Design and Calibration of a Custom Force Sensor for Application in Pinch Force Measurement

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Introduction: Measuring kinetics is critical for robust analysis of human movement. For example, when studying the lower limb, force plates are used extensively to characterize the force vectors associated with foot-floor contact. In contrast, the standard approach for measuring forces produced by the hand is to record only pressure (i.e., normal force). Sensors that have the appropriate size and sensitivity to record 3D finger-tip force vectors are typically bulky, expensive, and difficult to embed in household objects used for manipulation experiments. Thus, the objective of this study is to design and test the first iteration of a low cost, custom force sensor that uses Hall effect sensors to measure the magnitude, direction, and position of small forces produced by the hand.

Materials and Methods: The custom force sensor (Fig. 1A) was designed to act like a miniature force plate. Specifically, four magnetometers (MLX90393, Sparkfun, Boulder, CO) are arranged in a square. An acrylic grid suspends a magnet above each magnetometer and is attached to the platform by an elastomer. An Arduino microcomputer (Redboard, Sparkfun, Boulder, CO) enables data collection from the sensors.

The custom force sensor was tested for sensors drift and magnetic interference, and then calibrated. Sensor drift was tested by recording 1000 measurements at 1 Hz and noting any change in output given constant force application. Magnetic interference was tested by collecting data with and without known magnetic materials on and around the sensor, and analyzing whether there were effects on the sensor output. The calibration experiment defines the transformation from magnetic field strength to force magnitude and position. Force magnitude was calibrated first by measuring the magnetic field strength produced by 6 calibration masses ranging from 0g to 1000g (0N to 9.81N) placed on the center of the force sensor. This represents a range of pinch forces necessary to complete many daily activities [1]. A penny between the mass and sensor controlled for varying surface areas of the calibration masses. For each mass, 3 trials were recorded; each trial consists of 100 measurements at 5 Hz. Force position is calibrated by measuring the magnetic field strength produced by each mass at 4 additional positions (±2cm vertical, ±2cm horizontal) on the sensor. The transformation from magnetic field strength to force magnitude was calculated using established methods [2]. Change in magnetic field strength (ΔB) from baseline (0N force) is plotted against the applied force, and the R^2 value is calculated to test linearity.

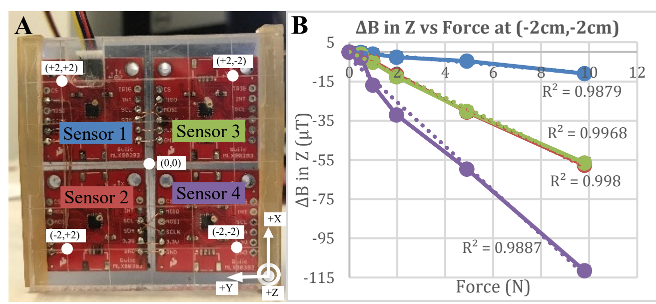

Figure 1. (A) Photo of custom force sensor. (B) Representative calibration data. Output from each sensor is displayed for a single force direction (Z; vertical) and position (-2 cm, -2 cm). Average R^2 = 0.993.

Results and Discussion: The designed force sensor did not demonstrate sensor drift. Variation in magnetic field due to magnetic interference was also negligible.

The calibration experiment produces 108,000 unique magnetic field strength measurements organized by mass, location, trial, and component direction. The relationship between force and ΔB is linear (Fig. 1B). The largest ΔB consistently occurs in the sensors closest to the point of force application (e.g., Fig. 1B, purple) with smaller ΔB occurring in the further sensors (e.g., Fig. 1B, red, green, and blue). The results indicate that the magnitudes and positions of forces within the tested range can be accurately measured with this custom force sensor. The measurement error (standard deviation of all trials, positions, and masses) ranged from 1 to 4μT. This sensor provides a small, low-cost method to measure small forces produced by the hand.

Conclusions: The custom force sensor accurately measures forces from 0N to 9.81N, indicating that it can be used to measure small forces in the hand. Future work for this project will include testing multi-directional forces to investigate if the sensor can accurately measure force direction, testing larger forces to define this sensor's functional range, and iterating on the design to make it more compact.

References: [1] Smaby N et al, *J Rehabil Res Dev*, 2004, 41(2):215-24. [2] Higa M et al, *Sensors and Materials*, 2018, 9:1989–1996