Transforming any object into a tactile interface using Dragonfly®

Emil Garnell, R&D Engineer at Wormsensing
Catherine Cadieux, Application Engineer at Wormsensing
www.wormsensing.com | contact@wormsensing.com
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Abstract
Wormsensing Dragonfly® is a strain sensor with a sensitivity 1000 times higher than standard resistive 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 curved metal plate is equipped with three Dragonfly® sensors to transform it into a tactile interface. Four buttons, and a set of eight gestures (slides in different directions and at different locations) are identified and used to control a small game on a Raspberry Pi.

Key Words
Tactile interface, piezoelectric sensor

Figure 1: Transforming a basic steel chair into a tactile interface using three Dragonfly® strain sensors.

1 Introduction

Tactile interfaces are the most common type of human-machine interfaces today to interact with the electronic devices around us. Among them, capacitive sensors emerged as the most widely used technology. Their main advantages are a high sensitivity, the ability to detect multiple touches independently, and a low cost due to their widespread use.

Capacitive interfaces however suffer from well-known drawbacks. First, they do not work when the surface is wet, as water perturbates the capacitance measurement. Also, the full active area needs to be covered with two layers of electrodes, which may not be possible on curved surfaces. Moreover, they do not have the ability to capture the applied force. These limitations typically restrain the design of automotive access devices, which should work with gloves, in wet environments, and on curved surfaces.

Other technologies of touchpads have been developed, among which piezo touchpads arise as promising candidates for instrumenting arbitrary surfaces, as they require 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 [1].

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 manufactured by Wormsensing 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 and lead-free. Moreover, the Dragonfly® sensor is compatible with standard semiconductor packaging processes and is easily integrated in standard rigid or flexible PCBs.

In this paper, we transform a curved metal surface into a tactile interface capable of recognizing various gestures. The lightweight processing algorithms are executed by a Raspberry Pi microprocessor in real time, and the identified gestures are used to control a snake game [2] to demonstrate the user-friendliness of the proposed solution.

2 Manufactured device

2.1 Mechanical integration

The instrumented surface is shown in Figure 1. It consists of the seat of a standard chair, made of an approximately 1.5mm-thick curved steel plate. The seat area was cut to a 25*35cm^2 area, which was fixed on a plastic support through three contact points. On the top side of the metal plate, buttons and predefined gesture areas have been identified with black paint. On the bottom side, three Dragonfly® sensors have been glued, close to the three support points, see Figure 1c.

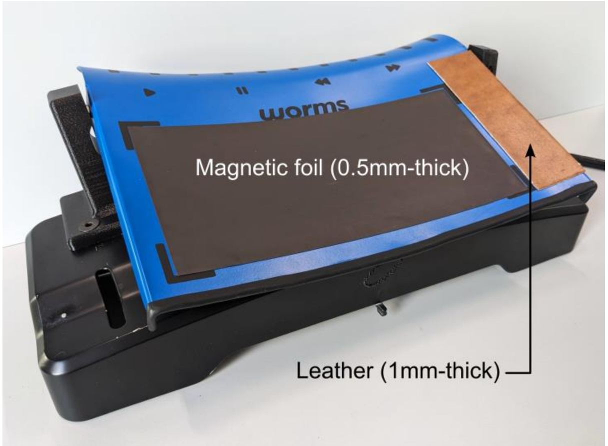

Figure 2: Magnetic and leather covers added on the metal plate.

As the event classification algorithm uses only the signals from the Dragonfly® strain sensors, the method is not influenced by cover layers added on the plate. To demonstrate this, a layer of soft leather is added to the right-hand side of the plate, and a layer of magnetic sheet to the central area, see Figure 2. We will illustrate in the video (see section 4) that these covers do not affect the performance of the gesture classification algorithm.

2.2 Signal acquisition

The three sensors are connected to an STM32 dev board, through a custom developed analog front-end (charge amplifier). The 16bits ADCs of the STM32 are used for the analog to digital conversion. The three sensor signals sampled at 100Hz are then streamed to a Raspberry Pi where the gesture-classification algorithm is implemented. The results are displayed on a basic screen.

