Infrared Wireless Tracking Device for Human Motion Sensing

Azman Hilmi Bin Mohd Zaili

Department of Electrical Engineering
University of Technology MARA
40000 Shah Alam, Selangor, Malaysia
azmanxhilmi@gmail.com

Abstract—This article presents an infrared wireless tracking device for human motion sensing. An infrared LED is fabricated; the IR-pen and IR-head device. The IR-pen and IR-head device signals will be detected by the Wiimote and webcam and followed by transferring the signal to the computer via simulation application program. Basic principle of the Wiimote is studied and had been implemented on the flight simulation program. The accuracy of the IR-motion via Wiimote and webcam is then compared to determine the efficiency for real-life human motion sensing used in many aviation academies. The result shows that the Wiimote has the high accuracy in capturing the infrared signal thus it fulfills the requirement of human motion sensing.

Index Terms- Wiimote, infrared LED, human motion sensing

I. INTRODUCTION

Wireless sensor had been used in mostly of our life, such as the automatic gate system, automatic water sprinkler system, reverse sensor system for cars, and many more. Some of these systems are using either active or passive sensor. Active motion sensors work by transfer out bursts of ultrasonic sound waves, after the sensor waits for the energy to be reflected back and the passive motion sensor are also known as passive infrared sensors (or PIR sensors) because they detect and measure incoming infrared energy. Most passive infrared sensors can actually detect emissions in the range of 8 to 12 micrometers.

For the infrared detection, firstly the infrared LED characteristic is vital. This is to determine the capability of the LED for infrared emission. Various LEDs in the market that is available not suitable as the wavelength each of the LED is differ. Wavelength ranging between 800 and 950 nanometers is the suitable for the infrared detection especially for wireless transmission to the receiver. This concept is almost similar to television remote control, where an electric impulse is created when the remote button is pushed.

Infrared emission is then detected by the Wiimote or webcam. Two of these devices were used to compare its efficiency intended for better accuracy in support of human motion sensing. Infrared sensor implemented in the Wiimote act as detector as the sensor consists of IR camera. Same as the Wiimote, the webcam also act as a detector because it may well detect the infrared signal coming from the IR-pen or IR-head device.

The infrared signal detected is then delivered to the computer and the signal will be translated by computer as human motions. Before executing this project, Microsoft® Visual C# and DirectX SDK is installed for the program to run smoothly. These two is needed for running the infamous Dr. Johnny Chung Lee's WiimoteWhiteboard application program [1]. From this observation, the capability of Wiimote is understood and some analysis is done to determine the distance needed for the Wiimote infrared signals detection. After the understanding of the Wiimote nature, next is the implementation of it to simulation program by using the Microsoft® Flight Simulation X program.
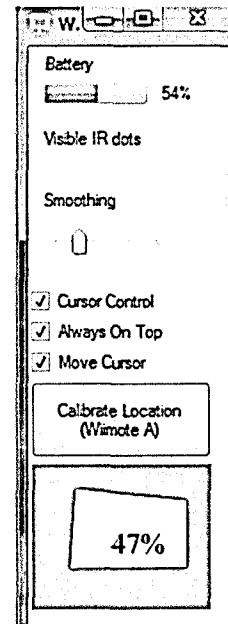

Figure 1: Wiimote Whiteboard Interface

II. PRINCIPLE OF WIIMOTE WHITEBOARD AND GLOVEPIE

Principle of this program is based on the programming in Microsoft® Visual C#. The interface had been designed to make the Wiimote detects one infrared as a signal, and then transferred to the computer via Bluetooth communication. For the program to perform as a whiteboard, a calibration between infrared and IR sensor in the Wiimote and computer is needed. In order for the Wiimote to set its wanted area of

IR detection, some of calculation has been included in the command of C#. The math for the calibration as follow;

The camera model could be written as,

$$X = Hx \tag{1}$$

where X is vector of world plane coordinates, x is the vector of image plane coordinates, and H is a matrix transform.

