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An Accurate and Cost-Effective Tactile Sensor for Force Vector and Contact Location

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***Abstract*—Affordable yet capable and accurate tactile sensors are essential for enhancing the reliability of robot grasping and manipulation in unstructured environments, such as homes. While a wide range of tactile sensors have been developed across literature, integrating them into realistic deployable robots often involves a design tradeoff between expensive, fragile sensors that offer accuracy and more affordable ones with limited functionality. This work bridges this gap by introducing a novel cost-effective tactile sensor ($10 per sensor) capable of accurately measuring 3-DOF force vectors (0.4 N RMSE) as well as contact locations (2mm RMSE). Leveraging MEMS barometers along with additional 3D-printed mechanical structures, the sensor exhibits sensitivity to both shear and normal forces and effectively eliminates dead zones. The fabrication process, employing 3D printing and polymer casting, is streamlined, and all associated printed circuit board (PCB) designs and code are made open source, facilitating rapid prototyping for everyone. To showcase its practical applications, the tactile sensor is integrated into a Yale Open Hand [1], demonstrating its efficacy in realistic manipulation tasks. This work not only presents a viable solution for tactile sensor integration into various robot hands but also offers opportunities for human data collection, thereby paving the way for advancements in tactile sensing across robotics and human-machine interaction.**

I. Introduction

Robots rely on effective tactile sensing for reliable grasping and dexterous manipulation in unstructured environments like homes [2]–[5]. This is because tactile sensing provides essential information about object geometry, surface properties, contact force, and location, which enables slip estimation and overall grasp stability [6]. While highly instrumented robot hands excel in controlled lab settings, household integration demands affordability. Current approaches, employing technologies like computer vision and costly tactile sensing, face challenges in occlusion, cost, consistency, interpretability, and accuracy [7]. To bridge this gap, here we introduce a novel cost-effective tactile sensor for robot hands that accurately measures both the force vector as well as the contact location.

II. Method

As shown in Figure 1 (A-a), we design a PCB (16 mm $\times$ 40 mm) housing six MEMS barometers (Infineon DPS310), each measuring 2 mm $\times$ 2.5 mm $\times$ 1 mm. To tackle the sensitivity challenge in the shear direction as identified in the prior art on barometer-based tactile sensors [8], we design a 3D-printed flexure-like structure and mount them on two out of the six barometers. This structure is then covered with a rigid plate to eliminate dead zones, as illustrated in Figure 1 (A-b). As illustrated in Figure 1 (B), we use an external probe equipped with a force sensor (ATI Nano17. Resolution: 1/160 N, 1/32 Nmm) and fiducials for pose tracking (Atracsys Fusion Track 500, Accuracy: 0.090 mm RMS), mounted to a robot arm (UR-5) to collect calibration data. We train a fully connected neural network that takes the barometer sensor readings and outputs the contact force and location. After calibration, six tactile sensors (distal and proximal links for each finger) are integrated with a Yale Open Hand [1].

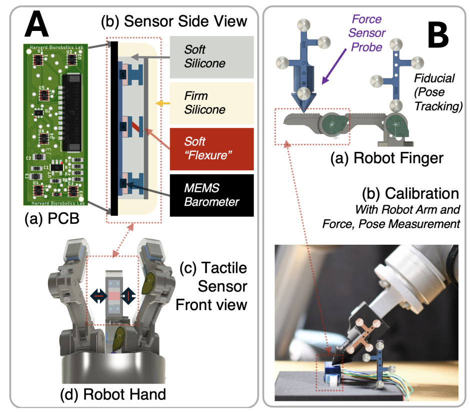

Fig. 1. (A) Tactile Sensor Design. (A-a) PCB with six MEMS barometers and a 11-pin Molex connector for easy fabrication. (A-b) A side view of the tactile sensor design which consists of four layers: (1) the PCB with barometer sensors, (2) a soft flexure-like structure for enhanced shear-force measurement, (3) a right plate that eliminates dead zones, filled with soft silicone for support, and (4) a firm layer of silicone for enhanced grip. (A-c) The tactile sensor is integrated with a Yale Open Hand [1]. (B) Calibration Protocol: A force sensor probe equipped with fiducials for pose tracking probes the robot finger mounted with our tactile sensor (B-a) with varying force magnitude, direction, and contact location enabled by a robot arm.(B-b)

III. Results

Preliminary results indicate that we can attain a Root Mean Squared Error (RMSE) of 0.4 N in the force vector and an RMSE of 2 mm in the contact location with a cost as low as $10 per sensor ($60 per hand with full coverage).

IV. Discussion

This work presents a novel open-source design of a tactile sensor measuring 3-DOF force vector and contact location, that is affordable, accurate, and easy to fabricate, requiring minimal equipment. This represents an exciting solution not only for robot hands but also for collecting human tactile data.

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