A Computer-based Touch-less 3D Controller Using Capacitive Sensing Method

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***Abstract*— This paper focuses on the application of touch-less interaction between human and computer using capacitive sensing technique. A computer–based analysis for touch-less 3D controller using capacitive sensing method in [1] is developed. In this project, Arduino UNO is used as a microcontroller to bridge the interface connection between the sensor hardware and the computer. This method uses capacitive based sensor as the main component to sense the gesture movement near it. The capacitive based sensing depends on the duration to charge a capacitor (known as the time constant). By placing an object within the electric field of a capacitor, it will immediately affect the capacitance value and it will correspond to the time constant. In the final analysis, the touch-less hardware will be linked to MATLAB software to study its characteristic and behavior. Using the data obtained from the analysis, a touch-less control from the hardware will control the computer keyboard. To show its additional functionality, a Google Earth program will display the ability of the touch-less interface.**

***Index Terms*— 3D, Arduino, Capacitive Sensing, MATLAB, Touch-less.**

I. INTRODUCTION

Nowadays, studies of human-Computer interactions have been emerging rapidly due to the fast growing technologies in digital multimedia such as gaming, digital television, smart home system and many more. Since computers are becoming increasingly integrated in our everyday life, new technologies and applications are being introduced from time to time in order to improve the interactions between the users and the computers. However, this interaction is limited to the device systems such as keyboards, mice, touch screen, trackball, and keypads. These device systems need a full interaction that requires a contact with the device so that it can read the input data of interactions to control the computer [2].

The HCI (human-computer interactions) can be defined as the study, planning, design and uses of human interface between the users and the computers. Developers ought to improve the technologies in order to make them more intuitive and have a more natural interaction between the computer and human themselves [3]. User's feedbacks and comments on their experience with the available prototype and the developer provide valuable information to refine the design of the technology [4].

Capacitive sensing method has received much attention mainly in the applications of touch screens as it enables a compelling interface for displays, such as smartphones, tablets and many other products related to touch screen [5]. By using the same concept, a 3D sensing where gestures that can be sensed in the out-of-plane distance of 20 to 30 cm could enrich the experience of the user's interaction with the computer. However, there are challenges when using gestural input method [6]. The capacitive concept determines how it can achieve sensitivity at a certain distance when sensing a capacitance distortion as the user interacts with the sensing electrodes regions.

The requirements needed in the development of the capacitive sensing will result in analogous design decisions [7]. The design enables us to use Low-Cost Electrode Material in building a mechanism of the gesture sensor hardware.

Given the promising improvements for a more futuristic user interface for human computer interactions, it is timely to conduct this study. Examples of the technology are Leap Motion [8], MYO armband [9], and Microsoft Kinect [10] to name a few. All of the mentioned products can apply touch-less application for human-computer interactions and smart systems. In this respect, most developers and researchers are motivated to expand their research and studies on how to fulfill the highly demanded technologies for a more futuristic development of human-computer interactions.

II. RELATED WORKS

There has been a surging interest in the studies of a touch-less human-computer interactions system. This system has taken its toll to be implemented in various applications wherein a few are described in Table 1. As a matter of fact, the system does not only apply to human-computer interactions, but it can also be used in a much wider application, such as robot control, smart mobile and home devices. This shows that the studies related to this field are not limited to its application as long as it can be useful and suitable to the users.

The strengths and weaknesses of the system are identified from the studies of four different gestural interactions by different methods and hardware, as shown in Table 2. The strengths of each technique are analyzed based on its accuracy and stability. On the other hand, the weaknesses are based on its complexity, factors that affect its accuracy and the suitability of the techniques for the system.

Table 1
Method description

Reference	Hardware	Application
Afthoni *et al*., 2013 [11]	Microsoft Kinect	Control system for robot controls using servo motor
Chen *et al*., 2015 [12]	Leap Motion	Captures 3D motion trajectories and recognitions
Qifan, Yang, *et al*., 2014 [13]	Ultrasonic-based	Smart mobile device
Gonzalo *et al*., 2015 [14]	MYO armband	Home devices control

Table 2
The performance of the methods

Reference	Strength	Weakness
Afthoni *et al*., 2013 [11]	The system is stable when tested repeatedly	The movement pattern for detection is high computational and complex
Chen *et al*., 2015 [12]	Total recognition with average rate of 90.92%	Uses SVM and HMM training that is high computational and took longer time
Qifan, Yang, *et al*., 2014 [13]	The accuracy of 93% gesture recognition	Need to maintain environment noise threshold
Gonzalo *et al*., 2015 [14]	Can save a library of gestural input	Using HGCS that is intuitive and a brief description needed for its functional

