HumTouch: Localization of a finger in purified water using humming-noise-driven human-body electric currents

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***Abstract*—HumTouch is a sensing technology that can convert semi-conductive materials into touch sensors by using the humming noise in the surrounding area. Human bodies contain minerals that react with these surrounding AC humming noises. The electric currents driven by the humming noise flow into a semi-conductive surface when the human touches it. We localized a finger in a plastic tank filled with purified water. The tank had electrodes to detect the electric current leaked from the human hand. The finger position in the tank was then estimated using the voltage levels at two electrodes; the mean localization error was 0.90 cm. The results proved that human body parts in purified water can be localized using the HumTouch technique.**

***Index Terms*—Human antenna, human touch sensing, liquid touch sensor**

I. INTRODUCTION

Touch-sensing technologies are widely used for consumer electronics nowadays. Although capacitive sensing on a rigid glass plate is the most commercially successful method, several studies have focused on methods that can be used for curved or flexible objects made of various materials [1]. Herein, we studied a humming-noise-based touch-sensing method called HumTouch.

HumTouch [2] can be used for gesture recognition and touch localization by using semi-conductive materials with curved or flexible surfaces [3]–[8]. The humming noise used for HumTouch is caused by AC power lines in buildings [9]. The conductive elements in human bodies react with the AC hum, resulting in electric currents. When a human touches a conductive object, the current leaks from their finger to the surface. HumTouch records the leaked electrical signals at multiple points on the surface and localizes the touch [7].

HumTouch technology allows any semi-conductive materials to be used as touch sensors. In this study, purified water was used as a semi-conductive material for HumTouch. The circuit model for the water is shown in Fig. 1, where purified water is considered an electrical resistor. Touch localization was achieved via a regression model built from training samples of the recorded voltages for different touch locations.

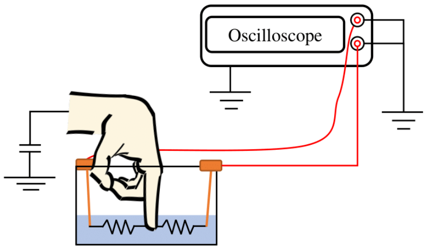

Fig. 1. Circuit model of the HumTouch sensor using water. The tank is insulative.

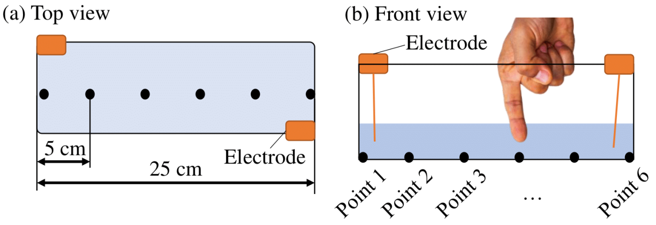

Fig. 2. (a) The tank was marked at the bottom with six points, with two electrodes attached at the corners. (b) During the experiment, the participant placed his/her finger near the marked points.

Unlike previous studies on HumTouch, which used solid objects, such as paper, wood and stone [3], [5], [7], [8], we demonstrate that liquids, such as purified water, can also be used as sensors. Water can be placed in containers of any shape and HumTouch functions enabled by simply inserting electrodes into the water. These characteristics broaden the usage of HumTouch technology. Although we did not specify the application of the water-touch sensor, the sensing method proposed in this paper is expected to be the foundation of liquid HumTouch technology.

II. MATERIALS, APPARATUS, AND EXPERIMENT

A $25 \times 12.5 \times 10$ cm^3 plastic tank with 600 ml of purified water was used for the experiment. Two electrodes were attached to two corners of the tank and connected to an oscilloscope (HS6 DIFF, TiePie Engineering, Netherlands; sampling frequency: 500 kHz) to record the voltage signals. The bottom of the tank was marked with six points at 5-cm intervals, as shown in Fig. 2(a).

