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Technical note

Development of a shear measurement sensor for measuring forces at human–machine interfaces

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ABSTRACT

Measuring shear force is crucial for investigating the pathology and treatment of pressure ulcers. In this study, we introduced a bi-axial shear transducer based on strain gauges as a new shear sensor. The sensor consisted of aluminum and polyvinyl chloride plates placed between quadrangular aluminum plates. On the middle plate, two strain gauges were placed orthogonal to one another. The shear sensor (54 mm × 54 mm × 4.1 mm), which was validated by using standard weights, displayed high accuracy and precision (measurement range, −50 to 50 N; sensitivity, 0.3 N; linear relationship, $R^2 = 0.9625$; crosstalk error, 0.635% ± 0.031%; equipment variation, 4.183). The shear force on the interface between the human body and a stand-up wheelchair was measured during sitting or standing movements, using two mats (44.8 cm × 44.8 cm per mat) that consisted of 24 shear sensors. Shear forces on the sacrum and ischium were almost five times higher (15.5 N at last posture) than those on other sites (3.5 N on average) during experiments periods. In conclusion, the proposed shear sensor may be reliable and useful for measuring the shear force on human–machine interfaces.

1. Introduction

Shear force or stress on the skin surface is one of the pathological causes of pressure ulcers in the elderly and in patients with spinal cord injuries (SCI) or diabetes, and of soft tissue damage in patients that use a prosthesis or wheelchair [1–6]. The development of such ulcers and tissue damage can lead to severe complications such as amputation or even death. Therefore, analyses of shear force on the skin are important for investigating the pathology of pressure ulcers or soft tissue damage and for developing methods of treatment, prevention, or both.

To date, numerous attempts have been made to analyze shear force or stress. Gilsdorf [7] measured the shear force and normal force on the interface between a human and the seat of a wheelchair by using a piezoelectric-based force plate. However, this force plate was unable to measure the shear force on deformed seat surfaces because it consisted of a rigid plate. Novak used a capacitance-based sensor; however, this sensor had limitations, such as a large hysteresis during load reduction [8]. Sanders et al. developed strain-gauge-based transducers, each approximately 1.7 kg in weight (their dimensions were not described), which were plugged into a socketto measure the stress on the residual limb–prosthetic socket interface in three orthogonal directions, and then estimated the shear force [9]. However, measuring the shear force on the interface between a human and a machine, bed, or wheelchair seat was impossible because of the thickness of the transducers. Tappin et al. measured the shearing force on the sole of the foot by using a magneto-resistor [10]. This shear force transducer was small (15.96 mm diameter, 2.7 mm depth) and robust; however,