$$\begin{bmatrix} XW \\ YW \\ W \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{2}$$

W is actually,

$$W = gx + hy + 1 \tag{3}$$

rewriting the equation in a way that exposes its true non-linear form where the numerator supplies the parameters needed for affine transformation, and the denominator allows for the non-linear effect of perspective,

$$\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = \frac{\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}}{\begin{bmatrix} g & h & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}} \tag{4}$$

this is equivalent to the possibly more familiar, non-vector form of the perspective transform,

$$X = \frac{ax + by + c}{gx + hy + 1}$$

$$Y = \frac{dx + ey + f}{gx + hy + 1} \tag{5}$$

By multiplying each side of the equation by the denominator,

$$X(gx + hy + 1) = ax + by + c$$

$$Y(gx + hy + 1) = dx + ey + f \tag{6}$$

and multiplying through by X and Y gives,

$$gXx + hXy + X = ax + by + c$$

$$gYx + hYy + Y = dx + ey + f \tag{7}$$

the X and Y is isolated and zeroes are added,

$$X = ax + by + c - 0d + 0e + 0f - Xxg - Xyh$$

$$Y = 0a + 0b + 0c + xd + yd + f - Yxg - Yyh \tag{8}$$

Then the final result of the equation is obtained in a matrix vector as,

$$\begin{bmatrix} x_1 & y_1 & 1 & 0 & 0 & 0 & -X_1x_1 & -X_1y_1 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & -Y_1x_1 & -Y_1y_1 \\ x_2 & y_2 & 1 & 0 & 0 & 0 & -X_2x_2 & -X_2y_2 \\ 0 & 0 & 0 & x_2 & y_2 & 1 & -Y_2x_2 & -Y_2y_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_n & y_n & 1 & 0 & 0 & 0 & -X_nx_n & -X_ny_n \\ 0 & 0 & 0 & x_n & y_n & 1 & -Y_nx_n & -Y_ny_n \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \end{bmatrix} = \begin{bmatrix} X_1 \\ Y_1 \\ X_2 \\ Y_2 \\ \vdots \\ X_n \\ Y_n \end{bmatrix} \tag{9}$$

By this equation as proposed by A. Criminisi, I. Reid, and A. Zisserman [2], the plane of X and Y of could be determined and it gives the dimension of the Wiimote IR surface area as shown in Fig.2.
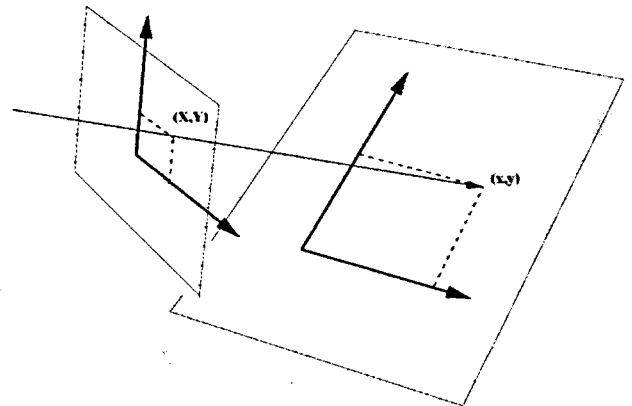

Figure 2: Quadrilateral of Image Plan and World Plane

After the area is defined by the Wiimote then the IR sensor from it will track any incoming IR sources, in this case, the IR-pen. The IR-pen was made from the hollow marker pen casing, and simple series circuit connection. The push-on button acts like a switch and its principle is similar to laser-pointer that is available on the market. A model had been fabricated as shown in Fig.3.
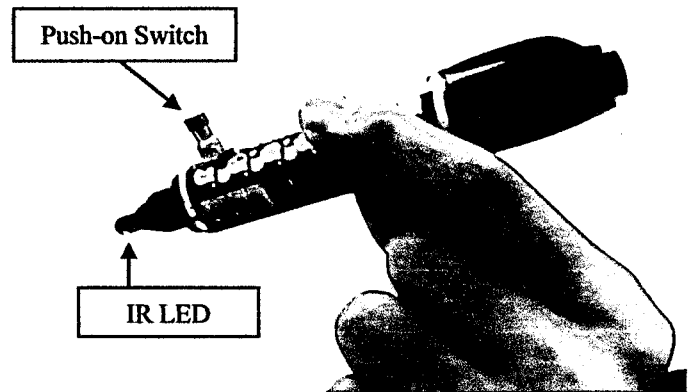

