Research on human-computer interaction technology based on electrical detection technology

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ABSTRACT

This paper sheds light on a proposed approach to non-contact Human-computer interaction(HCI) based on human body static electricity where detection-electrode arrays are aligned properly to track and recognize hand motion. By setting an electrode array made of polyimide, the induced current signals which is generated on the electrodes caused by hand motions can be measured by detection circuit and collected into micro-controller and the micro-controller would convert and collect the signals. Then we can detect the direction of a hand motion by processing the collected signals. Furthermore, a direction display program by microcontroller can work with this HCI system. Numerous experiments are conducted to determine the feasibility and the success rate of the proposed hand tracking and recognition system.

Keywords: electrostatic detection, gesture recognition, human-computer interaction(HCI)

1 INTRODUCTION

Human-computer interaction (HCI) technology has emerged as a crucial dimension of computer science and information industry. HCI with keyboard and mouse has started to lose ground, as people tend to harness the power of body language to facilitate HCI and computer operation, which promises to render HCI more easily and naturally.

There are two major ways which are based on wearable device and visual sense to interact with computer. Wearable devices are used in many of the HCI system because they have a higher recognition rate and accuracy than visual sense. DataGlove allows the operator to enhance the immersion characteristic of virtual reality system by measuring the date of pressure and direction from the hand，which can give the operator more realistic sense of the surrounding environment and the state. Another way called Surface Electromyography signal (SEMG) can collect SEMG of forearm for analyze hand motion[1-4]. Canadian companies Thalmic Labs launched innovative armband—MYO which can enable you to control technology with gestures and motion wirelessly. However, Wearable devices must be on the operator’s body, which may cause discomfort.

Visual sense with camera is a very suitable method to get information from the human body movement[5-8]. Recently, Leap company has made a new equipment called Leap Motion. This equipment uses two cameras taking pictures at the same time, then it will analyze phase information and position of the human hand. But Visual sense will require particular light source, otherwise the recognition rate may be low.

Since human body in motion will be electrostatically charged, human body has an electrostatic field where we can detect the change. Measuring human stepping movement by electrostatic signals has been achieved [9-10]. Furthermore, there is a method which can detect three-dimensional hand motion by a six spherical electrode array arranged in two planes [11]. In this paper, therefore, we design a hand tracking and recognition system in a 10*20cm rectangle, which proves that non-contact HCI can be achieved by using hand motion parameters gained from examining electrostatic induction signals produced on metal plates when hands are in motion.

2 THEORY

The electric field will change while a hand takes an action in space as the pointed end of the charged body. According to the theory of electrodynamics, electric charges in the conductor will be redistributed because the electric field is disturbed by the human hand motion. As a result, there will generate induced current in the conductor. So we can detect the information about the change of electric field by putting a charge detector connected with electrode. And then we can deduce the the relationship between charge change and hand movement. If we ground the conductor, the change of the induced would be detected by an amplifier.

Figure 1 shows the schematic diagram of hand motion in front of one electrode. We assume that a man sits on a tool. When the man moves his hand in parallel with the electrode, the grounding electrode will generate an electrostatic induced current which, after being converted and amplified in the detection circuit, can be measured. The relative position relationship between electrode and hand will be figured out by the method above.

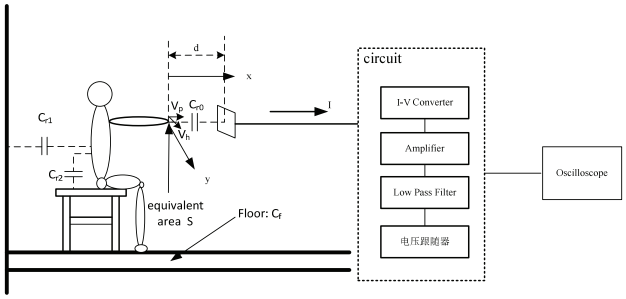

Fig.1 Schematic representation of the interaction between the human body and the electrode

The capacitance of the feet relative to the ground is C_f. The sum of C_{r0}, C_{r1} and C_{r2} is the capacitance between the body and other objects in surrounding environment. Assuming that the equivalent capacitance between electrode and human body is C_{r0}, which, in the process of a hand moving in parallel with the direction of the electrode with a velocity v , according to the theories of electrodynamics, can be expressed as follows:

$$C_{r0} = \frac{\varepsilon_\alpha S}{\left(d - \Delta x\right)} \tag{1}$$

Where d, S, ε_α are respectively the vertical distance between hand and electrode, the equivalent area and the dielectric coefficient of air between them.