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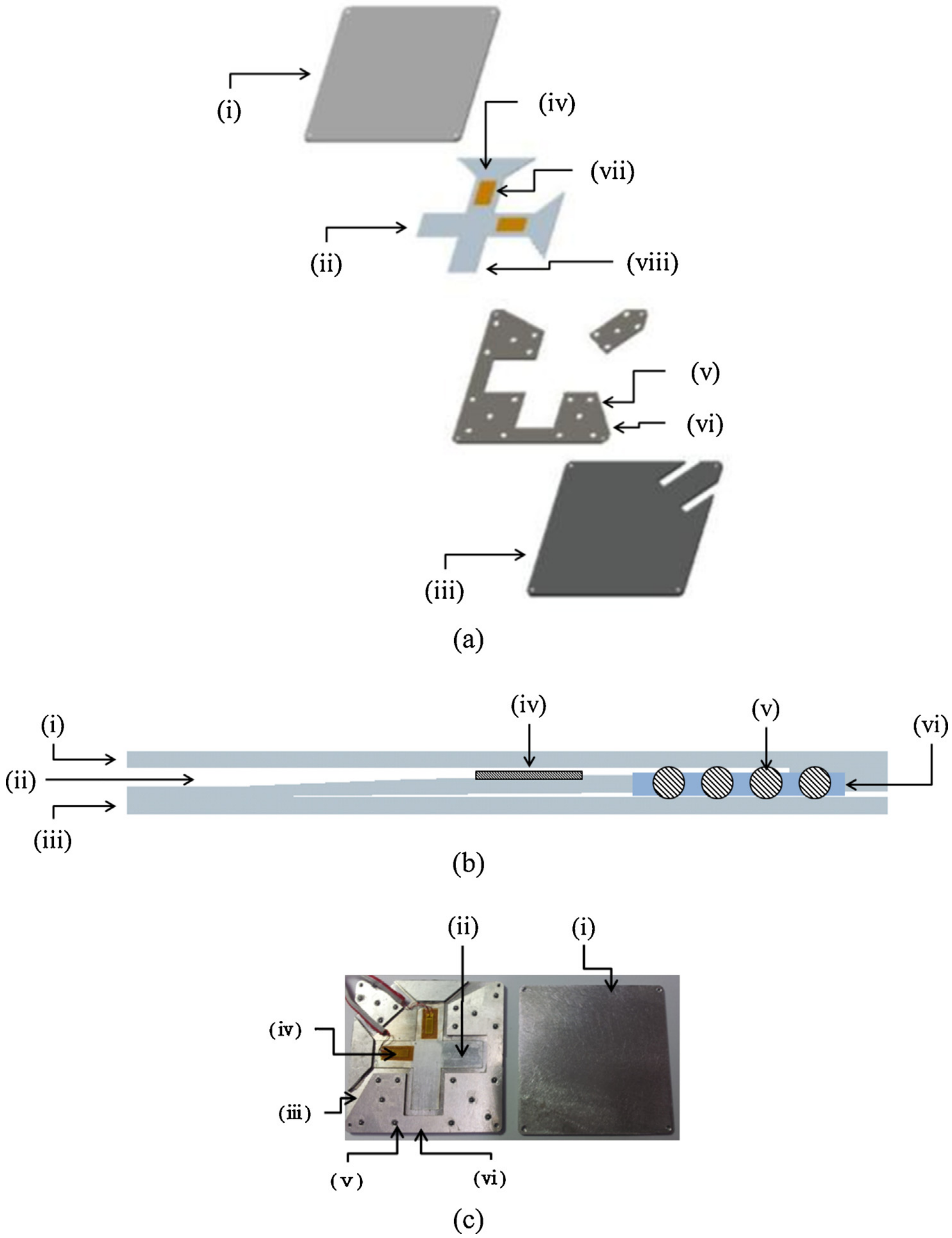

Fig. 1. Views of shear sensor. (a) Enlarged diagram, (b) side view, and (c) photograph of the fabricated sensor. (i) Upper plate, (ii) middle plate, (iii) lower plate, (iv) strain gauge, (v) ball bearing, and (vi) guide component, (vii) bridge, (viii) edge of the middle plate.

the magnet in the transducer could only slide in a single direction, and measuring shear forces in bi-axial directions at a specific point simultaneously was difficult. Lord et al. also measured shearing forces under the plantar surface of the foot in-shoe during walking with a sensor based on magneto-resistive principles [11]. The transducer, which was surrounded by a band of high-density material (also used across the metatarsal head) and consisted of a disk (16 mm diameter, 4 mm depth) and form inlay (6 mm depth), measured the shearing force in not only a single direction but also two orthogonal directions simultaneously. However, because of the transducer and band volume, although shear forces on a major pressure region are measured by a single sensor, measuring those on the entire contact area under the feet requires a matrix of sensors. In addition to these traditional methods, other methods for measuring shear force have been introduced: electromagnetic force measurement, piezoelectric circuits, and microelectromechanical systems (MEMSs) [12–14]. However, these methods also have several drawbacks including redundant transducer depths and a broad band for measuring a single point (electromagnetic technique); sophisticated procedures such as lithography for manufacturing with special and highly expensive instruments and facilities (piezoelectric and MEMS techniques); and narrow measurement ranges less than 5 N (MEMS technique). Recently, a sensor constructed of flexible plastic has been used to measure not only the shear force with a strain gauge but also the pressure with air displacement [15,16]. However, the normal force on a grid of strain gauges could cause great interference (crosstalk), e.g., almost 25% [14], and thus induce grid deformation with erroneous output. In this study, therefore, we proposed and validated a shear force measurement system based on strain gauges.