RSJ2010AC1K3-6

Development of a Sensor Using Electro-conductive Yarns in Recognition of Human Rubbing Action

*VAN ANH HO (立命館大学), 近藤　大介 (立命館大学), 岡田　志麻 (立命館大学), 牧川　方昭 (立命館大学),
荒木　隆宏 (岡本株式会社), 藤田　恵美 (岡本株式会社), 平井　慎一 (立命館大学)

Abstract—We have developed a slip sensor which is knitted by tension-sensitive conductive yarns. Because the yarn is only sensitive with lateral deformations, a special way to knit these yarns has been proposed. To do so, this sensor is both sensitive to normal and tangential pressure which is troublesome for detecting incipient slips on the surface on the sensor. Therefore, DWT (Discrete Wavelet Transform) method is employed to distinguish the slip and the change of normal force. Finally, an experiment to detect the rubbing action of human finger on the surface of the sensor is constructed to show the potential of the system.

Key Words: Slip sensor, electro-conductive yarn, rubbing action, differentiation, DWT.

1. Introduction

Touch is a common but important action of everyday life. It permits us to accurately determine the surface properties and other properties of an object, including its weight and shape, facilitating grasping tasks, as well as to determine many functions of the motor system. Until the 1970s, however, research on touching was limited to psychophysical studies. Since neural mechanisms underlying tactile sensation have been found to be critical to the success of adept manipulations [1], recent robotics research on dexterous manipulation has sought to imitate the natural touch mechanism, as well as the anatomy of human fingers to optimize the ideal anthropomorphic artificial hand. Among the factors constituting an artificial hand, tactile perception is the most important. Without tactile feedback, failures in adept manipulation can occur, both to humans and robots. A sensory system must provide information about contact force, friction, and roughness, all of which are helpful for identifying objects. Moreover, during stable grasping, a sensory system must be able to recognize incipient and overt slips between the touching system and the object. Recently, therefore, research in tactile sensor design and development has increased considerably. Engel *et al* [3] developed an integrated flexible tactile sensing skin that was sensitive not only to common surface characteristics such as frictional force and roughness, but also to thermal conductivity, hardness, and temperature. To our knowledge, however, these sensors have not been utilized in robotics manipulations, including incipient slip detection. Beccai *et al.* [4] fabricated a tactile sensing skin using miniaturized silicon-based sensors that could detect three components of external force. A joystick-like mesa was attached to a sensor base to transfer external force. It was afterward embedded under a polyurethane skin to form a soft, compliant, tactile micro sensor. This system was shown experimentally to be sufficient in detecting incipient slip transition because the sensor was embedded right under the elastomeric skin, which in turn is highly sensitive to the disturbance and danger of fragileness. The mesa is easily broken at high loads, when the tactile systems grasp a sufficiently heavy object. A similar design of tactile sensor, conducted by Boissieu *et al* [5], performed ability to sense the structure of fabric or to differentiate papers by using supervised classification methods. Recently, Teshigawara *et al* [6] developed a high sensitivity slip sensor including a pressure conductive rubber. By using advanced data processing methods, the authors demonstrated promising results of detection of incipient slip.

In this paper, we introduce the construction of a slip sensor which is knitted by electro-conductive yarns; and data processing methods to detect the incipient slips on the surface of this sensor. This sensor is simple in design, sensitive in slip detection, and durable in operation regardless to change of experimental environments.

2. Construction of The Slip Sensor

2·1 Tension-Sensitive Electro-Conductive Yarn

An electro-conductive yarn is a mixture of polyester fibers, and stainless steel fibers which hold high electro-conductivity (Fig. 1). This yarn is tension-sensitive in a way that when a tension force is applied to the yarn, it is deformed laterally thanks to elasticity of polyester fiber. This causes the number of contact points of electro-conducive elements change, leading to the change of total resistance of electro-conductive elements, also the yarn. In detail, when pulling the yarn with high tension force, the density of electro-conductive elements increases, causing the fall of the resistance. On the other hand, if the tension force is smaller, the density of electro-conductive elements decreases, the resistance rises up. An experiment was set up to measure the change of resistance of one yarn which was hauled by increasing tensile forces. Fig. 2 shows the resistance-load relationship of the tensile experiment. Two distinguishing phases were recorded, including linear and saturation ones. The linear phase, in which the resistance of the yarn changes significantly when the load increases, only happens in a small range of load [0 through 30 g]. Over this value, the saturation phase occupies causing the stable value of resistance even at high load. To increase the linear range, a double coupling structure is employed. Around one elastic core

