Active calibration of tactile sensors mounted on a robotic hand

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I. INTRODUCTION

Touch is one of the most important human capabilities. If vision can help people to recognize the environment, touch is the fine controller for all motions. Tactile sensors measure information arising from physical contact with the environment and are generally modelled after the biological sense of cutaneous touch, that are crucial for many micro tasks, such as in-hand manipulation.

Here, we focus on the BioTac tactile sensors[1], that mimic the human skin, by using a flexible finger-shaped rubber, mounted on a rigid bone-like structure (see Fig. 1). Extensive research has been carried out to calibrate the BioTac sensors, i.e. to derive the relationship between raw values and actual force. For instance, machine learning approaches have been used in [1], [2]. But since these have proved to be time consuming, an alternative, analytic method, has been designed in [3]. Ciobanu et al. [4] established a preprocessing pipeline to overcome the signal's non-compliances and issues for further processing.

Here, we propose a method to actively calibrate the BioTac sensors embedded on the fingertips of a Shadow Dexterous robotic Hand[2]. Since this is a common setup in many robotics laboratories, we are confident that the proposed procedure may be of interest to a wide community. The hand fingers sequentially push on a force sensor plate. An automatic procedure converts the static pressure values measured by the BioTac sensor to force values using techniques similar to those in [1]. Finally, the computed force values are compared to those measured on the force plate, and are found to be coherent. Complementary to [3] and [4], in this paper the shadow robotic hand is *actively* calibrating by moving the tactile sensors. This setup makes the calibration process easy and fast and enable the use BioTacs for force sensing or force regulation if mounted on a hand. The methodology used here is applicable for active calibration of BioTac sensors in a myoelectric/prosthetic hand for precise grasping.

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[1]www.syntouchllc.com

[2]www.shadowrobot.com/

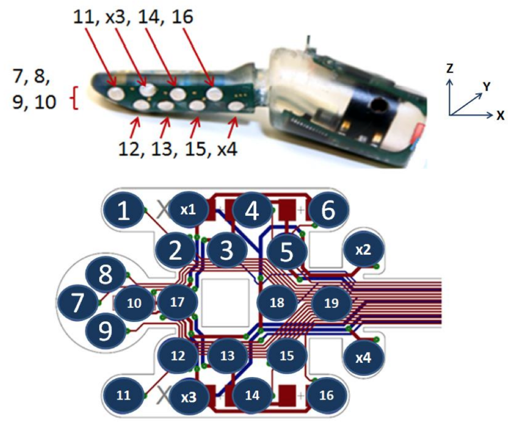


Fig. 1: Electrode orientation and loaction [1]

II. SENSORIZED HAND

The Shadow Hand is a robot that closely reproduces the kinematics and dexterity of the human hand. The model that we use (right hand) has 20 degrees of freedom: 2 in the wrist, 5 in the thumb, 4 in the little finger, and 3 in the other fingers. Each finger is equipped with a BioTac sensor.
Each BioTac sensor embeds 19 electrodes, a hydro-acoustic pressure sensor (for both static and dynamic pressures), and a thermistor for the temperature [5]. In this work, we focus on the measure of the static pressure magnitude (noted P). The mapping from this to the corresponding force magnitude F is given in [3], by the linear relationship:

$$F = (P - P_0) * K, \tag{1}$$

with P_0 the offset pressure measured by the sensor when not in contact, and K an unknown gain. The goal of this work is to determine P_0 and K, as will be explained hereafter.

III. METHODS

To automatically calibrate the BioTac sensors, we use a custom-made plate (shown in Fig. 2) mounted on a Nano25 Force Sensor from ATI Industrial Automation[3]. Both are held by a vertical support, also designed and manufactured in the LIRMM laboratory.
One-by-one, each of the five fingers sequentially touches the force sensor plate three times with increasing pressure. The contact is kept for n iterations, then released. This is done by moving the finger metacarpophalangeal-equivalent joint by an angle of 18^o, 20^o and 22^o, and then resetting it to 0^o. For the thumb, it is also necessary to actuate the distal-equivalent joint by 40^o. Figure 2 shows a movement of each finger as it pushes the force plate.
Then, data from the force sensor and BioTac, is processed,

[3]www.ati-ia.com/

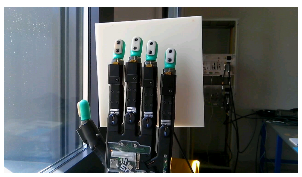
to derive K and P_0.
For the force F, we simply consider the norm of the three measured components:

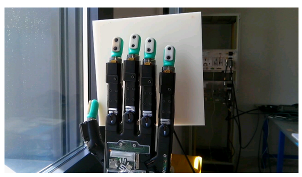
$$F = \sqrt{F_x^2 + F_y^2 + F_z^2}. \quad (2)$$

