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RESEARCH ARTICLE

Integrated Hand and Eye Communication Device for Intensive Care Unit (ICU) Patients

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ABSTRACT - Numerous Intensive Care Unit (ICU) patients may be unable to speak or move their body due to being intubated or weak muscles. This makes communication to be harder, as they are voiceless in expressing their thoughts and needs. This study focuses on the development of an integrated hand and eye communication device based on hand gesture recognition and eye movement tracking with an output display. The device comes with a dual mode, where the hand gesture and eye movement are detected using flex sensors and reflectance sensors respectively. Arduino Uno is used as the microcontroller and the output window is programmed using Java programming language. Four messages communicated in ICU patients are installed on the system. The device has been tested at the laboratory stage with healthy subjects. The results with healthy individuals in the laboratory validate that the device is successful in conveying the intended messages correctly for all trials. The resulting sensors measurement curves are consistent across all subjects and messages. The developed device will contribute towards a better communication between the patients and healthcare providers, leading to a more convenient and efficient patient care.

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1.0 INTRODUCTION

Communication device for weak Intensive Care (ICU) patients or those who are unable to move at all or impaired, refers to any assistive tool that helps a person with disabilities such as hearing loss or voice, speech or language disorder, physical or brain damage and others to understand things clearly and express thoughts easily.

Over 50% of patients reported the difficulty to communicate to be moderate to extremely stressful levels. Ineffective communication is constantly linked to the patients' negative emotion such as frustration, fear, anxiety and anger. The frustration then led to the patients to give up expressing their needs and instead, limit their communication to only essential information [1]. The healthcare staff might speculate the signals given by the patient and end up making the wrong decision and not addressing their messages correctly. As a result, the patients' stress level increased, which will in turn affect the current treatment, care and recovery process. Other than the inability to express their thought, the patients also have the difficulty to understand and respond to the information conveyed by the healthcare providers about their own condition and treatment procedures.

For ICU patients, the inability to move or speak after surviving critical and life-threatening situations can be stressful. Some of them are relying on the mechanical ventilation, which causes them to be unable to speak. Some of them do not have the strength to move their bodies due to muscle weakness. Most of the time, they can only move their eyes or fingers a little bit. Post ICU is an important recovery phase for the patients, in which, if it is not attended properly, their health condition could become worse. Many healthcare staffs are struggling to attend to the ICU patients' requests due to the difficulties in understanding their messages. Due to these reasons, a communication device that facilitates the communication between the ICU patients and the healthcare provider is crucial. The patients need to be able to express their needs clearly so that they can be attended accordingly, and this may lead to lower stress level and a smoother recovery process.

Communication device is as a tool used to improve the communication between the patients and health provider. These tools can be grouped under augmentative and alternative (AAC) strategies, which can be categorized into low and high technologies. In the low AAC technologies, patients with preserved cognition and fine motor abilities are given a pen and a piece of paper to write. If the patient is unable to write, communication boards consist of icons and pictures are

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available for them to convey their messages. Low technology only requires the patients to either write or point. High-technology AAC enables the communication to be done through a handheld device such as speech-generating device or voice-output communication aids. Navigations through the device can be done through buttons, mouse-clicking, touch screen or eye-tracking systems. This message will be delivered, which can be read or amplified by the voice synthesizer. The technology also incorporated language translator and Internet connectivity that allows the utilization of social media and computer functions.

This study focuses on the development of an integrated hand and eye communication device for post ICU patients with dual communication modes: (i) hand gesture detection and (ii) eye movement tracking. This device can be utilized interchangeably according to the patients' conditions. It can be used under the bright light and in the dark. Data are collected from flex sensors and reflectance sensors for the communications based on hand gesture detection and eye movement tracking respectively. The device is also accompanied with an output display screen showing the patient's messages, which makes it easy for the healthcare providers to understand them. At this stage of study, tests have been conducted on the developed system with healthy subjects in the laboratory.

The rest of this article is organized as follows: Section 2 presents the previous related works on hand gesture recognition and eye movement tracking; Section 3 describes the conceptual design of the prototype including its block diagram, components, electrical circuit and operational sequence. Results and discussions are presented in Section 4 and finally conclusion is drawn in Section 5.

2.0 RELATED WORK

This part provides a brief overview of the previous communication devices and are divided into two categories, which are the systems based on hand gesture recognition [2]- [8] and eye movement tracking [9]-[14].

2.1 Hand Gesture Recognition

Glove-based method

Lee et al. [5] designed a smart wearable hand-gesture recognition device that utilizes the dynamic time-warping (DTW) method. The device consisted of three IMU sensors placed on the thumb and index finger to detect the fingers and back of the hand for hand movement. The gestures are detected by the sensors, in which the data are processed in Arduino Pro Mini 328 and analyzed using DTW method. The results are then transmitted to mobile application via Bluetooth. Before testing the device, the DTW model must be trained for the gesture recognition. The system determines the optimal matches through a temporal transformation technique. Six gestures had to be performed five times before taking the averages to be stored in the training dataset. The result shows that the device can achieve a mean accuracy of 93.19%. However, only six simple gestures performed by the thumb and index finger can be recognized due to the utilization of only three sensors.

With the aim of providing a communication system for people with speech disability, Gajul et al. [6] developed a wearable assistive vocalizer, comprised of gesture sensing module on the wrist and a portable speech synthesizing module. The Gesture sensing module has a data glove mounted with ADXL335 accelerometer at the back of hand and flex sensors along the fingers. Data captured by the sensors are then processed by microcontroller that assigned a message to a respective gesture. The message is transmitted to the receiving module wirelessly through 433.93 MHz RF receiver and transmitter which will result in audio playback and LCD display of the message. PIC24FJ64GB002 is used as the text to speech module. Delay is applied at a certain time interval while fetching data from the sensor module to reduce the error of taking unwanted gesture while switching from one gesture to another. By incorporating wireless transmission, the device ensures portability as far as 30 m. The messages have been delivered perfectly without any error. Instead of the usual one-to-one communication, the person now can be involved in a community talk using this system.

Vision-based method

Fayyaz et al. [7] proposed an idea of adjusting hospital bed position by hand gesture through an image processing method. A webcam embedded to the computer or tablet is placed in front of the bed to create computer vision system. The captured imaged is sent to Arduino UNO through Bluetooth. A DC motor is connected to Arduino UNO and the bed to adjust the angle of the bed following the hand gesture. The system achieved an accuracy of 95%.

