Robotic Finger Force Sensor Fabrication and Evaluation Through a Glove

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ABSTRACT

This force-feedback approach compares the effect on the sensing ability through a worn glove of the force application of an i-Limb Ultra robotic hand for several experimental scenarios. A Takktile sensor was integrated into a fabricated fingertip to measure the applied force of the i-Limb Ultra. A controller was then designed using MATLAB/Simulink to manipulate the finger motion of the i-Limb to apply force to an external load cell. Testing was performed to check the force measurements and sensing ability/quality for two cases: hand with no glove and hand with a nitrile glove. Each of these scenarios were tested by applying fingertip force in 3 different modes: open/close with no contact, continuous tapping and constant force.

Keywords

Force feedback, Powered prosthetic Hand, Robotics, Glovebox, Hotcell.

1. INTRODUCTION

The US Department of Energy's Office of Environmental Management oversees one of the largest environmental cleanup efforts in the world. The cleanup is a consequence of six decades of research/development and production of nuclear weapons in the US. Some of the current and future cleanup work presents real challenges to the workforce. The work is not only dangerous but also tedious and repetitive. One example is the use of gloveboxes and hotcells to process radioactive materials. This research will aid in the identification of better technologies to assist humans in these type of challenging tasks. Because gloveboxes and hotcells are designed to accommodate human workers, an anthropomorphic solution such as a prosthetic limb is required as a replacement to obviate expensive retrofitting requirements. Although prostheses have existed for centuries, the most extensive research and development of prosthetics occurred in the last few decades [1]. Many existing prosthetics have the ability to perform multi-finger dexterous movements to replace human limbs [2]. Electromyogram (EMG), or myoelectric, control is one of the most common user interfaces for powered prostheses and generally is used when possible [3]. The reason for the widespread use of EMG control systems is the minimal effort required for operation due to the relatively small muscle signal needed [4]. The success of prosthetic hands hinges on the simplicity and reliability of the control system provided [5].

Moreover, in the recent years, the focus has been to provide force control to prosthetics [6], which provides an important form of communication between the user and the environment and an ease of control [7, 13]. As said by the hand surgeon Sterling Bunnell in 1944, "Without sensation, a worker can scarcely pick up a small object, and he constantly drops things from his grasp. The so-called eyes of his fingers are blind" (p. 222) [8]. Force control systems are becoming increasingly relevant in prosthetics as they restore some of the user ability to naturally control his hand. Without such systems, the user relies on visual feedback or control systems to operate the prosthetic limb in everyday applications [9]. However, with the use of embedded force control systems, prosthesis users will have the ability to perform delicate tasks that otherwise would be impossible.

The achievement of force sensing and measurement through a prosthesis is done by embedding a force sensor on the fingertip. Tactile force sensors are being used by researchers to examine their reliability and their performance in force control operations. Tactile sensors acquire information through physical touch [10]. In this paper, the TakkTile sensor by RightHand Robotics was used as it offers a reliable source of data at an inexpensive price. The sensor consists a MEMS barometric sensor embedded in a rubber material to not only protect the electronics but also to allow a wider area for sensing capabilities such as detecting subtle contact with objects [11].

Humans have the ability to sense the applied force on external objects despite the effects of wearing a glove. They are also able to adjust their

