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Assistive Technology for Locked-in Syndrome Patients Using Eye Tracker

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ABSTRACT

Locked-in syndrome or LIS is a whole body voluntary muscles paralysis excluding muscles that control the eye movements but they are awake and conscious. The cognitive function is usually not affected and they can communicate through blinking or eye movements. LIS patients loses their productivity since their everyday living are greatly affected and needs a continuous help. Nowadays, assistive technology is widely used to compensate for the impairments they experience. The main objective of this research is to design and develop an assistive technology controlled by an eye tracker to help improve the lives of those patients suffering from LIS in controlling some electrical/electronic devices. The study utilized the experimental research design and the creation of a functional prototype for its hardware and software requisites. Several test trials were conducted and test results show that with respect to distance from the user, the Tobii eye tracker performs best at the range of 40-70 cm far from the user and at the range of 20°-40° angle of elevation. Test results also reveal that the shorter the distance the early detection of the Bluetooth connection and distance is also a predictor of time recognition. Moreover, the beta coefficient of 0.858 shows that distance variable recorded an approximately 85.8% contribution to time variable. This amount of contribution is considered noteworthy based on the computed t – value of 2.577 which is significant at a level of 0.026 which is lower than the acceptable levels of 0.05 or 5%. The remaining 14.2% may be accounted to variable/s that is/are not included in this study. A null hypothesis stating that "distance does not affect the time" was rejected because it is not true. The statistical basis of this decision is the F – value equal to 30.574 which is highly significant at 0.000 levels. It shows that distance is a predictor of time.

Key words: Assistive Technology, Eye Tracking, Locked-In Syndrome, Regression Analysis

1. INTRODUCTION

Locked-in syndrome or LIS is an uncommon neurological condition that might affect both male and female, including children, but adults are at more risk for brain bleeding and stroke. It is also a whole body voluntary muscles paralysis excluding muscles that control the eye movements. Usually LIS patients cannot utter words nor produce body movement, but are awake and conscious. The cognitive function is usually not affected and they can communicate through blinking or eye movements. The LIS patient's ventral pons are damaged wherein they are a part of the brainstem that relay information to other areas of the brain. People with this kind of disorder are having a high cost of living because of the necessity or dependence on medicines and personal or special care [1]. Usually if a person has this condition, he has also lost his productivity and their quality of life, maybe lowered since their everyday living is greatly affected and needs a continuous help. With the advent of technology, equipment and devices are present everywhere such as TV's, kitchen hardware, automatic doors, and assistive devices, various household tasks can be automated and manipulated. Thus, efficient control systems to access these devices can considerably enhance the quality of life for many disabled people around the world [2].

There were several studies [3-12] conducted in dealing with developing an assistive technology for Locked-in Syndrome patients. [13] felt the need of developing a system using Brain Computer Interface (BCI). The main objective of the study was to expose the patients with the low cost BCI system and collect their users' experience. They use the Electro Dermal Activity Sensor and Cognitive Suite of Emotiv's Control Panel. Results of the study showed that the BCI system was accepted by the participating neurological patients and they claimed that it is safe to use. [14] evaluated the usability and feasibility of an assistive technology (AT) prototype using P300-based brain-computer interface (BCI). The system provides an environmental control and communication applications. The system usability was evaluated in terms of user satisfaction, efficiency and effectiveness. They also concluded that a BCI can be used as an input by persons with ALS. [15] presented a proof of concept for a flexible Brain Computer Interface (BCI) Robot system to control a humanoid robot for locked-in subjects. All participants were able to control the robot through a BCI interface. Based on the results from this study, the researcher's architecture boosts the Locked-in syndrome patients' abilities. [16] presented their paper entitled design and development of an eye-tracking based home automation system for locked-in patient. The eye movement, pupil position, size, and velocity were established using a built-in laptop camera in combination with a sequence of algorithms coded using MATLAB. The camera is placed levelled horizontally with the patients' eye-sight. [17] developed An Image Based Eye

Controlled Assistive System for Paralytic Patients, by just using the eye movements, the patient can communicate with the system. It is an application developed for paralytic patients to know their requirements timely, especially the ones suffering from locked-in syndrome. The system consists of three main modules: Face and Eye Detection, Pupil Detection and Gaze Detection, and Assistance. They concluded that their developed system is safe, cost efficient, user friendly, and faster as compared to other methods.

