ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

Study of Sensor Development for Measuring Shearing Force

[1]Young-Kuen Cho, [1]Seong Guk Kim, [1]Dae Won Lee, [1]Dong Hyun Kim, [2]Hyung Joo Kim, [3]Chang-Yong Ko, [1]Han Sung Kim[*]
[1]Department of Biomedical Engineering, Yonsei University, Wonju, Korea
[2]Hyundai Motor Company, Uiwang, Korea
[3]Research Team, Korea Orthopedics & Rehabilitation Engineering Center, Incheon, Korea
[*]hanskim@yonsei.ac.kr

SUMMARY
Shear force or stress is of importance to research the pathology. Some researchers attempted to analysis shear force/stress, however there are several problems to take a measurement of pure shear stress. The purpose of this study was to introduce a novel strain-gauge-based inexpensive shear sensor which is easier to fabricate it but more reliable than others. It showed that when the wide operational range loaded by the standard weights (2, 4, 6, 8, and 13 N) there were good agreements regardless of directions of shear force applied (R2 = 0.953~0.999).

INTRODUCTION
It has been known that shear force or stress on the skin surface is one of the pathological causes for pressure ulcers in the patients with spinal cord injury (SCI), diabetic patients, or the elderly or soft tissue damages in the patients using a prosthesis, or wheelchair (Bennett et al., 1979; Bennett et al., 1984; Dinsdale, 1974; Goossens et al., 1997; Goossens and Snijders, 1995; Treves, 1884). These diseases can lead to severe complications such as amputation surgery or death of the patients. Therefore, an analysis of shear force on the skin is one of importance to research the pathology of pressure ulcers or soft tissue damages and establish the treatment and/or prevention methods for them.
Up to date, there have been a number of attempts to analysis shear force/stress, however there are several problems to take a measurement of pure shear stress.
The purpose of this paper is to introduce a novel strain-gauge-based inexpensive shear sensor which is easier to fabricate it but more reliable than others.

Materials and Methods
System configuration
A shear force sensor was quadrangular in shape (W × H × T, 54 × 54 × 4.1 mm^3) and made up of two aluminum layers of (upper and lower; 1 mm for height, respectively) and one poly-vinyl chloride layer (middle; 1 mm for height). The middle layer was nearly parallel to the upper and lower layers to ignore the normal force applied on the middle layer. The two strain gauges (12 × 6 × 0.1 mm^3, 120 Ω, CAS, Korea) were pasted to the two bridges of middle layer, which were orthogonal to each other, and thus all the elements of shear force in X-axis and Y-axis can be concurrently measured.
Our systems had two solutions that measuring pure shear force as well as preventing or minimizing an interference of normal force. First, ball bearings were used between the upper and lower layers (Φ = 1.5 mm). Several ball bearings whose diameter was larger than the width of the middle layer were used to prevent contact between the strain gauges and the upper and lower layers and to minimize friction between layers. Second, the aluminum upper and lower layers were used to minimize their deformations by external force. If the upper and lower layers were deformed by external force, others forces could delivery to the strain gauges resulting in difficulty to measure pure shear force. Moreover, a guide structure for preventing a contact between the strain gauge and the upper plate was fixed on the lower plate. When a shear force was applied on the upper plate of the sensor, the strain gauges embedded on the middle plate were deformed and electronic signals occurred. Then shear force were calculated from such signals by the following formula;

$$F_\tau = 20607.4 \times E_\tau \quad (1),$$

Where F_τ is shear force and E_τ is output voltage of strain gauge. To derive this formula, shear forces using standard weights, 2, 4, 6, 8 and 13 N, were applied to the shear sensor, and then electronic signals of shear sensor corresponding to shear forces were measured. In sequence a correlation test was performed (R^2 = 0.999, p=0.000) and this formula was derived

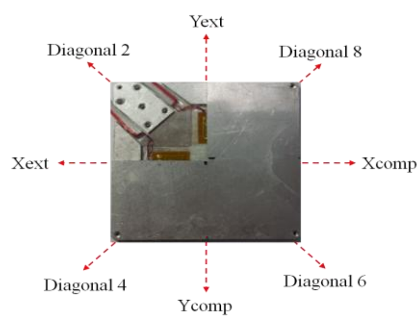

Figure 1: Direction of measurement of shear force, Xext: Tensile in the direction of the X axis, Xcomp: Tensile in the direction of the reverse X axis, Yext: Tensile in the direction of the Y axis, Ycomp: Tensile in the direction of the reverse Y axis, Diagonal 2, 4, 6, and 8: Tensile in the direction of the diagonal axis 2, 4, 6, and 8, respectively

Validation
We also designed a sensor test appliance for validate our sensor, which could load shear forces to the shear sensor at

eight directions concurrently (Fig. 1). In addition it can be used as calibration system before and after measurement of shear force by the shear sensor. The standard weights (2, 4, 6, 8, and 13 N), which were applied on the shear sensor that equivalent to shear force, were positioned on supporting hangers at eight directions (Fig. 2). Then shear force corresponding to each weight was repeatedly measured more than two times for each weight. A linear regression analysis was performed to evaluate the correlation between shear force applied and that measured by the shear sensor. Furthermore, to verify the accuracy and reliability of the shear sensor performed the Bland–Altman analysis.