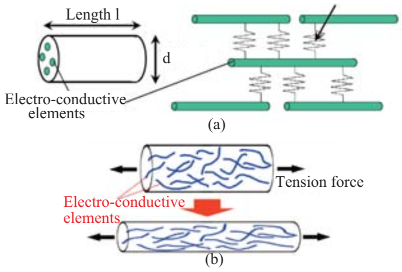

Fig.1 Model of a a tension-sensitive electro-conductive yarn.

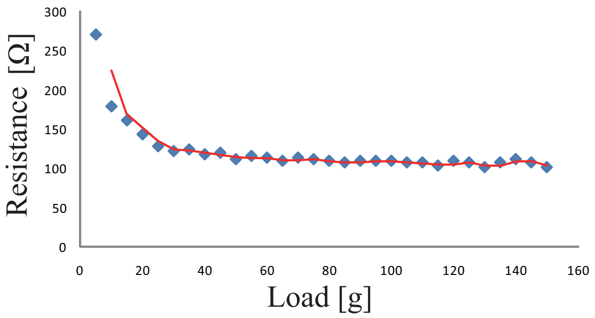

Fig.2 Relation of resistance and load in the tensile experiment, and its fitting curve.

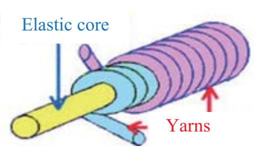

Fig.3 Yarn with double coupling structure.

made from polyurethane rubber, two yarn are winded, one over the other and in the opposite directions to get rid of the twists of these yarns themselves (Fig. 3). By doing so, the elasticity and the tensile ability of the yarn increases remarkably. The linear range is widen up 20 % of tensile strain. More information can be found in [7].

2·2 Slip Sensor

To form a fabric sensor which can detect the slip on its surface, we knitted the double coupling conductive yarns (as warps) mentioned above on the basal yarns (as wefts) which are not tension-sensitive or conductive. However, if we employed the knitting method used in fabrication of normal T-shirt or similar products in which the surface of the fabric is flat and smooth, tension strain of yarns caused by traction stress on the surface is small, resulting insufficient output change of resistance. Therefore, to enhance the tension strain of the sensor, yarns are weaved to form the so called *pile cloth*, which means each yarn has many continuous loops coming up on the surface called *piles*. Fig. 4 shows a complete fabric slip sensor with 5.0 cm in length and 3.5 cm in width. The length of each pile on the surface is about 1.0 mm. These piles take important role in detect traction on the contact surface of the sensor.

3. Slip Experiment

3·1 System Overview

The configuration of the sensor's data acquisition is fairly simple. All heads, which are not weaved, of warps (*i.e.* conductive yarns) on one side are connected by a metal clamper to form one electrode pole for the sensor. The other pole is formed in the similar way. To measure the output of the sensor, one pole is connected to a 5 V DC power supply through a 1 kΩ. This forms a simple potentiometer circuit. The voltage V_t changes when the resistance of the sensor varies, and is directed to an ADC (Analog to Digital Converter). This signal is read and processed by a PC through a Microsoft Visual C++ data acquisition program with sampling time of 1 KHz.

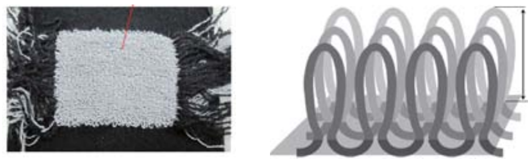

Fig.4 Slip sensor with piles shaping the surface.

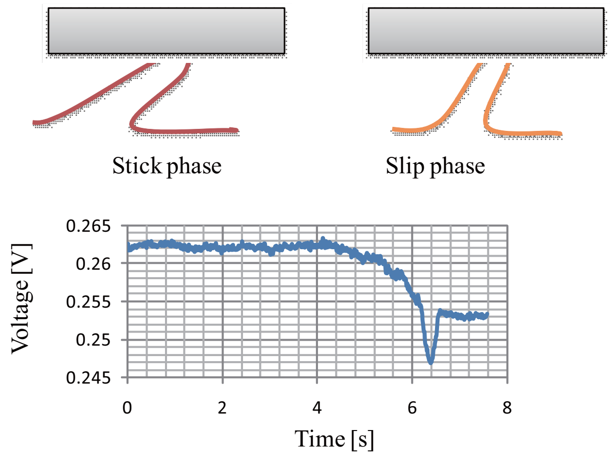

Fig.5 Slip detection principle.

