HumTouch: Localization of Touch on a Cylindrical Object

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***Abstract*—HumTouch is a passive touch sensing method that utilizes the environmental electromagnetic waves. Unlike the commonly used touch sensing technology (e.g. capacitive sensing), the method we propose does not need surface activation. In this paper, we applied HumTouch to a semi-conductive wood cylinder (diameter = 3 cm, length = 30 cm) to localize the human touch on the surface. This was achieved via the model built by the kernel regression analysis and the performance was evaluated through the leave-one-out cross validation. The mean estimation error was 0.22 cm which is smaller than a fingertip. This proves that HumTouch is functional not only on a flat surface but also on a cylindrical surface.**

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

I. Introduction

Touch sensors have been widely employed in commercial devices (e.g. smartphones, laptop computers, etc.). Unlike the traditional keyboard or mouse, they provide a more direct means to operate a computer interface. Although touch sensors have been already commercialized, HumTouch [1]–[5] provides another approach for sensing the human touch. It is a touch method capable of sensing touch on daily objects including furniture and walls. A human body in a building reacts to the electromagnetic waves that cause 50/60 Hz electric signals in his body [6]. By attaching electrodes on a conductive or semi-conductive object surface, the voltage of these signals can be detected when the surface is touched by a human. Therefore, HumTouch does not need any surface activation and can be effortlessly applied by installing electrodes on a surface.

In our previous study, we conducted localization of touch on a semi-conductive paper [5]. This method is conducted by attaching four electrodes to each corner of the paper. Each electrode is represented as an orthant of the Cartesian coordinate system so that the touch location can be computed as a linear combination of the voltages recorded by the four electrodes. However, the locations thus measured were found to be distorted; this issue was resolved by implementing the kernel regression analysis. The mean error for the estimated location was 0.88 cm on a 19×16 cm^2 paper. On the other hand, unlike papers, the surface of a three-dimensional object is continuous. Therefore, the allocation of electrodes and subsequent calculations adopted in [5] could not be applied for 3D objects.

In this study, we attached six electrodes to a wood cylinder. Unlike the two-phased localization in [5], the method used in the present study did not rely on the preprocessing of location of touch; instead, it directly computed the location by using the differential outputs obtained from the electrode pairs and applying the kernel regression method. This method is expected to serve as a general localization method for three-dimensional objects.

This study was in part supported by the Mazda foundation.

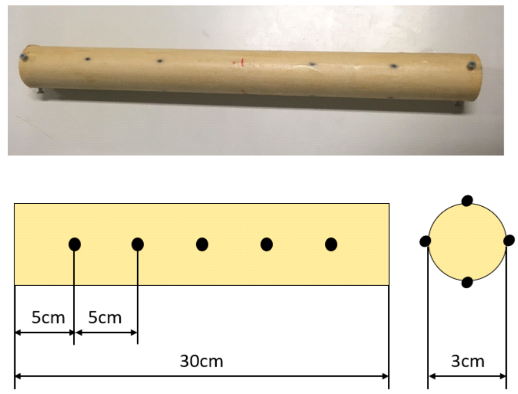

Fig. 1. A semi-conductive wood cylinder of 3 cm in diameter and 30 cm in length. Five points with 5 cm interval were marked at $\varphi = 0°, 90°, 180°$ and 270° on the surface. 20 points were marked in total.

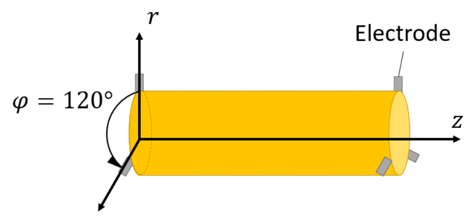

Fig. 2. Three electrodes (screws) were nailed at $\varphi = 0°, 120°$ and 240° on each side of the cylinder.

II. Materials and Apparatuses

We painted a wood bar (diameter = 3 cm, length = 30 cm) with a semi-conductive ink, which contains polyvinyl alcohol, polyethylene glycol and glutaraldehyde [4]. Three screws (5.0 mm $\times$ 10 mm) were attached on either of the ends, i.e., total six screws were used as electrodes. The interval between each screw was 120° as shown in Fig. 2. An oscilloscope with six channels (HS6 DIFF, TiePie Engineering, Netherlands;

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sampling frequency: 500 kHz) was used to record the signals obtained from the electrodes.

III. Experimental Procedure

Five points with 5 cm intervals were marked on every 90° of the cylinder as shown in Fig. 1. Furthermore, these twenty marked points were touched one at a time by a participant with his index finger for approximately 1 s in a normal office room. The contact force of the touch was not restricted and the procedure was repeated seven times to collect seven data sets. In this way, a total of 20×7 samples were recorded.

IV. Data Processing

We applied a moving average filter with a span of 5 to the collected signals and the resultant maximum voltage in each channel was recorded. For a sample i, the recorded maximum voltage of the jth channel is denoted by v_{ij} where $i = 1, ..., 140$ and $j = 1, ..., 6$. Typical v_{ij} values ranged 0.2–0.7 V.

