HumTouch: Finger gesture recognition on hydrogel-painted paper using hum-driven signals

Kyoichi Tachi, Shogo Okamoto, Yasuhiro Akiyama, and Yoji Yamada
Department of Mechanical Systems Engineering, Nagoya University, Nagoya, Japan

***Abstract*—We propose a passive touch sensor that can be implemented on semi-conductive materials, such as paper. This sensor detects electric currents leaked from a human body when touched with bare fingers. Such electric currents are mostly produced by AC power lines in the environment. We tested the potential of the sensor for gesture recognition by using a paper sheet painted with a hydrogel ink. A gesture classification algorithm combining the k-means method and Mahalanobis' generalized distance could successfully classify 90% of the gestures drawn on the paper with a fingertip. Gestures including multi-directional lines and circles were nearly perfectly classified whereas digits, such as 2 and 8 exhibited difficulties with classification. The hydrogel ink can turn other non-conductive materials comprising woods and plastic into touch sensors, and such hum-based touch sensors are expected to find practical applications in gesture recognition.**

***Index Terms*—Hum noise, touch sensor, gesture**

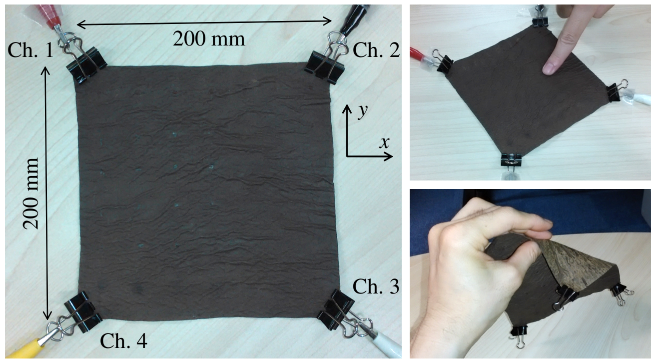

Fig. 1. Paper after being painted with hydrogel ink. Each of the four electrodes was connected to an oscilloscope. Top right: Touch with a bare finger. Bottom right: Dry and flexible semi-conductive paper.

I. Introduction

Most commercially popular touch sensing devices detect capacitive or resistive changes of surfaces when they are touched by humans. Although these principles are used for specific or designed surfaces, camera-based or force-sensing-based methods [1] are potentially used for turning any surface into a touch sensing medium. Nonetheless, they require structured environments and camera-based interfaces suffer from occlusion problems. Unlike these touch sensing techniques, hum-based touch sensors [2], [3] can be implemented on semi-conductive materials, such as stone and paper that commonly exist in our living spaces without large modification of environments. When a human touches a semi-conductive surface, a current in the human body caused by the electromagnetic field of AC power lines in the environment flows on the surface. It is then detected by an electrode placed on the surface. Hence, this sensor is a passive-type sensor and does not apply any energy to object surfaces. In addition, by using multiple electrodes placed on the surface, the touch position can be localized [4].

When using a hum-based touch sensor on a large area surface, applications involving gesture recognition can be realized. However, localization of the contact point using a hum-based touch sensor is not precise due to the environmental electromagnetic noises and non-uniformity of the material properties of the surface. Therefore, it is necessary to evaluate the gesture identification abilities of a hum-based touch sensor. In this study, we verified the feasibility of gesture recognition using a paper and hum-touch sensing method. This was achieved through the identification of one-stroke gestures that are frequently used for gesture interfaces by using a conventional gesture classification algorithm.

This study was in part supported by the Mazda Foundation.

II. Material and Apparatus

A. Paper with hydrogel ink

We used a paper towel of 20 $\times$ 20 cm that was soaked into a polymer ink and dried. The formulation and constitution of the ink were chosen according to [5]. The same ink can turn other non-conductive materials such as woods and plastics into touch-sensitive surfaces. Although we used the paper in the present study, similar gesture performances are expected for woods and plastics.

B. Signal measurement

We placed four electrodes, one at each corner of the paper towel, as shown in Fig. 1, and measured the voltages detected using an oscilloscope. The measured voltage amplitudes changed according to the distance between the finger and electrodes [4] and the signal frequency was 60 Hz, which is equal to that of the AC power supply. We refer to these amplitude envelopes detected at the four electrode channels as $v_i(t)$ $(i = 1, 2, 3, 4)$, as shown in Fig. 2.

III. Experiment

We recorded the voltage outputs from the four electrodes when seven types of gestures were drawn with a fingertip on the paper. The gestures comprised circles (CW, CCW), a vertical line from top to bottom, horizontal line from left to right, diagonal line from top left to bottom right, and Arabic numerals: 2 and 8. If straight line gestures in one direction

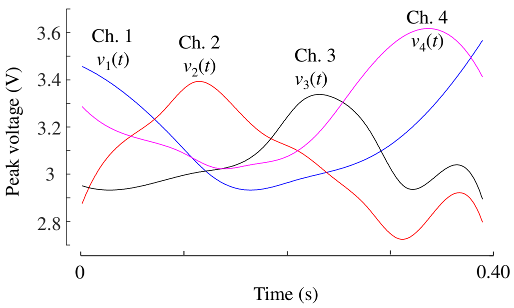

Fig. 2. Envelopes of 60-Hz voltages recorded at four electrodes on the paper when a circle was drawn.