Figure 2 shows the trajectory of a charged object in front of the electrode with a certain angle. Where S represents the charged object, x stands for its horizontal distance to the center of electrode and y the vertical distance. ∂ is the included angle between the direction of the field strength and the normal direction of the electrode surface. θ represents the angle between the surface of the probe and the direction of movement of the charged object. We assume that the trajectory of object always parallels with the electrode.

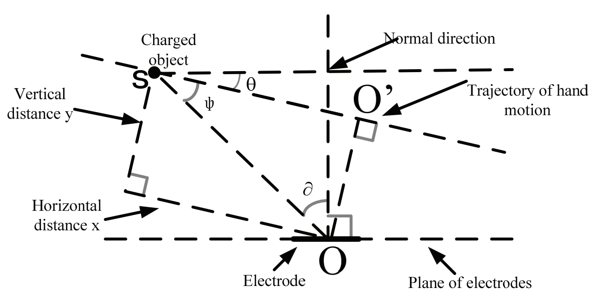

Fig.2 The trajectory of a hand motion

Given that the hand is moving along an approximate linear path, the hand and electrode is getting closer in the process. that's to say, as the x decreases, the electric field strength component in normal direction E_n will change. the induced current generated on the electrode can be represented as:

$$\begin{aligned} i &= \frac{dQ_E}{dt} = \varepsilon_0 \frac{dE_n}{dt} \\ &= \varepsilon_0 \frac{d\left[\frac{Q}{4\pi\varepsilon_0\left(x^2+y^2\right)^{\frac{3}{2}}}\left(y\cos\theta + x\sin\theta\right)\right]}{dx}\frac{dx}{dt} \\ &= \frac{Q}{4\pi}\frac{\sin\theta\left(y^2-2x^2\right) - 3xy\cos\theta}{\left(x^2+y^2\right)^{\frac{5}{2}}}\frac{dx}{dt} \end{aligned} \tag{2}$$

If the O' is the coordinate origin, the equation for linear motion of human hand can be expressed as:

$$U = R_e i = R_e \varepsilon_0 \frac{dE_n}{dt} = R_e \frac{Qv}{4\pi}\frac{\sin\theta\left(y^2-2x^2\right) - 3xy\cos\theta}{\left(x^2+y^2\right)^{\frac{5}{2}}} \tag{3}$$

Therefore, when the human hand which has been charged moves in front of the electrode, the change of relative location of electrode and hand can be obtained by measuring the induced current generated on the grounding electrode because of the change of the equivalent capacitance between them.

We can figure out that the waveform of the voltage is an upward trend when human hand gets close to electrode and a downward trend when human hand gets gradually away from the electrode, which we can find the distance relationship between the motion of human hand and the electrode.

There is a special time when the waveform of voltage changes from positive-to-negative or from negative-to-positive called Zero Crossing Point (ZCP). In other words, the ZCP indicates the moment when the human hand is closest to the electrode.