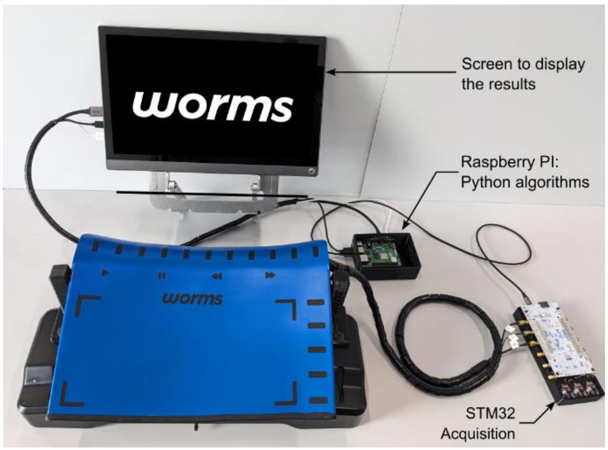

Figure 3: Picture of the setup, with the different elements used for the signal acquisition and processing.

2.3 Description of the identified gestures

Any touch event on the plate will generate a deflection of the plate which results in local strains at the sensor locations. Depending on the location of the interaction with the plate, the strain distribution will be different. Thus, by analyzing the sensors signals during the interaction, it is possible to retrieve the location and the type of gesture.

Dragonfly® sensors are so sensitive that they can measure an elongation of a 1m-long bar by only 10 nanometers, which represents a deformation of 10ndef. This very high sensitivity enables the detection of gestures on rigid surfaces and far away from the sensor locations.

The gestures which will be identified by the algorithm are described in the Figure 4.

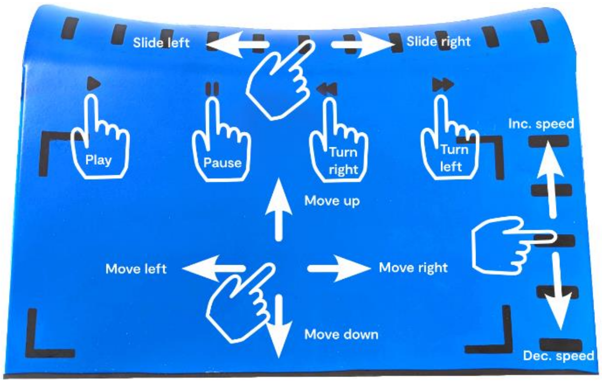

Figure 4: Description of the gestures which will be identified by the algorithm to control a snake game.

They consist of:

- Four press-buttons (Play, Pause, Turn left and Turn Right)
- Eight sliding gestures:
  - o Increase of decrease the snake speed by vertical slides in the right area.
  - o Move the snake in four directions by slides in the central area.
  - o Lock and unlock the app by horizontal slides in the top area.

To increase the robustness of the algorithm to unwanted interaction on the plate, another gesture type is included and denoted as *Trash*. We include in this category all gestures which are different from the eight gestures identified above, and which are not supposed to trigger any event.

3 Signal processing

To classify the gestures performed on the instrumented metal plate, a machine learning approach is implemented, using deep neural networks.

3.1 Gesture detection

The first step consists of splitting the continuous stream of sensor data into distinct events, starting when the user touches the plate and ending when the user removes his finger from the plate. This step is carried out by advanced thresholding on various indicators built from the sensor signals (variance, level, etc).

Each touch event consists at this point of a N*P matrix, where N is the number of samples during the event, and P is the number of channels (here 3). Examples of sensor signals during two types of events are shown in Figure 5.

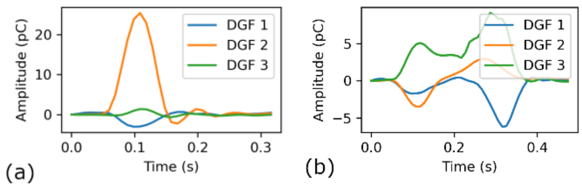

Figure 5: Measured signals during touch events on the metal plate. (a) Press on the Play button. (b) Slide right gesture in the top area.