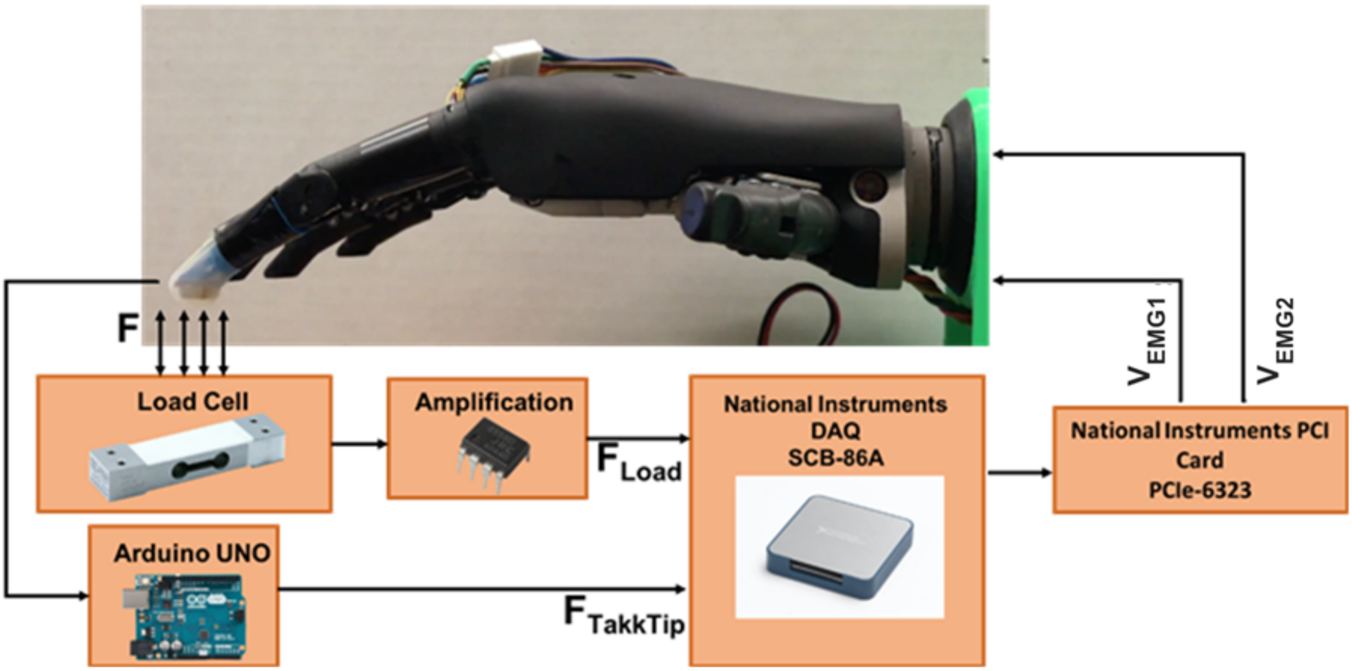

Figure 1 . System level diagram illustrating the experimental setup. Presented is the i-Limb Ultra with a TakkTip sensor mounted at the tip of the index finger. This sensor, the i-Limb and a load cell are connected to Simulink 2016b through a PCIe-6323 from National Instruments.

grip accordingly to perform various tasks with the ability to sense the applied force while wearing that glove, however, the effects of the glove on a robotic hand have not been examined as deeply yet.

This paper presents the effort taken to examine the effects of the glove on a robotic hand. This was done by designing a new force sensor geometry utilizing Takktile sensor and testing the sensor ability to detect force applied through various modes with and without gloves. An i-Limb Ultra Revolution prosthetic hand was used to perform the testing (Figure 1). A Takktile sensor from RightHand Robotics was embedded into a fingertip to be mounted onto the index finger of the i-Limb hand. This sensor was coined the TakkTip. The hand is inserted into the glove to compare the effect it has on the force. The experiment had three modes and each mode was tested with and without the glove.

2. TAKKTIP SENSOR FABRICATION

This new design, called the TakkTip, is comprised of a Takktile force sensor from RightHand Robotics (Figures 2, 3), and fabricated in three steps. The first step was modeling the desired geometry. The second focused on 3D printing the structure to support the sensor and the third was to embed the assembled sensor into a semi-soft rubber called DragonSkin 50.

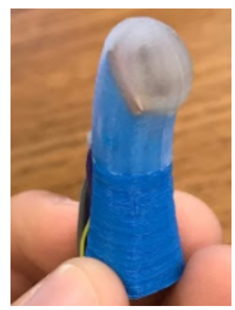

Figure 2 . Fabricated TakkTip sensor for measuring the forces of all experiments in this paper.

2.1 Takktile Force Sensor

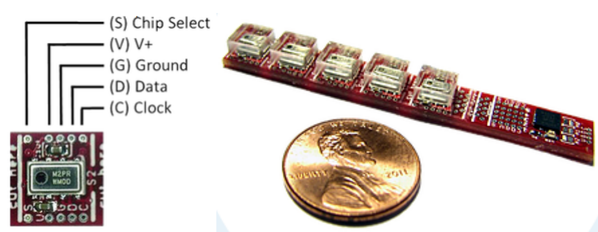

Figure 3 – TakkTile sensor used to fabricate the TakkTip. On the left is and individual sensor and wiring diagram. On the right is the array or sensors the individual TakkTile sensor is separated from a Takkstrip [12].