Push-on Switch

IR LED

Figure 3: IR-pen

From this application created by Dr. Johnny Chung Lee, many developers, entrepreneurs or even public community had taken their interest to make more research based on the capabilities that Wiimote has to offer. This growing community has been increasing from time to time; in fact more user-friendly programming application also had been created which is available to be explored. Next is the GlovePIE, which stands for Glove Programmable Input Emulator.

With this emulator made by Carl Kennel, writing a command for programming seems to be much easier. To implement this emulator for understanding the Wiimote principle, a simple Media Player Remote command has been made.

Once more, with this Media Player Remote, the Wiimote has been programmed to perform as a remote control or a mouse via Bluetooth communication. Each of the buttons has their own function, for example, if the user pressed button A, it is similar to clicking the left-side button of the mouse, and when the user pressed button B, it is similar to clicking the right-side button of the mouse.

III. WIIMOTE MECHANISM

To use the Wiimote as a signal receiver, communication with the Wiimote via a Bluetooth wireless link must be established. The Bluetooth controller is a Broadcom 2042 chip, which is designed to be used with devices which follow the Bluetooth Human Interface Device (HID) standard, such as keyboards and mice. The Bluetooth HID is directly based upon the USB HID standard. The Service Discovery Protocol (SDP) is one such protocol, but this protocol is itself a feature of Bluetooth where it provides a service to other Bluetooth devices to allow them to search for application services on a device.

The Wiimote does not appear to require any of the authentication or encryption features of the Bluetooth standard. In order to interface with it, one must first put the controller into discoverable mode by either pressing the 1 and 2 buttons at the same time, or by pressing the red sync button under the battery cover. Once in this mode, the Wiimote can be queried by the Bluetooth HID driver on the host. If the HID driver on the host does not connect to the Wiimote within 20 seconds, the Wiimote will turn itself off. Holding down the 1 and 2 buttons continuously will force the Wiimote to stay in discoverable mode without turning off. This does not work with the sync button, however. When in discoverable mode, all 4 of the Player LEDs will blink.

The IR Sensor inside the Wiimote is great for tracking infrared sources. It can track up to four sources independently and give out the coordinates and the strength of each tracked object. For incoming infrared signals, it can be detect by using a camera or webcam. This is due to the human eye spectral sensitivity. Normal human eye could see colours of it wavelengths are between 400 to 700 nanometers range [3]. Beyond that range or less is considered as non visible through the eye of the human and the relative intensity versus colors wavelength as shown in the Fig. 4.
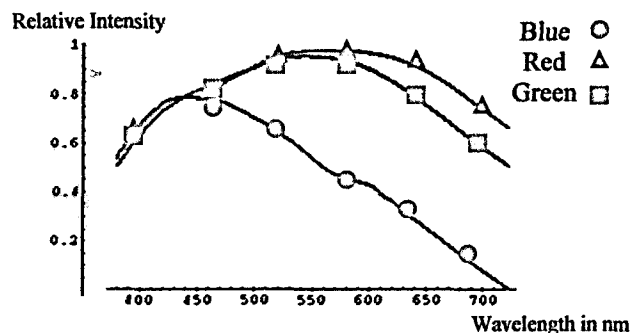

Figure 4: Wavelength Visibility Range

Infrared wavelength lies between visible and microwave portion of the electromagnetic spectrum. There are two category of infrared wavelength, one is the far infrared and near infrared. Far infrared also considered as thermal, in other words the infrared radiation which came from the heat. Heats from the fire, human body, sunlight were all classified under infrared radiation. Whilst near infrared were the shorter wavelengths and normally used in remote control, toys, automatic sensors and many more.