III. THEORY

The basic principle theory for the study on capacitive sensing is that the capacitor will work and function similar to a small accumulator. This happens when two metal plates are placed close to each other without touching, and a current known as a simple capacitor is supplied to it. It can store energy if there is a current placed on those two metals. Thus, when the current is removed and the plates are connected to a circuit, the stored energy initiates a current. The capacitance size, C is determined by the size of their plates, A and the distance, d between each other [15]. The formulation of this concept is shown in Equation (1).

$$C = \frac{\varepsilon A}{d} = \frac{k\varepsilon_o A}{d} \quad (1)$$

where:
$\varepsilon_o = 8.854 \times 10^{-12}\,\mathrm{Fm}^{-1}$; permittivity of space
k = relative permittivity of the dielectric the material between the plates
k = 1 for free space, k > 1 for all media

The hypothesis is that the capacitance is directly proportional to the sensor area and the dielectric property of material between the plates. Therefore, the larger the area of the sensor, the larger is the dielectric range. In order to use the concept of measuring and tracking the distance between the sensors and an object, one of the two plates of capacitors needs to be replaced by any relatively high dielectric constant material. The materials are usually electrically conductive for example metal, water or human body. When the material moves closer to the capacitive plate, the capacitance value will increase. Thus, data resulted from the changing capacitive value can be used to estimate the distance between the sensor plates and the shunt object.

IV. METHODOLOGY

The development of this project hardware is inspired from the original open source implementation by media artist Kyle McDonald [1]. The project, proposed from this website, produces the prototype of the work without any application or computer-based analysis. Therefore, an application implementation using MATLAB software to control the programs on a computer is added as a part of the important requirement of this project. The hardware and software system design are shown in Figure 1. The hardware consists of 3D sensor where the prototype is based on the idea from [1]. A computer-based analysis is performed using MATLAB software. This software allows data to be displayed in graphical form so that observation on its characteristic and behavior can be conducted. The main objective of this project is to implement the data obtained from the hardware and manipulate the data based on its behavior that happens when free hand movement inside the 3D sensor controls the computer program, Google Earth.

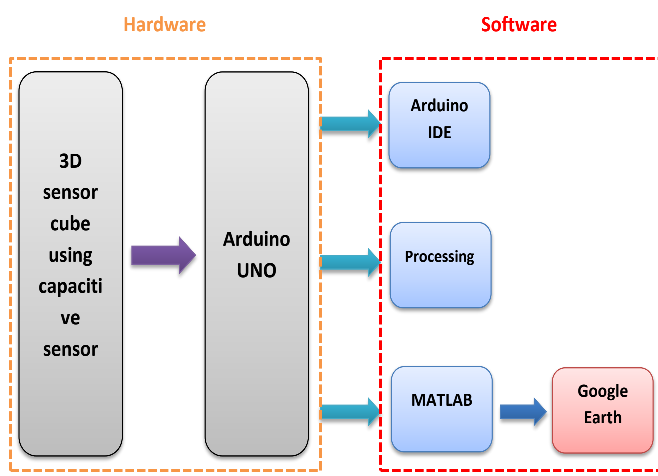

Figure 1: Hardware and software system design

A. *3D sensor cube*

The 3D sensor cube has three conductive plates that are designed in the 3D structural form, as shown in Figure 2. Each plate contains all the building block to read and sense the input system where it has x, y and z positional data. The changes in the capacitive values are used to provide data to determine the position of the free hand movements within the 3D sensor cube area in real time.

Figure 2: 3D sensor cube

In addition, each sensor cube is covered with paper. It will not affect the sensor region of the plate because of the low conductive value of the paper. The paper covered the plates will have an instruction point that determines the exact movement of the hands in the region and its effect on how it will control the program in the computer, as shown in Figure 3.