2.2 Modeling and 3D Printing

Solidworks 2017 was used to create the CAD model for 3D printing (Figure 4). This was achieved by removing the preexisting fingertip on the i-Limb Ultra robotic hand. This exposed the mounting post which allows the fingertip to be removable with minimal effort. Multiple images were taken of the post to create a 3D model of the cavity needed for mounting. This design was printed using PLA filament (Figure 5).

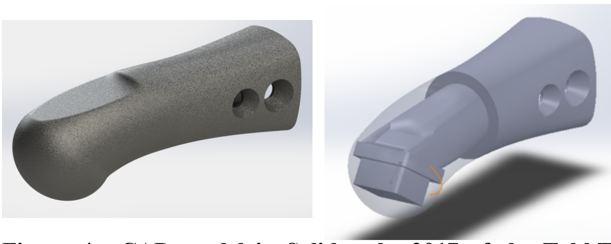

Figure 4 . CAD model in Solidworks 2017 of the TakkTip sensor.

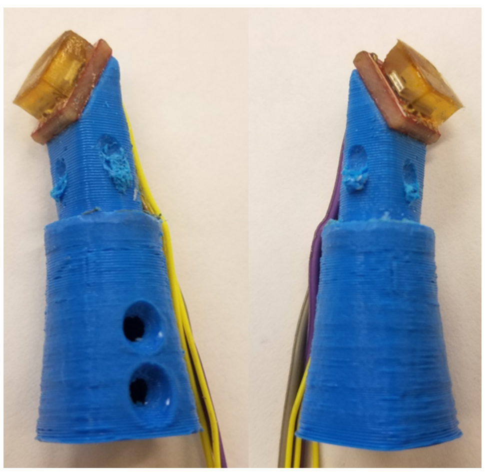

Figure 5 . 3D printed structure used to mount the sensor to the i_Limb Ultra hand.

2.3 Molding

A 3D mold was created from the negative of the model described in the previous section (Figure 6). This was then 3D printed and prepped by sanding the edges smooth to achieve no visible gap between the two halves when clamped together. The supplies shown in Figure 6 were used to make Dragonskin 50 mix. The mix was prepared with a 1:1 ratio of Dragonskin A (yellow container) and Dragonskin B (blue container) using a digital scale and then the mixture stirred for one minute to completely combine the two parts of the mixture.

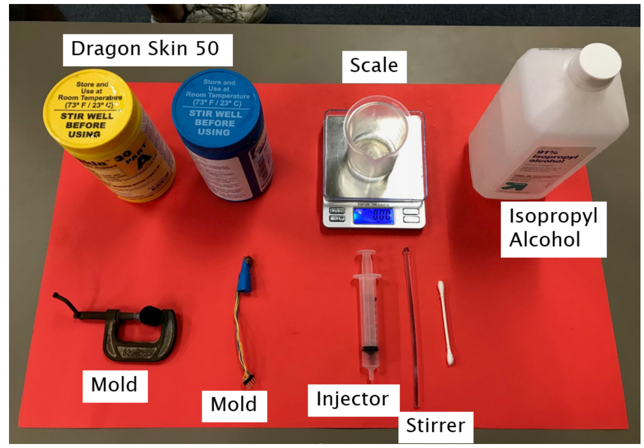

Figure 6. Supplies used to mold the soft tip of the TakkTip sensor in Dragonskin 50.

This was then placed into a vacuum chamber to degas until all of the bubbles stopped forming (Figure 7). Once this was complete the Dragonskin was poured into the mold using the injector to fill the mold to about 50%. The 3D printed structure (Figure 5) was inserted into the Dragonskin-filled mold and allowed to set overnight (Figure 7). This completed the fabrication of the TakkTip sensor.

