Visual and Gyroscope Sensor for Head Movement Controller System on Meal-Assistance Application

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ABSTRACT:
Head movement utilizes gestures to aid people with disabilities so that they can have hands-free human-computer interaction. Currently, motion-based sensor is the most widely used approach to recognize head gestures. Identification of head movement is important to control a robotic manipulator in an assisting device. However, the most effective methodologies to assess head angular movements are yet to be discovered. This paper combines two algorithms, the visual sensor and the gyro sensor, to identify head orientation movement with high precision. Head orientations were measured using data distribution and this was done with a meal-assistance robot manipulator used in a sitting position. Evaluation of the accuracy of the system shows a visual sensor and gyro sensor. Experimental results show that a correct head movement with the average accuracy is 82%. Therefore, we propose the application of position control of meal assistive robot based on user's head movement in a sitting position.

KEYWORDS: Head Movement, Position Control, Assistive Robot, Visual Sensor, Gyro Sensor.

1. INTRODUCTION

In a rehabilitation centre, human-computer interaction plays a key role in assisting handicapped patients operating electronic devices such as an assistive robot [1]. Providing aid to a disabled person who cannot use his/her hand means a reliance on other body parts like the head. Human-computer interaction using head gestures is a hands-free approach that works by providing initial input to control a robotic manipulator from the recognition of the head movements. A motion-based sensor is by far the most widely used head movement identification.

Head movement can be identified in different ways, such as by using a vision-based and sensor-based approach. A vision-based measurement detects and identifies the characteristics of objects such as head, face or other human body parts, by using a camera that produces image sequences [2]. Recorded image data of the objects becomes the basis to determine the position and the orientation of the head. Such identification can subsequently be used to provide commands to desired electronic devices. This method has been widely used and it determines head angular movements by locating the facial features i.e. eyes, mouth, or nose [3] and the passive markers [4].

As described in [5] and [6], head movement sensor-based detection can be operated either with an inertial technique or a bio-signal technique. The former senses acceleration and rotational forces to measure pitches, rolls, and yaws of an object. Bio-signal sensor systems are commonly used to detect human body movements, such as detecting the muscle electromyography signal. The sensor records a user's muscle potential in voltage and evaluates the movements based on the head's flexion. However, determining head angular movements remains a challenge and so does the implementation of this measurement in assistive devices. Research has been conducted to examine head gestures used by people with disabilities. Nabati et al. [7] examined head pose estimation based on image processing and pattern recognition in front of a horizontal plane to make a mouse pointer control. Tolle and Arai [8] used head

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movement detection as a controller of mobile devices. The system shows user movements on a 3D image display when a mobile phone is mounted on user's head. Davy [9] used pattern recognition of head movement data from an accelerometer sensor placed inside of a hat. From the findings, he suggested using dual-axis to enhance head movements that were presented as 2D information.

According to Zhang [10], head movement controller systems can help people with disabilities in their daily lives, especially to assist eating and drinking of those with disabilities in their upper limbs. To do this, head movements can be detected by a camera attached on the interface of meal assistance robot controller.

The movement data is needed for making instructions to the robotic controller that assists the user's eating and drinking. Camera as a visual sensor is placed in front of a user's face to capture the movements and then, the images are sent to the processing program to detect the user's head flexion. Gyroscope sensor is mounted on the head to recognize its movement. The signal pattern system analyses the head pose estimation from the movements. This method has been tested in other parts of human body. In our previous work, we proposed a leg swing detection system as a controller to design a robotic leg [11]. Bio-signal sensor system has also been implemented to detect biceps muscle activity in determining arm movement [12].

Head movement controller system proposed in this study is expected to improve the control of meal-assisting devices so that they become hands-free. The aim of this study is to examine and compare each head movement from different users in a sitting position. The main objective of this research is to develop a head movement controller system in a meal assisting device by using a combination of visual and gyroscope sensors. The combination was expected to improve the precision of the recognition of head orientation and movement.

