A Sense of Touch for the Shadow Modular Grasper

Nicholas Pestell, Luke Cramphorn, Fotios Papadopoulos and Nathan F. Lepora

***Abstract*— We have designed and built a set of tactile fingertips for integration with a commercial, three-fingered robot hand, the Shadow Modular Grasper. The fingertips are an evolution of an established optical, biomimetic tactile sensor, the TacTip. From these fingertips, we extract a set of high-level features with intuitive relationships to tactile quantities such as contact location and pressure. We present a simple linear-regression method for predicting roll and pitch of the finger-pad relative to a surface normal. Finally, we apply this prediction to a grasp-control method with the Modular Grasper and show that it can adjust the grasp on three real-world objects from the YCB object set in order to attain a greater area of contact at each fingertip.**

I. INTRODUCTION

Robot hands have seen accelerated development in recent years [1], advancing attributes such as dexterity, grip strength and ease of use, yet a gap persists for automation of small scale production, where robots are required to grasp and manipulate unknown objects [2]. This gap can only be filled by dexterous, multi-fingered robot hands.

Given the advances in the state-of-the-art of robot hands, it is surprising such hands have not yet found widespread application. One contributing factor may be a lack of sufficient tactile sensing capabilities.

Although many researchers have integrated tactile sensors with dexterous robot hands [3]–[6], a common shortcoming is the nature of the tactile data available and/or the amount of data required to interpret it. Here we present a more flexible platform by integrating a highly sensitive, high-resolution, optical tactile sensor with a fully-actuated industrial robot hand and we demonstrate the potential for this system to improve grasps on unknown, real-world objects using simple algorithms and relatively small amounts of training data.

II. MATERIALS AND METHODS

A. Hardware

1) Shadow Modular Grasper: The Shadow Modular Grasper is fully actuated with 9 degrees of freedom (three per finger). Each joint has a dedicated torque sensor for closed loop control and also features a back-drivable gearbox enabling inherent compliance, which is an essential component when working in unstructured environments.

2) Tactile Fingertip Design: Tactile sensing is enabled with three custom-built tactile sensors based on an established biomimetic, optical tactile sensor, the TacTip [7]. The inside of a deformable skin is tessellated with a triangular pattern of 97 white markers that provide a visual representation of the tactile stimulation. The pins are imaged via a 2.0 megapixel CMOS array USB web-cam (ELP cameras) mounted on the back of the fingertip. The markers are illuminated by four LEDs arranged on two narrow PCB strips of two LEDs each.

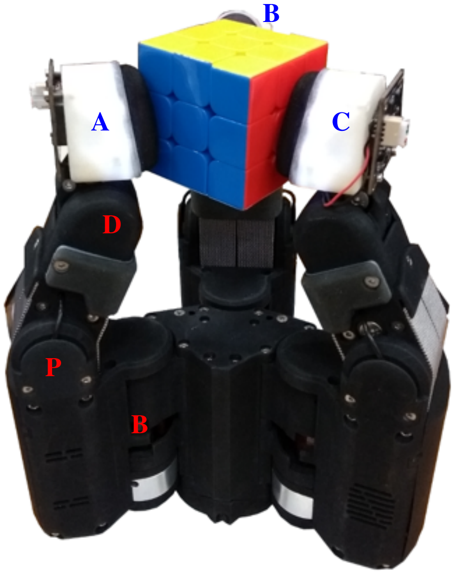

Fig. 1: Image of the developed tactile sensors integrated with the Shadow Modular Grasper. Base, proximal and distal joints are labelled in red, **B**, **P** and **D** respectively. Tactile fingertips **A**, **B** and **C** are labelled in blue.

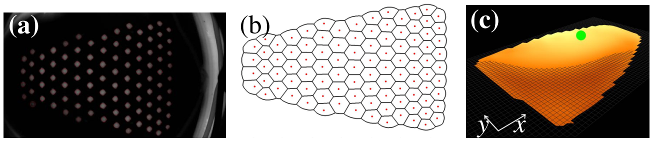

Fig. 2: **(a)**: View of markers imaged by the camera and tracked with OpenCV. **(b)**: Voronoi tessellation over markers. **(c)**: Visual representation of surface deformations with centre-of-pressure shown as a green spot.