Five university students over 20 years old participated in the experiment. The participants were required to remove their shoes and sit still, with both feet in contact with the floor, during the experiment. Each participant was asked to insert

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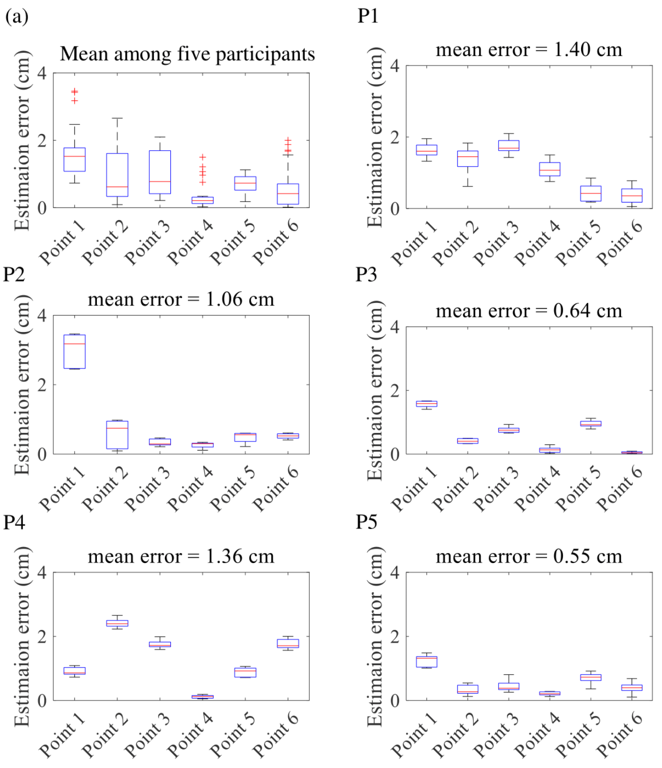

Fig. 3. Estimation errors of the linear regression model when applying the leave-one-out cross-validation for the five participants (P1–P5). (a) shows the average of all participants.

their index finger into the water and hold it near each of the six marked points for approximately 1 s, as shown in Fig. 2(b). The procedure was repeated five times to collect five datasets.

III. LOCALIZATION METHOD

A. Linear Regression Analysis

The maximum voltages during the 1-s period at each of the two electrodes were recorded as v_{1i} and v_{2i} for the marked point i. The detected voltages changed with the finger location, and their relationship was nearly linear. Therefore, we applied linear regression analysis to estimate the finger locations for the ith point ($\hat{x}_i$). The regression analysis model was

$$\hat{x}_i = b_1 v_{1i} + b_2 v_{2i} + a, \tag{1}$$

where a is the regression constant, and b_1 and b_2 are the slopes for v_{1i} and v_{2i}, respectively. The regression constant and the slopes were computed from the training samples.

B. Leave-one-out Cross-Validation

To evaluate the localization method, we applied leave-one-out cross-validation. For each participant, four out of five datasets were used to build the regression model and the remaining one was used to test the estimation. The procedure was conducted five times with different testing datasets.

TABLE I
MEAN ESTIMATION ERRORS (cm) FOR EACH PARTICIPANT.

	P1	P2	P3	P4	P5
Point 1	1.63	3.00	1.57	0.91	1.24
Point 2	1.36	0.58	0.41	2.42	0.33
Point 3	1.75	0.33	0.76	1.75	0.45
Point 4	1.10	0.26	0.13	0.12	0.21
Point 5	0.44	0.48	0.95	0.88	0.70
Point 6	0.37	0.52	0.05	1.77	0.40

IV. RESULTS

Fig. 3 shows the estimation errors for the six different locations. Table I exhibits the mean errors for each participant among the five trials. Participant P1 exhibited the largest mean estimation error of 1.40 cm, and Participant P5 exhibited the smallest mean error of 0.55 cm. In addition, the mean estimation error was 0.90 cm among the five participants.

V. DISCUSSION

For 66.7% of all the trials, the estimation errors were less than 1.0 cm, which is smaller than the size of a fingertip. These errors are acceptable for some applications; however, we do not speculate on concrete applications here. To study the localization accuracy, we calculated the proportion of samples with a localization error smaller than 1 cm. Three out of the five participants exhibited proportions of 83.3%, one exhibited 50%, and the last exhibited 33%. These proportions suggest a moderate individuality of localization; however, the reason for the individual differences remains to be studied. The estimation errors are potentially reduced by using the nonlinear regression model because the relationship between the voltages detected at the electrodes and distances between the electrodes and fingertip is not perfectly linear. Such methods were adopted in [7].

VI. CONCLUSIONS

We examined the HumTouch sensor using purified water. To localize a finger in the water, a linear regression model was established using the voltages detected at two electrodes in the $20 \times 12.5 \times 10$ cm^3 water tank as independent variables. The mean estimation error was 0.90 cm, which is nearly the size of a fingertip. This indicates that human body parts can be localized in purified water using the HumTouch sensing method.

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