Kinect based real time gesture recognition system has been built in [8]. The system is made of three subsystems, namely image acquisition, segmentation and fingertip and canter of palm detection. During image acquisition, a depth sensor of the Kinect acquired the 3D position of hand. The sensor captures depth and colour images simultaneously, in which the depth helps to segment the area of interest from the whole body. After the segmentation, the fingertip and the center of the palm are calculated. These points are compared to the pre-defined gestures. If it is a match, it will be used to manipulate objects on desktop. Hidden Markov Model (HMM) is trained to recognize the gestures. The important key points in training HMM are the position of the palm, fingertips and the angles between corresponding fingers. As a result, the system accomplished an accuracy of 89% with more than 1200 gestures being used in the training process. The drawbacks of this system are it only works as far as 1 m at best and there are some noises during the calculation of the center of the palm that affect the performance of the system.

2.2 Eye Movement Tracking

Abu-Faraj et al. [13] focus on developing a low-cost eye tracking system as an alternative for a completely locked-in patient to communicate. The system used a head mounted webcam namely Genius from KYE Systems Corp. to capture real-time image of the eye. Despite having a low-cost, the camera is a good match in terms of resolution and sensitivity. The external part of the camera was altered to lessen the weight so it can fit on a headset. The headset is made of a simple mechanical framework with the camera lens mounted 5 cm away from eyes and connected to a notebook via USB port. The captured image of the eyes is developed by MATLAB, which in return will give the coordinates of the pupil. The user interface is developed using JAVA programming language to display pictograms that will aid the communication. The message is conveyed through an audio playback. The system achieved an accuracy of 96.11 ± 5.58% and repeatability of 94.44 ± 2.51%. The system exhibited a good performance despite of the low-cost hardware. It is easy to operate with a little bit of training and does not burden the patient. The only drawback is, since it requires a screen, it might be disadvantageous for bedridden patients. They cannot look at the screen on their own unless someone hold it for them or there is a mechanical support for the screen.

Garand et al. [14] worked on a low-cost wireless eye tracking system consisted of a head-mounted portion (headset), an interface to a personal computer (PC) and PC software for configuration. The image sensor is typically used for optical light ranges, but it can also detect lower frequencies into the infrared region, which will aid greatly in tracking the pupil. The image is captured by the camera directly from the eyes. The system uses a frame grabber to capture frame-by- frame images from the camera. The frame grabber converts the analog output of the camera image into a digital signal through its USB output. Then, the system uses a TI EZ430- RF2500T target board to perform some signal processing and transmit the data wirelessly to a PC where software will further process the signal, track the pupil and display the results. The camera is attached to the hat with screws and bolts, which will allow the system to be adjusted to focus on the eye. The brim of the hat is trimmed down to let the light shine on the eyes to increase the visibility of the image. The microcontroller software consists of two different programs running in parallel on two MSP430F2274 microprocessors. Each processor is included in an evaluation module, together with a CC2500 2.4GHz RF transceiver, which is used as the communication link between the two processors. The image is compressed to transmit it to the PC. The software in the PC will reconstruct the camera frame and calculate the center of the eye in the picture.

Most of the previous works have good performance and high accuracy in transferring a person's message using the electrical devices. However, they can only translate the information from either the hand gesture or eye movement. The systems that are based on hand gesture recognition are less suitable for patients who are weak and unable to move their hands, whereas some systems that are based on eye movement tracking may need screens, which can be less comfortable and accommodating for the bedridden patients. Due to the various severity of ICU patients' conditions, they have different levels of ability during their stay in the hospital wards. Some of them can lift their fingers, while others are only able to move their eyes and unable to make any motions by themselves without the assistance from others.

This study proposes an integrated communication device based on hand gesture recognition and eyes movement detection to provide more options for the ICU patients to communicate their needs. The device will help the healthcare providers to understand and cater the patients' necessities better. The system can be utilized both under the light and in dark environment.

3.0 CONCEPTUAL DESIGN OF INTEGRATED COMMINUCATION DEVICE FOR ICU PATIENTS

3.1 Proposed Design

The developed communication device set up is shown as in Figure 1. It consists of a microcontroller Arduino UNO R3, three flex sensors connected in series with 220 Ω resistors and two reflectance sensors. Arduino UNO R3 is used as the microcontroller for this device. It consists of 6 analog inputs and 14 digital inputs, which are sufficient to accommodate all the input and output components required. The power is supplied to the microcontroller by connecting it to the computer using USB cable or attaching it to the batteries. The flex sensor is of 2.2-inch-long and used to obtain data from the hand gesture. Its resistance increases whenever the fingers are flexed or bent. The flex sensor is connected in series with a fixed value resistor of 220 Ω to create a voltage divider circuit. With this method, a variable analog voltage can be read by the Arduino. The resistance of the flex sensor can be obtained from the equation of the voltage divider,

$$V_{220} = V_s \frac{220}{220 + R_{flex}} \tag{1}$$

where V_{220} is the voltage across the 220 Ω resistor, V_s is the voltage across the voltage divider and R_{flex} is the resistance of the flex sensor. Rearranging Equation 1, R_{flex} can be obtained by

$$R_{flex} = 220\ (V_s / V_{220} - 1) \tag{2}$$

QTR-1A reflectance sensor is used to track the eye movement. It consists of a single infrared light emitting diode (IR LED) and a phototransistor pair mounted on a tiny module. IR LED is the most important component for eye tracking. When IR LED emits radiation, it reaches the pupil of the eye. Some of the radiation is reflected on the photo detector. The resistance and output voltage of the photo detector change proportionally to the intensity of the radiation received. The reflectance sensor's operating range is 5 V and its optimal sensing distance is 3 mm. Its dimension is small, which is 0.3-inch x 0.5-inch x 0.1 inch and can be attached to the spectacles. Referring to the block diagram in Figure 2, the flex sensors and reflectance sensors act as the input to the system while the window display with the messages from the patients serve as the output of the system. This window display has been programmed using Java language. Three flex sensors are attached to a right-hand glove, at the thumb, index finger and middle finger as depicted in Figure 3. Its resistance is measured with respect to the finger's bending angle. The reason for choosing these three digits is because they are the most dominant digits in providing the required hand movements compared to the other fingers. The flex sensor acts as a variable resistor, in which the resistance varies according to the bending angle. In Figure 4, two reflectance sensors are attached side by side on the right side of a reading glass at the corner of the eye. The IR LED on the reflectance sensor tracks the eye movement by the reflected light on the pupil of the eye. When the pupil approaches the sensor on one side, the reflected light decreases. The pupil moves away from the opposite sensor and the reflected light increases. This working principle tracks the eye movement, whether it is moving to the right, left or blinking.