2. DESIGN OF HANDS-FREE CONTROL SYSTEM

A hands-free control system works with a microcontroller device that is equipped with an inertia sensor such as a gyroscope. This is then integrated with a camera and a digital image processing system to recognize human head and eye movements. Users can control the device by moving the head to a certain direction. Detected head movement data from both visual and gyroscope sensors will then be collected and analysed.

2.1. Block Diagram Visual and Gyroscope Sensor for Head Movement Controller System

As shown in Fig. 1, the system block diagram consists of two main parts. The first part is the Logitech C270 webcam camera which aims to capture facial movements. The second part is the MPU6050 gyroscope sensor to detect user's head movements. Data from the camera is processed by a computer by using OpenCV digital image processing program. Data from the gyroscope sensor is processed by using a microcontroller device and sent to a computer via a serial data connection. Both sets of data will then be used to map the head movements so that they can be categorized in accordance with the direction of the head. With this, controls to position command can be determined

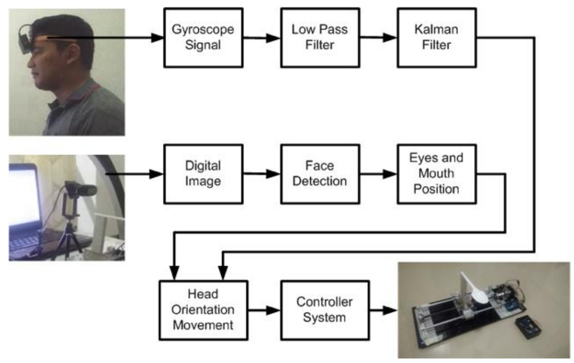

Fig. 1. Block diagram of the visual and gyroscope sensor of the head movement controller system.

2.2. Wearable Gyroscope Sensor Device

As shown in Fig. 2, the wearable gyroscope sensor device detects user's head movements. The data from the sensor in the form of inertia movement will then be converted into digital data and sent to the control unit in the meal robot assistance manipulator via serial communication.

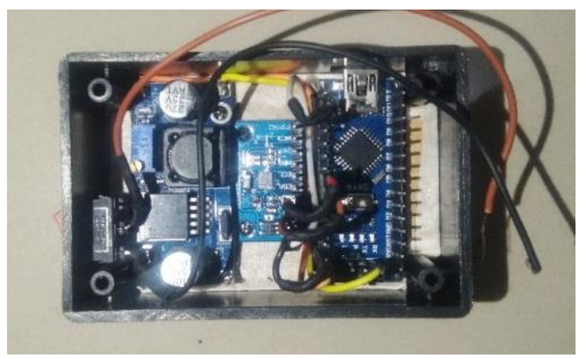

Fig. 2. The wearable gyroscope sensor device.

This device is worn as a headband attached to the forehead perpendicularly. The device is placed on a nine-volt battery with a five-volt regulator, which serves as a power supply for the sensor and the microcontroller. Then in the data transmission system, there is a serial cable that functions as a data transmission medium when the system detects a movement.

The head movement detection system uses the IMU

MPU6050 sensor, which consists of a gyroscope and an accelerometer sensor. Kalman filter is a complex filter algorithm that takes measurements that still have noise. This Filter has two steps, namely prediction and correction. The prediction step is expressed by the equation (1).

$$\hat{X}_{k+1} = A_k\hat{X}_k + B_k U_k \quad (1)$$

The correction step is shown by the equation (2).

$$\hat{X}_{k+1} = \hat{X}_k + K_k\hat{y}_k \quad (2)$$

Where, $\hat{X}_k$ is vector state, U_k is control input and A_k $and\ B_k$ each is a transition matrix of the vector associated with it. Raw sensor data will be processed using a complementary filter and Kalman filter to make it more stable. Subsequently, the stable data will be put into direction-based categories. The pitch and yaw signals from gyroscope sensor are shown in Fig. 3.