Many studies and researches have already been conducted in using eye trackers and assistive technology. However, most of these designs are used for computer interactions and in home automations, controllers that receive the user's input in the eye tracker are directly connected to the appliances. On the other hand, eye trackers that are made commercially available are also mostly developed for gaming purposes. Hence, to improve these designs, this research integrated a wireless communication between the user input and the appliance controller using Bluetooth and used Tobii eye tracker 4C – which is mainly used for gaming purposes but was designed to work as an input to assistive technology.

The main objective of this research is to design, develop, and test an assistive technology controlled by an eye tracker to help patients suffering from LIS in controlling electrical appliances. The study addressed three specific objectives: (1) to design an assistive technology that is capable of controlling appliances using an eye tracker, appliance controller, and a tablet PC with installed application; (2) to develop an appliance controller and software application for the tablet PC that can accept input/s from the eye tracker and (3) to test the effectiveness of the Tobii eye tracker 4C as an input device of the system and to test the effect of the distance on the time before the Bluetooth of the tablet PC connects to the Bluetooth of the appliance controller.

In this study, the LIS patients are the prime beneficiaries, their everyday life is much easier because they are provided with a control method to access some of the appliances around them.

The system consisted of software and hardware that help those patients suffering from LIS in controlling some electrical equipment. The assistive technology is composed of a circuit board that is controlled by an eye tracker which acts as the main controller of the overall system. This circuit board is equipped with a wireless communication interface that sends the detected input from the user to the attached appliance or any electronic device. The experiment was conducted in the patients' home. The selection depends on the willingness of the patients and their relatives to participate in the experiment. A variety of eye tracking devices already exist today, so instead of developing another system to simply track eye movement, the researcher has taken it one step further. The study did not cover the controlling of the device or the appliances other properties, e.g. an electric fan's speed button. The study is limited to turning on and off an appliance or any electronic devices.

2. METHODOLOGY

2.1 Evaluation Phase

In the evaluation phase of the research, the researcher carefully studied what features to be included in the system. Thorough reading about LIS patients' was done to analyze their situation as well as their environment. Interviews were also done with the family of the patients to know their daily routine and needs. Based on the readings and interviews, the problem was identified to testify that there is a need to pursue the study and the project's objectives, scopes and limitations were defined. Initially system architecture was designed to show the principal parts or functions. The architecture diagram shown in Fig 1 was primarily used to clarify the overall concept of the study without the concern for the details of implementation.

The system initially works by detecting an input from a person using the eye tracker and sends signal to the tablet application. The input command entering the tablet application directed the Arduino Nano to control the on and off function of the electrical equipment attached to the sockets.

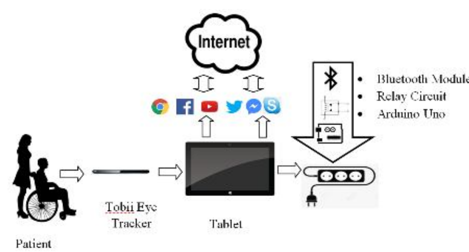


Figure 1: System architecture. This shows the architecture or concept of the whole system.

Flowcharting is another method used in the study. Flowchart is an illustration that denotes an algorithm presenting the steps as boxes of various kinds and their order. This figure gives a step-by-step solution to the problem. A system flowchart design was achieved as shown in Fig 2.

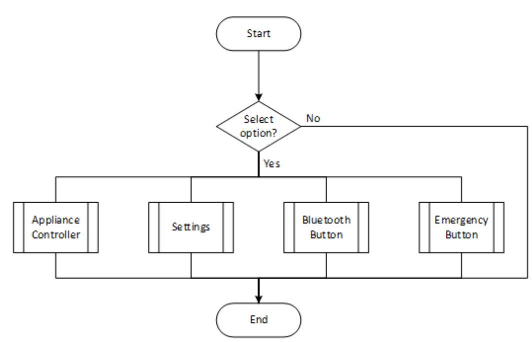


Figure 2*:* Main Menu Flowchart. This shows the main menu flowchart of the system. If the user decides to use the system, the user can choose between going to the appliance controller, settings, turning on the Bluetooth button or the emergency button

On the appliance controller of the system, the user can choose to turn off all the appliances or choose whether to turn off appliance 1, appliance 2, appliance 3, or appliance 4. After choosing which to turn off, the system will send the signal to turn the user's choice of appliance off and will then return to the main menu.

