Using the Dragonfly® sensor for tactile interfaces

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Grenoble, France - 2023/07/06

Abstract
Worms Dragonfly® sensors are strain sensors with a sensitivity which outperform standard strain gauges. Deformations down to 10ndef can be measured accurately. Combined with a flat form-factor, their high sensitivity makes them ideal candidates for developing tactile interfaces based on strain measurements, which solve some of the main issues of other technologies such as capacitive or resistive sensing. In this paper, a keypad made of a metal plate equipped with four Dragonfly® sensors is presented. The position of a touch event is captured, as well as the force applied by the user on the metal plate. The keypad natively works with gloves or any other touching object, is fully functional in wet conditions, and requires only four acquisition channels.

Key Words
Tactile interface, piezoelectric sensor, force sensing, touchpad

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1 Introduction

Tactile interfaces are the most common type of user-machine interfaces today to interact with the electronic devices around us. Among them, the capacitive p-cap touchscreen emerged as the industry-wide standard for interacting with smartphones, tablets, computers, smartwatches and other devices [1]. Its main advantages are a high sensitivity, the ability to detect multiple touches independently, and a low cost due to its widespread use.

Capacitive touchscreens however suffer from well-known drawbacks. First, they do not work when the surface is wet, as water perturbates the capacitance measurement. Also, they require a large number of acquisition channels, and the full active area needs to be covered by two layers transparent electrodes. Moreover, they do not have the ability to capture the applied force.

Other technologies of touchpads have been developed, among which piezo touchpads arise as promising candidates for instrumenting arbitrary surfaces, as they required typically very few sensors which can be placed at the edges of the active surface. For example, Elo TouchSystems developed algorithms to sense the bending waves created by the impact of a finger on a surface, using piezoelectric transducers [2].

a) Bottom side of the aluminum plate with the Dragonfly sensors.

b) Top side of the touchpad with keys identified by marker drawings.

Figure 1 - Pictures of the manufactured keypad, made of a 2mm-thick aluminum plate, equipped with four Dragonfly sensors.

Piezo sensors for touchpads are usually either made of Lead Zirconium Titanate (PZT) or Polyvinylidene Fluoride (PVDF). PZT sensors contain lead which is not acceptable for many applications. PVDF films are sensitive to temperature and aging, and their sensitivity and piezoelectric properties will evolve over time. The Dragonfly® sensor combines the advantages of both technologies: it is thin (<10µm) and flexible, exhibits a high sensitivity and is made of a high-quality piezoelectric ceramic which is temperature stable. Moreover, the Dragonfly® sensor is compatible with standard semiconductor packaging processes and is easily integrated in standard rigid or flexible PCBs.

In this paper, a fully functional keypad based on a metal plate equipped with four Dragonfly® sensors is designed and tested. Using simple algorithms, the position and the force of the touch event are retrieved from the signals generated by the piezo sensors.

2 Manufactured device

2.1 Mechanical integration

The keypad is made of a 2mm-thick aluminum plate, which is 9cm long and 7cm wide. The sensors are glued using cyanoacrylate glue on the bottom side close to the edges of the plate, and 12 keys are identified by marker drawings on the top side, (see Figure 1). The plate is clamped at its outer edges by screwing two frames with the plate in between them.

2.2 Signal acquisition

Depending on the type of acquisition device they are connected to, piezoelectric sensors can be modelled either as voltage generators or as charge generators. In the current application we chose to connect the Dragonfly sensors to a Kistler LabAmp5167 charge amplifier, which is also used to acquire the signals. A block schematic is shown in Figure 2. The sampling rate is set at 100Hz, and the measurement range is +-3000pC. Any standard acquisition system could be used equivalently, for example by using the ADCs of an STM32 microcontroller.

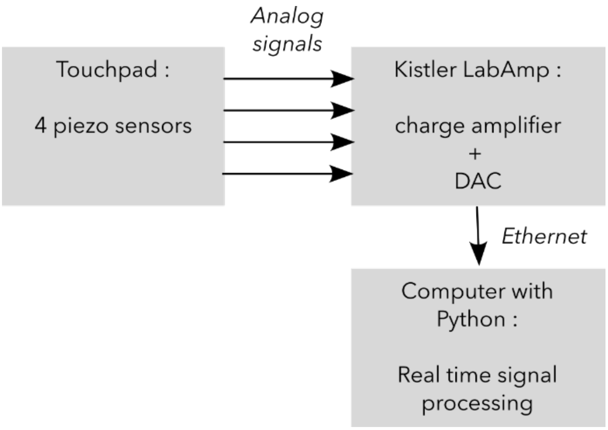

Figure 2 - Block diagram of the data acquisition and signal processing system.

3 Signal processing

Any touch event on the plate will generate a deflection of the plate which results in local strains at the sensor locations. Also, if the impact is sufficiently short, bending waves will propagate in the plate and will be sensed by the piezoelectric sensors. These two different phenomena can be used to capture the position of the impact.

3.1 Identification of the touch event using bending waves

This approach has been widely studied in the literature, and various algorithms have been suggested to retrieve the impact location, either based on time-of-flight calculations, or on more evolved algorithms to compensate for the dispersion of bending waves in plates [3].

3.2 Identification of the touch event using a machine learning approach

Depending on where the impact occurs on the plate, the strain distribution on the plate will vary. By comparing the shapes of the signals generated by the piezoelectric sensors, the location of the impact can be estimated. In order to obtain a robust processing technique, a machine learning approach has been used. The signals generated by the sensors during 50 impacts on each key have been recorded and used as a training set to train a convolutional neural network (CNN) which predicts the key which has been pressed.

