The Presstip: A Hybrid Soft Tactile Sensor for Robot Pose Estimation and Texture Classification

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I. Introduction

Robust tactile sensing is vital for enhancing robotic interaction with the physical world [1], [2], [3], [4]. While high-resolution optical tactile sensors [5], such as the TacTip, deliver exceptional accuracy, their complexity and cost could limit their practicality in resource-constrained scenarios. To address this, we developed the Presstip, a low-cost, soft-bodied sensor that combines piezoelectric sensing, an accelerometer, and an array of pressure sensors [6]. This hybrid design enables the Presstip to capture a broad range of tactile data, from detecting surface textures to measuring forces and pressures.

The Presstip (figure 1c) offers versatility through its multi-sensor integration. The piezoelectric sensor and accelerometer collaboratively detect textural features, while the pressure sensor array, located on the underside of the device, provides detailed spatial information, such as edge and shape detection. These combined capabilities allow the Presstip to support tasks like robot pose estimation and texture classification in an affordable and accessible manner [6]. This extended abstract highlights two distinct experiments demonstrating the Presstip's capabilities.

II. Results

A. Pose Estimation

In the first example, the Presstip serves as a foot sensor for a robot from figure 1e. Using the pressure array, we trained a Random Forest regression model to estimate the robot's pose based solely on foot pressures (input) and ground truth labels derived from an accelerometer placed on the robot's head (output). Figure 1b shows an example of the inputs.

The Presstip demonstrated robust performance as a foot sensor for robotic pose estimation. The regression model trained on pressure data (input) and accelerometer-derived ground truth labels (output) achieved a high level of accuracy in predicting the robot's pose during transitions from two-leg to one-leg stances (chassis seen in figure 1e). This indicates that the pressure sensor array is capable of capturing nuanced changes in contact forces that correlate with the robot's overall body orientation. The regression model mean squared error averaged at 0.06 (results seen in 1a). The robot could additionally predict the direction of an edge with 91.8% (visualisation seen in figure 1b). The experiment highlights the versatility of these sensors, predicting complex 3D orientation using force detection.

B. Texture Detection

The second experiment focused on texture classification. By moving the Presstip over 15 distinct textures [7], [8], we collected temporal sensor data from the piezoelectric sensor and accelerometer. These textures consisted of Carpet, a laced mat, wool, cork, felt, a long carpet, cotton, flat plastic, flat rubbery tape, foam with large groves, foam with small groves, bubble wrap, flat foam, jeans, and leather. Most tactile datasets consist of similar textures, or at least a range of household items. The textures were gathered using the rig seen in figure 1d. We then trained a variety of classifiers on the input data from both sensors (accelerometer and piezoelectric) to predict the texture class. We compared these results to a high resolution tactile sensor (TacTip) on the same dataset

In texture classification, the Presstip's hybrid sensing approach significantly outperformed individual sensing modalities. The combination of piezoelectric and accelerometer data yielded higher classification accuracy compared to using either sensor alone. Averaging 87.5% on a random forest classifier with both sensors, and only 62.31% with the accelerometer and 74.56% with the piezoelectric sensor. Notably, the hybrid system successfully identified 15 distinct textures with an accuracy on average 10-12% less than the TacTip. These results emphasise the strength of sensor fusion in compensating for the limitations of low-cost tactile sensors. Furthermore, the Presstip's cost-effective design makes it an attractive alternative for applications where budget constraints or simpler designs are prioritised over the ultra-high accuracy offered by optical sensors.

III. Conclusions

Our findings demonstrate the Presstip's potential as a versatile and economical tactile sensor for robotics, capable of performing complex tasks such as robot pose estimation and texture classification with respectable accuracy.

While high-resolution optical sensors like the TacTip outperform the Presstip in terms of precision, the Presstip's hybrid sensing approach - combining piezoelectric and accelerometer data - narrows this gap considerably. This underscores the potential of combining complementary sensing modalities to maximise performance in low-cost systems. Future work will explore expanding the dataset and further optimising the hybrid sensing strategy to improve performance across additional applications.

These results highlight the potential of integrating multiple sensing modalities to enhance performance while maintaining affordability.