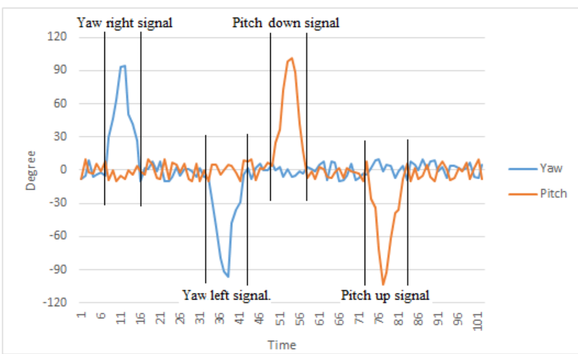

Fig. 3. The pitch and yaw signals from gyroscope sensor.

2.3. Vision-based Head Orientation Estimation

Most of the face tracking methods are based on eye detection approach, like [13][14][15]. Ramezanpour et al. [16] introduced an eye detection technique used to approximate region of the eye from the image by skin-color information and used it in the application of face recognition to gaze tracking. Face tracking is done by using vision-based head orientation estimates. The system used in the current research tracks the facial position by using a camera that captures digital images. These images will then be processed to be positions of pixel coordinates. Meanwhile, head orientation estimates are derived from the coordinates of the eyes and the mouth. The computer programs are designed by using Microsoft Visual Studio and OpenCV programs, and using the Haar Cascade algorithm for facial recognition that detects the position of the eyes and the mouth. As shown in Fig. 3, these three positions are marked by a circle with a centre point. With a three-point parameter, it forms a letter T which can be used as a proxy to determine the head orientation estimates.

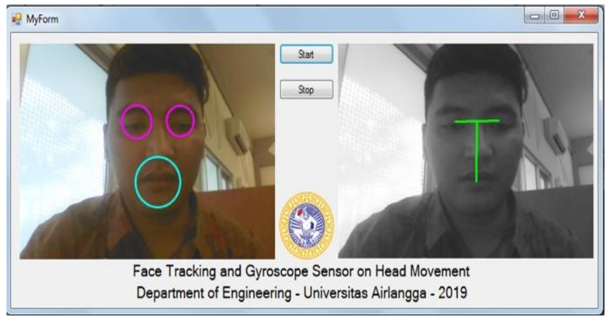

Fig. 3. Vision-Based head orientation estimates.

With the letter T parameter, as shown in Fig. 4, the face and head orientation estimates are calculated by comparing the distance between a, b and c by using a calibration procedure.

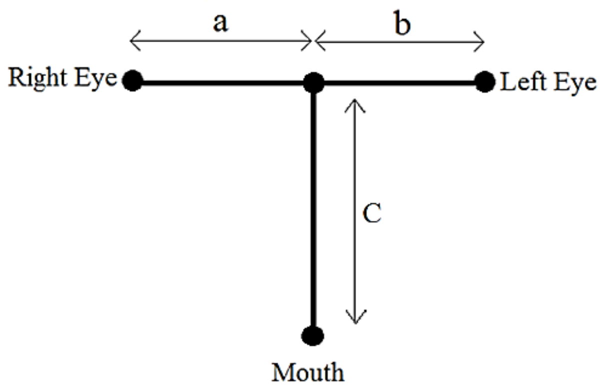

Fig. 4. Letter T parameter from eyes and nose.

2.4. The Algorithm of Control Commands

Head movement information processing is a method to detect and identify the head orientation based on the analysis of the movements of yaws, rolls and pitches. Left and right movements are only affected by the yaws. The system will record yaw's angle that is higher than a certain threshold. The yaw's basis line is the horizontal direction. Meanwhile, the up and down movements, the vertical directions, are determined by the pitches. Illustration of the head's vertical and horizontal movements are shown in in Fig. 5.

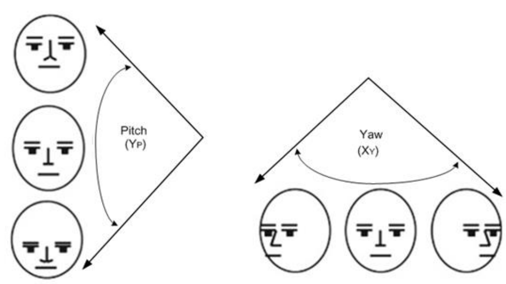

Fig. 5. Illustration of head movement vertically and

horizontally.

