HumTouch: Kernel Regression-based Localization of Touch on a Paper

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***Abstract*—Herein, we propose a method for localizing touch on semi-conductive materials such as paper. For this purpose, we use the principle of HumTouch, wherein hum-originated signals in the human body leak through the touched surface and are detected by electrodes on the surface of the material, to turn the surfaces of everyday objects into touch-sensitive surfaces. We employ four electrodes and a 19 $\times$ 16 cm square sheet of paper with hydrogel ink as the representative material. In addition, to rectify the distortion of the signals detected at each electrode, kernel regression analysis is used. The actual locations where the paper is touched and the detected signals are non-linearly linked, and its performance is tested by leave-one-out cross validation. The mean error of the predicted locations is 0.88 cm, which is smaller than the size of the human finger pad. This shows that the proposed method has the potential for practical applications with regard to the localization of touch.**

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

I. Introduction

The advancement of touch sensors can provide a more direct way for humans to use computer interfaces. Although it has been widely used in commercial products such as cellphones and laptops, HumTouch [1], [2] can be used to provide a brand new application for touch sensing techniques by turning objects in daily environments into touch-sensitive surfaces. The AC power lines in buildings can generate 50/60 Hz electric signals in human bodies, which are conductive, owing to the presence of internal minerals and salts. When a bare finger touches a conductive or semi-conductive material, a current flows from the human body to the surface of the material. By detecting this signal via electrodes attached on the surface, the recognition of the occurrence of touch events [1] and finger gestures [2] can be achieved. The HumTouch technique is a passive method that does not apply any energy on the surface; hence, it can be applied to a large surface area without the concern of energy consumption.

In previous research, the HumTouch technique was used for making a keyboard [1]. Furthermore, it was demonstrated that this technique can be applied to semi-conductive materials such as paper by using hydrogel ink and is successful at recognizing gestures [2]. By placing multiple electrodes on the surface of the material, it is possible to localize touch on the surface; however, because of the impedance properties of the material, the use of a simple localization method will lead to inaccurate localization [3], [4].

One quick solution to improve the localization accuracy is to increase the number of electrodes on the surface of the material [3]. However, in this study, nonlinear localization correction is applied, and its effectiveness is investigated. With such a localization method, the HumTouch technique is expected to function well even with a small number of electrodes, leading to the cost-effective and accurate touch sensors based on hum.

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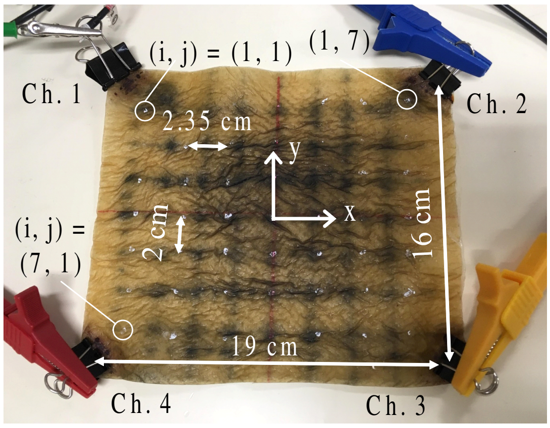

Fig. 1. The semi-conductive wiping paper with four electrodes. The surface was marked with 7×7 grid points. The distances between neighboring points were 20 mm and 23.75 mm along the x and y-axes, respectively. The points are specified by a pair of row and column indices (i, j).

II. Materials, apparatuses, and experiments

We used a 16 $\times$ 19 cm wiping paper that was soaked into a semi-conductive hydrogel paint and completely dried. This material was also used in [2], in which the compounds in the hydrogel paint are described. An oscilloscope (HS6 DIFF, TiePie Engineering, Netherlands) was used to record the voltages at the four electrodes, each of which was attached to each corner of the paper as shown in Fig. 1. We applied a low-pass filter with the cut-off frequency of 100 Hz to the signals and recorded the maximum magnitude that occurred at each channel during the finger–material contact period of 1 s as v_i. The range of v_i recoreded ranged approximately 6–0.7 V. It should be noted that in principle, it is sufficient to record half a signal cycle, i.e., 8–10 ms to determine the maximum voltage value. However, such a period is too short to ensure complete contact between the fingertip and the material, and the minimally required recording period is still unknown. In the present study, to avoid such a discussion, we recorded the signals for a longer period.

Seven by seven grids were drawn on the paper to form 49 points. Each of these points were statically touched by a man using his index finger for 1 s in a single set; this was repeated seven times to obtain seven sets in total. The contact forces were not restricted.

III. Localization algorithm using kernel regression analysis

Four electrodes record four different voltages (v_a, where $a = 1, 2, 3, 4$) that primarily depend on the distance between the electrode and the finger. We calculate the location ratio $\boldsymbol{p} = (p_x, p_y)^{\mathrm{T}}$:

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

$$p_y = \frac{v_1 + v_2 - v_3 - v_4}{v_1 + v_2 + v_3 + v_4} \quad (2)$$

where p_x and p_y represent the dimensionless x and y coordinates, respectively.