IV. HARDWARE AND SIMULATION

A. Hardware Design

By using the infrared LED, a head device had been designed. Stereo headphone had been used to ensure that infrared tracking would be more precise. Three LEDs mounted on the headphone represents the axis of X, Y and Z. The X and Y axis is the horizontal and vertical motion plane or the yaw and pitch plane. This plane covers 360° of angles, in other words, it is similar to head rotation from the front, left-side, back, right-side and to the front again.

In this study, we only take from 0° angle up until 90° of X and Y axis. This is also similar to the motion from front to the left, or front to the right. Below is the final design of the head device as shown in Fig.5.
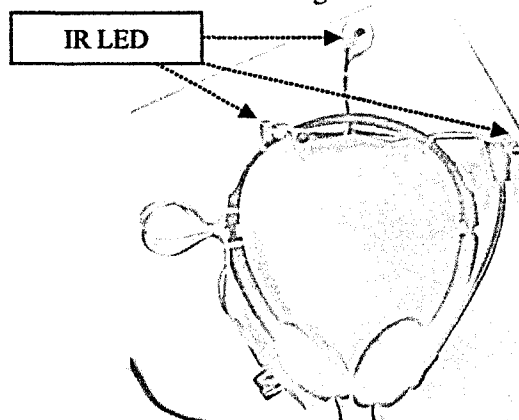

Figure 5: Infrared Head Device

Supplied voltage for this head device is 5V. The voltage is determined by using the multi-meter to check the voltage supplied across the Universal Serial Bus 2.0 (USB) cable. Besides checking it manually, the value also could be determined by referring to the datasheet provided. This is due to the standardized value for all USB 2.0 cable power supply.

Furthermore, the long cable from the USB could enhance the user movements or head motions. In other words, users could move freely without any restriction as the cable is one meter in length. If there were any changes made to improve the circuit, notice that the longest of the cable must not exceed more than five feet as it will result delays. However, the head device doesn't use any data transfer, thus the cable length wouldn't affect much on the voltage supply efficiency. At the end of the cable, a DC jack is mounted to improve the longevity of the circuit and to make it easy for storage.

After the process of determining the power supply value, next is the characteristic of the IR LEDs which can be referred from the datasheet. All the values for maximum and minimum current and voltage must be compliance with the whole circuitry system as it will ensure the performance of the IR LEDs. To ensure the performance of the IR LEDs, testing and debugging must be done by using the breadboard. From there, any mistakes in connections of the circuit, biasing of the power supply or resistivity of the potentiometer could be identified.

Selection of the IR LEDs is the main concern due to every IR LEDs has their own wavelengths. TSAL6400 is chosen mainly because of the characteristic that it has. More detail specification of the IR LEDs can be referred from the datasheet and Fig.6 below shows the bottom view of the fabricated circuit.
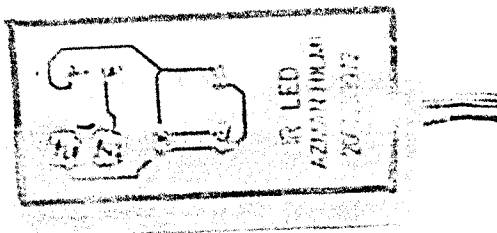

Figure 6: Bottom View of the Infrared LED Voltage Supply

B. Simulation Software

For the simulation process, a program is needed and the Microsoft® Flight Simulation X has been chosen. Main reason of why the simulation program is chosen due to its realistic surrounding and the aim for this project is the study of the wireless head tracking device.

There were two measurements taken, one is the human angular motion, and another one is the simulation angular motion or the actual angular motion. The head angular motion is taken from the emulator called FreeTrack.