3 ALGORITHM

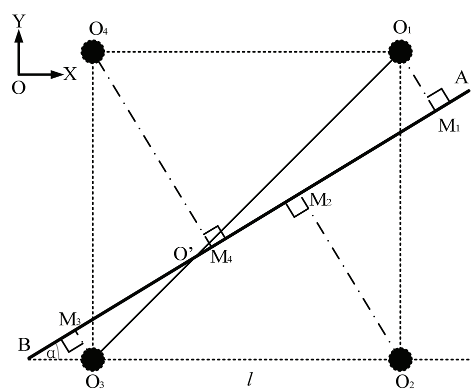

Fig.3 Position of four electrodes

Figure 3 shows the relative position of four electrodes on plane XOY. The four electrodes, with geometric centers at O_1, O_2, O_3, O_4, are placed on the vertices of a square with side length l. AB represents the trajectory of hand motion. M_1, M_2, M_3, M_4 are respectively closest positions from the four electrodes O_1, O_2, O_3 and O_4 to the trajectory. When the hand passes points M_1, M_2, M_3, M_4, the time points are defined as t_1, t_2, t_3 and t_4, respectively. α is the angle between the trajectory AB and O_3O_2. O' embodies the intersection of AB and O_1O_3.

According to the geometric relations,

$$\angle M_3O'O_3 = \frac{\pi}{4} - \alpha,\ M_1M_3 = O_1O_3 \cos\left(\frac{\pi}{4} - \alpha\right), \tag{4}$$

$$M_2M_4 = O_2O_4 \sin\left(\frac{\pi}{4} - \alpha\right).$$

Assuming that hand is in uniform motion, t_3-t_1 is the time from M1 to M3 , the speed v_{13} determined by electrodes 1 and 3 can be expressed as:

$$v_{13} = \frac{O_1O_2 \cos\left(\frac{\pi}{4} - \alpha\right)}{t_3 - t_1} = \frac{\sqrt{2}l \cos\left(\frac{\pi}{4} - \alpha\right)}{t_3 - t_1} \tag{5}$$

Meanwhile speed v_{24} determined by electrodes 2 and 4 can be expressed as:

$$v_{24} = \frac{O_2O_4 \cos\left(\frac{\pi}{4} - \alpha\right)}{t_4 - t_2} = \frac{\sqrt{2}l \cos\left(\frac{\pi}{4} - \alpha\right)}{t_4 - t_2} \tag{6}$$

If $v_{24} = v_{13}$, in Equations (5) and (6), the following equations can be expressed as:

$$\tan\left(\frac{\pi}{4} - \alpha\right) = \frac{t_4 - t_2}{t_3 - t_1} \tag{7}$$

$$\alpha = \frac{\pi}{4} - \arctan\frac{t_4 - t_2}{t_3 - t_1} \tag{8}$$

$$v = \frac{\sqrt{2}l}{\sqrt{(t_3 - t_1)^2 + (t_4 - t_2)^2}} \tag{9}$$

4 DESIGN OF HARDWARE

Our system has seven parts like Figure 4, including four electrodes, I-V converter circuit, amplifier circuit, low pass filter circuit, voltage follower circuit, micro-controller and display circuit.

Electrostatic induction current is difficult to measure because the current is almost no more than 10 pA. We design a circuit high magnification, which can covert 5pA to 5V, meanwhile the low pass filter can keep the noise out.

In this paper, we set up an array which contains four 0.3 cm × 5 cm sized plate rectangular electrodes. The distance of electrode is 5 cm. In order to achieve a real-time display, we use an OLED screen to display the direction of human hand. The total size of the electrical detection system is 10cm × 20cm, so it is very convenient to use this system.

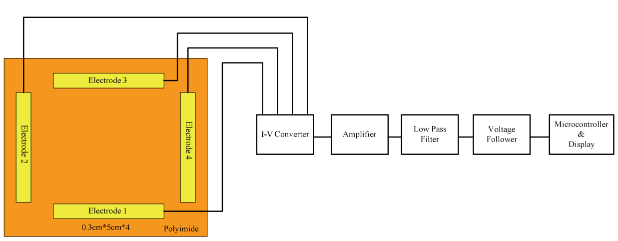

Fig.4 System structure

We design and debug the hardware like Figure 5.