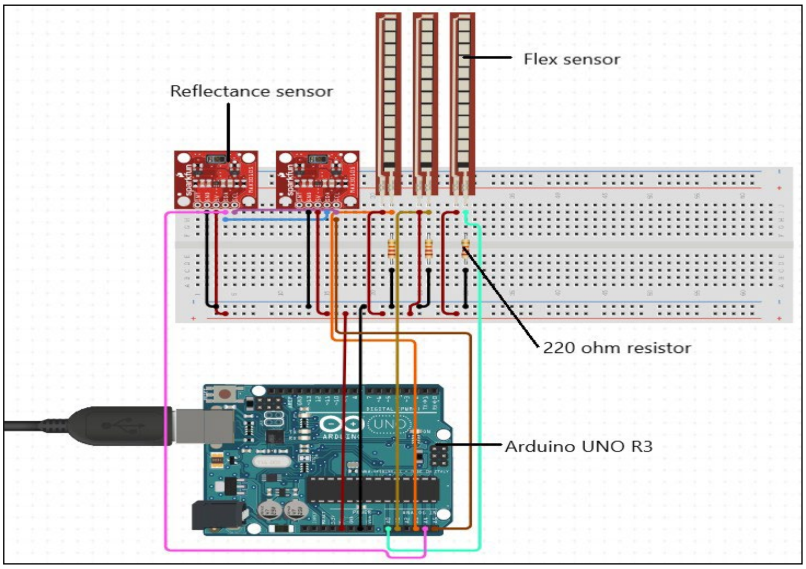


Figure 1. Integrated communication device setup

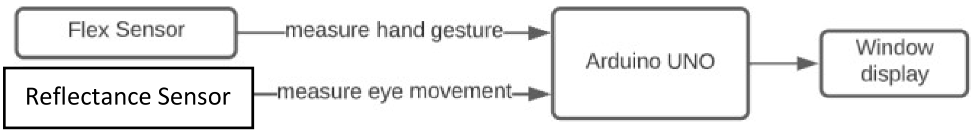


Figure 2. Block diagram of the system

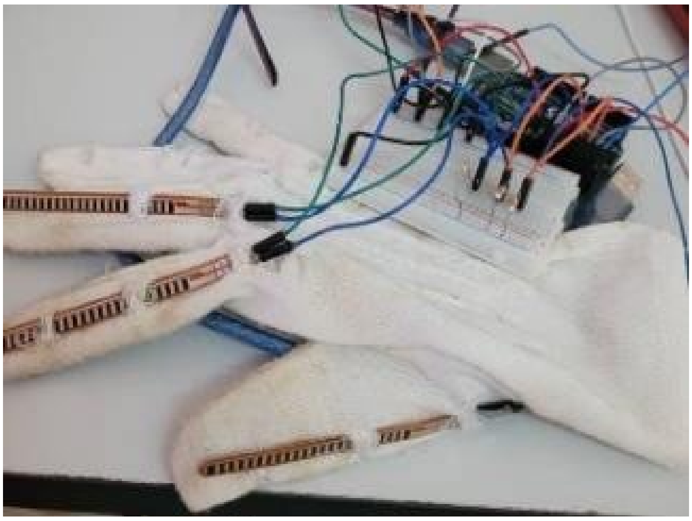


Figure 3. Flex sensors on glove

Figure 4. Reflectance sensor on glasses

Each hand gesture and eye movement are assigned with a message that is frequently used by patients. The window displays acts as an output that portrays the messages assigned to the respective hand gestures or eye movements. Tables 1 and 2 show the assigned messages for the respective hand gesture and eye movement.

Table 1. Assigned messages for hand gesture

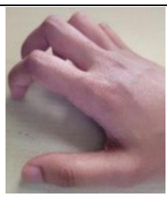
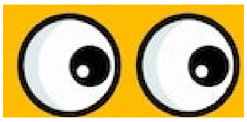
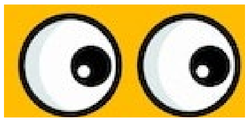
Bend index finger	Bend thumb
 Message: Yes	 Message: No
Bend index and middle finger	Bend thumb, index and middle finger
 Message: Talk to the family	 Message: Go to the toilet

Table 2. Assigned messages for eye movement

Blink once	Blink twice
 Message: Yes	 Message: No
Left	Right
 Message: Talk to the family	 Message: Go to the toilet

3.2 Operational Sequence

The operational sequence is shown as in the flowchart in Figure 5. In the beginning, the user must choose either to use the hand gesture or eye movement-based communication. If there are changes in flex sensor readings within 5 seconds, the system will proceed with interpreting the input data from hand gesture. The messages assigned will be identified and conveyed through a window display. In contrast, if there are no readings from the flex sensors within 5 seconds, the system will proceed with communicating through the eye movement tracking. The system receives the input data from reflectance sensor and interpret the data to match the assigned messages. The messages are also then conveyed through the window display.