3·2 Principle of Slip Detection

As this sensor is actually a pieces of cloth, it is flexible and compliant to any attached object, taking the role as a *skin*. By using the sensor, the slip of the object over outside environment can be perceived with the principle illustrated in Fig. 5(a). Assuming that there is an object of outside environment about to slide on the surface of the object. At the beginning, the object sticks to the surface, *i.e.* piles, causing piles to be stretched. The stickier the contact is, the more piles stretch; resulting the overall resistance of the sensor falls based on the principle reported above. When the object starts to slide relatively over the surface of the sensor, piles are less tensile, resulting the resistance of the sensor rises up.

Figure 5(b) shows the output of the sensor in one slip trial of one object on the surface of the sensor. We can observe the sudden change of the output when the object has its incipient slip on the contact surface. When the objects slides, piles keep their deformed shapes, resulting smaller value of the output of the sensor compared to the initial state. In short, by observing the change of the resistance of the sensor, we can judge the states of slide of the object over the surface of the sensor.

4. Data Processing Methods to Detect the Slip

The slip between an object and the sensor depends on many factors, such as loading force, friction coefficient, speed of slide, *etc*. Moreover, the output of the sensor is not always stable due to characteristic of cloth. Therefore, if the judgment of slip only bases on the changes of the output, it will cause the ambiguity for the controller. For example, with rubbing action of human finger on the surface of the sensor, *i.e.* changing the direction of slip continuously and periodically, the output changes continually but unclearly (the blue plot in the graph of Fig. 6). As a result, it is necessary to use some techniques to assure the judgments.

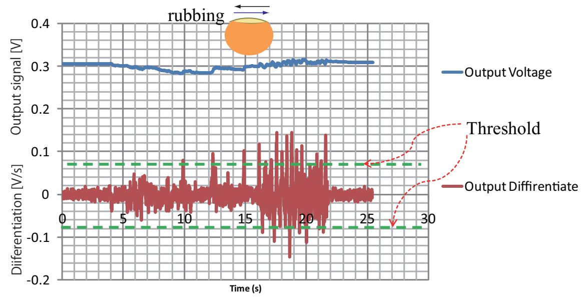

Fig.6 Output of the sensor and its differentiation during rubbing action.

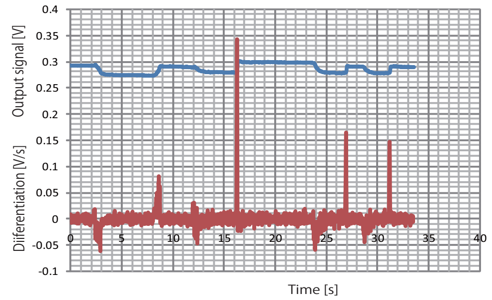

Fig.7 Output of the sensor and its differentiation during load/unload action.

4·1 Differentiation Method

Let u_i and u_{i-1} be discrete output voltage value of the sensor at moment t and $(t - \Delta t)$, respectively, with Δt being sampling time. Therefore, the differentiation of the output at moment t, say d_i, is calculated as:

$$d_i = \frac{u_i - u_{i-1}}{\Delta t}. \tag{1}$$

This can be considered as stress rate of the shear traction over the surface of the sensor. By using this processed signal, sudden change of the output voltage of the sensor can be perceived easily via peaks. As we can see from the graph of Fig. 6, whenever the human finger reserves the slide direction, means the incipient slip between the finger and the surface of the sensor occurs, there is an corresponding peak appears in the stress rate d of the output voltage. The higher the speed of the incipient slip is, the higher the peak is. Therefore, if we can choose a suitable absolute value of threshold, the slip detection can be judged if value of d is over the threshold absolutely.

