EVALUATION OF THE FSA HAND FORCE MEASUREMENT SYSTEM

Kihyo Jung[1], Heecheon You[1], and Ochae Kwon[2]

[1]Division of Mechanical and Industrial Engineering
Pohang University of Science and Technology, Pohang, South Korea
[2]Design Team, Mobile Communication Division, Samsung Electronics, Seoul, South Korea

The FSA (Force Sensitive Application) system measures hand force by using force resistance sensors. Compared to conventional hand force measurement systems such as Lafayette hand dynamometer and Jamar hydraulic hand dynamometer, the FSA system can be applied to analyze use of hand forces while the hand is manipulating objects for a task, However, the measurement performance of the FSA system has not been objectively evaluated. The present study tested the FSA system in terms of stability, repeatability, accuracy, and linearity at sensor (one sensor) and system (hand motions; power grip, pulp pinch, pulp press) level. In sensor level, the FSR sensor has good stability (CV≤2%) and linearity (R^2=0.82), but has low repeatability (CV=11%~19%) and accuracy (22% of under evaluation on average). In system level, accuracy is dramatically worsened by increasing the number of sensors involved. For example, mean differences (MD) between the FSA and NK dynamometer are -0.09kgf, -1.15kgf, and -1.49kgf for pulp press (1 sensor), pulp pinch (2 sensors), and power grip (18 sensors). However, there is strong linear relationship between values from the FSA and NK dynamometer (R^2=0.82, 0.94, and 0.99 for pulp press, pulp pinch, and power grip). This performance result indicates that measurements from the FSA system should be used for relative comparison rather than for absolute comparison.

INTRODUCTION

Hand force has been identified as a risk factor for musculoskeletal disorders (MSDs) and a source of biomechanical stress. NIOSH (1997) reports, based on a comprehensive literature review, hand force positively associated with Carpal Tunnel Syndrome (CTS) and Tendinitis. In addition, Ayoub (1990) and Putz-Anderson (1988) mention that biomechanical stresses and musculoskeletal injuries may be caused by exerting excessive force.

Hand force can be quantified by using two types of sensor (load cell and FSR sensor). Hand dynamometers (see Figure 1) measure force applied on a handle and have been widely used to quantify hand force. Batra et al. (1994) and Bishu et al. (1995) evaluate glove designs in terms of grip strength by using the hand dynamometer. Moreover, Blackwell et al. (1999) investigates effect of grip span on maximum grip force by using the Jarmar hand dynamometer. Compared to the conventional hand force measurement systems, the FSA system (see Figure 2; incorporates FSR sensors on palmer side of a glove) can be applied to analyze use of hand forces while the hand is manipulating objects for a task. However, the measurement performance of the FSA system has not been objectively evaluated.

(a) NK Digit-Grip (b) Lafayette dynamometer (c) Jamar hand dynamometer

Figure 1. Hand dynamometers

Figure 2. FSA hand force measurement system (NexGen, 2004)

The present study tested the FSA system in terms of stability, repeatability, accuracy, and linearity at sensor and system level. In sensor level evaluation, one sensor was evaluated using 3 weights (0.5kg, 1kg, and 2kg). In system level, the FSA system was evaluated along with hand motions (power grip (18 sensors), pulp pinch (2 sensors), and pulp press (1 sensor)).

METHODS

Tasks

Two tasks (static and dynamic task) were applied to test the FSA system at sensor and system level. First, static task was conducted for the sensor evaluation by using 3 weights (0.5 kg, 1 kg, 2 kg) laying each on the sensor (see Figure 3). Measurements were made 10 trials for each weight and a cube-shaped auxiliary tool (0.6 g; see Figure 3) was used to contact a weight on the sensing area of the sensor. Second, dynamic task involved hand motions (pulp press, pulp pinch, and power grip) was carried out to evaluate the system level performance. For example power grip task, griping NK Digit-Grip (see Figure 5), was conducted by attaching 18 sensors on the palmer side of the glove where possibly related to involve griping an object. The performance was analyzed by comparing values from the FSA and NK dynamometer as a gold standard.

Evaluation criteria

The FSA system evaluated in terms of stability, repeatability, accuracy, and linearity. Stability defined fluctuation of measurements under constant force and quantified as Coefficient of Variation (CV). Repeatability

(a) Weights (b) Cube-shaped auxiliary tool on the FSR sensor

Figure 3. Weights and auxiliary tool used for sensor evaluation

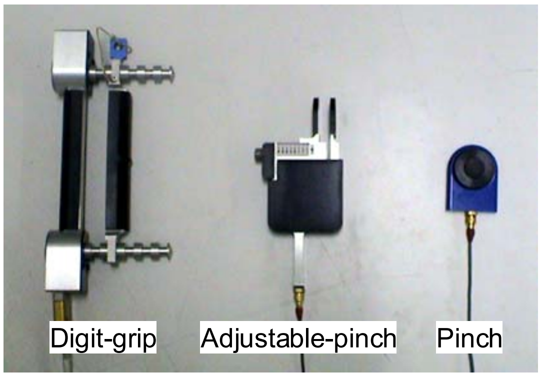


Figure 4. Modules of the NK dynamometer

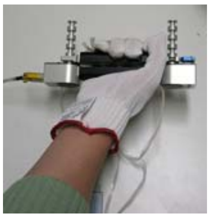
Classification	Power grip (18 sensors)	Pulp pinch (2 sensors)	Pulp press (1 sensor)
Sensor attachment			
Measurement motion			