The user can also change the settings of the system. This feature is where the user can input the name of the Bluetooth device to be connected in and change the names of appliances that the system will be connected to.

2.2 Development Phase

In the development phase, the researcher gathered all the necessary materials/equipment used in the study and set-up the needed hardware. The connection shown in Fig 3 was used for the appliance controller part of the prototype.

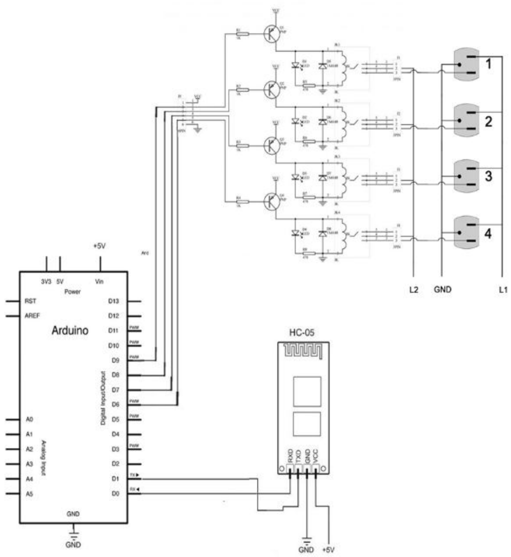
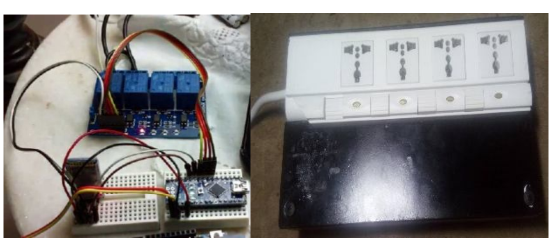


Figure 3: Schematic Diagram of Appliance Controller. This shows the connections between the Arduino Nano, 4-channel relays, sockets and Bluetooth module.

The development of the prototype started with testing the functionality of the hardware components individually, a simple Arduino code was created to test the Arduino and the relay circuit by plugging it with the electrical lamps as shown in Fig 4.



(a) (b)

Figure 4: The developed appliance controller. (a) shows the setup for the relay circuit and the Arduino nano, (b) shows the finished product of the appliance controller with its case

The software of the system was also developed in this phase. The system was programmed or developed based on the comprehensive design specifications. The clicking process was coded using Visual Basic while the functionality was coded using C#.

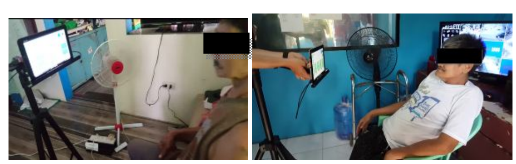
Tobii eye tracker specifically model 4c was utilized in this research as an input device. An SDK or Software Development Kit comes with the purchased eye tracker and was meaningfully used in developing the software application. The Tobii eye tracker consists of cameras, projectors, and algorithms. The algorithms control the sensors and the illuminators. These sensors capture high-frame-rate images of the user's eyes and reflection patterns while the illuminators are used to create a reflection pattern of Near-Infrared light on the eyes. The Tobii eye tracker will then work its image-processing algorithms - the intelligence of the system, which finds specific details in the user's eyes and reflection patterns and interprets the image stream generated by the sensors. After that, the device calculates the user's eyes and gaze point on a device screen using its 3d eye model and gaze mapping algorithms.

2.3 Implementation Phase

In this phase, all the necessary materials and equipment were installed. After the construction of the software and hardware part, integration of the two systems was done to guarantee that there are no major interface disputes that remain undiscovered for the system testing. The researcher sets up the system as show in Fig 5.