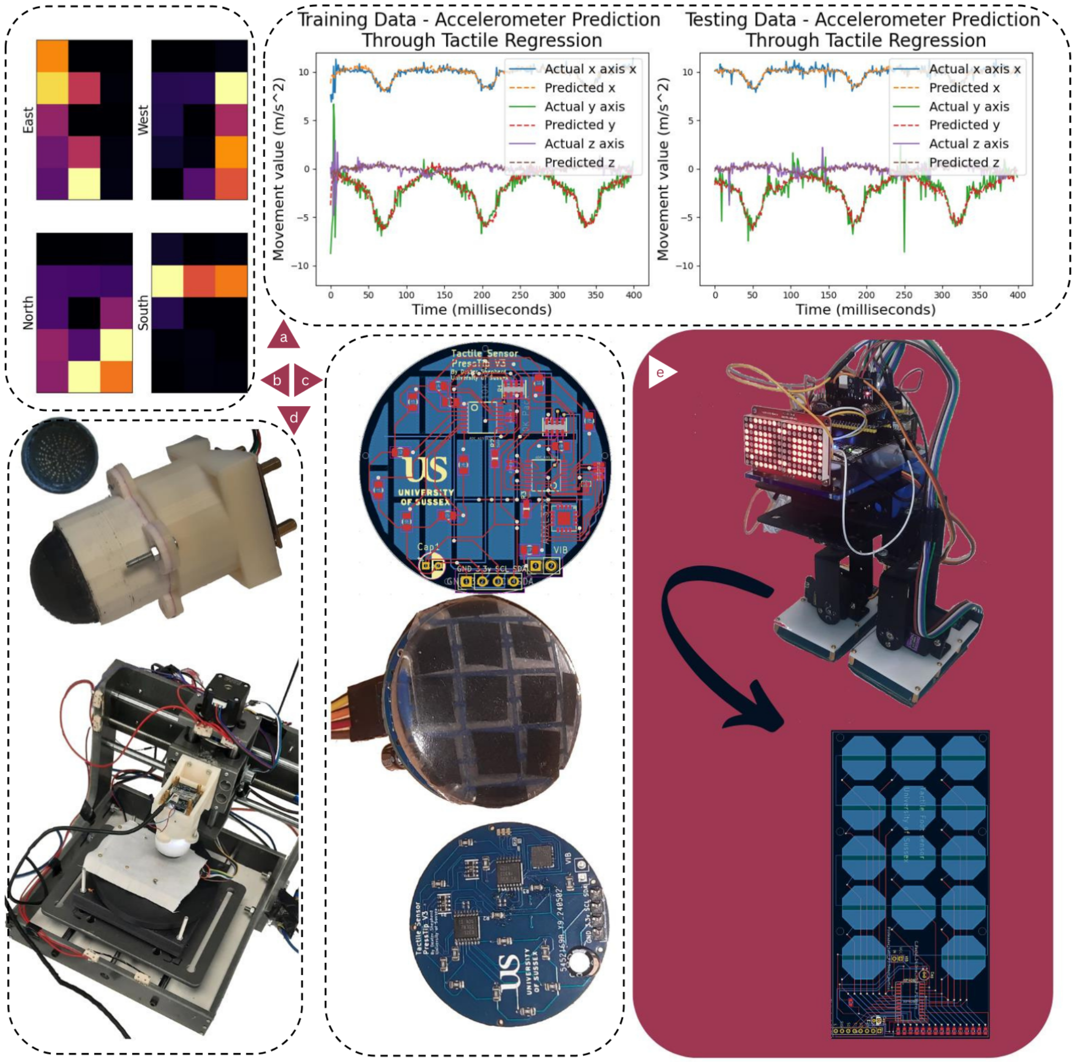

Fig. 1. *a*: Results of the regression model showing actual and predicted value from the robot tilt experiments. *b*: Shows the averaged sensor values from the foot sensor shown in *e*when dragged in different directions. Black is no pressure, yellow is higher pressure. *c*: shows the PressTip final version PCB and velostat pads placed on the tactile pads underneath the silicone body. *d*: The Optical tactile sensor (TacTip) and the rig used to collect the datasets. *e*: shows the chassis and foot PCB design.

ACKNOWLEDGMENT

This work was funded by the Leverhulme Trust

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