We conducted an experiment in which some innocent subjects were asked to rub their fingers freely on the surface of the sensor. They were not taught how to rub it, for example loading stress or rubbing speed. A Microsoft Visual C++ program was used to process the output voltage of the sensor using differentiation method, judge whenever the slip happened, and displayed in real time on the computer screen by turning on/off an digital indicator. The operation of each object was filmed and investigated after each trial. The rate between the number of slips detected by the program and that of one object is averagely 78 %. By interviewing and analyzing movement of each object's finger after the experiment, we realized that the sensor is more sensitive with action with fairly high speed of rubbing, and the loading stress which is rather high. It is specially insensitive with the action with very high loading stress or very low speed of slide. The reason comes from the quite small range of linearity of the sensor, and the ambiguity of the controller between loading state and slip state. As shown in Fig. 7 with upper plot recording the output voltage of the sensor during load and loading test, and the lower one drawing its differentiation, peaks are still assessed during this experiment even without any slip. High peaks are observed at high rate of loading and unloading steps, causing the controller to misjudge the slip detection. Therefore, with the rubbing action in which the load changes suddenly, it is inefficient if only using this processing method. Consequently, the differentiation method is an efficient method to detect fast slips with constant load. Moreover, this method can be implemented easily in the program in real time, offering high chance in real applications. However, with load changes remarkably during slip action, it needs to employ method to distinguish slip and loading/unloading states.

4·2 Discrete Wavelet Transform (DWT) Method

As aforementioned, it is necessary to discriminate load/unload states and slip state in which trends of the signal are similar (downfall/uprise). At those states, it is believed that there exist distinguishing high frequency components ([6]). However, the Fourier transform, which performs well spectrum in frequency domain, can not reveal where exactly (in time domain) it happens. In the other way, one of major advantage of wavelets is an ability to perform analysis of localized/small area of a large signal, in which the Fourier transform can not show. Wavelet analysis can extract information of discontinuities, breakdown points, trends, *etc*. Therefore, it is efficient to employ this method to solve the above problem. In this work, we use discrete wavelet transform (DWT) to obtain more efficient (fast) and accurate analysis. By using DWT, the original signal is passed through two complementary filters (low-pass and high-pass filters) and then emerged into two signals. One signal is called *approximation* which is the high-sale, low-frequency component of the original signal. The other one called *detail* which is low-scale, high-frequency component over time domain. As a result, by using this method, we can perceive both low-pass filtered signal, and especially high-pass filtered signal showing which frequency dominates at one specific time.

In Fig. 8, from top to down, there are graphs of original signal, approximation signal, and detail signal, respectively; during the loading/unloading test. At the moment of load/unload, there are unremarkable changes at the output of detail signal which are recorded with the values smaller than 0.0008 V. In the other hand, when the slip happens, there is a significant fluctuation at the output of detail signal, with amplitude around 0.0015 V (Fig. 9). As a result, at the moment of slip, there exists much higher frequency component than that of load/unload states. By setting the proper threshold as mentioned in the above section of differentiation method, the controller can easily discriminate two ambiguous states of load/unload and slip, as well as judge the slip detection. Fig. 10 demonstrates the DWT during the simultaneously loading, and rubbing test. Results show that, it is possible to discriminate those states. By employing DWT method, we

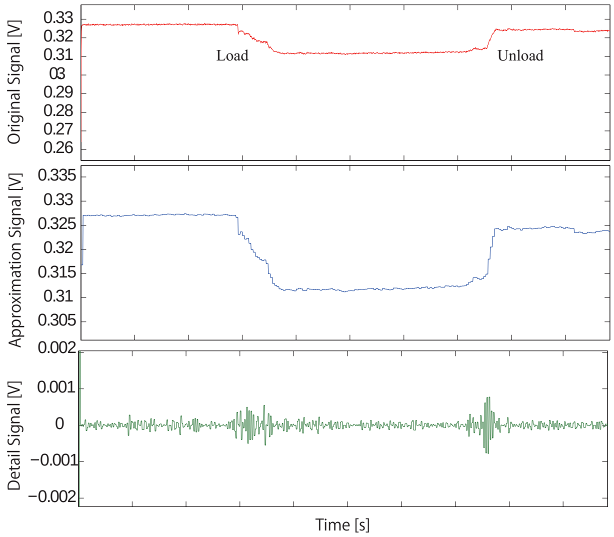

Fig.8 Output of the sensor and DWT signals during load/unload test.

