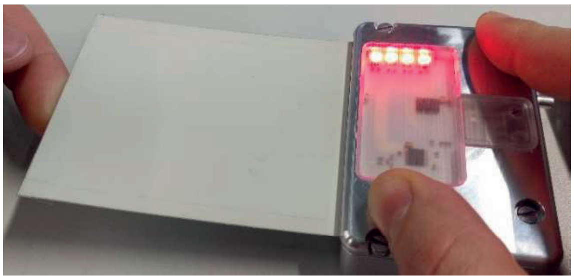

Figure 5 Strain gauge in compressive strain mode.

Capacitive Sensor readout

The capacitive sensor is read out with the MSP430G2452 directly. Each capacitive sensor is connected to the micro-controller directly via a GPIO port. The MSP430 has two different modes to measure capacitive loads. The first mode utilizes an oscillator based capacitive measurement, while the second implementation is based on resistor based capacitive charging. In this work, the oscillator-based method is implemented, resulting in a simpler setup. No additional components but the sensor structure combined with the µ-Controller as well as some signaling LEDs are needed. The printed sensor structures have an inherent line resistance of about 2 Ω/cm line resistance; therefore, it is sufficient to use that in combination with the approximate capacitive values of 5 pF to 15 pF for the four different designs. This design features are sufficient to connect the capacitive sensors directly to the MSP430 and use it in oscillator mode to detect a shift in oscillation frequency when an interaction with the sensor changes its capacity. The measurement runs in constant a loop with a digitally controlled oscillator (DCO) of 1 MHz and measurement intervals of 8192 cycles, resulting in a measurement taken every ~ 6ms. In addition to that, a constant baseline monitoring assures that capacitive drifts are taken into account. This drifts are inevitable because every resistive element has a temperature dependence, additionally the PCB stability and other factors all influence the base capacity. This baseline correction is done by determining the base capacity right after switching the system on. Each following measurement is then compared to a preset threshold to determine whether it is a valid touch action or not. Only if no valid touch action is detected, the baseline will be corrected to accommodate for drifts.

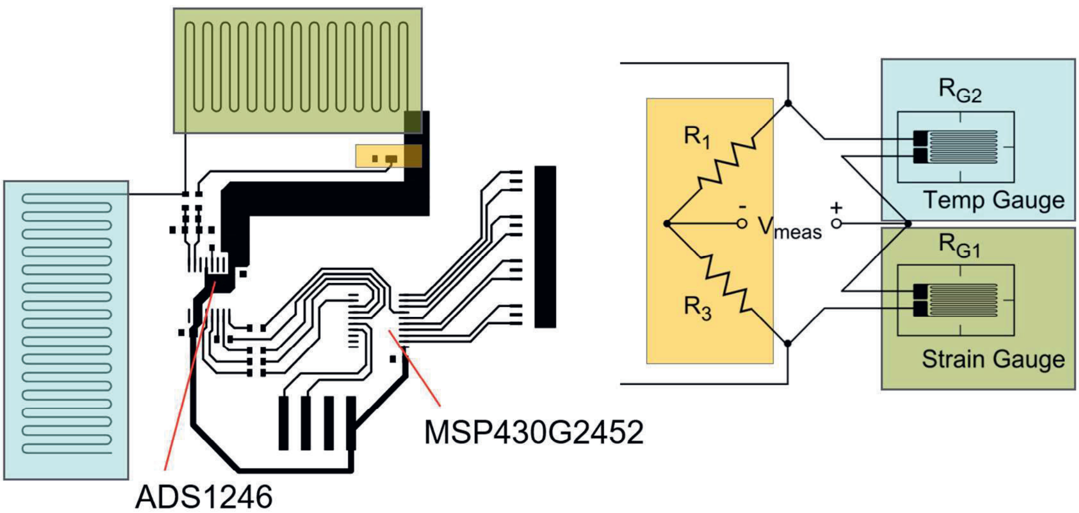

Figure 6 Schematic of the Wheatstone half bridge sensor and circuit setup.

Strain gauge readout

For the second demonstrator, which reads and displays the strain applied to the substrate, the same µ-Controller MSP430G2452 is used. This time an additional ADS1246 as an external 24-Bit ADC is needed. The built-in ADCs of the MSP430 feature only 10-bit resolution and this is not sufficient to determine a resistive change of the silver based strain gauges. The base resistance of the strain gauge is 30 Ω – 50 Ω and the change is in the range of 0.01%. Therefore, an ADC with a higher resolution is required. The ADS1246 is able to communicate with the MSP430 via the SPI interface and thus it is rather easy to implement as shown in Figure 6. The ADS1246 features a high input impedance programmable gain amplifier PGA that can be set to 1,2,4,8,16,32,64 and 128. This PGA is used to read the Wheatstone bridge voltage of the half Wheatstone bridge setup. A gain of 64 results in a full-scale range of +-0,032V, sufficient to resolve the strain gauge sensitivity. This measurement is then read by the MSP430, which in turn displays the delta on a four red or blue LED signal bar for either compressive or tensile strain.

Conclusion

We reviewed the integration and direct evaluation of capacitive and piezoresistive sensors structures based on screen printing technology in combination with their SMD based µ-Controller readout circuits. This approach avoids intermediate layers and places the sensors directly on top of the point of origin of measurement parameters.

Acknowledgements

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