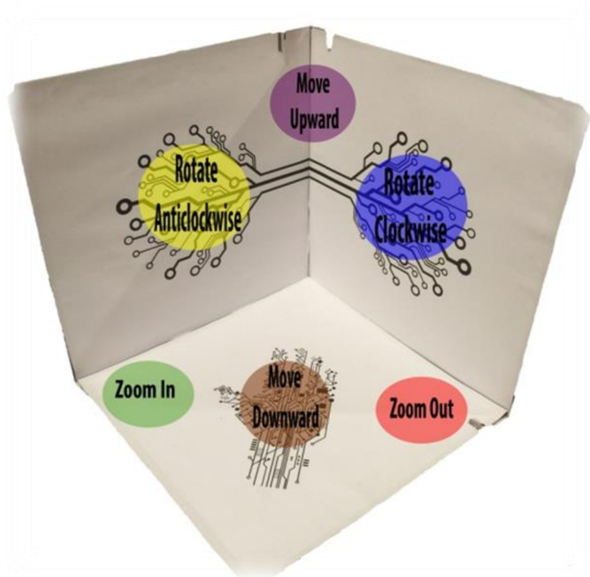

Figure 3: Area of function

B. Circuit

All the plates are linked to Arduino UNO using alligator clips joined on shielded cable. Shielded cable is used to reduce the antenna effect that can occur if the normal wire is used. Two different values of resistors 220kΩ and 10kΩ are paired and connected to the cable at each plate. Then, all of the cables are connected to 5V pin on the Arduino UNO. The pins used are 8, 9, and 10 to represent each plate, as shown in Figure 3. Each pin will read the value of the capacitance for final analysis and displayed on the Arduino terminal. The final connection to the Arduino UNO is shown in Figure 4.

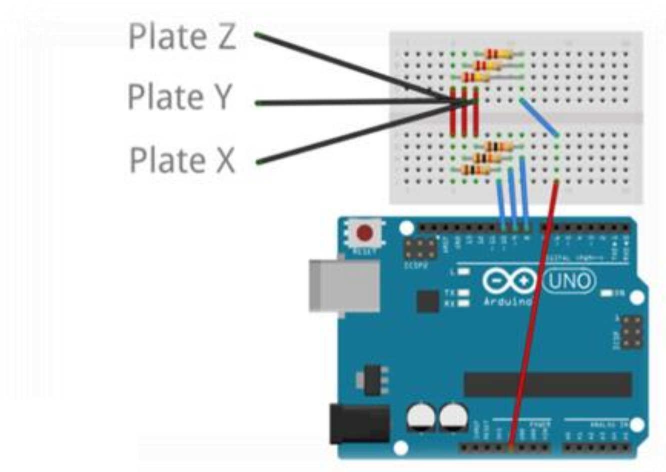

Figure 4: Connection diagram

C. Arduino sketch

The Arduino UNO board will be uploaded with a code that has the ability to read the capacitance value. The changes of the value depend on the activity of the 3D cube sensor. The value will be displayed on the software terminal. All the changes and the increment or decrement of the value happens in real time, as shown in Figure 5.

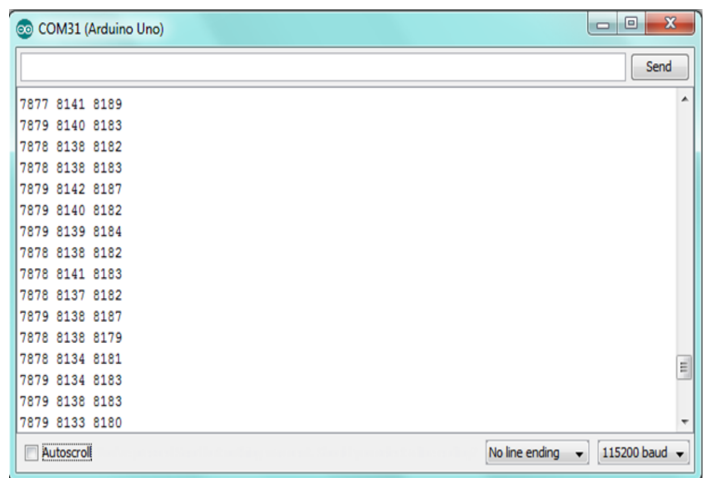

Figure 5: Serial monitor of Arduino IDE

From the terminal in Figure 5, it is observed that the first column represents the X-plate, the second column represents Y-plate and the last column represents the Z-plate of the 3D cube sensor.

D. 3D interface using processing software

The Processing software is used to display the interface design so that we can verify that the hardware can determine the hand position within the sensor cube region in a simple interface design by [1], as shown in Figure 6. The interface defines the sensing area of the cube. The small boxes act as virtual reference position and the sphere represents the hand that will move based on our hand activity.