3.3 Estimation of the impact force

To calibrate the force sensing capabilities of the touch pad, a piezoelectric force cell is used. The applied force during the whole touch event is recorded along with the Dragonfly signals.

As the plate deflection is small compared to its thickness, the deformations measured by the piezo strain sensors are proportional to the applied force. Thus, the force can be estimated by a linear regression between the force and the charge generated by the strain sensors:

$$F_i = \sum a_n^i q_n \ ,$$

where F_i is the force at position i, q_n is the charge generated by sensor n, and a_n^i is the fitted coefficients which depend on the sensor position and on the impact location. Touch events at different locations generate different strain distributions, so the linear relation between the measured strains and the force must be calibrated for each touch position.

The procedure to estimate the force is summarized in Figure 3.

Figure 3 – Procedure to estimate the force of the touch event.

4 Results

4.1 Touch position

The dataset containing the time series of the strain sensors and the impact position (the key number between 1 and 12) is split into a training dataset and a validation dataset with an 80/20% split ratio. The sparse categorical accuracy during the training is plotted in Figure 4– Evolution of the performance of the convolutional neural network during the training. Figure 4. At the end of the training, the accuracy on the validation dataset reaches 1.0, meaning that all touch events in the validation dataset are correctly sorted by the neural network.

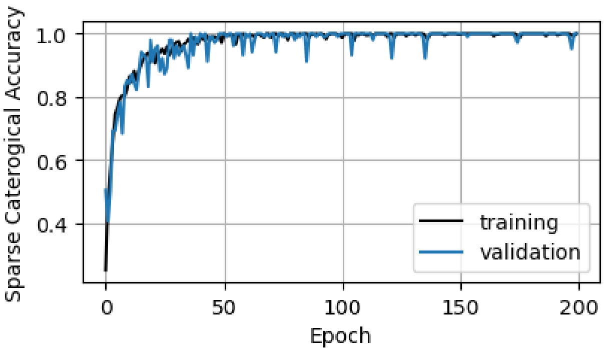

Figure 4 – Evolution of the performance of the convolutional neural network during the training.

4.2 Touch force

Similarly to the training for the touch position, the linear regression to derive the force from the strain sensor signals is performed on a training dataset consisting of 80% of the measured data, and the remaining is used for validation. After fitting the force for all key positions, the mean squared error is 0.08N. A comparison between the measured and predicted force during a typical touch event on key number 4 is plotted in Figure 5.

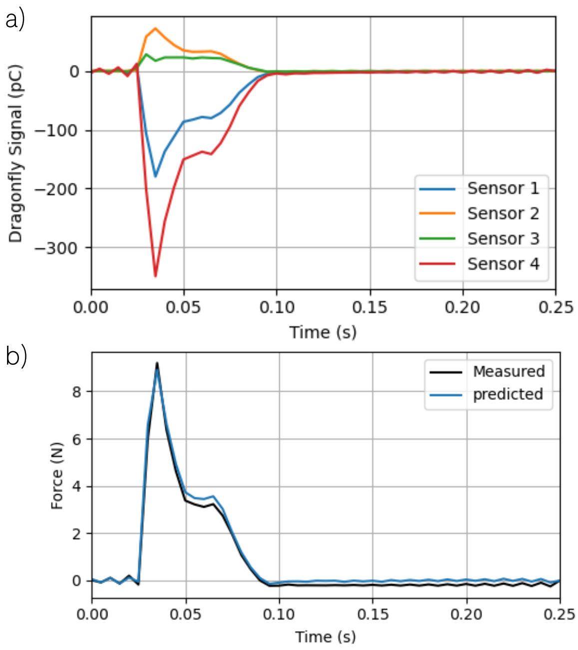

Figure 5 – Signals during a touch event on key number 4. a) Signals measured by the piezoelectric sensors. b) Measured and estimated force.

4.3 Live demo

A video demonstrating the live operation of the force sensing keypad is available on YouTube, see Figure 6. Four-digits passwords are typed with a bare finger, a glove and a pen, and analyzed in real time. The force level applied during all events is also estimated live.

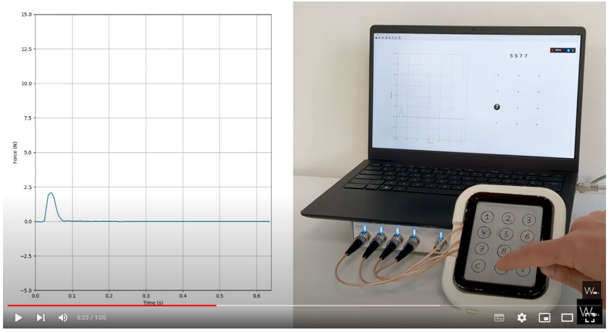

Figure 6 – YouTube video demonstrating the real-time operation of the keypad with force-sensing.

https://www.youtube.com/watch?v=BE-ostNEEoo

5 Conclusions

To conclude, we demonstrated the use of Dragonfly® strain sensor to transform any surface into a tactile interface. Using only four thin piezoelectric Dragonfly® sensors (the sensitive element is less than 10µm-thick) and standard acquisition devices, a robust detection of the location of touch events, as well as an estimation the applied force have been implemented. The high sensitivity of Dragonfly®, the lead-free design, its stability over time, and its easy integrability makes it an ideal candidate to manufacture tactile interfaces for harsh environments, where the standard capacitive technology fails.

References

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