Design and Development of a Rehabilitative Eye-Tracking Based Home Automation System

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***Abstract*— Locked-in syndrome is known to be a condition in which a patient loses the ability to control nearly all voluntary muscles in the body except for the eye. In today's world, healthcare facilities have the means and equipment necessary to help such patients and take care of their needs, which includes medical care and patient comfort. However, such dedicated professional services are not commonly provided at the patient's dwelling, and more can still be done when it comes to patient's comfort and self-reliance. This paper delineates the design and development of an eye-tracking based home automation system that provides the targeted locked-in patient with the ability to control appliances using his/her eyes. In the developed system, eye movement, pupil position, size, and velocity are determined using a built-in laptop camera in conjunction with a series of algorithms coded in MATLAB®. The camera is adjusted in such a way so as to be leveled horizontally with the eye-sight of the patient. Further algorithms are to allow the user to control and move the mouse cursor with his/her eye movements. A specially designed graphical user interface provides the individual with the options as to what he/she wishes to control. An Arduino microcontroller differentiates the received instructions from the user and provides an output to the intended device. The controlled appliances within the patient's habitat are doors, window shutters, lightings, bed control, television set, and heating ventilation and air-conditioning. Further modular improvement of this system could be introduced as need arises. The system was validated using a series of tests on normal control individuals. The validation results show high accuracy and precision. The significance of this system lies in helping locked-in patients gain control over some aspects of their lives; accordingly, they will no longer require continuous assistance to secure their comfort but rather be self-reliant.**

Keywords—Locked-in Syndrome; Eye Tracking; Home Automation.

I. Introduction

Locked-in syndrome is a condition in which a patient is aware of his/her surrounding but cannot communicate verbally or move due to complete paralysis of almost all voluntary muscles in the body apart from the eyes [1]. This disorder has been recognized since as early as the 19th century; however, the term for this condition was coined by Fred Plum and Jerome Posner in 1966 [2]. Locked-in syndrome is also known as cerebromedullospinal disconnection, ventral pontine syndrome, pseudocoma, and de-efferented state [3]. Figure 1 shows a sketch of a locked-in child.

It is imperative to recognize that patients with locked-in syndrome have no loss of cognitive function and, accordingly, are not unconscious; however, they are unable to respond to most stimuli [2,4]. Hence, while rehabilitating these patients, discussion about the patient should be directed to the patient as a conscious individual, and not to surrogates about an unconscious individual. In this sense, locked-in patients may suffer profoundly if they are treated by healthcare providers as if they are non-responsive [2].

Given the above argument, there must be a means that allows the locked-in patient to interact with his/her environment and communicate with the outside world. One mechanism that offers such ability is the human eye. As a matter of fact, the position and movement of the human eye is controlled via six extraocular muscles that are innervated by three cranial nerves [5] rendering it as one of the finest control organs of high accuracy and precision in the body.

Our research group has previously introduced a low-cost eye-tracking-based brain-computer interface system for the rehabilitation of the completely locked-in patients having an

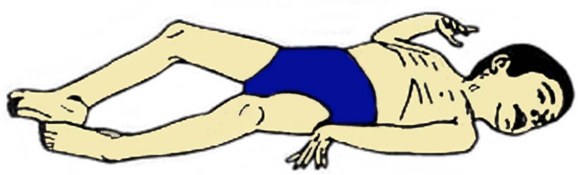

Figure 1. A drawing of a locked-in child. Adapted from: Abu-Faraj ZO, Bou Sleiman HC, Al Katergi WM, Heneine JLD, Mashaalany MJ. A Rehabilitative Eye-Tracking Based Brain-Computer Interface for the Completely Locked-In Patient. In: Wickramasinghe N and Geisler E; Editors. Encyclopedia of Healthcare Information Systems, First Edition, Hershey, PA, USA: IGI Global, Vol. III, pp. 1153-1160, 2008.

Manuscript received June 27, 2016, and accepted August 8, 2016. This work was supported by funds from the Research Council of the American University of Science & Technology (AUST, Beirut, Lebanon).
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978-1-5090-2555-8/16/$31.00 ©2016 IEEE

intact ocular motor control to serve as an alternative means of communication. The system was recognized with simplicity of operation, little training requirements, minimal disturbance to the patient, and ease of customization to mother tongue. Validation results revealed 96.11±5.58% accuracy and 94.44±2.51% repeatability [6,7].

The aim of this project is to combine home-automation (a.k.a. domotics) and eye-tracking technologies to provide individuals with locked-in syndrome with a system that would serve them at their convenience. Such a system will help these individuals gain control over some aspects of their lives; accordingly, they will no longer require continuous assistance but rather become self-reliant.