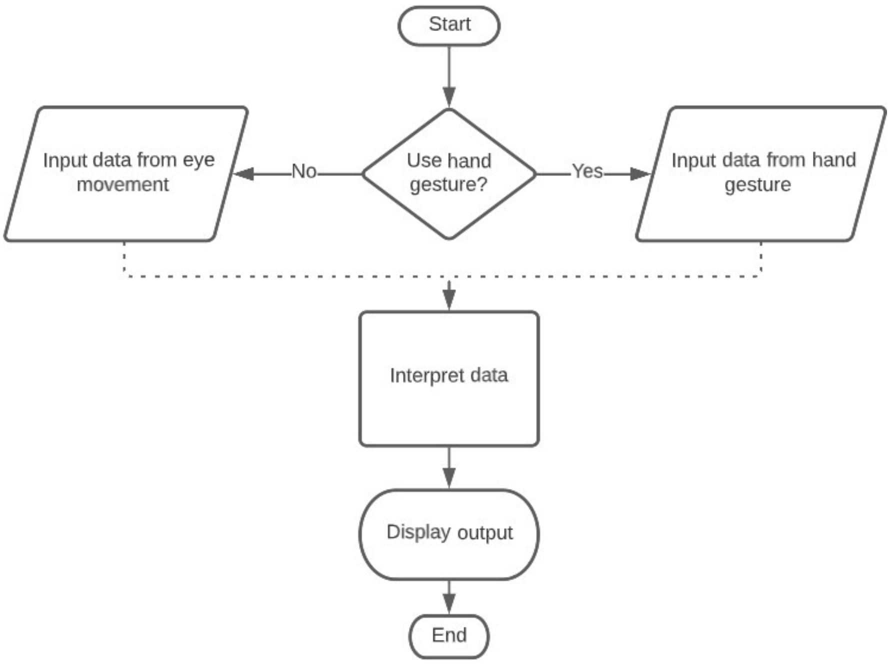


Figure 5. Flowchart of the integrated communication device for ICU patients

4.0 RESULTS AND DISCUSSIONS

4.1 Sensor Calibration

Before testing the developed integrated communication device for ICU patients, the three flex sensors must be calibrated to ensure that the resistance of the flex sensors corresponding to the respective bending angles are taken correctly. The sensors have been bent from 0 to 90° at an interval of 30°. The bending angles have been measured as illustrated in Figure 6. For each interval, 3 readings have been taken and the average resistance are calculated and recorded as in Tables 3-5. The average resistances for the thumb, index finger and middle fingers with respect to the bending angle are plotted in Figures 7-9 respectively and the relationship between the two parameters are obtained by curve-fitting technique.

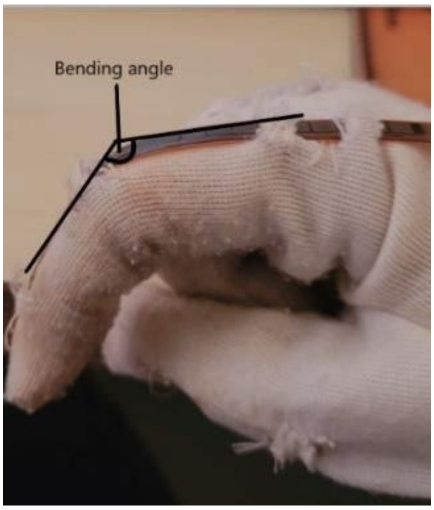


Figure 6. Bending angle

Table 3. Flex sensor reading for the thumb

Bending angle (°)	Resistances (Ω)			
	Trial1	Trial 2	Trial 3	Average
0	31931.43	31931.43	31931.43	31931.43
30	44792	44792	44792	44792
60	44792	44792	44792	44792
90	74800	74800	74800	74800

Table 4. Flex sensor reading for the index finger

Bending angle (°)	Resistances (Ω)			
	Trial 1	Trial 2	Trial 3	Average
0	14784	14784	14784	14784
30	20240	20240	20240	20240
60	31931.43	31931.43	31931.43	31931.43
90	56045	56045	56045	56045

Table 5. Flex sensor reading for the middle finger

Bending angle (°)	Resistance (Ω)			
	Trial 1	Trial 2	Trial 3	Average
0	31931.43	31931.43	31931.43	31931.43
30	37290	37290	37290	37290
60	44792	44792	44792	56045
90	56045	56045	74800	59796

