MINIMUM NUMBER OF THIN-FILM FORCE SENSORS NEEDED TO REPRESENT OVERALL HAND GRIP FORCE DURING TOOL USE

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Introduction

Accurate and robust measurement of hand grip force is an important parameter of interest in studies of human biomechanics, especially in the assessment of vibratory tool use and hand-arm vibration exposures, where exposure levels may change with changes in grip. Several studies exist that introduce various methods of determining grip force levels. Wimer et al.[1] developed a strain-gauge instrumented cylindrical handle having six cantilever beams in order to obtain a high level of accuracy and repeatability beyond assessments of grip strength using a traditional dynamometer. Mentzel et al.[2] investigated dynamic grip forces using the TUB-sensor glove (FSR 151, Conrad Electronics, Hirschau, Bavaria) equipped with ten pressure sensors, while Lemerle et al.[3] investigated the precision of a pressure mapping glove used to measure the grip forces on an ordinary breaker and an anti-vibration breaker. Nikonovas et al.[4] used 20 thin-film FlexiForce sensors (A101, Tekscan, Boston, MA) in an array on each hand to measure the forces generated on gripping a golf club while striking a golf ball and determined that the FlexiForce sensors allowed for versatility and adequate spatial resolution. Peterson et al.[5] used six thin-film force sensors (400 FSR, Interlink Elec., Camarillo, CA) to measure grip forces during a manual hammering task and determined that thin-film sensors are adequate and remain non-invasive but only if used in small numbers.

In practical laboratory and field applications that seek to investigate overall hand grip patterns associated with tool or device use, not much is known about the minimum number of point-force measurements that are needed on the hand to adequately characterize overall grip. In this paper, the optimal number of single-point thin-film force sensors needed to accurately model overall cylindrical grip force was determined using data collected simultaneously from the instrumented cylindrical handle (developed by Wimer et al.) and several thin-film force sensors placed at several locations on the hand.

Methods

Eight thin-film FlexiForce sensors were connected to a custom-built electronic unit that provided sensor power and signal conditioning. Calibration on each sensor, and each measuring arm of the instrumented cylindrical handle, was accomplished using a randomized sensor loading routine and a linear regression to correlate voltage with force. Grip force data was collected from seven subjects of varying hand sizes and gender. All force data from the FlexiForce sensors and the instrumented handle were simultaneously captured at 5 Hz using a LabVIEW-based (National Instruments, Austin, TX) data acquisition system. The instrumented handle served as the grip reference and a real-time data stream from the handle provided a visual scale of applied grip force. To limit sensor bulk during the measurements, only eight FlexiForce sensors were used and a force mapping of the dominant hand was conducted until force data from 24 different locations across the fingers and palm were collected. The mapping consisted of six trials and the sensor placements for each of the trials can be seen in Figure 1. During each trial, the subject slowly gripped up to 80% of their pre-determined maximum force level three times.

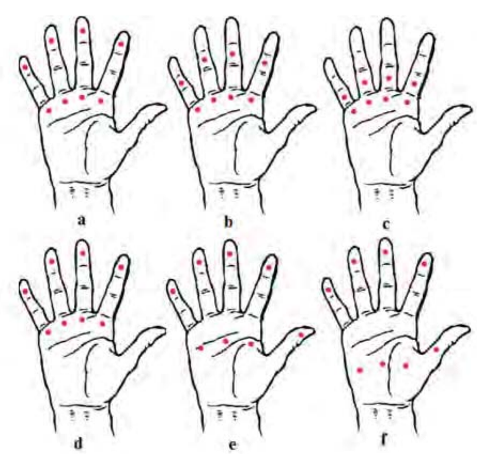

Figure 1: Sensor positions for the six trials (a-f)

Results

For each trial, the instrumented cylindrical handle produced six force waveforms (i.e., one for each cantilever) that were summated into an overall grip force waveform and served as the reference. A FlexiForce grip force waveform was produced by each sensor and data from each of the eight sensors were summated into one waveform. In addition to the set of all eight sensors, summation waveforms were also generated by summating the signals from sensor sets containing: 7 sensors, 6 sensors, 5 sensors, 4 sensors, 3 sensors, 2 sensors, and 1 sensor, where the sensor having the worst response in each particular set was eliminated to obtain the next descending sensor set. Each of the eight waveforms from the sensor sets was divided by the reference waveform to yield a ratio, or 'conversion factor', waveform. All the values in each of the conversion factor waveforms were averaged to obtain an overall conversion factor for each sensor set. Eight conversion factors were determined for each subject and are displayed in Figure 2 according to the number of FlexiForce sensors used in the calculation.

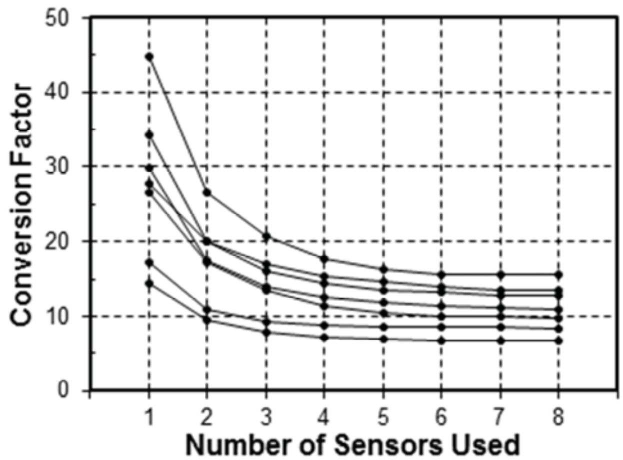

Figure 2: Conversion factors for each individual subject

Discussion

Minimizing the number of thin-film force sensors used to accurately represent total grip force behavior during tool or device use is necessary in order to limit sensor bulk in laboratory and field instrumentation systems that incorporate grip force measures. As shown in Figure 2, the conversion factors between the sets of eight and four sensors were observed to be very similar for each subject, while the conversion factors for the sets of three and two sensors began to show deviation and loss of meaningful point-force resolution. The conversion factor for one sensor was observed to be an unreliable estimate of overall grip force. The results suggest that a minimum of four thin-film force sensors placed at high contact locations between the handle and the hand is required in order to accurately represent overall grip force. In ongoing work, the influence of gloves, sensor positioning, and hand size are being investigated.

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