Process of the simulation is started when the transmitter gives an input to the receiver, which in this case the infrared LED head device as transmitter and the Wiimote, or webcam, as receiver. What the transmitter does is it transmits the infrared signals, and then the receiver will capture the signals from the receiver.

Transmission or emission of the signals from the infra-red LEDs will be captured by Freetrack emulator. What the software does is it receives the signals, and then it will translate it as a motion of human. There were three axes of planes could be traced by the software which is X-axis, Y-axis and Z-axis, but for this study, only X and Y axis is considered for the analysis.

C. Flight Simulatoion using Wiimote

Before proceed to the measurement part, the sensitivity of the FreeTrack axis, or the required axis of the X and Y

axis is set to become double the actual head rotation. Method used were based on the Wiimote's IR sensor since higher sensitivity took only 45° of human head rotation to achieved 90° rotation in the simulator. This is explained further as shown in Fig.7.
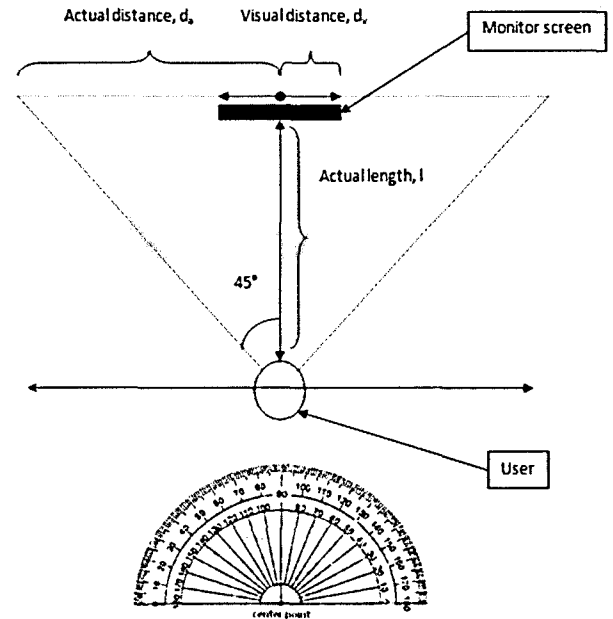

Figure 7: Top View of Head Angular Rotation in Real-view for Simulation

These two measurements taken by calculating its distance,

$$\tan\theta = \frac{Actual\ distance, d_a}{Visual\ distanced_v}$$

(10)

applying the algebraic theorem, hence we could obtain the angular of the simulation,

$$\theta_v = tan^{-1} = \frac{Actual\ distance, d_a}{Visual\ distanced_v}$$

(11)

the product of visual angular is then multiplied by two to obtained the actual angular,

$$\theta_a = \theta_v\ x\ 2$$

(12)

The actual angular calculated is multiplied by two since the sensitivity in the emulator had been increased twice its original sensitivity.

D. Flight Simulation using Webcam

Similar as the Wiimote's concept used, the angular of actual simulation could be determined by measuring the visual simulation distance, and then the visual angular obtained is multiplied by two.

Since the webcam doesn't have an IR filter, it could track other infrared sources. The webcam threshold must be set high as possible so that it could make the outer source of infrared signals almost nil. The simulation process and

calculation of actual angular was done by using equation (10).