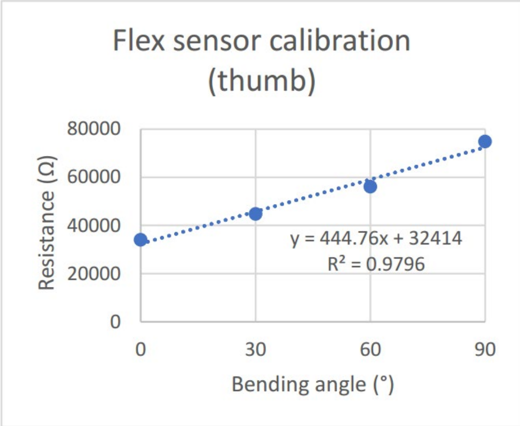


Figure 7. Flex sensor reading and calibration for the thumb

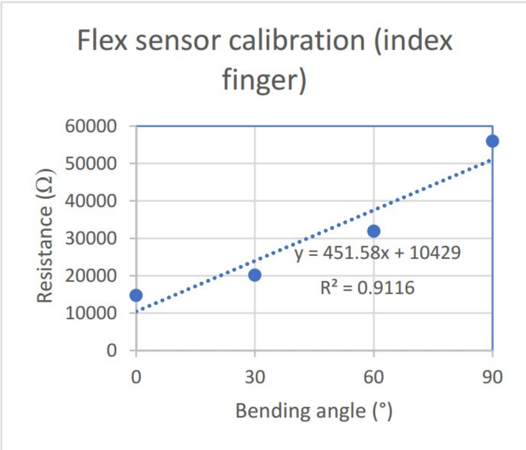


Figure 8. Flex sensor reading and calibration for the index finger

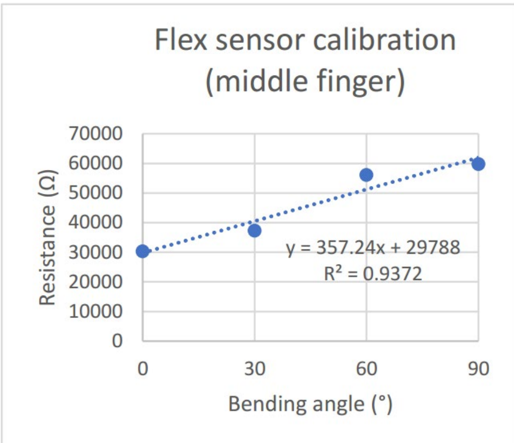


Figure 9. Flex sensor reading and calibration for the middle finger

4.2 Hand Gesture Detection Results

At this stage of study, the integrated communication device based on hand gesture and eye movement tracking has been tested on three healthy subjects in the laboratory. The subject is a 23 years old female, Malaysian and right hand dominant. The flex sensor readings taken from their thumb, index and middle fingers are illustrated in Figures 10 – 12. From the results, all the flex sensor readings from the three subjects are consistent with the assigned messages. In Figures 10 (a) – 12 (a), the flex sensor reading for the index fingers are decreasing and then increasing while the other two sensors reading gives lower variation. This is in line with the message “Yes”, where the user only needs to move only the index finger to communicate this message. Figures 10 (b) – 12 (b) illustrate the highest changes in the reading for the flex sensor attached to thumb, which signifies that the subjects are moving this digit to convey the message “No”. It can also be observed from the curves in Figures 10 (c) – 12 (c) that the flex sensors attached to the index and middle fingers of the three subjects are changing significantly, giving the message wanting to ‘talk to family’. Finally, it is clear that the three flex sensor readings for all the subjects in Figures 10 (d) – 12 (d) have been bent, communicating the message need to go to the 'toilet'. From the results, it also evident that the flex sensor readings for all the subjects have similar pattern and are consistent for the assigned messages.