Figure 5: Prototype Set up. This shows the actual setup of the system for its testing.

Concerned persons were properly oriented regarding the set up and implementation of the developed system. In using the system, caregivers, companions and the patients were oriented on how to properly set up and utilized the system to maximize its use and benefits. The actual setup with the patient is shows in Fig 6.



(a) (b)

Figure 6: (a) Patient a and (b) Patient b trying to use the system.

2.4 Testing Phase

For the testing phase, the developed application went through installation testing or installability testing first. It is a software testing technique that focuses on what the customers need to do to install and set up the software successfully to their Tablet PC. Table 1 shows the result of the installability testing done by the researcher on different tablet PC.

Table 1: Testing results on the installability of the developed application

Tablet PC	Installed? (Yes/No)	Running? (Yes/No)
Fujitsu Lifebook T726	Yes	Yes
Chuwi Hi12 CWI520 12.0 inch Tablet	Yes	Yes
Cube i7 Book 2 in 1 Tablet PC	Yes	No
Microsoft Surface Pro 3	Yes	Yes
ASUS Transformer T101	Yes	Yes
Galaxy Tab Pro S	Yes	Yes
OndaObook 20 Tablet PC	Yes	No

Table 1 shows the testing results on installing the application to different tablets.

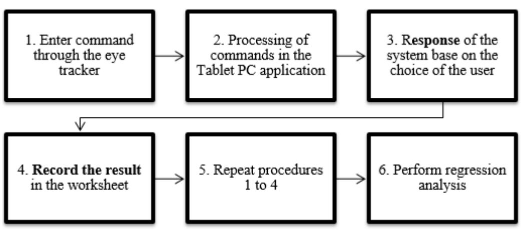


Figure Testing phase diagram

Fig 7 shows the testing phase diagram which shows the different activities to be carried out during this phase. The researcher observed any inconsistency in the system and recorded the testing results.

3. RESULTS AND DISCUSSIONS

The researcher was interested to know the relationship between distance and time that Bluetooth connects from the tablet PC to the appliance controller. Linear regression is the next step up after correlation. It is used in predicting the value of a variable based on the value of another variable. The dependent variable (or sometimes, the outcome variable) is the time. The other variable's value is called the independent variable (or sometimes, the predictor variable) which is the distance. The researcher formulated a hypothesis.

Ho: Distance has no significant effect before the Bluetooth of the tablet PC connects to the Bluetooth of the Appliance controller.

Series of testing were done using first the distance variable and another series of testing were repeatedly done for the angle variable. For either variable, the user's eyes height from the ground is 110 cm above the ground while the Tobbi Eye Trackers' height from the ground is 93 cm.

The Tobii Eye Tracker 4C was subjected for calibration for every distance and angle tested; and the results are summarized and presented in the tables shown.

Table 2: Effectiveness test results of the Tobii eye tracker at a given distance

Trial #	Distance (cm)	Tracking of Gaze at a given distance	User's gaze control
1	10	No	No
2	20	No	No
3	30	Yes	No
4	40	Yes	Yes
5	50	Yes	Yes
6	60	Yes	Yes
7	70	Yes	Yes
8	80	Yes	No
9	90	No	No

Table 2 data is retrieved from the observation made with Patient A. It shows that if the user's eyes were positioned as near as 10 to 20 cm or as far as 80 to 90 cm away from the tracker, the system can no longer read or track the user's gaze. The effectiveness or functionality of the Tobii Eye Tracker has been observed when it is located within the distances of 40 – 70 cm away from the user. It means that, at these given distances, the system can recognize the command of the user's eye in controlling any electrical appliances to be opened or to be switched off.

Second testing was done to test the effectiveness or functionality of the Tobii Eye Tracker with respect to the angle of elevation and depression from the user' eyes. The data is from the observations made with Patient B.

