An Optical 3-Axis Force and Displacement Sensing Array*

O. Leslie[1] & D. Córdova Bulens[1] and S. J. Redmond[1]

***Abstract*— A small optical tactile sensing array is presented which can estimate a distributed array of 3D force and 3D displacement. The sensing array is designed to have ten measurement points with relatively free movement between the sensing elements to allow for slip detection. The preliminary results demonstrate the successful sensing of 3-axis force and displacement from all ten individual elements, making it useful for improving robotic manipulation.**

I. Introduction

Enabling robotic hands with tactile sensing is essential for improving robotic manipulation, allowing robots to maintain a secure grasp [1]. The human fingertip has a dense array of mechanoreceptors providing tactile feedback about deformations and slips happening on the skin [2]. To mimic such tactile feedback, tactile sensors require a distributed array of sensing elements [3]. Previously, we designed and implemented the Light-Vector (LiVec) sensor for 3D displacement and 3D force sensing [4]. Here, we present a small distributed array of sensing elements (D-LiVec) as a new member of this sensor family. This is a proof-of-concept design to investigate the ability too densely array this new sensing method. A distributed sensing array more closely mimics the human sense of touch and may enable precise grip control.

II. Array design and sensing principle

The D-LiVec sensor array (Fig. 1) consists of a ten-element array of individual sensing protrusions which can estimate 3D point forces and 3D point displacements with a compact size of L 26.44 mm x W 38.22 mm x H 12 mm, respectively. The D-LiVec has an overall thumb-like form factor, designed to be integrated onto the OnRobot RG2 2 finger robot gripper (Fig. 1B & C).

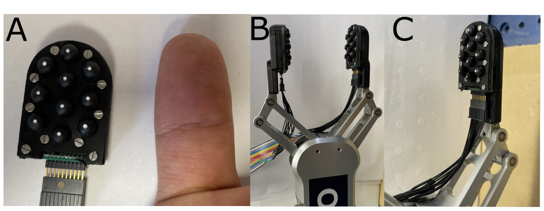

Fig. 1. Images of the D-LiVec sensor. A) Font view of the sensor, next to a human thumb for size reference. B) D-LiVec sensors mounted on the OnRobots RG2 gripper C) Front view on the gripper.

The sensing principle of each individual protrusion is the same as the LiVec sensor, described in detail in [4]; however, the protrusions are smaller, and the electronic sensing components are more densely layed out.

III. Calibration procedure

The calibration platform consists of the D-LiVec sensor, a six-axis force sensor (ATI mini-40, ATI Industrial Automation, USA) mounted on a six-DoF hexapod robot (H-820, Physik Instrumente, Germany) with a transparent acrylic plate containing an individual small cubic outcrop (also transparent acrylic) which makes contact with the protrusions, and a camera (Logitech Streamcam, Logitech, Switzerland) positioned above the sensor. Each individual pillar is individually compressed against the outcrop and moved laterally at multiple compressions (i.e., Z displacements) in various patterns to explore 3D space. The camera is used to track the pillar tip displacement. This procedure is similar to the LiVec sensor, described in detail in [4].

Six separate multivariate polynomial regression models are trained for each sensing element, using the biased (at the start of the experiment) light angle sensor photocurrent signals and the intensity (sum of four photocurrent signals) as the inputs, and the reference force or pillar tip displacement as the regression targets. This results in three separate 3rd-order models for estimating orthogonal X, Y, and Z forces and three separate 4th-order models for estimating orthogonal X, Y, and Z displacements.

IV. Preliminary results and conclusion

The D-LiVec array can successfully sense XYZ force and XYZ displacement from all ten individual elements in real time. The average force estimate error across all protrusions is 0.046 ± 0.025 N, 0.027 ± 0.066 N, and 0.042 ± 0.039 N for the X, Y, and Z forces, respectively. The average displacement estimate error across all protrusions is 0.055 ± 0.054 mm, 0.037 ± 0.048 mm, and 0.015 ± 0.015 mm in X, Y, and Z, respectively. The shape, size and distributed sensing make it a promising tool for grip force control via incipient slip detection.

Our future work will focus on calibrating global force and torque, implementing the D-LiVec sensor on the RG2 gripper and demonstrating the sensing capabilities.

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[1]All authors are with the UCD School of Electrical and Electronic Engineering, University College Dublin (UCD), Ireland. e-mail: stephen.redmond@ucd.ie

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