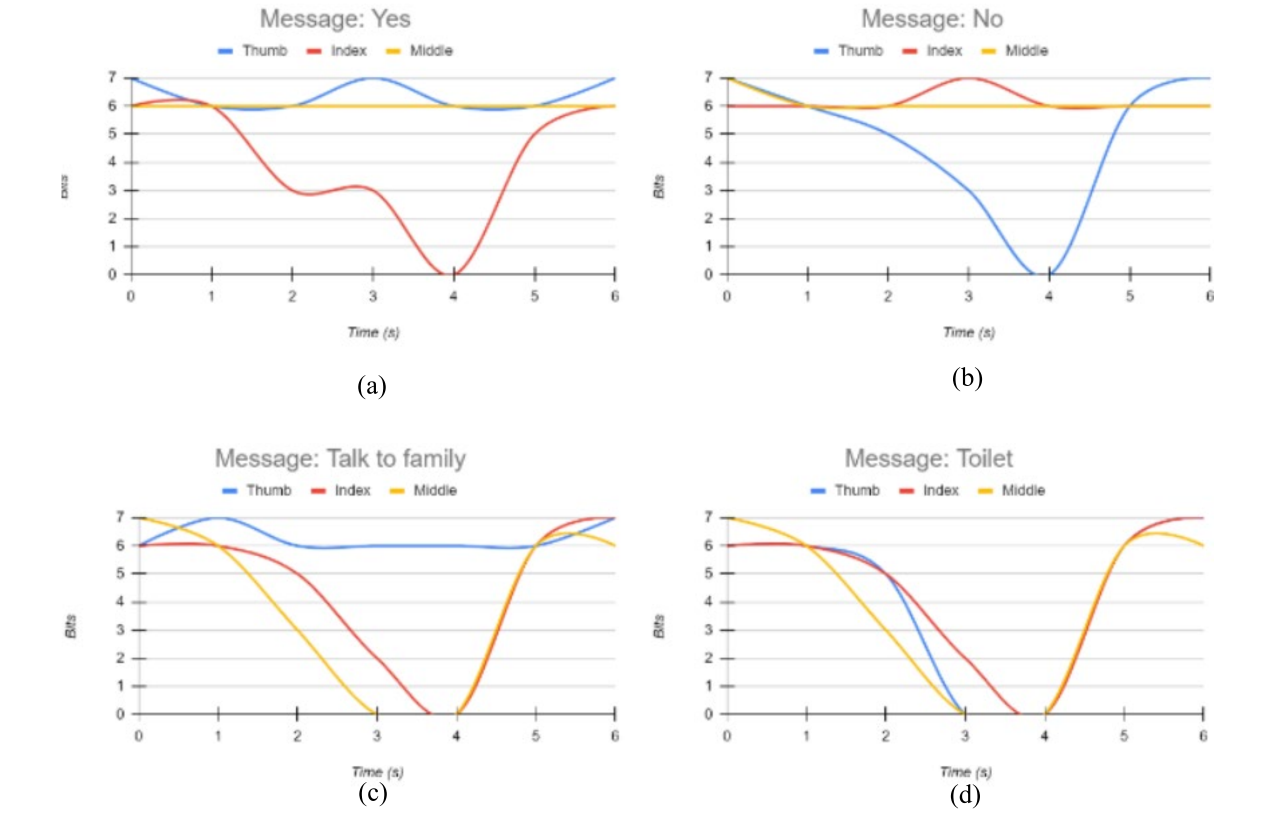


Figure 10. Flex sensors reading for Subject 1's hand gesture recognition

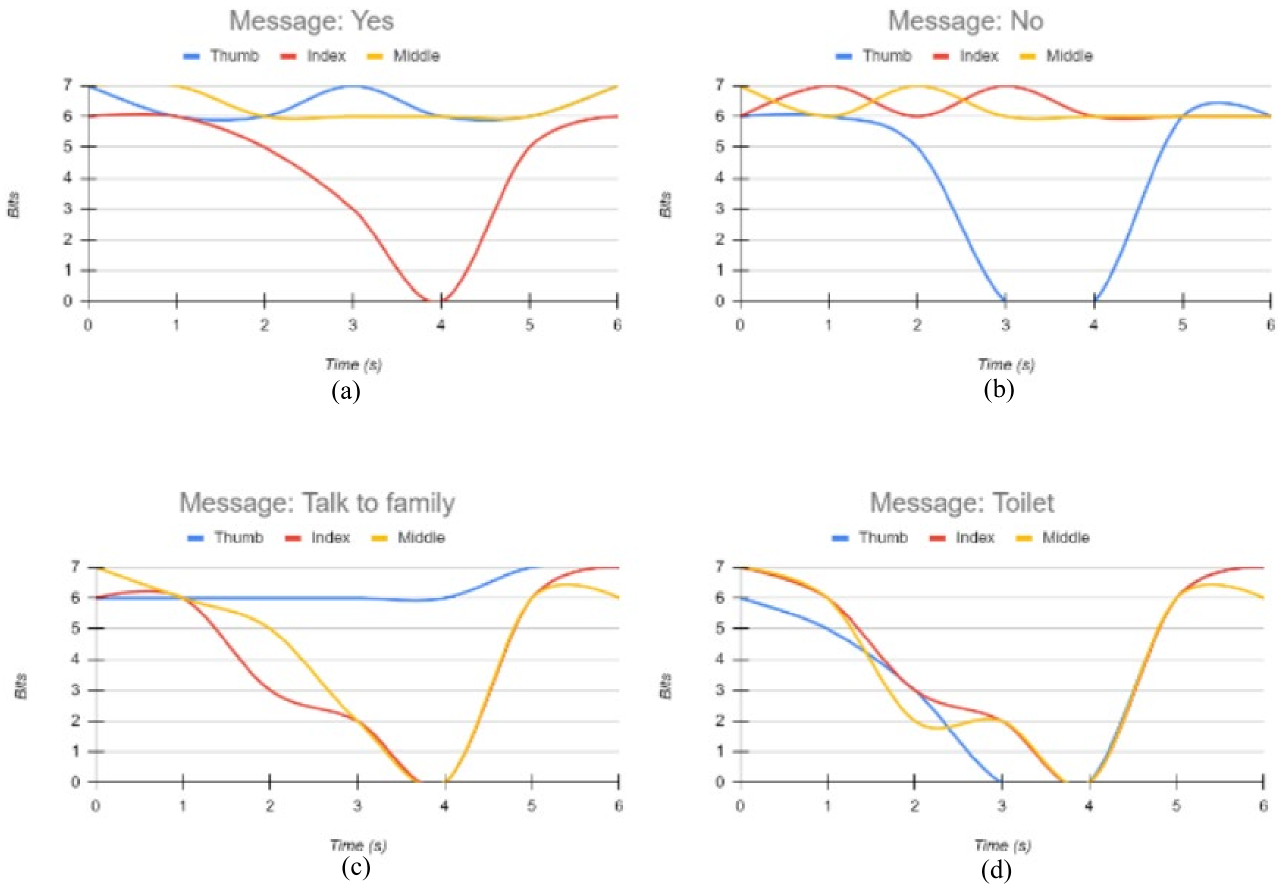


Figure 11. Flex sensors reading for Subject 2's hand gesture recognition

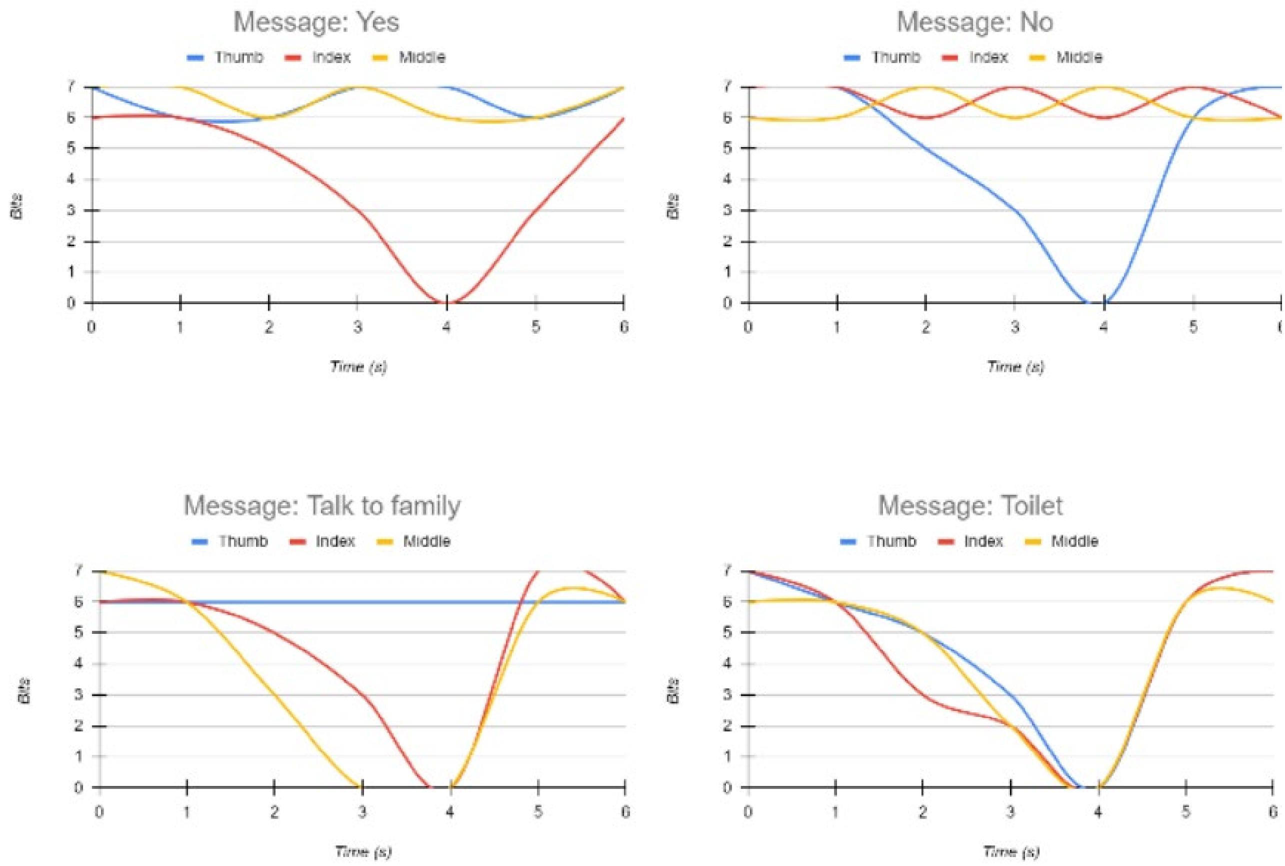


Figure 12. Flex sensors reading for Subject 3's hand gesture recognition

4.3 Eye Movement Tracking Results

The results of the eye tracking movement for the developed integrated communication device are depicted in Figures 13-15. It can be observed that the sensor reading patterns are consistent across all the three patients, for all the four messages intended. The reflectance of the pupil of the eyes in these figures are being represented in percentage. Higher percentage means that the pupil is moving towards the sensor, while the lower percentage means the eyes is looking away from the sensor. From Figures 13 (a) – 15 (a), both reflectance sensors reading increase and decrease once due to the eyes blinking, signifying the message "Yes". During eyes blinking, the value of the reflectance sensor measurement is higher since the colour of the subjects' eyelid is lighter than the eye pupil and iris. The results in Figures 13 (b) – 15 (b) are aligned with the results in these graphs since it can be observed that the graph increase and decrease twice, due to the eyes blinking two times for communicating the message "No". Figures 13 (c) – 15 (c) show a high reflectance value of the left sensor since the eyes is looking to the left, giving a low value in the reflective sensor on the right side. These signals give the message "Talk to family". The results in Figures 13 (d) – 15 (d) shows the opposite pattern since the eyes is looking towards right direction, communicating that the subjects need to go to the "toilet".

