**Force Based Sensor Calibration**

**Metric**

Force based sensor calibration is important for many state-of-the-art robotic grasping and manipulation control algorithms that use force-based control approaches. That is, in order to control contact forces, force sensor readings must be accurate. Moreover, force capabilities can be used for touch-based grasp planning, controlled interaction for texture discrimination and object localization.

**Dependencies**

This characteristic is a function of the tactile sensor mechanical design, and its calibration.

**Test Method**

Apparatus:

Three axis load cell ($F\_{x}$, $F\_{y}$, $F\_{z}$) or single axis load cell.

Object of desired geometry attached to load cell.

Description:

This test method seeks to capture the performance of force based tactile sensors by comparing the force readings by the sensor to force data recorded simultaneously using an external load cell. Using the desired sensor-object orientation, position the sensor under test just above the force sensor and verify a zero force reading. Press the sensor against the load cell and record both the sensor force reading and the load cell readings.

Performance Measures:

1. **Force Magnitude:** Calculate the Root Mean Squared Error (RMSE) between the tactile sensor force magnitudes and those measured by the reference force sensor for all data collected. In the case of a single axis load cell, the sensor force should be applied along the load cell axis.
2. **Force Direction:** Compute the RMSE between the force direction as measured by the tactile sensor and the external load cell. This measure gives an indication of how competent the sensors are with predicting the correct contact force directionality. This test requires the use of a three axis load cell.
3. **Maximum Force Error:** Calculate the absolute maximum error between the contact force magnitude as measured by the hand sensor and the reference force. This measure will give an upper bound to the sensor’s worst force predictions.

**Example Implementation**

Test Setup:

The test was conducted for a robotic hand “Hand 1” for two tests. In the first test, the hand was retrofitted with impedance sensors at the fingertips and in the second test, the hand was fitted with resistance based sensors at the fingertips. The collected data came from the finger force tracking test where each finger was commanded to seek a certain force against a flat object surface that was rigidly attached to a three-axis load cell (Figure 1). Four different force profiles were issued consisting of 1 N, $\frac{F\_{finger,max}}{2}$ N, $F\_{finger,max}$ N, and a time-varying trajectory defined as

 $\left‖F\_{d,z}\right‖=5log\left(sin\left(\frac{π\left(t+3\right)}{2}\right)+cos\left(\frac{t}{4}+π\right)+3\right)+1$ (1)

where $t$ is time, and $F\_{d,z}$ is the desired force trajectory in the world coordinate system’s z-axis. Each test was conducted for a continuous 60 seconds. In the future, static calibration verification will be performed while incorporated multiple approach points to more thoroughly test larger regions of the sensor response space.

Results:

Three performance measures were extracted from the collected data. First, the Root Mean Squared Error (RMSE) was calculated between the sensor force magnitudes and those measured by the reference force sensor for all data collected. This measure gives an indication of how competent the sensors are with predicting the correct contact force magnitude. Next, the RMSE was calculated between the force direction as measured by the each sensor and the reference load cell. Lastly, the maximum force error is calculated between the desired contact force magnitude and the measured contact force magnitude. Combined results are shown in Table 1.

Data:

|  |  |
| --- | --- |
| *Data File Archive:*   | [Finger Force Tracking.zip](http://www.nist.gov/el/isd/upload/Finger-Force_Tracking.zip) |
| *Data Files:*  | **Hand 1 Impedance/Set Point**/**Finger***[No.]***\_***[File Type.]***\_** *[Magnitude]***N****Hand 1 Impedance/Time Varying**/**Finger***[No.]***\_***[File Type.]***Hand 1 Resistance/Set Point/Finger***[No.]***\_***[File Type]\_ [Magnitude]***N****Hand 1 Resistance/Time Varying/Finger***[No.]***\_***[File Type]***Hand 2/Set Point/Finger***[No.]***\_***[File Type]\_[Magnitude]***N** |
| *File Type:* | LoadCell - reference load cellImpedance - impedance contact sensingResistance - resistance contact sensing |
| *File Format:*  | ASCII, comma delimited |
| *Data Values:*  | $F\_{x}$, $F\_{y}$, $F\_{z}$(one set per line) |
| *Units:* | Newtons |
| *Data Sample Rate:* | 3 kHz |



Figure 1. Test setup for measuring performance of force calibration fidelity.

Table 1. Shows the various force calibration performance errors for Hand 1 under both impedance and resistance-based contact sensing.