3.2 Data collection

In order to build a gesture dataset which will be used to train the gesture classifier, each gesture is repeated several times on the metal plate. We asked eight users to perform gestures on the interface, to capture data which is representative of the diversity of real situations. All touch events detected during the data collection phase are added to the dataset, together with an integer label indicating the gesture type.

The dataset is then split into a train and a test dataset, using a split ratio of 70-30%.

3.3 Training

A convolutional neural network similar to the work by Kwon et. al [3] is implemented. It is trained using the train dataset, over 200 epochs.

The model is then evaluated on the test dataset, and its cross categorical accuracy reaches 95%, with most confusions occurring for *trash* events. The confusion matrix is shown in Figure 6. It demonstrates that all gestures are almost equally well detected.

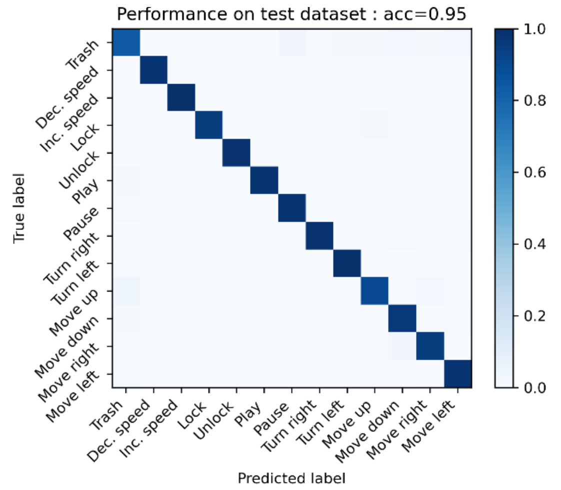

Figure 6: Confusion matrix calculated on the test dataset.

3.4 Inference

Once trained, the model is deployed on a Raspberry Pi device, which receives the raw sensor signal stream from the STM32 dev board, performs the event detection using thresholds, and then feeds the neural network with the event data. The result of the neural network is used to trigger actions in a snake game, which is displayed on the screen (see Figure 7).

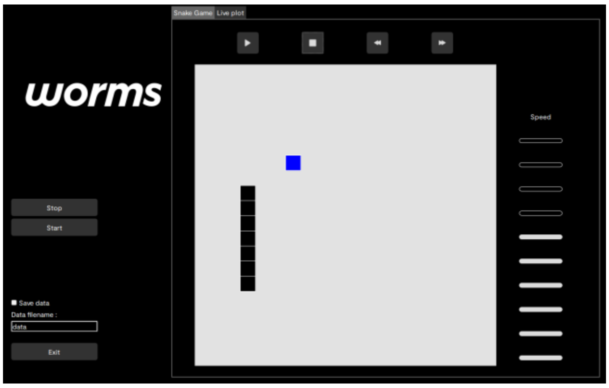

Figure 7: Graphical interface displayed by the Raspberry Pi on the screen. In the grey area, the black line is the snake, and the blue dot is the apple it must eat. The snake movements are controlled with the sliding gestures in the main area of the metal plate. On the right-hand side, a cursor indicates the speed of the snake, which can be controlled by sliding gestures in the right-hand side area of the plate. The buttons at the top are controlled by the corresponding buttons on the metal plate.

4 Live demo

To demonstrate the reactivity of the algorithm, even once implemented on a lightweight processor such as the Raspberry Pi, a video of the demo is available on YouTube:

https://www.youtube.com/watch?v=Yf2NIC7Qz84.

5 Conclusions

To conclude, we demonstrated the use of Dragonfly® strain sensors to transform any surface into a tactile interface. Using only three thin piezoelectric Dragonfly® sensors and standard low-cost acquisition devices, a robust detection of the location of touch events and sliding gestures has been implemented. The high sensitivity of Dragonfly®, the lead-free design, its stability over time, and easy integrability makes it an ideal candidate to manufacture tactile interfaces for harsh environments, where the standard capacitive technology fails.

The approach based on machine learning could be very easily extended to other types of gestures, and even to machine monitoring if typical machining sequences are considered instead of touch gestures.

At Wormsensing we have developed all the software and signal processing tools to quickly demonstrate the potential of Dragonfly® sensors for tactile interface on any object. Please get in touch if you want a demo in your own mechanical context!

References

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