Table 3: Effectiveness test results of the Tobii eye tracker at a certain angle

Trial #	Angle (°)	Tracking of Gaze at a given distance	User's gaze Control
1	70	No	No
2	60	No	No
3	50	Yes	No
4	40	Yes	Yes
5	30	Yes	Yes
6	20	Yes	Yes
7	10	No	No
8	0	No	No
9	-10	No	No

Table 3 shows that if the angle of elevation and depression of the system from the user's eyes are from -10° to 10° or from 60° to 70°, the Tobii Eye Tracker will not respond to the user's gaze control. It means that, at those observed angles, the system is no longer functional. At angles 20° to 40°, the system can recognize the command of the user's eye in controlling any electrical appliances to be opened or to be switched off.

Third testing was done to test the effect of distance on the time before Bluetooth of the tablet PC connects to the Bluetooth of the Appliance Controller. Simple regression analysis, using SPSS, was done to statistically test if distance is a predictor of time. Distance as predictor variable was regressed against time as the outcome variable using the data summarized in table 4.

Table 4: Effect of distance on time

Distance (meter)	Time (milliseconds)
1	1.4538390
2	1.4836317
3	1.5377465
4	1.6554482
5	1.6871274
6	1.7610735
7	1.7669133
8	1.8688753
9	2.6674604
10	3.3678256
11	4.0978202
12	4.7675206
Mean Distance = 6.5 meter	Mean Time = 2.34294 milliseconds

Table 4 shows the shortest considered distance is 1 meter with equivalent time recognition of 1.453839 milliseconds and the farthest distance is 12 meters with a recorded time of 4.7675206 milliseconds. The recorded distance is more or less than 6 meters with a corresponding time of more or less than 2 milliseconds, as shown by the computed mean distance of 6.5 meters and mean time of 2.34294 milliseconds. These numerical information only show that the shorter the distance, the lesser time needed to connect Bluetooth of the tablet PC to the Bluetooth of the appliance controller. It means that time connection between two Bluetooth is directly proportional to distance.

To further investigate this finding, the observed and recorded data in Table 4 were subjected to regression analysis and results are reflected in Table 5.

Table 5: Regression results showing the effect of distance on time

Variable	Beta Coefficient	t - Value	Significance Level	F - Value	Significance Level
Distance	0.858	2.577	0.026	30.574	0.000

Table 5 shows that distance is a predictor of time. This result suggests that in the analysis of this project regarding this matter, distance should be given much emphasis in connection to time. The beta coefficient of 0.858 shows that distance variable recorded an approximately 85.8% contribution to time variable. This amount of contribution is considered noteworthy based on the computed t – value of 2.577 which is significant at a level of 0.026 which is lower than the acceptable levels of 0.05 or 5%. The remaining 14.2% may be accounted to variable/s that is/are not included in this study.

5. CONCLUSION

From this paper, the development of assistive technology for locked-in syndrome patients using eye tracker was presented, tested and implemented. The system was successfully designed with the following features: Detection of the user's eye and its movement and using it as a means of navigation cursor for the user. Detection of eye movements is reactive and real-time. The Tobii Eye tracker is effectively tracking movements of the user's eye and the tablet is instantaneously computing the registered movement, displaying it on the screen as it tracks the eye with little to no delay with the help of efficient programming of the software. Controlling the Desired Ports in the Appliance Controller is almost instant and easy to use. LED lights indicate if a port is on. The Tobii eye tracker performs best at the range of 40-70 cm far from the user and at the range of 20°-40° angle of elevation. Test results also reveal that the shorter the distance the early detection of the Bluetooth connection and distance is also a predictor of time recognition.

The beta coefficient of 0.858 shows that distance variable recorded an approximately 85.8% contribution to time variable. This amount of contribution is considered noteworthy based on the computed t – value of 2.577 which is significant at a level of 0.026 which is lower than the acceptable levels of 0.05 or 5%. The remaining 14.2% may be accounted to variable/s that is/are not included in this study. A null hypothesis stating that "distance does not affect the time" was rejected because it is not true. The statistical basis of this decision is the F – value equal to 30.574 which is highly significant at 0.000 levels. It shows that distance is a predictor of time.

Based on the findings and results of the trainings and testing that have been done, the researcher recommends the following for the improvement of the system;To be able to control an appliance with a large power consumption and add more ports on the appliance controller, and to be able to control the levels, degree, and speed of an appliance to the user's desired extent.

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