Feature extraction is performed using a Voronoi method previously demonstrated to achieve direct inference of pressure and contact locations with the TacTip [8]. A centre-of-pressure, a tactile analogue of centre-of-mass, is computed as an average of marker positions weighted by their corresponding cell area (Fig. 2c).

3) Hardware Integration: Integration of three sensors has, to date, not been attempted with TacTip-based sensing. A solution proposed here is to connect each tactile fingertip to its own dedicated USB-hub. With three dedicated hubs, the data transfer occurs in parallel without reducing the frame rates, ∼20 fps per camera.

B. Experimental Procedure

Orientation of the fingertip relative to the contact surface may be of importance when grasping an object. For example, greater frictional forces are achieved with a larger contacting surface area, which is affected by relative angle between fingertip and object.

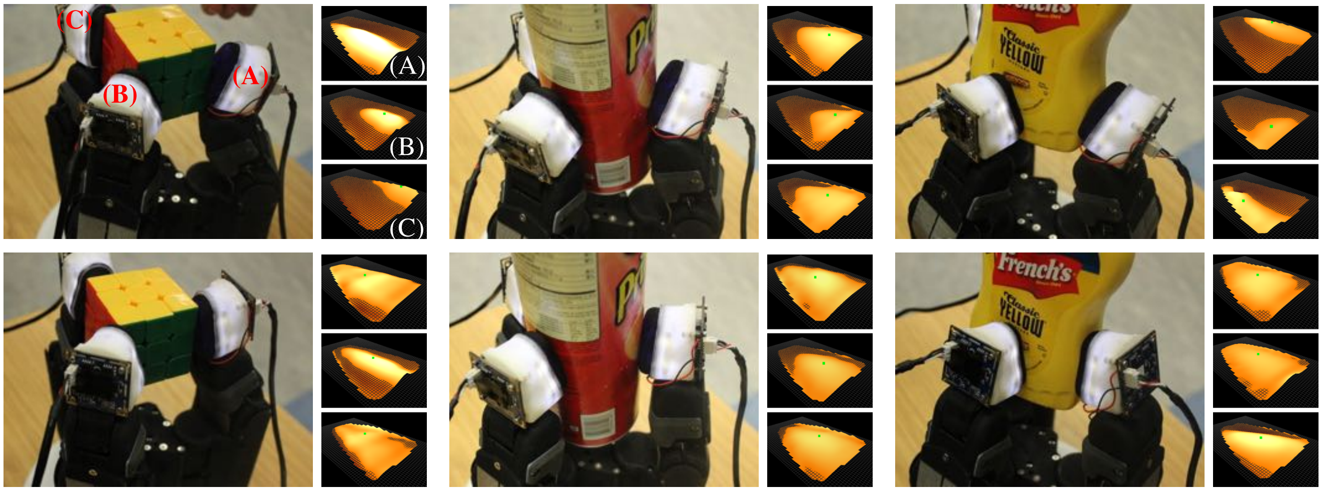

Fig. 3: Images of the grasps on the Rubik's cube, Pringles can and mustard bottle, before and after tactile adjustment; top and bottom rows respectively. Tactile visualisations for the three fingertips are displayed to the right of each grasp image. Fingertips are labelled on the top left image and visualisations for reference.

1) Data collection and training: The fingertip is mounted as an end-effector on a six degree-of-freedom robot arm (UR5, Universal Robotics). The sensor maintains continual contact with a flat acrylic plate and the robot re-orients the sensor relative to the plate. Data is sampled randomly from a 2D grid of roll, ϕ, and pitch, θ. We map centre-of-pressure-xy position to ϕ and θ via a 2^{nd}-order polynomial regression model.