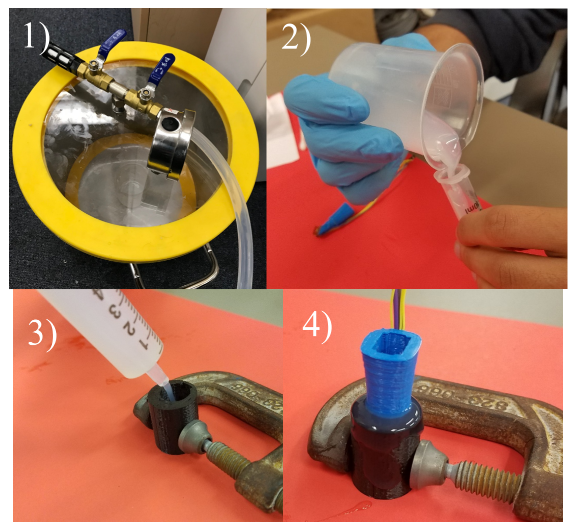

Figure 7. Molding the TakkTip into Dragonskin 50

2.4 Electronics

An Arduino Uno was used to connect the Takktile sensor and acquire the force data. This was output on one of the PWM channels and input into Simulink 2016b through a PCIe-6323 board from National Instruments with a SCB-68A data acquisition module attached. Additionally, a load cell (esp-35 from Transducer Techniques, Temecula, USA) was connected using an INA129p amplifier to amplify the signal and to provide analog low pass filtering.

The existing electromyogram signals used to control the movement of the i-Limb hand were measured during some testing cases to determine the signals needed to actuate the hand and replace the electromyogram sensors. This signal was found to be a square wave with a magnitude of 4.7V. This allowed the creation of two control signals, V_{EMG1} and V_{EMG2}, as outputs from Simulink to provide the controllability to achieve the desired modes for testing.

2.5 Calibration

Both the load cell and the TakkTip needed to be calibrated to measure force accurately. This was done by placing known masses on the load cell and measuring the output voltage for a series of different weights. A linear fit was found using Microsoft Excel that related the force to the voltage. Once this was complete, the load cell was used to calibrate the TakkTip in the same manner.

3. EXPERIMENTAL METHODS

3.1 Donning and Doffing the Glove

This was very important in the analysis of whether there is an effect of wearing the glove on the force that can be sensed. To minimize the variability from test to test, all measurements were gathered during the same session and all mounting hardware was marked to easily perform testing in the same location after putting the glove on and taking it off, minimizing the possibility of error.

3.2 Measuring the Forces

The force measurements gathered during each test were made using the load cell, $F_{LoadCell}$, and TakkTip sensor, $F_{TakkTip}$. The TakkTip was connected to an Arduino Uno and a library found online was used to read data from the TakkTile sensor and send it out through one of the PWM pins. There were noticeable variations in force measurements due to the sensor being temperature sensitive. This was compensated for by calibrating the voltage of the sensor with the temperature and a correlation to map the two and compensate for temperature changes.

The load cell was connected to an amplification board prior to connecting to Simulink to both amplify and filter the signals.

3.3 Mode 1 – Open/Close

The open/close mode was tested by starting with the hand in the open position and continuously closing and then opening the hand at a rate of 9 rad/s (Figure. 8). The measurements were gathered with the glove on and the glove off.

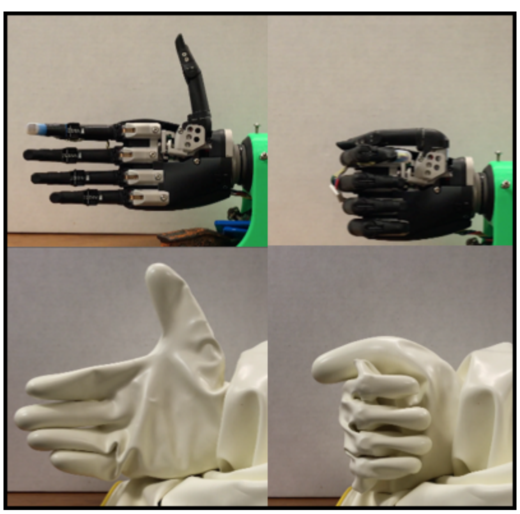

Figure 8. Mode 1 representing a fully opened hand posture cycling repeatedly to a closed posture and back.

Mode 2 – Tapping

The second mode, shown in Figure 9, measured the force applied by the i-Limb when intermittently in contact with an object. This formulated a tapping scenario. For consistency purposes, a load cell was utilized as the object in contact and also served as a way to confirm the measurements with an externally calibrated device. The reason for this is because a load cell offers a flat surface that helps with repeatability as well as a direct way of measuring the force being applied.