By using the visual sensors derived from the head movements, commands could then be identified. The data consists of head pitch down, head pitch up, head yaw right and head yaw left. Meanwhile, reference commands collected from the gyroscope sensor signal include gyro down signal, gyro up signal, gyro right signal and gyro left signal.

Based on the data of the head movements, commands can be made to adjust the meal assistance robot positions. The control commands are: control command down, control command up, control command right, control command left and control command disabled. The algorithm of the control commands is as follows:

1. If <head pitch down> and <signal gyro down> then <control command down>
2. If <head pitch up> and <signal gyro up> then <control command up>
3. If <head yaw right> and <signal gyro right> then <control command right>
4. If <head yaw left> and <signal gyro left> then <control command left >
5. then <disable control command>

3. EXPERIMENTAL RESULT

The experimental environment setup on our hardware configuration is depicted in Fig. 6. The camera as a vision sensor was placed on top of the display and the gyroscope sensor was attached onto user's forehead perpendicularly. This experiment was carried out to compare the angular values generated by a vision sensor and a gyroscope sensor with a predetermined slope. The head orientation changes in angular direction were the angles of + 30°, + 15°, 0°, -15° and -30° for both pitch and yaw movements. The Accuracy evaluation of head orientation based on each sensor is presented in Table 1 and Table 2.

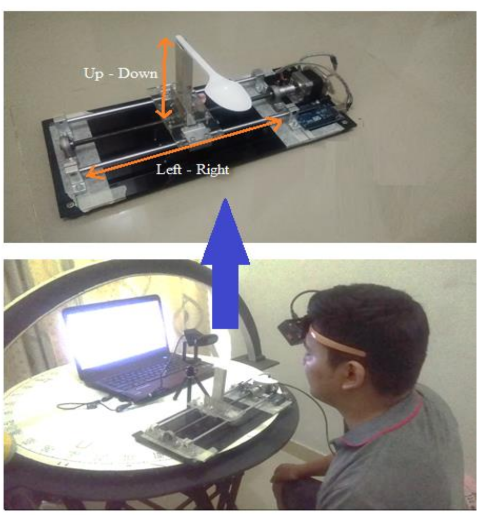

Fig. 6. Experimental environment setup.

Table 1. Accuracy evaluation of head orientation based on visual sensor.

Head Orientation	Desired Degree	Error Average	Accuracy
Pitch	+30°	0.63°	97.91%
	+15°	0.45°	97.00%
	0°	1.87°	98.13%
	-15°	0.39°	97.42%
	-30°	2.34°	92.24%
Average Accuracy Pitch			96.54%
Yaw	+30°	1.77°	94.13%
	+15°	1.24°	91.71%
	0°	1.95°	98.05%
	-15°	1.88°	87.47%
	-30°	1.79°	94.03%
Average Accuracy Yaw			93.08%

Table 2. Accuracy evaluation of head orientation based on gyroscope sensor

Head Orientation	Desired Degree	Error Average	Accuracy
Pitch	+30°	4.37°	85.43%
	+15°	1.45°	90.33%
	0°	2.98°	97.02%
	-15°	4.03°	73.13%
	-30°	3.45°	88.51%
Average Accuracy Pitch			86.88%
Yaw	+30°	7.91°	73.63%
	+15°	3.59°	76.07%
	0°	2.29°	97.71%
	-15°	1.55°	89.67%
	-30°	5.67°	81.12%
Average Accuracy Yaw			83.64%

The results show that the accuracy of the angle value using a visual sensor is relatively good, with an average accuracy of 96.54% for the pitch angle, and 93.08% for the yaw angle. The reading average accuracy of the gyroscope sensor was 86.88% for the pitch angle and 83.64% for the yaw angle. Measurement errors in the camera sensor were caused by non-optimal lighting. Errors in the gyroscope sensor were caused by noise produced by biased effect on the gyroscope and the noise that disturbed the testing process.