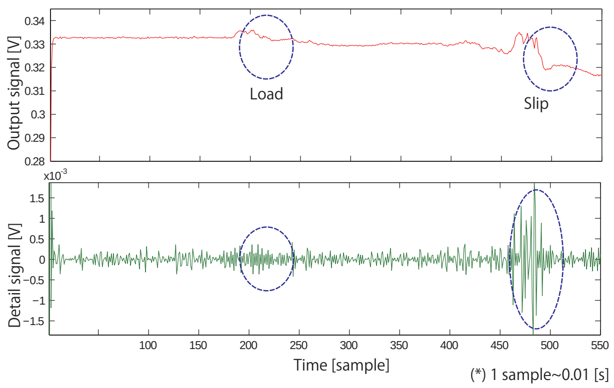

Fig.9 DWT signal of one loading and sliding test.

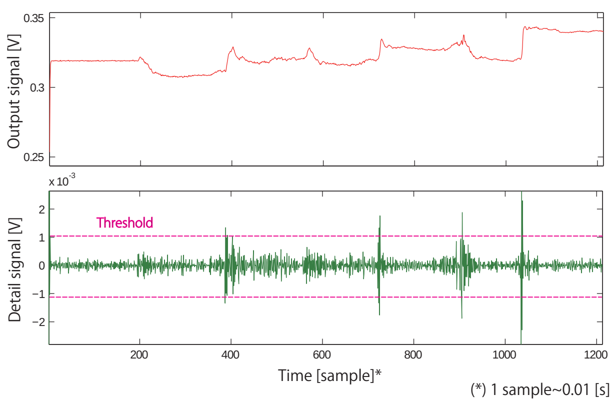

Fig.10 DWT signal during rubbing action.

conducted the experiments as mentioned in the above section, in which the objects were asked again to rub their fingers on the sensor. This time, the successful rate increased from 78 % to 91 %.

In summary, DWT method is an efficient tool not only to filter the signal, but also to extract high-frequency elements over time domain. This assists the system to distinguish between load/unload and slip states during rubbing test. However, this method takes a remarkable amount of calculations and memories to implement in realtime. This requires a further effort to optimize code and calculation time to apply this system in real applications.

5. Conclusion

We have introduced our primary research on development of low-cost, simple but highly sensitive slip sensor, by utilizing tension-sensitive characteristic of electro-conductive yarn. In addition, data processing methods have been applied to optimize the judgment of incipient slip. Promising results show the potential chance to apply this sensor into robotic dexterous grasp in the future. This sensor is flexible, and compliant; thus it can be attached to any object with complex shape such as robotic fingers, robotic skin.

Reference

[1] J. W. Morley, *Neural Apects of Tactile Sensation*, Amsterdam, The Netherlands:Elsevier, 1998.

[2] Y. Mukaibo, H. Shirado, M. Konyo, and T. Maeno, *Development of a Texture Sensor Emulating the Tissue Structure and Perceptual Mechanism of Human Fingers*, Proc. IEEE Int. Conf. on Robotics and Automation, vol. 1, pp. 2565-2570, April 2005.

[3] J. Engel, J. Chen, X. Wang, Z. Fan, C. Liu, D. Jones, *Technology Development of Integrated Multi-modal And Flexible Tactile Skin For Robotics Applications*, Proc. IEEE/RSJ Int. Conf. on Robotics System, vol. 3, pp. 2359-2364, Oct., 2003.

[4] L. Beccai, S. Roccella, L. Ascari, P. Vandastri, A. Sieber, M. C. Carrozza, P. Dario, *Development and Experimental Analysis of a Soft Compliant Tactile Microsensor for Anthropormorphic Artificial Hand*, IEEE Transaction on Mechatronics, vol. 13, no. 13, April 2008.

[5] F. de Boissieu et al, *Tactile Texture Recognition with a 3-Axial Force. MEMS integrated Artificial Finger*, www.roboticsproceedings.org/rss05/p7.pdf

[6] S. Teshigawara, K. Tadakuma, A. Ming, M. Ishikawa, and M. Shimojo, *High Sensitivity Initial Slip Sensor for Dexterous Grasp*, Proc. IEEE Int. Conf. on Robotics and Automation, pp. 4867-4872, May 2010.

[7] K. Kidono, H. Seki, N. Kuroda, Y. Kamiya, M. Hikizu, *Static Characteristic of Tension-Sensitive Conductive Yarn*, (in Japanese).