Home automation may include the control of lighting, heating, ventilation, and air conditioning (HVAC), appliances, and other systems that may contribute to an improved life in terms of comfort, ease, and convenience.

The relevance of such a system, when applied to healthcare facilities and personal dwellings, lies in its ability to help the locked-in patients in practicing simple daily life activities without any assistance. Psychologically speaking, such a system will be beneficial for the paralyzed individual as he/she may experience a certain degree of freedom in controlling his/her own environment.

II. Literature Review

An overview of relevant literature related to both home automation and eye-tracking is presented chronologically herein.

A. Home Automation:

In 2009, Nasr *et al.* introduced a friendly automated system to control home appliances remotely via the use of a mobile cell phone. The system is flexible, secure, efficient, and easy to utilize. It uses J2ME language to program the client mobile unit, which sends information to the service mobile unit, which in turn controls the operation of the appliances through a PIC microcontroller. The devices serving as an interface between the appliances and the PIC are a static power switch, also known as TRIAC, and an optocoupler [8].

In 2011, Piyare *et al.* designed and developed a flexible and secure cell phone-based home automation system, using a stand-alone Arduino BT board to control the home appliances using relays. The system is cost efficient and scalable, allowing a variety of devices to be controlled with minimal modifications [9].

In 2013, Ramlee *et al.* described the implementation and overall design of a Home Automation System with wireless remote control. Their project's aim is to assist and support the disabled at home. The system uses wireless Bluetooth technology to provide remote access from the host device. The objective is to control electrical devices and appliances in the user's abode with relatively low cost design, user-friendly interface, and ease of installation [10].

In 2015, David *et al.* presented a home control monitoring system. This system relies on micro web server fixed in an Arduino Mega 2560 microcontroller and IP connectivity to remotely access and control appliances. The control could be accomplished via a web application or through Bluetooth Android based Smart phone application [11].

B. Eye Tracking:

In 2004, Babcock and Pelz conceptualized the process of integrating a video-based camera into an eye-tracking system. The proposed system would monitor the eye with a commercially available tiny micro-lens video camera. Real-time eye-tracking could be achieved using pupil detection algorithms implemented in software. The paper then described a light-weight headgear that could be used with any dark-pupil eye-tracking controller, and which could be easily optimized for real-time performance [12].

In 2009, Azam *et al.* described a human computer interface system that is designed and implemented to track the direction of human gaze. The kinematics of the iris is used in this system to drive the interface by setting the position of the mouse cursor accordingly. The authors stated that such a system would aid in providing an alternate input modality to facilitate computer-user interface for patients with severe disabilities [13].

In 2011, Verma *et al.* described the development of low cost hardware and software architecture for a real-time wireless eye-tracking-based control system using the open-source image processing framework of AForge.NET. Validation of the developed system has been implemented in the field of remote robotic navigation, using the Lego NXT Mindstorm robot, and wireless home automation, using the X10 transmission protocol. In this system, eye movement is detected via a USB camera; the subsequently generated control signals are transmitted to their destination over a wireless channel. The authors stated that the developed system would provide a highly useful alternative control apparatus for a quadriplegic person [14].

In 2015, Karamchandani *et al.* presented several factors that precluded existing commercial eye-tracking systems from being a notable technology; these include: robustness, invasiveness, non-portability, cost, and availability. The authors then delineated the design and development of an alternative economical eye-tracking technology that can provide children having severe speech and motor impairments with the ability to communicate. The reported system is webcam and tablet-based, and does not require sophisticated hardware for operation. The system allows the user to gaze through and access one of 16 options on a 4″ x 4″ display [15].

III. Materials and Methods

The design scheme for the eye-tracking system developed in this study is delineated in Figure 2, and is described herein. Eye kinematics in terms of movement, pupil position, size, and velocity are determined using a built-in laptop camera that is leveled horizontally with the eye-sight. A series of algorithms coded in MATLAB® (MathWorks, Natick, MA, USA) allows the camera to track eye movements of the individual and move the screen's cursor accordingly. A Toshiba Satellite™ C55-C1649 (Toshiba Corp., Minato-ku, Tokyo, Japan) notebook is used as a server, which includes a 2.40 GHz Intel® Core™ i7-5500U Processor (Intel Corp., Santa Clara, CA, USA) and 16.0 GB of RAM.

