Exploring Kirigami Patterns for Soft Sensor Performance Enhancement: Toward Human Motion Sensing

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1 Introduction

Human motion detection has become popular in the field of medical robotics since it can be applied to a wide range of applications, such as medical treatment and virtual reality medical training. Recent studies have introduced different methods for employing various sensors to detect human motion. For example, in [1] they used standard sensors (like encoder and inertial measurement unit (IMU) sensors) for estimating human joint angles. However, these sensors can be uncomfortable for a subject when attached to their body since they are rigid and inflexible. Another method is to use a motion capture system [2]. While it does not disturb their and can provide accurate data on the subject's motion, it is expensive and requires a large setup space.

To overcome the aforementioned problems, soft sensors are an alternative solution. For example, soft/flexible tactile sensors were integrated into a loose piece of clothing, such as a coat or a blazer [3]. To improve sensitivity, sensing range, and robustness, a soft stretchable resistive strain sensor with a kirigami cutting pattern [4] was introduced. However, the kirigami cutting pattern has not been thoroughly investigated. Different kirigami patterns can lead to different mechanical properties, such as stiffness and deformability, which in turn can affect sensor performance. Therefore, in this study, we further investigate different kirigami cutting patterns applied to a synthetic conductive rubber to identify a proper cutting pattern for human motion sensing (Fig. 1).

2 Materials and Methods

For our investigation, we used a synthetic conductive rubber (EPT5074) as our soft/flexible sensor and applied different cutting kirigami patterns to it (Fig. 1(b)). The rubber basically functions as a variable resistor, with its resistance changing as it is stretched. Four different models were used: one original without cutting (M0) and three different kirigami cutting patterns including a pattern with large cuts (M1), a pattern with small cuts (M2), and a pattern with very small cuts (M3) (Fig. 1 (b)).

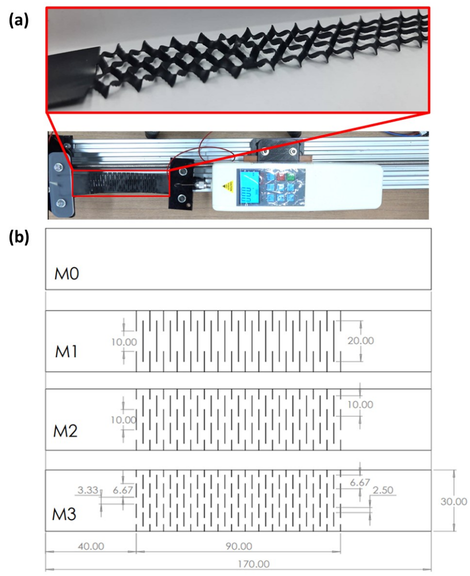

Figure 1: (a) Experimental setup and an example of kirigami pattern change during pulling. (b) Different models (conductive rubber without and with kirigami cutting patterns). All cutting patterns were achieved by using a laser cutting machine with a speed of 9.16 rev/min.

We evaluated each model's performance by pulling and releasing it using a one-dimensional ball screw linear slide guide controlled by a Dynamixel motor (XM430-W350-R). The pulling force was precisely monitored and controlled via a digital force gauge (HF-50) (Fig. 1(a)). A voltage divider circuit with a 47k ohm resistor (voltage output) was built to measure the model response. An Arduino board was used to transmit the voltage output to a computer, then recorded the data through a serial connection.

3 Experiments and Results

The four models were slowly pulled and released where an applied force was varied from 0 N to 2 N and returned to 0 N. The result is shown in Fig. 2. As can be observed, the non-kirigami patterned model (M0) had no significant response, whereas the kirigami patterned models (M1, M2, M3) exhibited significant responses at different operating (pulling) ranges (around 37-225 mm for M1, around 30-90 mm for M2, and around 62-80 mm for M3 as shown by the yellow highlight in Fig. 2). This suggests that kirigami can enhance sensor sensitivity and each kirigami pattern has a unique effective operating range. M1 has the highest sensitivity, while M2 and M3 have the medium and smallest, respectively. Furthermore, when comparing the pulling (yellow highlight) and releasing (green highlight) results, each model has different operating ranges, which might be caused by the cutting pattern and material properties.

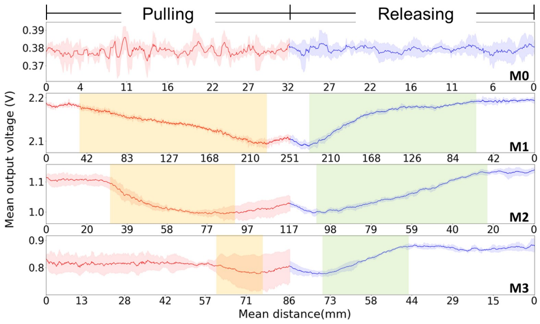

Figure 2: Conductive rubber behavior of each model during the pulling and releasing test.

From this point, for full-body human motion sensing, the soft sensors with different kirigami patterns should be applied to different body parts according to the movement ranges. By choosing the appropriate kirigami patterns for specific body parts, one can ensure that the soft sensors accurately capture the movements of the corresponding parts and provide reliable data for analysis. For instance, the M2 model is suitable for detecting wrist motion with a medium range (Fig. 3). It can distinguish different wrist movements, including flexion (Fig. 3(a)), straight (Fig. 3(b)), and extension (Fig. 3(c)). During wrist flexion, the sensor generated the lowest output signal. The signal was higher during wrist straightening and became highest during wrist extension (Fig. 3(d)).

4 Conclusion

This study investigates different kirigami cutting patterns on a soft conductive rubber sensor. Thanks to the cutting pattern, the sensor can be transformed from 2D to 3D profiles and easily stretched (Fig. 1). This reduces sensor resistance; thereby increasing sensor sensitivity and improving its operating range. Different patterns can be defined and are sensitive to different operating ranges; as such, they can be applied to detect different joint movement ranges. Due to the sensor's soft/flexible nature, it can be attached to a full-body suit without interfering with user comfort for full-body motion sensing (Fig. 3(e)).

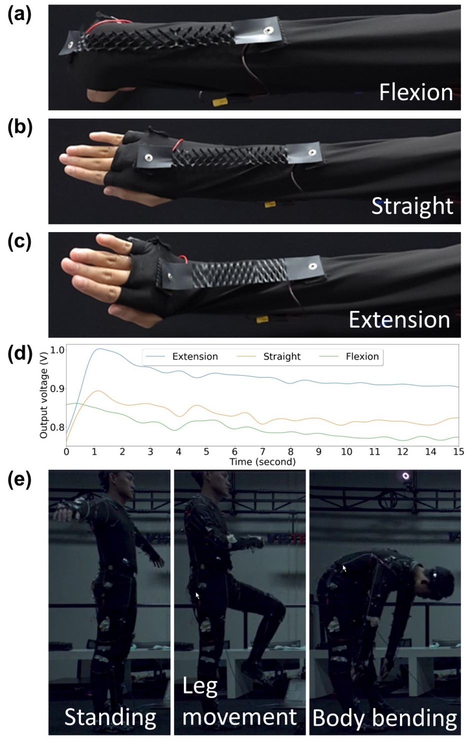

Figure 3: Different wrist movements detected by the soft sensor with a kirigami cutting pattern. The sensor is attached to a long sleeve suit. (a) Wrist flexion. (b) Wrist straight. (c) Wrist extension. (d) Sensor output signal at different wrist movements. (e) Implementing the sensors on a full-body suit with a preliminary test for human motion sensing (see https://manoonpong.com/AMAM2023/ks/video.mp4).

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