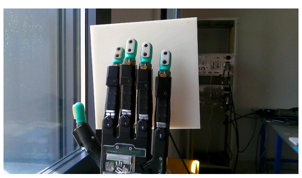
For each BioTac, to reduce the electrode noise perturbation, a *Single Pole Infinite Impulse Response Filter* is applied to the raw static pressure measure. Filtered values P_i at iteration i are expressed in function of the raw measures $\hat{P}_i$ via:

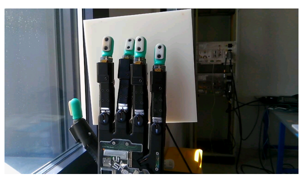
$$\begin{aligned} P_0 &= \hat{P}_0 \\ P_i &= \hat{P}_i * \alpha + P_{i-1} * (1-\alpha) \qquad i > 0, \end{aligned} \quad (3)$$

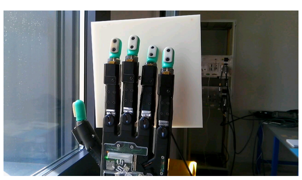
with $\alpha \in [0..1]$ a coefficient that controls the degree by which the weight of a measure decreases based on its age. It is common to set $\alpha = \frac{T_s}{\tau + T_s}$, with T_s the sampling time, and τ the time constant of the system. Here (as in [4]), we estimate both to be roughly 1 ms, so that α= 0.5 provides the best compromise between sensor noise reduction and response reactivity.


(a) Initial Position


(b) Thumb


(a) Fore Finger


(b) Middle Finger


(a) Ring Finger

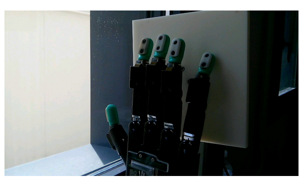

(b) Little Finger

Fig. 2: Calibration procedure, as fingers touch the force plate.

Without loss of generality, we hereby explain the procedure used to derive K and P_0 for one BioTac (the procedure is identical for all five).
The pressure measurements at iterations with finger vertical (i.e., not in contact with the plane) are averaged, to obtain P_0.
The filtered BioTac measures (from (3)) at iterations with finger in contact with the force plate (denoted as iterations $c, \ldots, c+n$) are used to form column vector:

$$\mathbf{P} = \begin{bmatrix} P_c - P_0 \\ P_{c+1} - P_0 \\ \ldots \\ P_{c+n} - P_0 \end{bmatrix}, \quad (4)$$

while the force measures are stacked in vector:

$$\mathbf{F} = [\ F_c \quad F_{c+1} \ldots F_{c+n}\ ]^T. \quad (5)$$

Then, K is simply derived by inverting (1):

$$K = \mathbf{P}^{\dagger}\mathbf{F}, \quad (6)$$

with $\mathbf{P}^{\dagger}$ the Moore-Penrose pseudoinverse of $\mathbf{P}$.

IV. RESULTS AND CONCLUSION

The five sensors parameters are given in Table I. In figure 3, we plot the values of $P - P_0$ and corresponding force measures at the iterations with fore finger in contact with the plate. It can be seen that the points lie on the trend-line of slope K. After calibration, we verify the tuned values of P_0 and K by running an experiment where the fingers again push the force sensor plate one-by-one, and the values computed with (1) are compared to the force sensor measures. The results are very near (for instance, we obtain a relative error of 5.91% for the fore finger).The same setup is being used to calibrate the electrode array and consequently estimate the force vector and point of force application.
A video of the complete experiment (three movements per finger for calibration, and a fourth for verification) is available at: `www.youtube.com/watch?v=kJm6jaVxBlI`

finger	thumb	fore	middle	ring	little
K (N/Pa)	0.016	0.010	0.013	0.009	0.009
P_0 (Pa)	85	86	106	57	70

TABLE I: Calibrated parameters of the five BioTac sensors.

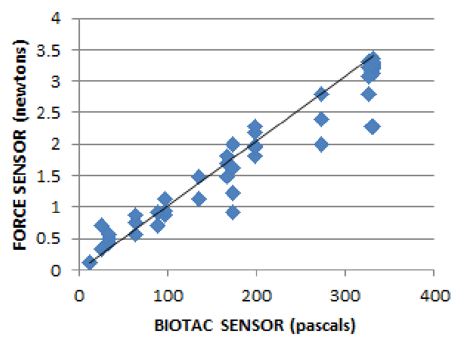


Fig. 3: Pressure ($P - P_0$) vs Force (F) measurements for the fore finger.

ACKNOWLEDGMENTS

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