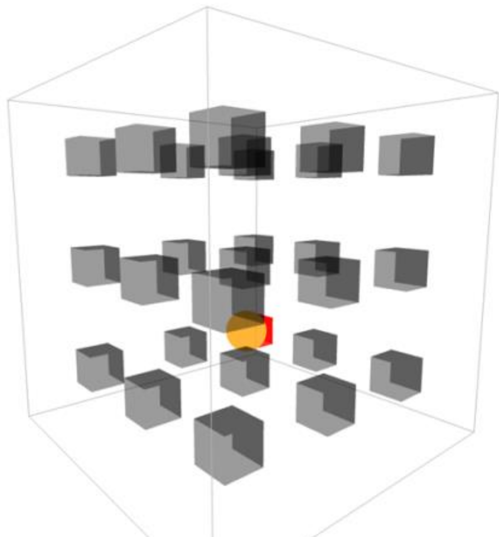

Figure 6: Interface

For the final analysis, MATLAB software is used. MATLAB has a data visualization suitable for this project. A better understanding of the analysis can be obtained from using MATLAB software due to its simplicity and visualization. It can also create a serial communication with external hardware. Arduino UNO has a serial port known as universal asynchronous receiver/transmitter (UART). The connection is established in MATLAB, and it is carried out by pairing the port and its baud rate of 115200. The result and analysis visualized by MATLAB software will be further explained in the next section.

V. RESULTS, ANALYSIS AND DISCUSSION

The sensor values obtained through a serial of communication between Arduino UNO and MATLAB software is acquired. The values are then plotted where the characteristic of the capacitance value changes over the hand activities in the software is visualized. The visualization is represented in colored circle marker shown in Figure 7, Figure 8 and Figure 9. The different colors, namely blue, red and green represent the X-Y-Z plate of the 3D sensor.

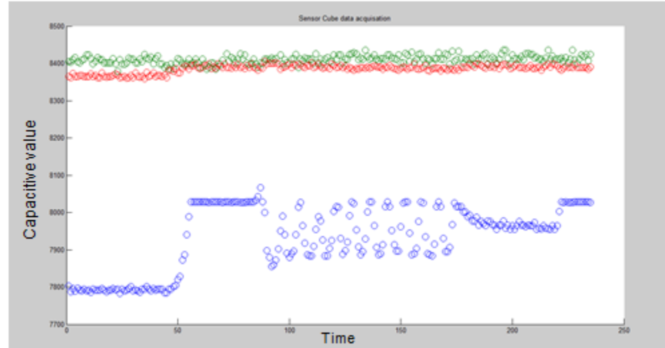

Figure 7: Blue representing X-plate

The visual pattern of the blue circle marker in Figure 7 represents the capacitive value activity occurs on the X-plate of the sensor cube. The analysis shows that when a hand approaches the X-plate, the capacitive value will increase. Each distance gives different value, therefore, the pattern shows the increment activity pattern on the visualization when the hand moves in closer to the plate. When the hand is statistically placed at a certain area of X-plate, the value will become constant. However, if the hand moves around the area, the value will vary as shown by the blue marker pattern.

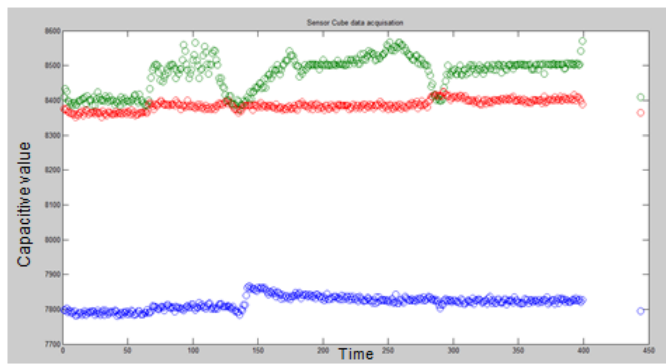

Figure 8: Green representing Y-plate

For Y-plate in Figure 8, the green marker represents the analysis of the Y-plate. The pattern varies as the hands move spontaneously around the plate area. When the hand is in between the plate for example in between X and Y- plate, both marker patterns on the graph will show a certain increase in the value of both colors. The values are used as a point to be used in assigning its function.