Figure 5. Sensor arrangement and measurement motions

defined the degree of agreement between repeated trials under identical condition and quantified as CV. Accuracy defined difference between measurement and the true value and quantified as mean difference (MD) and standard error (SE). Lastly, Linearity represented the degree of linear relationship between measurements and the true value and quantified as R^2 (determination of coefficient) and mean squared error (MSE) of linear regression.

Experimental procedure

Two experimental tasks (static and dynamic task) were carried out in a sequential manner. First, measurements from one sensor made 10 trials for each of 3 weights during 10 seconds at 10 Hz sampling rate. For example, weight 0.5kg was placed on the FSR sensor and measurements were taken for 10 seconds. After that, the weight was unloaded and 30 seconds break was given to minimize possible negative effects (e.g., creep and hysteresis effect). This procedure was repeated 10 trials. Then, 2 minutes break was given and the procedure was conducted again after changing the weight (e.g., 1kg).

Second, the system level evaluation was carried out after synchronizing measurements from the FSA system and the NK dynamometer. The sampling rate of the two systems was fixed at 10 Hz and the computer clocks (the two systems installed on different computer) were synchronized by using AboutTime (AboutTime, 2004) to compare values of the two systems. The measurement units of the FSA (psi) and NK (kgf) were changed into kgf for easy comparison and interpretation. After that, experiments for pulp press, pulp pinch, and power grip were conducted after taking 2 minutes break before changing the motion.

RESULTS

Sensor level evaluation

The stability of the FSR sensor shows fairly good but, it is slightly overestimate forces (see Table 1). CV was identified less than 2% (1.4%, 0.9%, and 1.2% for 0.5kg, 1.0kg, and 2.0kg), but relatively high at low (0.5kg) and high (2.0kg) forces. However, the FSR sensor overestimates forces (0.51kgf, 1.14kgf, and 2.52kgf for 0.5kg, 1.0kg, and 2.0kg).

Repeatability between trials is ranged from 11% to 19% along with object weights. Table 1 shows that CV decreases according to increasing weights (19%, 14%, and 11% for 0.5kg, 1.0kg, and 2.0kg). In accordance with stability, the sensor tends to overestimate forces (see Figure 6).

Table 1. Performance of the FSR sensor in terms of stability, repeatability, accuracy, and linearity

Weight (kg)	Stability (CV)	Repeat-ability (CV)	Accuracy MD* (%)	Accuracy SE	Linearity ($Weight_i = b_1 \times FSA_i$)
0.5	0.014	0.19	0.09 (18%)	0.12	$\hat{y}_i = 0.77x_i$ (R^2=0.95, MSE=0.04)
1.0	0.009	0.14	0.14 (14%)	0.18	
2.0	0.012	0.11	0.52 (26%)	0.52	

* Mean difference between FSA values and weights

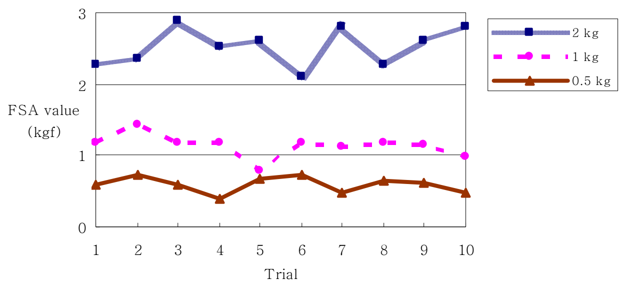


Figure 6. Mean value of the FSR sensor along with measurement trials

Accuracy in terms of MD (mean difference) and SE (standard error) are getting worse while increasing weights (see Table 1). MD is increasing according to increasing weight (0.09kgf, 0.14kgf, and 0.52kgf for 0.5kg, 1.0kg, and 2.0kg) and the sensor overestimates forces because of showing positive MD (18%, 14%, and 26% for 0.5kg, 1.0kg, and 2.0kg). Furthermore, SE is increasing by increasing weight (0.12kgf, 0.18kgf, and 0.52kgf for 0.5kg, 1.0kg, and 2.0kg).

Lastly, linear regression without intercept (not significant) between the sensor values and weights is statistically significant at 0.05 alpha level. Table 1 show that R^2 (0.95) and MSE (0.04kgf) are satisfactory. However, the sensor is overestimating forces because the slop (0.77) is less than 1.