To prepare for the input vector for kernel regression, the recorded voltage data was further processed. For the maximum voltages recorded at the ath and bth channel of sample i, $d_{i,ab}$ was computed as:

$$d_{i,ab} = \frac{v_{ia} - v_{ib}}{v_{ia} + v_{ib}}, (a, b = 1, 2, ..., 6; a \neq b). \tag{1}$$

We applied the kernel regression analysis to find the relationship between the actual locations of the marked points and the input vector. The relationship was used to build a model for the localization.

The actual location of the marked points is expressed as $(\boldsymbol{\varphi}, \boldsymbol{z})$ where $\boldsymbol{\varphi} = (\varphi_1, \varphi_2, ..., \varphi_n)^{\mathrm{T}}$ is the angular coordinate and $\boldsymbol{z} = (z_1, z_2, ..., z_n)^{\mathrm{T}}$ is the z coordinate of the location. The input vector for the ith sample is $\boldsymbol{x_i}$, where $\boldsymbol{x_i} = (d_{i,ab}; a, b = 1, ..., 6, a \neq b)^{\mathrm{T}} \in \mathbb{R}^{15\times1}$. In this study, we applied six data sets (n = 120 samples) to build the regression model and the estimated location $(\tilde{\varphi}, \tilde{z})$ for $\boldsymbol{x}$ was computed as:

$$\tilde{\varphi} = \sum_{i=1}^{n} \alpha_{\varphi i} k(\boldsymbol{x_i}, \boldsymbol{x}), \tag{2}$$

$$\tilde{z} = \sum_{i=1}^{n} \alpha_{\varphi i} k(\boldsymbol{x_i}, \boldsymbol{x}). \tag{3}$$

The kernel function $k(\boldsymbol{x_i}, \boldsymbol{x})$ used in this study was the Gaussian kernel, which is expressed as follows:

$$k(\boldsymbol{x_i}, \boldsymbol{x}) = \exp(-|\boldsymbol{x_i} - \boldsymbol{x}|^2), \tag{4}$$

where, $|.|$ is the L2 norm. The coefficients $\alpha_{\varphi i}$ and α_{zi} are the ith components of vectors $\boldsymbol{\alpha_\varphi}$ and $\boldsymbol{\alpha_z}$, which can be given as follows:

$$\boldsymbol{\alpha_\varphi} = (\boldsymbol{K} + \lambda \boldsymbol{I})^{-1} \boldsymbol{\varphi} \tag{5}$$

$$\boldsymbol{\alpha_z} = (\boldsymbol{K} + \lambda \boldsymbol{I})^{-1} \boldsymbol{z}. \tag{6}$$

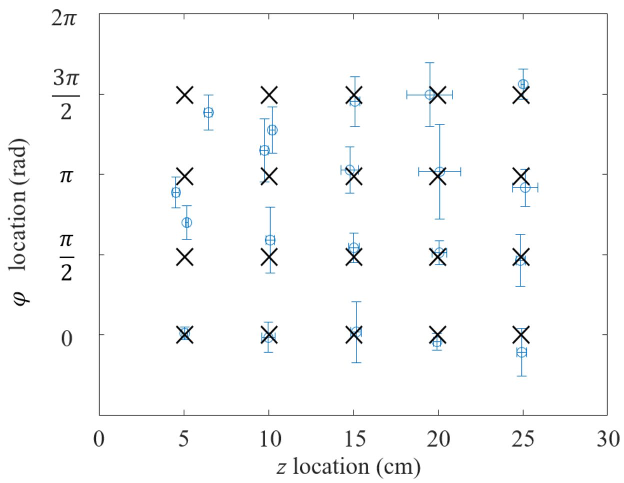

Fig. 3. Mean estimated coordinates of the twenty marked points after the application of the leave-one-out cross validation. The error bars indicate the standard deviations for each point and the black crosses are the actual locations of the marked points.

The Matrix $\boldsymbol{K}$ that comprises of the kernel functions is expressed as:

$$\boldsymbol{K} = \begin{bmatrix} k(\boldsymbol{x_1}, \boldsymbol{x_1}) & \dots & k(\boldsymbol{x_1}, \boldsymbol{x_n}) \\ \vdots & \ddots & \\ k(\boldsymbol{x_n}, \boldsymbol{x_1}) & \dots & k(\boldsymbol{x_n}, \boldsymbol{x_n}) \end{bmatrix}. \tag{7}$$

The regularization term λ was the value that carried out the smallest estimation error. In this study, λ was set to 4.3×10^{-5} and $\boldsymbol{I}$ was a $n \times n$ identity matrix.

V. Results

The leave-one-out cross validation was applied to investigate the generalization of the localization method. The points in Fig. 3 are the mean estimated locations obtained from the seven trials for the twenty marked points and their error bars indicate their corresponding standard deviations. The estimation error for the location was 0.21 cm in the z direction and 26.4° (0.23 cm in circumference distance) in the φ direction. These errors are comparable to those of other methods. For example, a method based on electric tomography involves mean localization errors of less than 10 mm [7].

VI. Conclusions

We proposed a hum-noise based touch sensor (named HumTouch) that can be applied on cylindrical objects. In this study, twenty points were localized via the kernel regression method with a mean estimated error of 0.22 cm. The result shows that HumTouch can be implemented not only on 2D surfaces but also on 3D objects.

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