CALIBRATION OF PRESSURE SENSORS FOR HAND GRIP MEASUREMENT

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The purpose of this study was to assess the accuracy of grip force sensors. **Methods:** Several standard weights were used to calibrate the grip sensor in the static condition. The descriptive statistics and linear regression were used to present the accuracy and errors. **Results:** Results of this study showed a high level of sensing areas linear relationship under static loading. **Conclusion:** Data from this study showed high accuracy of the pressure sensor. The pressure sensor could be used for hand grip measurement.

KEY WORDS: accuracy, grip force, pressure calibration

INTRODUCTION: Thin, flexible pressure sensors allow for full range of hand motion to measure loads in the hand. For measurement of grip force, sensing elements can be placed directly onto a hand, on a glove, or onto a handle surface. Grip pressure sensors are used in ergonomics and sports applications to evaluate the different forces required for a human hand to grasp an object. For instance, Opperman, Waldie, Natapoff, Newman, et al. (2009) evaluated grip force to explore compression-induced blood flow occlusion causing hand injury. Komi, Roberts, and Rothberg (2008) measured grip force during a golf shot utilizing two different sensors. Prior to using sensors in biomechanical analysis studies, it is important to show that the results they offer are accurate under the proposed testing conditions. The current study aims to assess the calibration of force measurements to ensure the accuracy of grip sensor.

METHODS: The ultra-thin-film printed circuits 4256E grip sensor (Tekscan, Inc., Boston, MA) was chosen for this study. The sensor was 0.015 cm thick and maximum pressure range 20.69 kPa. Each 4256E grip sensor consists of eighteen sensing areas that was measured from 1.92 cm^2 to 9.44 cm^2 (Fig.1). The grip sensor was loaded via standard weights (0.25kg; diameter 1cm) and sliced acrylic sheets to make sure loads were full the sensing areas and a flat-face steel sheet as plant at the bottom (Fig.2). To determine the accuracy related with each pressure measurement device, it was necessary to find the known load being applied. The sensor applied pressures up to 17.85 kPa which were under the limit load of the grip sensor.

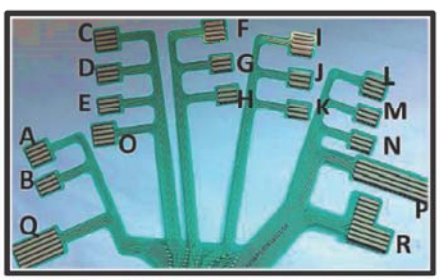

Figure 1: The real loading areas in 4256E grip sensor. (Area B,D,E,G,H,J,K,M,N are 1.92 cm^2 ; A,C,F,I,L,O are 2.56cm^2 ; Q is 7.20 cm^2 ; R is 8.32 cm^2 and P is 9.44 cm^2)

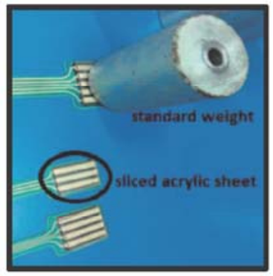

Figure 2: Illustration of loading with standard weight and acrylic sheets.

In the test, each sensing area was calibrated by applying a load-unload cycle with 0.5kg interval from 0.5 to 3.5 kg and was performed five times. The data were sampled at 50 Hz. Accuracy errors of the sensor output were showed mean ± stand deviation, which were calculated as the difference between applied and measured pressure divided by applied load as in equation:

$$\frac{1}{N}\sum_{n=1}^{N}\left[\frac{|\overline{F}_{sens}(n\Delta t) - F_{sens}(n\Delta t)|}{\overline{F}_{sens}(n\Delta t)}\right]$$

$\overline{F}_{sens}$: the mean measured raw value of sensor. F_{sens}: sensor raw value measurement. n: sample number of test run. N: total number of samples taken. Δt: chosen length of time which the sensor output is averaged at the beginning and end of each load.

In static loading condition, each sensing area was loaded with 0.5kg interval from 0.5 to 3.5 kg and each load during 5 seconds was performed five times. The data were sampled at 100 Hz. The analysis used linear regression which was applied to the calibration points and zero point to derive a linear equation, and to acquire r^2. The averages of measured raw values were taken, and the descriptive statistics were computed.

RESULTS: In a quasi-static test, each sensing area applied thirteen weights loading and unloading for calculation, for example, the relationship between applied pressures (loads divided area) of the area B and the means raw values were shown in Figure 3. An accuracy error of grip sensor was presented in Table 1. The results revealed that the all sensing area accuracy errors were (M= 0.023, SD= 0.013).

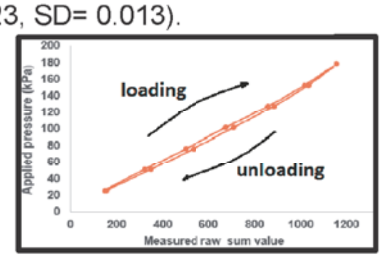

Figure 3: Grip sensor under loading and unloading pressure in area B.

Table1
Accuracy errors results of static loading tests.
The means shown as percentage, with standard deviation in parentheses.