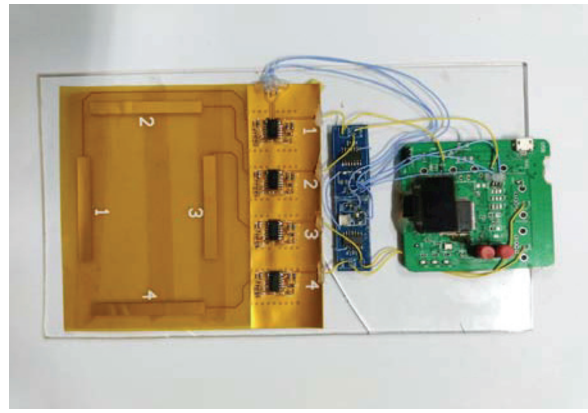

Fig.5 The HCI system

5 HARDWARE AND DATA ANALYSIS

Figure 6 shows the oscillogram measured when an experimenter moved his hand a few times with a motion parallel to the electrode from the left side to the right side. Red circle position is the ZCP.

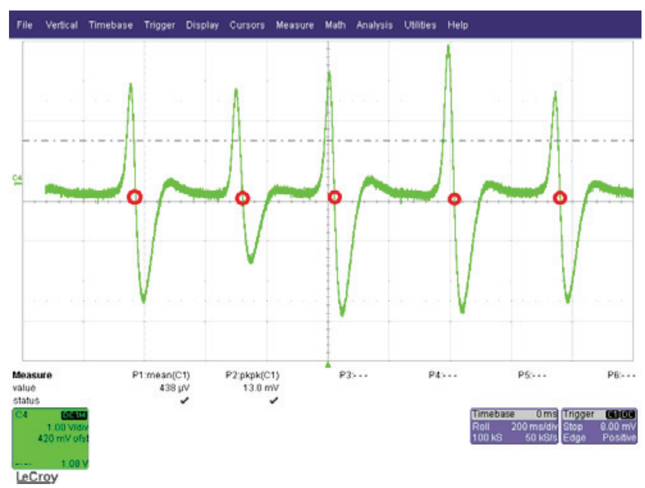

Fig.6 Waveform of a hand motion parallel to the electode

Figure 7 shows Wave forms of four electrodes when human hand moves slowly from B to A in Figure 3 at the angle of 60 degrees.

We can get the value of four ZCP from Figure 7. The ZPT of electrode 1, 2, 3, 4 are 325 ms, 285 ms, 200 ms and 220 ms respectively. According to Equations (8), we can calculate the value of α is 63.5 degrees which is very close to the actual value. Meanwhile, we can figure out the speed of human hand is 0.505 m/s.

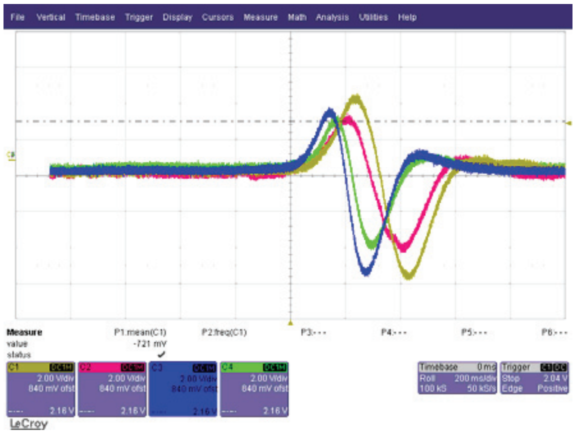

Fig.7 Wave forms of four electrodes

6 CONCLUSION

In this paper, we design a miniaturized non-contact HCI system. The induced electrostatic current can be measured by the designed electrode array. We can detect the direction of the human hand by a small-sized system. According to the ZPT, we can even figure out the speed of human hand motion in front of electrode array. This system can recognize the electrostatic induction current through an electrode array placed at a distance of 20cm from the charged hand. Compared with visual sense and wearable device, We need not wear anything or worry about the influence of ambient light. We can use this system on intelligent vehicle system to control some application conveniently through gesture recognition. So this system has a good application prospect.

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