V. RESULTS AND DISCUSSION

There were two parts of the result, one is from the Wiimote simulation and another one is from the webcam. Data taken is followed by tabulation to observe the linearity between human motion and simulation motion. The graph represents the head angular motion against the actual angular motion. Theoretically, the head angular motion and actual angular motion is directly proportional as in Fig.8 shown.
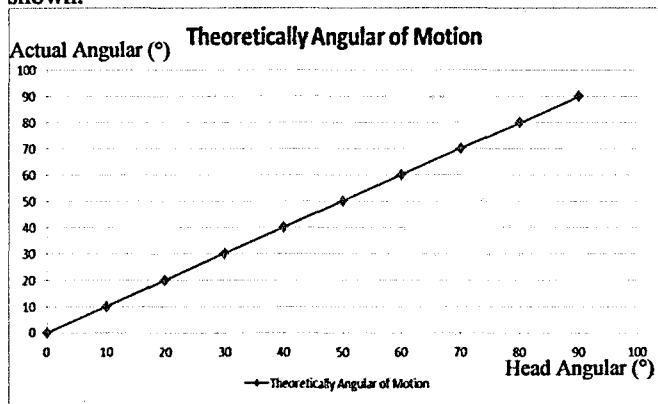

Figure 8: Graph oh Head Angular Motion against Actual Angular Motion

The graph describes the relativity of human motion and the simulation motion as the head moves toward certain angle, the simulation program will act in response. It means the corresponding angle of the simulation was a result from the head movement or motion.

A. Wiimote Simulation Result

The motion data were measured from 0° until 90° of human head rotation taken the Wiimote as the receiver. It has yielded an excellent output as the user moves and the simulation program also move accordingly. A sample showing movement of 0°, 10° and 20° as shown in Fig.9.

Figure 9: Simulation for First Person View for Wiimote

It is observed that the simulation went smoothly as the head moves, the simulator program moves consequently. The IR sensor from the Wiimote could attain up until 70 and above frame per seconds (fps). This fps determined the performance of the simulation, with a higher rate producing smoother signal detection. The actual angular motion calculated is next tabulated to construct the output graph of the Wiimote performance.

As expected, the result shows a very good performance as its linearity is close to the theoretical angular motion linearity as shown in the Fig.10.
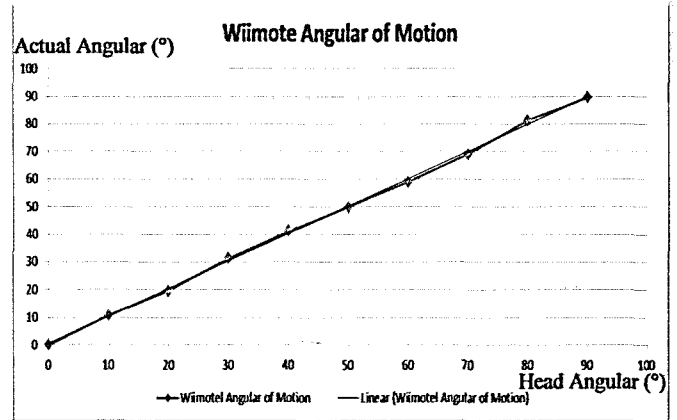

Figure 10: Graph Head Angular Motion Against Actual Angular of Motion

B. Webcam Simulation Result

Unlike the Wiimote, a lot of noises present during the measurement and the outcome from the analysis were interrupted. This is due to the webcam unavailability of an IR filter. An IR filter is the key element in filtering any excessive infrared signal coming from other sources, for example the sun glare or reflected light from the computer screen. The effect of noise is recorded and the results obtained and a sample is taken showing movement of 0°, 10° and 20° coming from the webcam as shown in Fig.11.
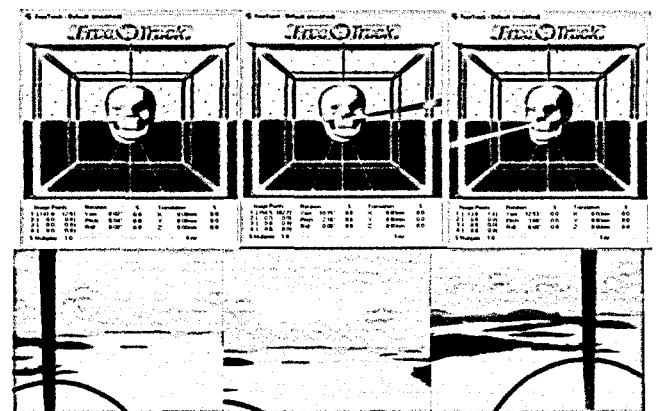