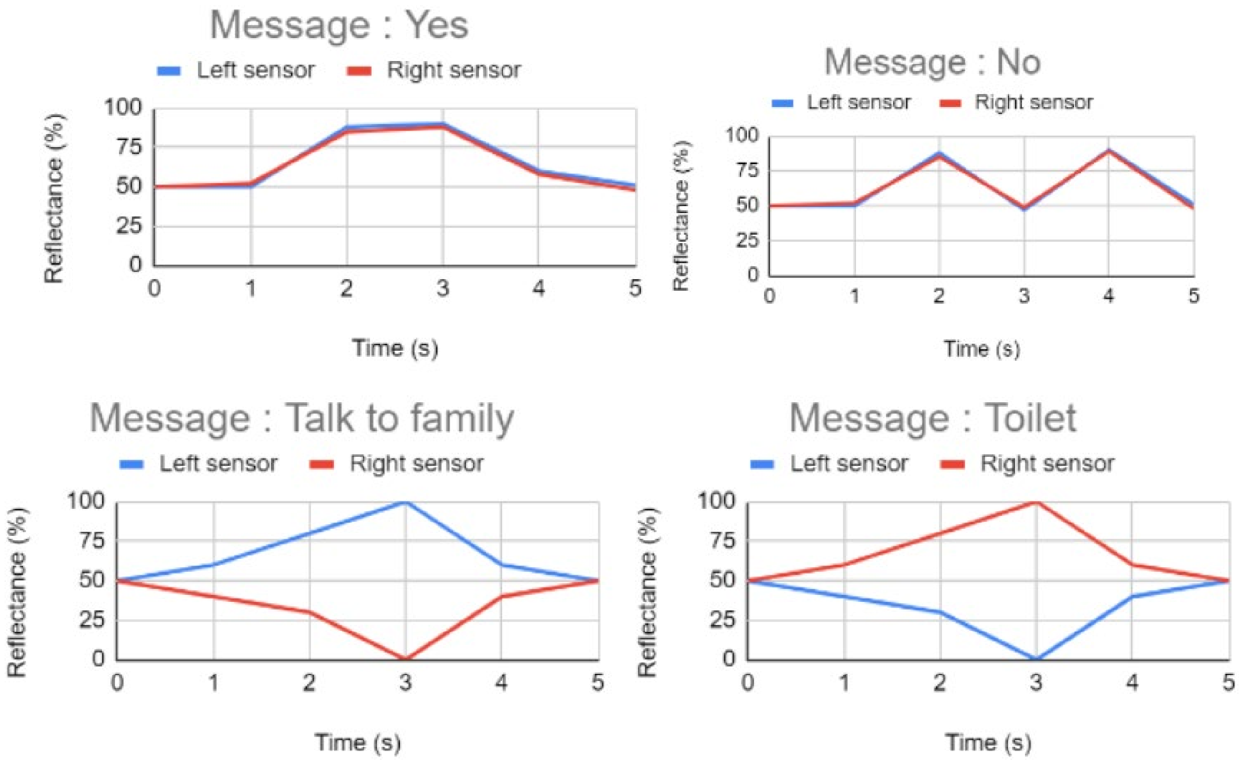


Figure 13. Reflectance sensor reading for Subject 1's eye movement tracking

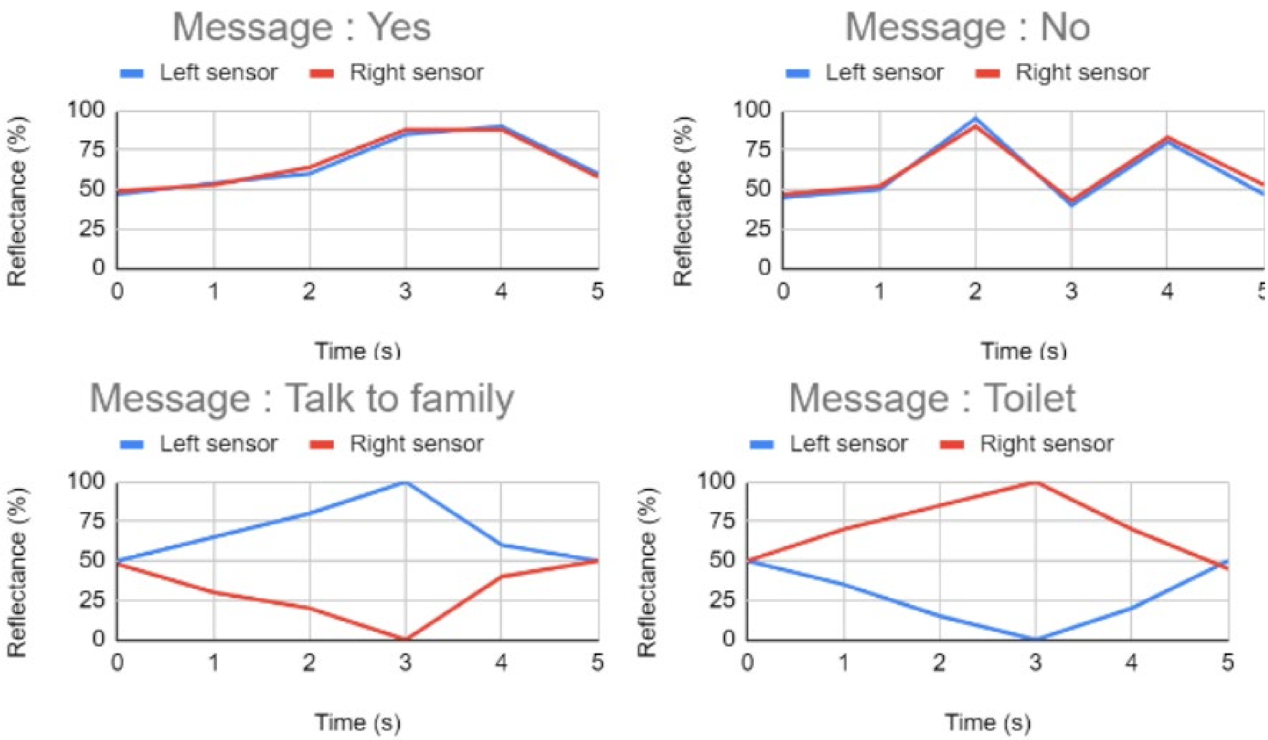


Figure 14. Reflectance sensor reading for Subject 2's eye movement tracking

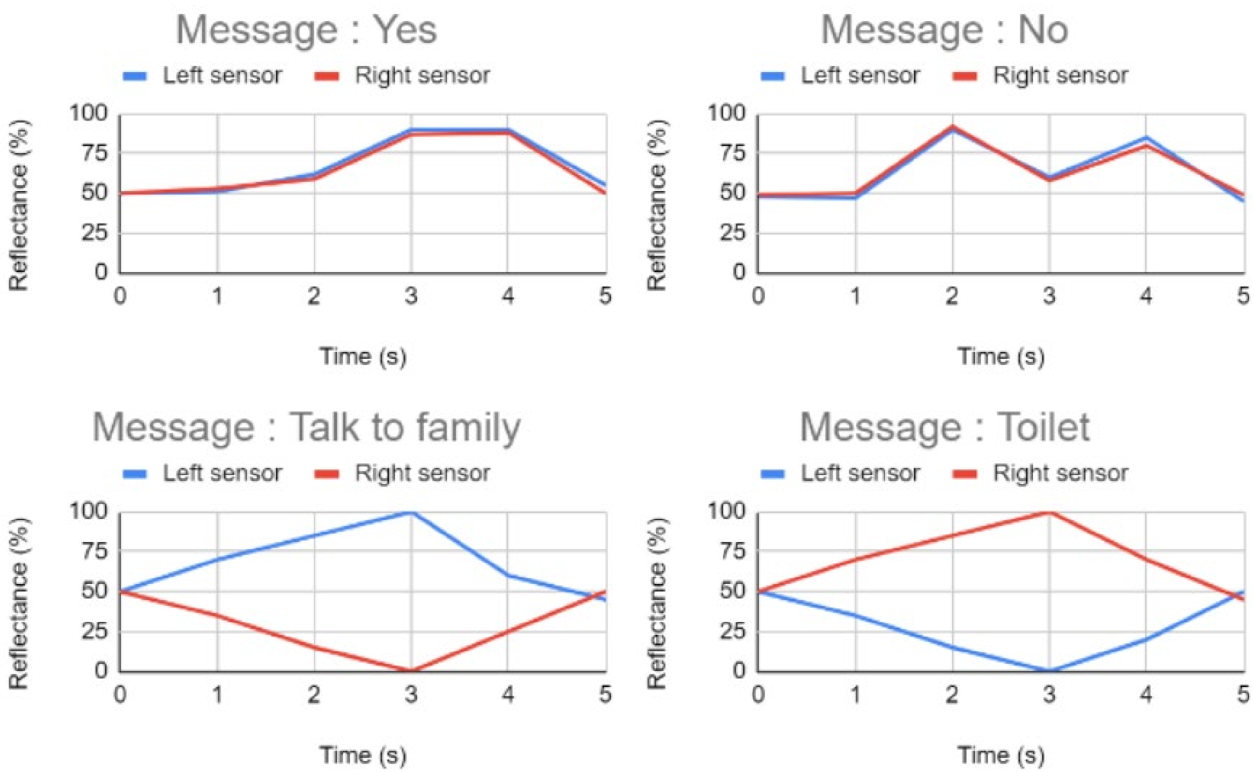


Figure 15. Reflectance sensor reading for Subject 3's eye movement tracking

4.4 Window Display

Figure 16 shows the resulting window displays corresponding to messages conveyed by each hand gesture and eye movement. The test results verify that the window display provide the correct messages with respect to these two quantities detected.

Figure 16. Resulted window display

4.5 Discussion

The results obtained validate that the developed integrated communication devices for ICU patients has successfully communicated the four messages from the subjects correctly according to the setting. All the sensor measurements are aligned with the programmed messages as in Tables 1 and 2. They also exhibit a consistent pattern of the flex sensors resistance and reflectance sensors reading across the three subjects. The graphs in Figures 10-16 show a uniform pattern of the curves across all subjects and messages. The construction of the proposed system is simple, and it is easy to be used. It is able to detect the hand gestures and eye movement correctly and convey the messages accurately. However, at this stage of study, the testing has been conducted on healthy subjects in the laboratory only. The number of subjects is low and only four of messages has been programmed on the developed system so far. The number of messages that can be conveyed by the developed system is lower compared to some of the previous studies. Therefore, it is highly necessary to test the proposed integrated communication device with the real ICU patients. Many subjects are required to participate in the test and more messages must be installed on the device to study its practicality and effectiveness in real situation. More messages that is usually used by the ICU patients in the hospital wards also need to be incorporated in the system in future. Depending on the findings and results attained, a more intelligent identification algorithm may be implemented to increase the device's capability and efficiency in communicating the messages from the ICU patients.

5.0 CONCLUSIONS

An integrated communication device based on gesture detection and eye movement tracking for ICU patients has been developed and its feasibility has been tested in this work. The flex sensors and reflectance sensors has been used to detect the hand signal and eyes motions respectively. The results of the tests with healthy subjects in the laboratory show that the proposed system has conveyed the intended messages correctly for all trials. Consistent sensor reading patterns are exhibited across all subjects and all messages. This may lead to a more convenient, proper and accurate communications between the healthcare provider and their patients. For future works, the device will be tested with many real ICU patients since the sensors data may differ between the patients and healthy individuals. More messages, covering a wider conversation spectrum in the hospital wards will be installed. An audio playback will be added to facilitate a more natural communication between the healthcare providers and patients. The system will also be incorporated with an automatically suggested words feature by exploring the implementation of Artificial Intelligence for predictive messaging based on patient intent detection. This will facilitate a faster communication process. The integration of wireless technologies for replacing the current sensors may also be further studied in future to provide more comfort in using the integrated communication device for ICU patients.

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