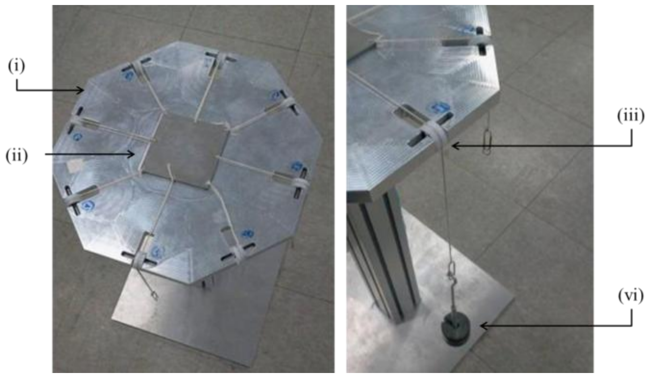

Figure 2: The validation and calibration apparatus (i) base plate (ii) sensor fixing unit (cover plate and lower fixing plate) (iii) pulley unit (wire and guide groove) (vi) standard weight

RESULTS AND DISCUSSION

The correlation between shear force applied and that measured by the shear sensor is shown in Table 1 over the wide operational range loaded by the standard weights (2, 4, 6, 8, and 13 N). Regardless of directions of shear force applied there were good agreements (R2 = 0.953~0.999). Furthermore, we confirmed the accuracy and precision of the shear sensor. All of the mean differences were relative closely 0 and were located within ±1.96SD regardless of measurement directions.

This paper demonstrated a novel strain-gauge-based low-cost sensor which is easier to fabricate it but more reliable for measuring shear force than others. The proposed shear sensor has advantages of some points. First, it has easy fabrication technique with relatively low-cost manufacturing materials. The material likewise aluminum of shear sensor was manufactured by simple metal cutter and hole saw, and fabricated by researcher's hand with metal adhesion. Second, since it has no fragile structures and bearing balls preventing from any contact to strain gauges, it can accept overpressure and independent from normal force in order to.

It would be noted that it was practical to measure the force with aimed operational shear range. This was because of that shear force was measured by the low range in the sit-in-bed position (Goossens et al., 1993). The same result would be produced in case of small movement on the chair or seat. The proposed shear sensor can be applied to measure shear force in variable circumstances. Such as shear force produced on the interfaces between human skin and exoskeletal robotic skin, wheelchair, prosthesis or bed. Especially, the proposed shear sensor can configure to measure all directions of shear forces

Table 1. Correlation between the applied shear force and measured shear force by the shear sensor

Tensile direction	R^2	p
Xext	0.999	0.000
Xcomp	0.999	0.000
Yext	0.998	0.000
Ycomp	0.999	0.000
Diagonal 2	0.953	0.000
Diagonal 4	0.995	0.000
Diagonal 6	0.995	0.000
Diagonal 8	0.996	0.000

generated to thereby provide a highly accurate data that can be used for designing contact surface between human and environment (car seat, chair, or bed, etc.) with a high degree of comfort or may help to reduce tissue damage in disabled individuals with wheelchair-bound or prosthesis-bound.

Further study with the wide operational range of the proposed shear sensor would require to improving the sensitivity, linearity and reproducibility. Some mechanical characteristic points (range of linear and non-linear, saturated force, etc.) could be measured testing all the components of shear force in X-axis and Y-axis with a displacement rate of very slow strain rate (e.g. 0.01 mm/min) using a universal testing machine, the microtest system (5848 series, Instron, Norwood, MA, USA).

REFERENCES

Bennett, L., Kavner, D., Lee, B.K., Trainor, F.A., 1979. Shear vs pressure as causative factors in skin blood flow occlusion. Arch. Phys. Med. Rehabil. 60, 309-314.

Bennett, L., Kavner, D., Lee, B.Y., Trainor, F.S., Lewis, J.M., 1984. Skin stress and blood flow in sitting paraplegic patients. Arch. Phys. Med. Rehabil. 65, 186-190.

Dinsdale, S.M., 1974. Decubitus ulcers: role of pressure and friction in causation. Arch. Phys. Med. Rehabil. 55, 147-152.

Goossens, R., Snijders, C., Holscher, T., Heerens, W., Holman, A., 1997. Shear stress measured on beds and wheelchairs. Scand J Rehabil Med 29, 131-136.

Goossens, R.H.M., Snijders, C.J., 1995. Design criteria for the reduction of shear forces in beds and seats. Journal of Biomechanics 28, 225-230.

Goossens, R.H.M., Snijders, C.J., Hoek van Dijke, G.A., den Ouden, A.H., 1993. A new instrument for the measurement of forces on beds and seats. Journal of Biomedical Engineering 15, 409-412.

Treves, F., 1884. TREATMENT OF PERFORATING ULCER OF THE FOOT. Lancet 124, 949.