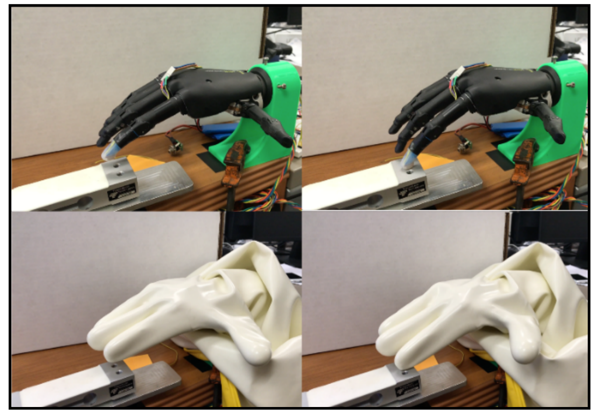

Figure 9. Mode 2 represents an intermittent tapping force to observe the effect that tapping has on the sensing ability through the glove.

3.4 Mode 3 Constant Force

The final mode (shown in Figure 10) tested the ability of the sensor to apply a constant load intermittently. Actuation was similar to the tapping mode but during contact with the load cell, the finger maintained contact and no additional movement commands were initiated until the sensor values reached steady state conditions. The finger was then extended to the fully opened position and the cycle repeated. This was performed with the glove and without the glove to observe the effect of the glove on the force measurement.

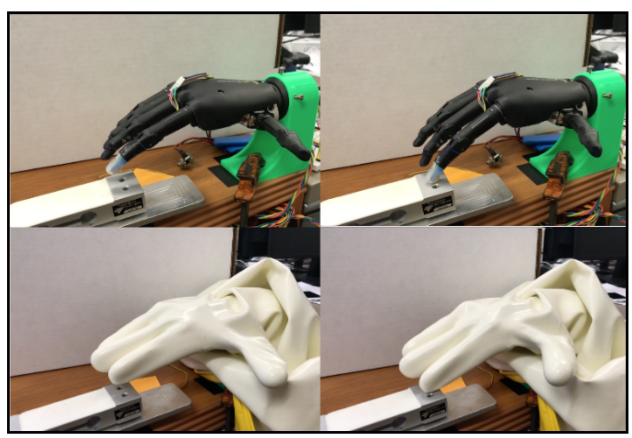

Figure 10. Mode 3 represents an intermittent constant force to observe the effect of the glove on a constantly applied load.

4. RESULTS

4.1 Mode 1 – Open/Close

The results for opening and closing the hand are presented below and show that there is a difference in the measured force when the hand operated with and without a glove (Fig. 11). Without a glove present the TakkTip had no observed force effects transferred from the motion of opening and closing the hand. When the glove is put onto the hand there is an inherent bias imposed on the force measurement through the TakkTip. This bias was consistently observed throughout many tests. Note that this bias varied in magnitude each time the glove was put on but once the glove was on the bias was consistent and discernable for force sensing capabilities through the glove during the opening and closing motions.

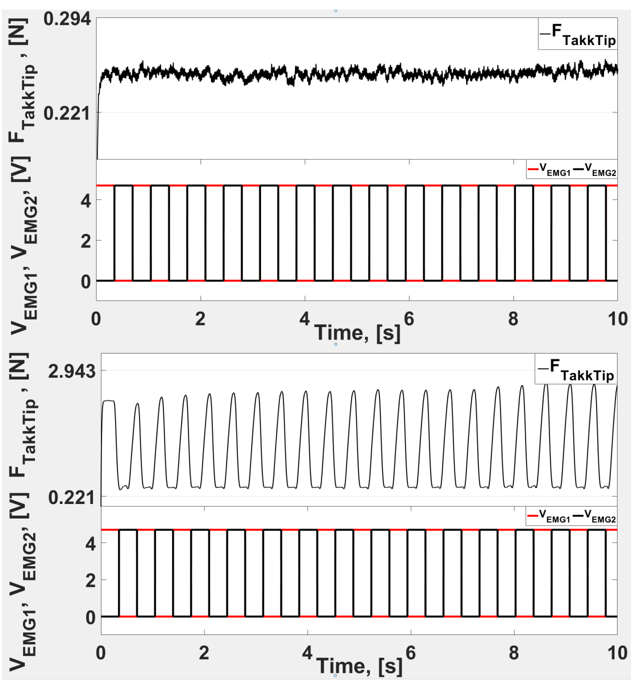

Figure 11. Results from opening and closing the i-Limb to the limits of its range for both no glove (top) and glove (bottom).

4.2 Mode 2 - Intermittent Tapping

Similar to the results from opening and closing the hand, there is an inherent bias when putting the glove on. In the case of intermittent tapping the force was discernable from test to test (Fig. 12). This justifies this sensor as able to detect an applied force through a glove for this mode. Note that the angle of contact between the TakkTip and the load cell remained consistent from test to test. This was important to obtain consistent results for determining the effect of the glove for this portion of the research. Future consideration will be discussed in the conclusion of this paper.