Figure 11: Simulation for First Person View for Webcam

After a few set-ups in the webcam camera option, the noise had been reduced and the data could be retrieved and

tabulated. The tabulated data is taken to construct the output graph of the webcam performance. However, the fps for the webcam could not be altered and the highest fps achieved is only seven and graph of the output as shown in Fig.12.
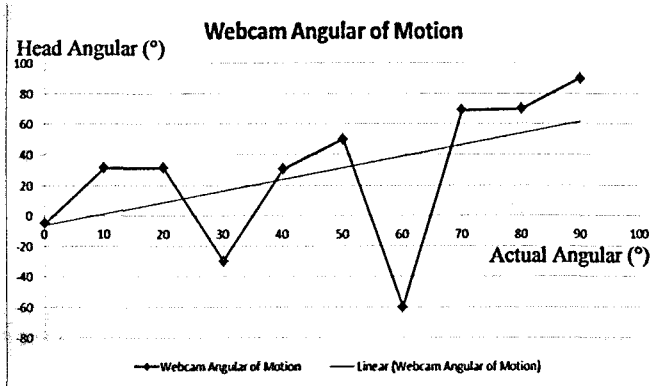

Figure 12: Graph of Head Angular Motion Against Actual Angular of Motion

C. Mean Square Error

In order to determine which one of the device could perform more efficient than another, the mean square error (MSE) is calculated. MSE measures the average of the squares of the "errors." The error of the value indicated by the estimator differs from the value to be estimated. The difference happens because of randomness or because the estimator doesn't account for information that could produce a more accurate estimation. Thus, the data for Wiimote and webcam is tabulated and the MSE is calculated to prove that the error is less, as shown in Table 1 and Table 2.

Table 1: Mean Square Error of Wiimote

Angular Motion (°)				
Head (x-axis)	Actual (y-axis)	Estimated Actual (y')	Error (y-y')	MSE (y-y')²
0	0	0	0	0
10	10	10.8	-0.8	0.64
20	20	19.7	0.3	0.09
30	30	31.3	-1.3	1.69
40	40	41.2	-1.2	1.44
50	50	49.9	0.1	0.01
60	60	59	1	1
70	70	68.9	1.1	1.21
80	80	81.4	-1.4	1.96
90	90	89.5	0.5	0.25
			Σ(MSE)	8.29
			Σ(Avg.)	0.829

Table 2: Mean Square Error of Webcam

Angular Motion (°)				
Head (x-axis)	Actual (y-axis)	Estimated Actual (y')	Error (y-y')	MSE (y-y')²
0	0	-5	5	25
10	10	31.4	-21.4	457.96
20	20	31.4	-11.4	129.96
30	30	-29.8	59.8	3576.04
40	40	30.5	9.5	90.25
50	50	50	0	0
60	60	-59.9	119.9	14376.01
70	70	69	1	1
80	80	70	10	100
90	90	89.9	0.1	0.01
			Σ(MSE)	18756.23
			Σ(Avg.)	1875.623

The mean error square is 0.829 for the Wiimote which is close to zero, thus the result from the Wiimote has the high accuracy in terms of head angular motion and the actual angular motion compared to webcam. It also indicates that the Wiimote has the high capabilities to perform as a receiver for the infrared signal.

VI. CONCLUSION

A full simulation via software and hardware has been demonstrated to show that it is compliant with any other simulator available in conventional air-academy flight-simulator. With this demonstration, the current conventional simulator could be improvised so that the realistic view inside the simulator could be achieved, thus increasing the ability of the pilot to navigate airplane. Since the realistic view could be achieved by using the Wiimote technology, hence the familiarity with the surroundings also could be increased to the pilot's ability as the view of the simulation is not restricted only inside the cockpit screen. The pilot may be seated comfortably while viewing around, inside or outside, as if navigating a real air plane.

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