The system is designed so as to enable the patient to control and move the mouse cursor with his/her eye movements, and then activate the desired command. A specially designed graphical user interface (GUI) provides the individual with the options as to what he/she wishes to control; e.g., open the door, dim the lights, activate the HVAC, control the television set, etc. Once selected, an Arduino MEGA microcontroller (Arduino LLC, Italy) receives these instructions, via an HS-06 Bluetooth® (Bluetooth SIG, Inc., Kirkland, WA, USA) module, and provides an output to the implemented interfaces/switches linked to the respective appliance or device. It is worth noting that the number of appliances to be controlled depends on the number of input/output pins that the microcontroller possesses. Figure 3, top, shows a mockup of the locked-in patient's room, while the bottom part of the figure shows the various options that the eye-tracking system has to offer – the figure demonstrates the control panel of an HVAC system.

IV. Results

Testing and validation of the developed system in terms of operability, accuracy, and reliability involved three phases, to ascertain the absence of any anomalies: i) making sure that the home-automation system is working properly by testing the appliances to be controlled; ii) testing all inputs of the GUI to ascertain that the intended appliances obey there corresponding commands; and, iii) determining the accuracy and precision of the eye-tracking camera in tracking eye movements and manipulating the mouse cursor using normal control subjects.

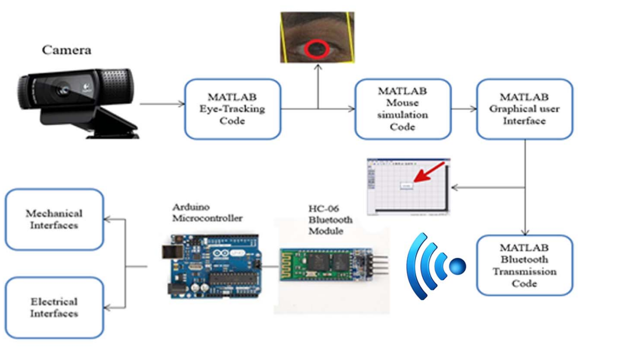

Figure 2. Schematic diagram portraying the overall design aspect of the eye-tracking system.

In order to determine the overall accuracy and precision of the system it was tested on 10 healthy adult volunteers (six males and four females) ranging in age from 20 to 55 years (mean ± S.D. = 33.5 ± 13.6 years). Test subjects were free from any neurological or musculoskeletal disorders, have proper conjugate eye movement, and intact ocular motor control. Two of these subjects have myopia.

The validation protocol consisted of a series of five trials per subject performed in a proper-illuminated environment. Test subjects were requested to execute a sequence of pre-instructed tasks designed to test three home automation buttons on the GUI. The time allocated to open the door, turn on the television, and control the bed was set between 30 and 60 seconds. Beyond that time limit, the subject was considered to have failed to activate the given tasks. The accuracy of the system is obtained through a subroutine coded in MATLAB that calculates the system's decision for moving the cursor into the desired destination. Two counters were instantiated: the first counter to increment the number of correct decisions pertaining to the desired direction and the second counter to increment the number of incorrect decisions. Each decision is acquired after the processing of eight video frames. Thereafter, the two numbers achieved are added and the percentage of accuracy is calculated accordingly.

Every individual has to perform a calibration process at the beginning of the application as the iris radius may vary with each user. The calibration is performed through a built-in MATLAB function, named iamfindcircle, which detects the radius of the individual's iris. Moreover, the function adjusts iris tracking sensitivity according to light conditions, as lighting along with iris color may have an impact in decision making of the system.

Figure 3. Top: A bird's eye image of a model of a locked-in patient's room. Bottom: A GUI screen showing the control panel of an HVAC system.

Validation results revealed a system accuracy of 95.7% ± 2.6% and system repeatability of 90.0 ± 9.1%. These values represent the ensemble mean ± S.D.

V. Discussion and Conclusions

This study integrates the eye-tracking technology into a home-automation system. The validation results show high accuracy and precision. Further testing of the system will involve a population of patients with locked-in syndrome. Results from these tests would allow the adjustment of flaws in eye-tracking and cursor movement not obtained from the normal control subjects.

The eye-tracking system developed in this study is easily modified to allow any aspect in the patient's dwelling to be controlled through this system provided that proper algorithms and components are used. The system may be easily customized to be used in healthcare facilities that rehabilitate the locked-in patient.

A more intriguing future scope will be Internet access. With the necessary modifications on the algorithms and technology used, the user may ultimately have access to the Internet and take part in social media, interactive games, and other contemporary applications.

The significance of this work lies in helping locked-in patients gain control over some aspects of their lives; accordingly, they will no longer require continuous assistance to secure their comfort but rather be self-reliant.

Acknowledgments

Special thanks are attributed to Mrs. Henriette Skaff, Department of Languages and Translation at the American University of Science & Technology (AUST, Beirut, Lebanon) for her valuable assistance in editing this article.

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