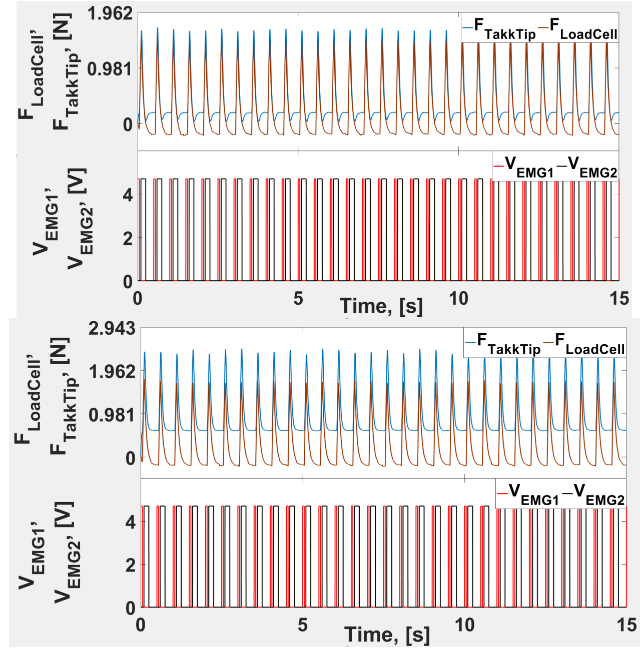

Figure 12. Results from intermittent tapping onto the load cell. This was done for both wearing a no glove (top) and glove (bottom)

4.3 Mode 3 – Intermittent Constant Force

The results for this mode have similar notes to mode 2. As illustrated in figure 13, all trials produced the same results and were consistent from test to test.

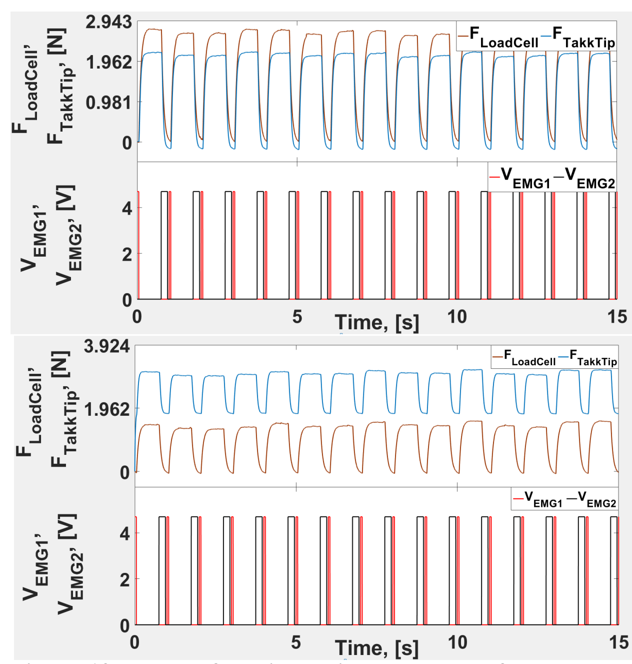

Figure 13. Results from intermittent constant force onto the load cell. This was done for both wearing a no glove (top) and glove (bottom)

5. CONCLUSION

This study found noticeable differences in tactile force sensor readings between the cases of a prosthetic hand wearing a glove and without the glove, however the force measurements from both cases were still recognizable and can be used to determine the force applied to an object. Note that an inherent bias was observed in the system when the glove was worn. Moreover, the sensing ability to the i-Limb was not substantially altered as the robotic hand performed the tasks for different modes with consistency throughout the experiment for the tested modes. The newly fabricated TakkTip sensor proved to detect contact with an object when compared to no object for the two studied modes, however, the sensor did not perform consistently if it was used at different contact angles. A future study can determine the characteristics of varied contact angles on the force sensing capabilities. Additionally, to address the inherent bias observed in all cases of force sensing through the glove, this can be compensated for by applying a zero-out calibration at the beginning of each test. Ultimately, these results suggest that the tested tactile sensor has potential to sense grasping forces in automated glovebox situations. The anthropomorphic solution afforded by a prosthetic hand offers direct application of electromyogram control methods [7], [13].

6. ACKNOWLEDGMENTS

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