2) System Integration - On-line Grasp Adjustment: For the purpose of this study, we intend to use the predicted ϕ and θ to adjust a grasp. Three Python drivers, one for each sensor, run on the host PC and interact with the grasp controller (C++) via a ROS-network.

After all sensors have detected contact of the grasped object an adjustment phase is entered: the controller switches all proximal joints to torque mode and applies a fixed squeezing torque to the object. Base and distal joints remain in position mode and are servoed with a PID controller. PID inputs are ϕ and θ predictions for base and distal joints respectively, thus, the hand attempts to servo the finger-pads to ϕ and θ = 0.

III. RESULTS

Fig. 3 shows successful grasps of all three objects. Alongside each image are tactile visualisations from each fingertip. The objects are initially held in place by a human participant before passing over to the robot when all three fingers have made contact. The top row shows images at initial contact detection (prior to tactile adjustment) and the bottom row shows images after tactile adjustment, $\sim$10 s later.

The top and bottom rows of Fig. 3 show noticeable differences in both the grasp images and the tactile visualisations. In general, the images show that the fingertips rotated around each object to minimise ϕ and θ. Inspection of the tactile visualisations suggests that overall deformation of each fingertip increased subsequent to adjustments in all cases. This suggests that, for these examples, the grasp controller performed as designed: to increase contact surface area and, thus, also the frictional forces at each fingertip.

IV. DISCUSSION

In this study, we presented the integration of an established optical tactile sensing technology, the TacTip, with a three-fingered, commercial robot hand: the Shadow Modular Grasper. The sensors were tested for predicting roll and pitch relative to a flat surface. Finally, we integrated tactile output with the hand control and demonstrated grasps on three real-world objects, using predicted roll and pitch angles to adjust the grasp for attaining greater contact surface areas at each finger-pad.

REFERENCES

[1] Z. Xu and E. Todorov, "Design of a highly biomimetic anthropomorphic robotic hand towards artificial limb regeneration," in *2016 IEEE International Conference on Robotics and Automation (ICRA)*, May 2016, pp. 3485–3492.

[2] Z. Kappassov, J.-A. Corrales, and V. Perdereau, "Tactile sensing in dexterous robot hands review," *Robotics and Autonomous Systems*, vol. 74, pp. 195 – 220, 2015. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0921889015001621

[3] J. Kwiatkowski, D. Cockburn, and V. Duchaine, "Grasp stability assessment through the fusion of proprioception and tactile signals using convolutional neural networks," in *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Sept 2017, pp. 286–292.

[4] Y. Chebotar, K. Hausman, Z. Su, G. S. Sukhatme, and S. Schaal, "Self-supervised regrasping using spatio-temporal tactile features and reinforcement learning," in *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Oct 2016, pp. 1960–1966.

[5] R. Calandra, A. Owens, D. Jayaraman, J. Lin, W. Yuan, J. Malik, E. H. Adelson, and S. Levine, "More than a feeling: Learning to grasp and regrasp using vision and touch," *CoRR*, vol. abs/1805.11085, 2018. [Online]. Available: http://arxiv.org/abs/1805.11085

[6] A. J. Spiers, M. V. Liarokapis, B. Calli, and A. M. Dollar, "Single-grasp object classification and feature extraction with simple robot hands and tactile sensors," *IEEE Transactions on Haptics*, vol. 9, no. 2, pp. 207–220, April 2016.

[7] B. Ward-Cherrier, N. Pestell, L. Cramphorn, B. Winstone, M. E. Giannaccini, J. Rossiter, and N. F. Lepora, "The tactip family: Soft optical tactile sensors with 3d-printed biomimetic morphologies," *Soft Robotics*, vol. 5, pp. 216–277, 2018.

[8] L. Cramphorn, J. Lloyd, and N. F. Lepora, "Voronoi features for tactile sensing: Direct inference of pressure, shear, and contact locations," in *2018 IEEE International Conference on Robotics and Automation (ICRA)*, 2018.