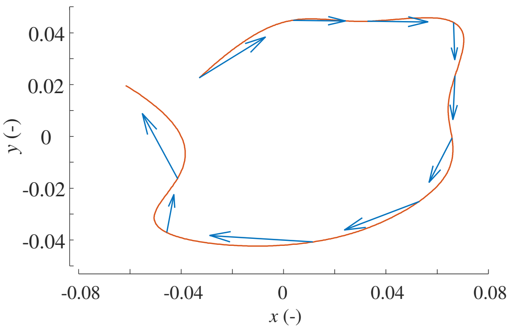

Fig. 3. Velocity vectors on the dimensionless and deformed Cartesian space when a circle was drawn. Red curve is the trajectory of the circle.

can be identified, those in the opposite direction can be also identified using the same algorithm. Hence, in order to avoid an apparent increase in the classification rate, we measured these gestures in only one direction. The most complex one-stroke gestures tested for were Arabic numerals because more complex gestures are unlikely to be used in practice. Each gesture was drawn 20 times by using a bare finger in an office environment; however, a few trials were judged invalid and were not used for the latter analysis. In these invalid trials, the one-stroke gesture was failed and the finger was not continuously in touch with the paper during drawing.

IV. Gesture Classification Algorithm

A. *Calculation of velocity vectors of gesture*

We converted $v_i(t)$ to dimensionless Cartesian coordinates by using following equations:

$$x = \frac{v_2 + v_3 - v_1 - v_4}{\Sigma v_i} \quad (1)$$

$$y = \frac{v_1 + v_2 - v_3 - v_4}{\Sigma v_i}. \quad (2)$$

The trajectory of a gesture was then acquired, as shown in Fig. 3. The red line is the trajectory in the dimensionless coordinate space when a circular gesture was drawn; however, as mentioned earlier, it is distorted due to the characteristics of the hum-based touch sensor. We calculated velocity vectors at each of the ten points that equally divide the trajectory in terms of time intervals.

TABLE I
Correct Gesture Classification Rates

Type of gesture	Recognition rates
Circle (CW)	18/20
Circle (CCW)	19/20
Vertical line	19/20
Horizontal line	19/19
Diagonal line	19/19
Number 2	15/19
Number 8	14/20
Total	123/137

B. *Algorithm and parameters used for classification*

We used four parameters for classification of gestures: mean velocities along x and y axes and two types of sums of differential arguments. The latter two parameters were computed by

$$\sum_{j=1}^{9} \angle(\boldsymbol{a}_{j+1} - \boldsymbol{a}_j) \quad (3)$$

$$\sum_{j=1}^{9} \angle(|\boldsymbol{a}_{j+1} - \boldsymbol{a}_j|) \quad (4)$$

where $\boldsymbol{a}_i$ is the i-th velocity vector among the ten vectors computed for each gesture. The first equation sums up the difference between two neighboring velocity vectors whereas the second equation sums up the absolute difference.

We used the k-means method with Mahalanobis' generalized distances to classify the gestures, each of which is defined by a combination of four-parameters. The centroid of each of the seven types of gestures was allocated on the four-parameter space. Then, when a new gesture was acquired, it was classified as the nearest gesture in terms of Mahalanobis' generalized distance.

V. Results

Table I shows the ratios of correct gesture recognition by a leave-one-out cross validation. The mean correct recognition rate was approximately 90%. The rates for Arabic digits (2 and 8) were remarkably low.

Potential causes of miss-classification include distortion of the gesture trajectory on the dimensionless coordinates. Especially when the finger touches near the electrode, the coordinates computed using (1) and (2) nonlinearly correspond to the physical coordinates on the paper. Such problems can be solved by application of a nonlinear coordinate transform as a preprocessing before the use of linear classification algorithms. In addition, we only used four types of parameters for classification; a greater number of parameters would lead to more successful classification.

VI. Conclusions

In this study, we verified the feasibility of gesture recognition using a hum-based touch sensing technique. Simple gestures, such as lines and circles drawn on a hydrogel-painted paper were classified at approximately 95% whereas digits of

2 and 8 were classified at approximately 70%. By adopting appropriate classification algorithms and feature parameters, the hum-based touch sensing technique can be employed in practical application.

REFERENCES

[1] T. Tsuji, N. Kurita, and S. Sakaino, “Development of a desk-type tactile interface using force sensors,” in *Proceedings of IEEE International Conference on Industrial Electronics, Control and Instrumentation*, 2014, pp. 5248–5253.

[2] H. Elfekey, H. A. Bastawrous, and S. Okamoto, “A touch sensing technique using the human body extremely low frequency fields,” *Sensors*, vol. 16, no. 12, p. 2049, 2016.

[3] H. Elfekey and S. Okamoto, *Turning surfaces into touch panels: A Granite-touch pad*, ser. Lecture Notes in Electrical Engineering. Springer, 2016, vol. 432, pp. 301–304.

[4] H. Elfekey, S. Okamoto, and Y. Yamada, “Localization of touch on granite based on ac hum noise,” in *Proceedings of IEEE Global Conference on Consumer Electronics*, 2017, pp. 1–2.

[5] K. Ramamohan, V. B. S. Achari, A. K. Sharma, and L. Xiuyang, “Electrical and structural characterization of PVA/PEG polymer blend electrolyte films doped with $NaClO_4$,” *Ionics*, vol. 21, pp. 1333–1340, 2015.