Tests on the detection of head movements were carried out to determine their characteristics. Experiments results are collected from 10 users trying to use the head movement controller system with head pose movement control. To get the results of the angle value when making certain movements, users stay put and look straight forward, or make movements such as looking to the left, looking to the right, looking up and looking down. The observed data was presented as a range of angle values shown on the Y-axis (for the pitches) and on the X-axis (for the yaws). The results of head movement detection using a camera and a gyroscope sensor are shown in Table 3 and Table 4.

Table 3. Results of head movement detection using the visual sensor.

Head movements	Y-axis Minimum Angle (Pitch)	Y-axis Maximum Angle (Pitch)	X-axis Minimum Angle (Yaw)	X-axis Maximum Angle (Yaw)
Head Yaw Left	+1.26°	+2.63°	-13.12°	-31.32°
Head Yaw Right	+1.44°	+2.12°	+18.37°	+34.40°
Head Pitch Up	+14.64°	+31.57°	+1.24°	+1.76°
Head Pitch Down	-14.80°	-36.17°	-2.67°	+2.75°
Head Not Move	-1.87°	+2.71°	-3.78°	+1.95°

Table 4. Results of head movement detection using the gyroscope sensor.

Head movements	Y-axis Minimum Angle (Pitch)	Y-axis Maximum Angle (Pitch)	X-axis Minimum Angle (Yaw)	X-axis Maximum Angle (Yaw)
Head Yaw Left	-2.37°	+3.12°	-13.45°	-39.76°
Head Yaw Right	+4.45°	+1.24°	+18.59°	+34.40°
Head Pitch Up	+12.52°	+33.50°	-1.67°	+2.58°
Head Pitch Down	-10.97°	-34.20°	-1.14°	+2.63°
Head Not Move	-2.98°	+1.09°	-4.48°	+2.29°

The results of the head movement reading of the data obtained from the camera can be seen in Table 5. The results show that the angle value of each movement, namely turning left and turning right displays differences with an X-axis range of -31.32 ° and -31.32 °. As for the Y axis, the maximum value of looking up was + 31.57 ° and looking down was -36.17 °.

From the gyroscope sensor, the reading test results of head movement show that maximum angle of the X-axis (the yaws) when turning left was -39.76 ° and turning right was + 34.40 °. Meanwhile, the maximum angle of the Y-axis (the pitches) when looking up was + 33.50 ° and looking down was -34.20 °. These maximum and minimum ranges emerged because of the differences in the users' physical conditions that affect their ability to move their necks.

Table 5. Response test results using head movement.

Head movement	Control Command	Total Tests	Correct	Incorrect	Accuracy
Head Yaw Left	Left	10	9	1	90%
Head Yaw Right	Right	10	8	2	80%
Head Pitch Up	Up	10	9	1	90%
Head Pitch Down	Down	10	7	3	70%
Head Not Move	Disable	10	9	2	80%
Average Accuracy Response Test					82%

The accuracy parameter is used to evaluate the performance of the proposed method of detecting user head movement. Accuracy is the overall success rate when the user moves the head into a particular movement. The system responds with corresponding control commands on the application. Response test results, as shown in Table 5, show that the success rate in particular head movement with the average accuracy is 82%.

4. CONCLUSION

Head motion control based on facial movements can be created by using a combination of vision sensor and gyroscope sensor data. This approach stems from the principle of the angular momentum. The testing of pitch movements and yaw movements using face tracking shows that pitch angles were prone to an average error of 1.91° and yaw angles an average error of 1.76°. Regarding the gyroscope sensor, the reading shows an error value of 2.95° for the pitch angle and 4.17° for the yaw angle. The results of the vision testing of the left and right movements show an X-axis of -31.32° and -31.32°. As for the Y-axis, looking up and down was + 31.57° and -36.17° respectively. The gyroscope sensor shows a maximum X-axis angle of -39.76° when looking left and +34.40° when looking right, +33.50° when looking up and -34.20° when looking down. Measurement error from vision sensor was caused by lighting factor and the gyroscope sensor was caused by noise from the refractive effect of the gyroscope. Experimental results show that a correct head movement with the average accuracy is 82%.

5. ACKNOWLEDGMENT

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