System level evaluation

The FSA system underestimates forces than NK dynamometer (see Figure 7) and this trend is worsened according to increasing number of sensors involved in measurement. Table 2 shows that SE is increasing according to increasing the number of sensors involved (0.79kgf, 1.40kgf, and 8.73kgf for pulp press (1 sensor), pulp pinch (2 sensors), and power grip (18 sensors)). The

FSA system provides less value than that of NK dynamometer because of showing negative MD (mean difference). Furthermore, MD is increasing while increasing the number of sensors involved (-0.09kgf, -1.15kgf, and -1.49kgf for pulp press, pulp pinch, and power grip).

Table 2. Performance of the FSA system in terms of accuracy, and linearity

Motion (# of sensors)	Accuracy (kgf)		Linearity ($NK_i = b_1 \times FSA_i$)		
	MD* (%)	SE	Slop	R^2	MSE
Power grip (18)	-1.49 (30.4%)	8.73	1.33	0.99	2.90
Pulp pinch (2)	-1.15 (40.0%)	1.40	1.57	0.94	0.79
Pulp press (1)	-0.09 (9.8%)	0.79	1.00	0.82	0.24

* Mean difference between FSA and NK measurements

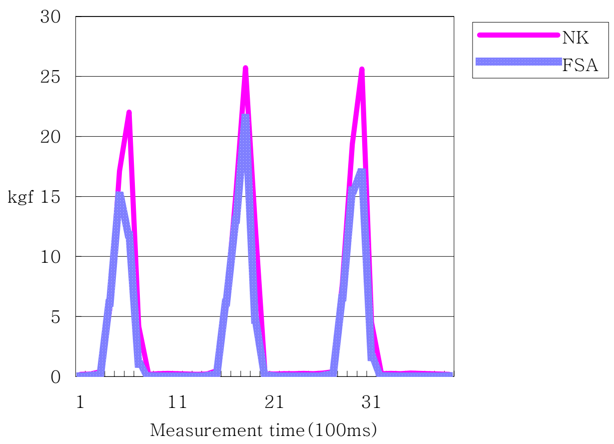


Figure 7. measurements from the FSA and NK dynamometer for power grip

Linear regression without intercept (not significant) between the FSA values and NK values is statistically significant at 0.05 alpha level (see Table 2). MSE (0.24kgf, 0.79kgf, and 2.9kgf for pulp press, pulp pinch, and power grip) and R^2 (0.82, 0.94, and 0.99 for pulp press, pulp pinch, and power grip) are increasing while increasing the number of sensors involved. The FSA system is underestimating forces because the slop (1.00, 1.57 and 1.33 for pulp press, pulp pinch, and power grip) is greater than 1.

DISCUSSION

It is necessary to use more accurate calibration equation to achieve the highest accuracy. In the sensor evaluation, the FSR sensor tends to constantly overestimate forces (e.g., 0.51kgf, 1.14kgf, and 2.52kgf for 0.5kg, 1.0kg, and 2.0kg). It means there is better way to minimize errors by adjusting coefficient (gain) of the calibration equation.

The experiment result shows that exponential calibration equation is necessary if application requires achieving the highest accuracy. In the sensor evaluation, the FSR sensor tends to overestimate forces and this trend is worsening at low (0.5kg) and high force (2.0kg) than middle range force (1.0kg). It should be noted that curve fitting calibration equation needed to achieve better measurements.

There is discrepant experimental result that the FSR sensor overestimates forces, but the FSA system underestimate. It is possibly contributed the difference of calibration and usage nature. Individual sensor is calibrated on flat hard floor, but in applications, the FSR sensors are attached on a glove (cushion effect). Besides, the FSR sensors are attached on eminence (not flat and hard) of hand. These effects might be contributing to the discrepancy.

Careful interpretation is necessary when several sensors are involved in measurements (e.g., power grip). In system evaluation, MD (mean difference) and SE (standard error) are increasing with increasing the number of sensors involved. It does not mean that the measurements are useless when involved many sensors because the values are highly related to the true value. It is noted that relative comparison of values are more appropriate than absolute comparison if many sensors are used.

ACKNOWLEDGEMENTS

The present study was supported by the Brain Korea 21 project and the Advanced Product & Production Technology Center at POSTECH.

REFERENCES

Ayoub, M. A. (1990). Ergonomic deficiencies: I. Pain at work. *Journal of Occupational Medicine*, 32(1), 52-57.

AboutTime (2004). Introduction about AboutTime. Retrived April 1, 2004 from http://www.arachnoid.com/abouttime/.

National Institute for Occupational Safety and Health (NIOSH). (1997). *Musculoskeletal Disorders (MSDs) and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back* (2nd printing). Cincinnati, OH: U.S. Department of Health and Human Services (DHHS).

NexGen (2004). FSA glove pressure mapping system. Retrieved April 1, 2004 from http://www.nexgenergo.com/ergonomics/fsaglove.html.

NK BioTechnical Corporation (2003). *NK Dynamometer User's Manual*.

Putz-Anderson, V. (1988). *Cumulative Trauma Disorders: A Manual for Musculoskeletal Diseases of the Upper Limbs*. Taylor & Francis: New York.