The actual physical coordinates of the marked point (i, j) are denoted by $\boldsymbol{t_{ij}} = (t_{ij,x}, t_{ij,y})^T$, where the origin lies on the geometric center of the paper. Here, i and j are the indices of the 49 points. $(i, j) = (1, 1)$ and $(7, 7)$ were the most upward point in the left side of the paper and the most downward point in the right side of the paper, respectively.

We linked $\boldsymbol{t}_{ij}$ and $\boldsymbol{p}_{ij}$ via a kernel regression method. The equation to predict the actual location $\boldsymbol{t}_{ij}$ corresponding to $\boldsymbol{p}_{ij}$ is

$$\tilde{t}_{ij,x} = \sum_{l=1}^{m} \alpha_{xl} k(\boldsymbol{p}^{(l)}, \boldsymbol{p}_{ij}) \quad (3)$$

$$\tilde{t}_{ij,y} = \sum_{l=1}^{m} \alpha_{yl} k(\boldsymbol{p}^{(l)}, \boldsymbol{p}_{ij}). \quad (4)$$

$k(\boldsymbol{p}, \boldsymbol{p}')$ is a Gaussian kernel:

$$k(\boldsymbol{p}, \boldsymbol{p'}) = \exp(-\| \boldsymbol{p} - \boldsymbol{p'} \|^2). \quad (5)$$

Furthermore, m is the number of samples used for training. We used six out of the seven data sets for training; hence, $m = 49 \times 6 = 249$. The coefficients α_{xl} and α_{yl} are computed using

$$\boldsymbol{\alpha_x} = (\boldsymbol{K} + \lambda \boldsymbol{I})^{-1} \boldsymbol{t_x} \quad (6)$$

$$\boldsymbol{\alpha_y} = (\boldsymbol{K} + \lambda \boldsymbol{I})^{-1} \boldsymbol{t_y} \quad (7)$$

where $\boldsymbol{\alpha}_x$ and $\boldsymbol{\alpha}_y$ are the vectors comprising α_{xl} and α_{yl} ($l = 1, ..., m$), respectively. $\boldsymbol{K}$ is a $m \times m$ matrix formed by $k(\boldsymbol{p}_{ij}, \boldsymbol{p}_{i'j'})(i, j, i', j' = 1, ..., 7)$. $\boldsymbol{t_x}$ and $\boldsymbol{t_y}$ are the vectors of the actual x- and y-axial coordinates of the samples used for training. The regularization term λ was set to 0.001, and $\boldsymbol{I}$ is the identity matrix. We then performed leave-one-out cross validation to test the effectiveness of the proposed method. We built the model using 6 data sets and then tested the model using the data set that was not used for training.

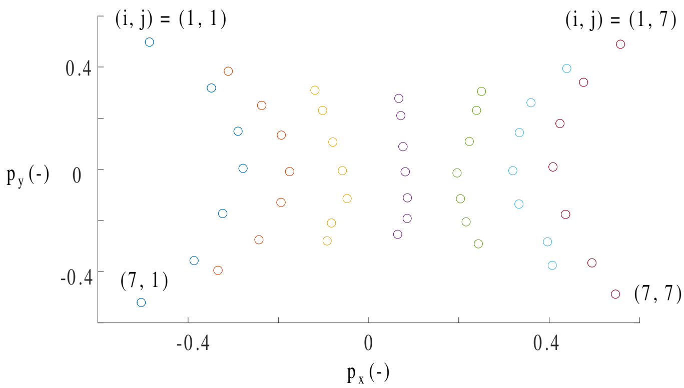

Fig. 2. Mean location ratios for all tested points

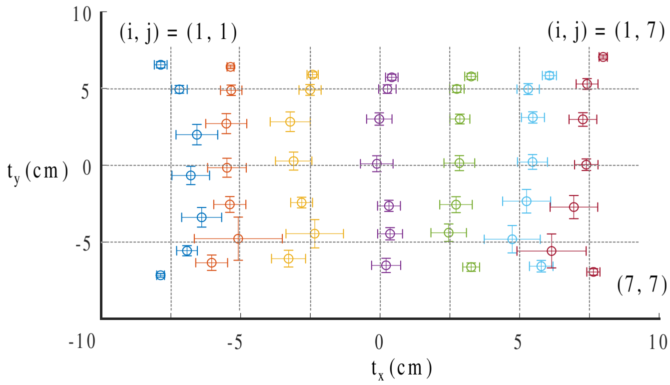

Fig. 3. Means and standard deviations of the predicted coordinates of 49 points after the application of leave-one-out cross validation. Intersections of the dotted grids are the 7×7 points that were actually touched.

IV. Results

Fig. 3 (top) shows the mean location ratios $\boldsymbol{p}_{ij}$ for each of the 49 points. Each point represents the mean of the seven trials. The bottom figure shows the means and standard deviations of $\boldsymbol{t}_{ij}$ for the seven cross validation tests. The mean error of the predicted location was 0.88 cm, which is smaller than the width of the human fingertip. Nonetheless, the prediction was still skewed, especially near the corners and the electrodes.

V. Conclusions

In this study, we proposed a method to localize touch on a paper using an AC-hum-based technique. By applying the kernel regression method, 7×7 grid points on a paper were localized with a mean error of 0.88 cm. This technique is applicable to semi-conductive materials such as treated paper, and its localization error is smaller than the size of a fingertip.

References

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