Area	Errors (%)	Area	Errors (%)	Area	Errors (%)
A	1.6 (0.5)	G	2.4 (1.0)	M	3.6 (1.5)
B	3.4 (1.8)	H	2.1 (1.1)	N	2.8 (2.1)
C	2.0 (1.1)	I	3.5 (2.2)	O	2.0 (1.1)
D	1.8 (1.0)	J	2.0 (0.7)	P	1.2 (0.2)
E	2.6 (1.2)	K	2.2 (1.2)	Q	2.8 (0.9)
F	2.2 (0.9)	L	2.3 (1.4)	R	1.3 (0.6)

For static loading method, sensing areas were applied to seven calibration points and zero point to derive a linear equation, of the form Y=aX+b, regression coefficient a and b. For all sensing areas, the data in Table 2 presented that the obtained r^2 were from 0.94 to 0.99.

Table 2
Linear regression for all sensing areas. Regression coefficient a and b.

Area	a(×10^{-2})	b(×10^{-2})	r^2	Area	a(×10^{-2})	b(×10^{-2})	r^2
A	0.06	15.9	0.98	J	0.09	19.2	0.99
B	0.08	21.4	0.98	K	0.07	30.2	0.96
C	0.07	19.5	0.98	L	0.06	12.1	0.99
D	0.08	23.0	0.99	M	0.09	17.0	0.99
E	0.08	25.6	0.98	N	0.09	1.6	0.99
F	0.06	23.8	0.98	O	0.05	24.5	0.94
G	0.09	31.0	0.99	P	0.02	3.8	0.99
H	0.08	34.8	0.97	Q	0.02	5.1	0.99
I	0.10	13.8	0.99	R	0.03	2.1	0.99

The relationship between eighteen sensing areas, which were combined to eight fields with five fingers and three in palm (Fig.4). All eight fields as shown in Table 4, the obtained r^2 were from 0.84 to 0.99. Only the r^2 from field 2 and field 6 were 0.68 and 0.47 respectively during the test.

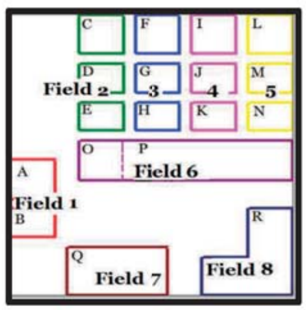

Figure 4: Eight fields consist of eighteen sensing areas.

Table 3
Linear regression for eight fields. Regression coefficient a and b.

	First test			Second test		
Field	a(×10^{-2})	b(×10^{-2})	r^2	a(×10^{-2})	b(×10^{-2})	r^2
1	0.07	19.5	0.85	0.11	29.6	0.84
2	0.07	25.8	0.91	0.09	24.5	0.68
3	0.07	31.8	0.86	0.10	23.2	0.86
4	0.08	23.1	0.96	0.09	14.6	0.92
5	0.08	11.0	0.92	0.09	9.8	0.85
6	0.04	8.6	0.47	0.07	23.4	0.96
7	0.02	5.1	0.99	0.03	33.3	0.99
8	0.03	2.1	0.99	0.03	7.4	0.99

DISCUSSION: The 4256E grip sensor was examined in this study. A related study had provided a comprehensive analysis of performance under static and dynamic loading, and also measured golf grip forces in swing by using three types of thin and flexible sensors (Komi, Roberts, and Rothberg, 2008). However, each 4256E grip sensor was comprised of eighteen sensing regions that can be individually positioned over anatomic sections of the fingers and palm. This study offered some information about calibration method for grip sensor. Quasi-static loading tests showed that for identical loads, sensor output was higher during unloading than loading. As the table 1 indicated, the average of grip sensor accuracy errors from 1.2 to 3.6% were quit low. In order to calibrate grip sensor, manufacturer provided the grip user manual by using two point calibration which one point had done with a light load, and the second calibration point had done with a heavy load. Therefore, mathematics were applied to the seven calibration points and zero point to derive a linear equation. For all sensing areas, linear relationship were high level, which suggested that the regression line perfectly fits the loading data for individual area respectively. In the other words, each sensing area can carry out calibrating one by one. Viewed in this light, grip sensors can be regarded as a reliable tool to measure force. The applications of grip sensor are used to improve design for a more ergonomically sound product, study carpal tunnel and repetitive motion syndrome, or analyze sports movement and equipment such as baseball bats and golf clubs. Komi, Roberts, and Rothberg, (2008) utilized sensors to measure pressure in golf shot after compared to characteristics of three different sensors. In addition, the relationship between eighteen sensing areas, the results showed that the r^2 of eight fields were from 0.84 to 0.99, expect that field 6 revealed low linear relationship with r^2= 0.47. The main reason was that field 6 is composed of two areas with different shape separately. Therefore, loading data summarized indicated no strong linear relationship between all sensing areas. The limitation in this study results were based on static loading test, not dynamic test.

CONCLUSION: The simple method of loading standard weights evaluated that grip sensors can accurately measure force. The results of this study clearly supported the notion that accuracy error of grip sensor was quite low and linear relationship of sensing areas were at a high level. It should be concluded, from what has been said above, that each sensing area can carry out calibrating one by one. Although the sample in this study was roughly progressing several calibrated force measurements, it could be served as some general principles for calibrating grip sensor. Overall, the results have been positive, 4256E grip sensor is reliable instrument to measure force.

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