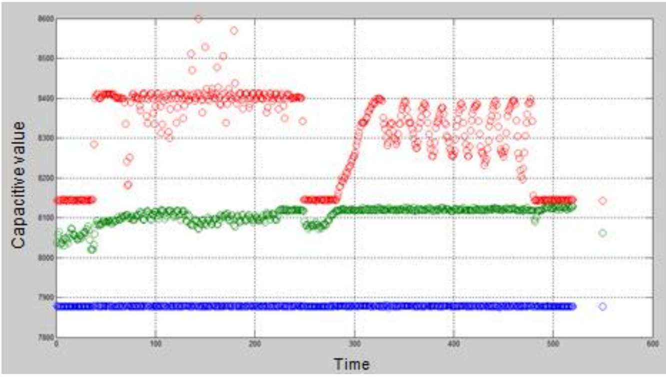

Figure 9: Red representing Z-plate

The red pattern in Figure 9 represents the hand movement activity around Z-plate of the sensor cube. The pattern shows that different value is obtained when the hand is moving around the area of the plate. This proves the hypothesis that when the hand is moving closer to the plate the capacitive value increases. The value is different when the hand is between the plates or in the middle of the sensor cube.

All of these patterns of activities are used and manipulated to create a function by MATLAB software to control the keyboard of the computer. To further prove its usage, we used Google Earth program to be controlled by the touch-less motion in the hardware. The Google Earth is a virtual globe, map, and a geographical information program. It is based on 3D map that can show 3D building and structures. To calibrate the data, few trials need to be conducted. Hands are placed on the region of interest and data of the capacitive value are tabulated. The collected data were then used in the MATLAB to command the function to control the Google Earth program. The globe is as shown in Figure 10.

Touch-less interaction using capacitive sensing method has proven to be able to control a program in the computer. The program controls are suitable to be used for this system. The program can be used to zoom in and out; the globe can rotate left, right, up and down relying on the keyboard control. Therefore, from the keyboard guide controlled from the Google Earth program, we matched the controls with the touch-less area. Six keyboard controls were chosen to be implemented at the area of the sensor cube as shown in Figure 3. The area is declared as presented in Table 3.

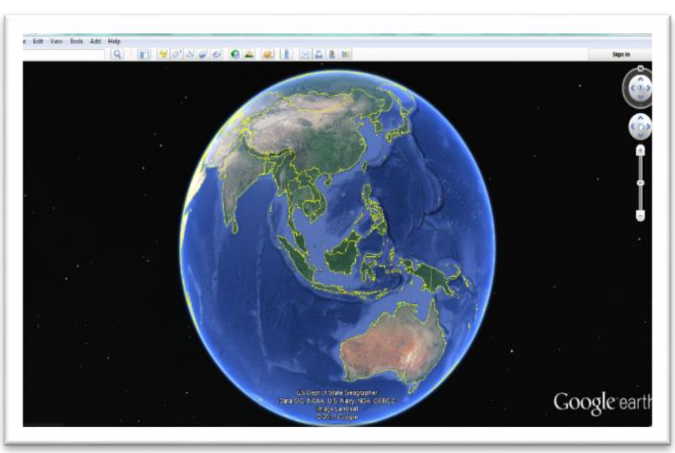

Figure 100: Google Earth program

Table 3
Area functions

Color area	Controls on Google Earth program
Yellow	Rotate anti-clockwise
Blue	Rotate clockwise
Purple	Move upward
Brown	Move downward
Green	Zoom in
Red	Zoom out

To operate the touch-less mechanism is relatively easy and user can easily learn how to control the program in the touch-less mode by following the reference indicated by the 3D sensor cube.

The hand detection accuracy is high as long as the hand move towards the area stated earlier. On the other hand, the sensor cube reacts with the ambience. Thus, when the ambience changes, the value of the capacitance also changes with ±30% value change. Due to that, calibration needs to be done every time the demonstration happens at a different place. Fortunately, this problem can be easily solved by creating its own program using Microsoft visual studio. In this case, it can be automatically calibrated every time when using it for future studies.

Delayed problems sometimes exist and this happens when users find it difficult to locate the spot at the sensor cube for its specific interaction with the program. Since the algorithm is not complex, the computational time is low, hence making it faster to process the interaction and the communication with the hardware.

VI. Conclusion

There are many methods that can be used to develop a touch-less interface, for example, the use of the 3D camera and IR sensor. However, each method has its advantages and disadvantages. Most of the tools have disadvantage associated with the high cost development and complicated hardware and software design. With the capacitive sensing designed in 3D sensing with X, Y, and Z coordinates, the application for computer based touch-less interaction is developed. Therefore, the program has the ability to be controlled. Implementing the concept of capacitive sensing as an application for human-computer interaction based on this method has made it sustainable and allowed the use of greener technology at a low cost in the establishment.

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