Preliminary Evaluation of a Prototype Integrated Capacitive Force Fingertip Sensor

Matthew S. Johannes[1], Kapil D. Katyal[1], Matthew P. Para[1], James R. Solberg[2], Eric L. Faulring[2], Alex Makhlin[2], Julio J. Santos[2], Erik W. Schluter[3], Sliman J. Bensmaia[3] Francesco D. Tenore[1]

[1]Johns Hopkins University Applied Physics Laboratory
Laurel, MD
[2]Hunter Defense Technologies
Evanston, IL
[3]University of Chicago,
Chicago, IL
matthew.johannes@jhuapl.edu, kapil.katyal@jhuapl.edu, matthew.para@jhuapl.edu, James.Solberg@hdtglobal.com, Eric.Faulring@hdtglobal.com, Alex.Makhlin@hdtglobal.com, Julio.Santos@hdtglobal.com, erikschluter@gmail.com, sliman.bensmaia@gmail.com, francesco.tenore@jhuapl.edu,

***Abstract*— The Johns Hopkins University Applied Physics Laboratory (JHU/APL) led the development of an integrated fingertip sensor node (FTSN) for prosthetic and robotic applications. This sensor consists of a 14 element capacitive force sensor and an integrated accelerometer and has been integrated into the Modular Prosthetic Limb (MPL), an advanced upper-extremity prosthetic limb, under the DARPA Revolutionizing Prosthetics 2009 program. The goal of this program is to perform closed loop cortical control and stimulation of a human patient using the MPL and the integrated fingertip sensor. In addition to its use as an advanced prosthetic, APL is also exploring more advanced autonomy including closed-loop force feedback control with the MPL for tasks such as automated grasp closure, teleoperated haptic feedback and scene exploration. In this poster, we will evaluate the capabilities of the sensor in an indentation and localization discrimination and task.**

Keywords—autonomous grasping; force feedback; robotics; modular prosthetic limb; localization; discrimination

I. OVERVIEW

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) led the development of the Modular Prosthetic Limb (MPL), an advanced upper-extremity prosthetic limb, under the DARPA Revolutionizing Prosthetics 2009 program that began in early 2006. The Modular Prosthetic Limb (MPL, Fig. 1) is an upper extremity neuroprosthesis designed to closely match the characteristics of the human arm it seeks to replace [1]. It consists of 26 articulating joints driven by 17 independently controllable motors, thus allowing for anthropomorphic limb motion from the shoulder down to individual fingers. In addition, the MPL is equipped with almost two hundred sensors of different types, which can provide a user with tactile and proprioceptive feedback. With these capabilities, the MPL is an ideal prosthesis with which to implement closed-loop cortical upper extremity control, in which a user's intent is decoded into appropriate arm and hand motions and interactions of the prosthesis with its environment can neurally be relayed back to the user in real time. These results work toward supporting capabilities of the neural interface in human closed-loop control experiments.

Fig. 1. The Modular Prosthetic Limb

II. FINGERTIP SENSOR OVERVIEW

In addition to its use as an advanced prosthetic, JHU/APL is also exploring implementation of more advanced autonomy with the MPL, including integration into hybrid control architectures to allow users to control the arm with high level interaction. For this purpose, JHU/APL in collaboration with Hunter Defense Technologies (HDT), Inc., has developed a fully integrated fingertip sensor with a capacitive force sensing array and a 3-axis accelerometer used for providing closed loop stimulation for human patients as well as an integral component for autonomous robotic manipulation. The FTSN consists of a 14 element capacitive sensor array with an integrated 3-axis accelerometer. The capacitive sensor array is capable of sensing force across 14 discrete regions up to 10 N with 16 bit resolution. The accelerometer is capable of measuring acceleration across the 3 axis with a configurable full range acceleration set to ±2g/±4g/±8g with 12 bit resolutions (Fig. 2).

Fig. 2. Fingertip Sensor Node v2.0 and sensing element locations

III. MATERIALS AND METHODS

The MPL FTSNs are anthropomorphic devices that correspond to the MPL's distal phalanges which articulate with its intermediate and proximal phalanges. To assess pressure discrimination capabilities, a custom-designed triaxial indention stimulator[2] was developed to allow indentation of hand of *M. mulatta* with high spatial and depth resolutions. It was repurposed in these experiments to produce indentations of varying depths on nine locations of the FTSN V2.0 tested on a 3x3 grid, with each location separated by adjacent locations by 5 mm in each direction (Fig. 3). For each location, each of the three prosthetic fingertips tested was indented at six indentation depths (25 µm – 50 µm – 100 µm – 200 µm – 400 µm – 800 µm). Each trial consisted of 1 s of no indentation followed by a 1 s indentation period followed by a 200 µs release. A total of 50 trials were collected for each location at each depth. Data was collected from each sensor and labeled according to indentation location and indentation depth. The training data was read by a simple linear classifier (Fisher discriminant analysis) which outputs its prediction for the row, column and depth.

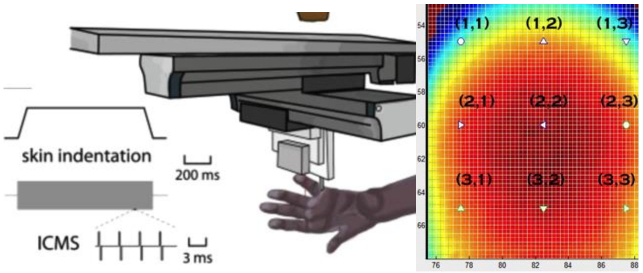

Fig. 3. Left Triaxial indentation stimulator (TIS); Right: Heatmap of prosthetic fingertip with locations indented by the TIS, spaced at 5 mm from each other.

IV. RESULTS

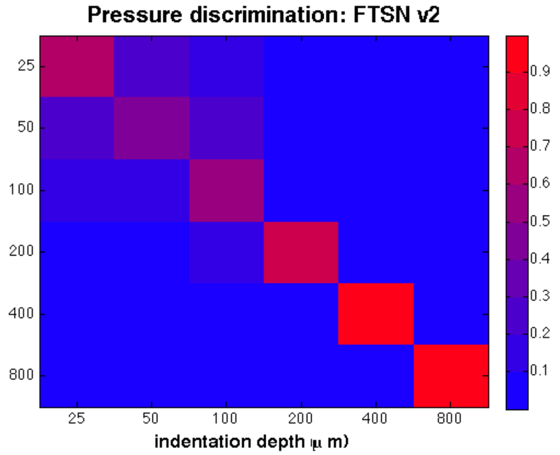

Fig. 4. Confusion matrices as a function of indentation depth (used as a proxy for pressure) for the FTSN.

To determine the indentation/pressure discrimination capabilities we selected one of the nine locations for each sensor and trained a classifier to discriminate between the six pressures. The resulting confusion matrix is shown in Fig. 4. The FTSN sensor experiences a significant improvement in performance between 100 and 200 µm and again between 200 and 400 µm and presents no errors at 400 µm and above ($p<0.05$). Recall that adjacent locations are separated by 5 mm.

V. CONCLUSION

We have demonstrated some of the sensory capabilities of the highly dexterous Modular Prosthetic Limb during systematic location and pressure discrimination tasks. The results show that the MPL FTSN v2.0 will be able to provide sensory information feedback, which can be translated through sensory encoding algorithms into electrical pulse trains that should provide intuitive sensory information back to a human user.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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