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PROTOTYPING SMART HOME FOR IMMOBILIZED PEOPLE: EEG/MQTT-BASED BRAIN-TO-THING COMMUNICATION

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ABSTRACT

Context. Immobilized people face additional barriers in almost all areas of life, including simple operations like turning the light on/off and controlling the air conditioner. The object of the study was to develop the brain-to-thin communication of affordable price to control the smart home appliances by immobilized people from neck to toes.

Objective. The goal of the work is to manage smart home appliances via brain-to-thing communication with EEG non-invasive electrodes, edge IoT devices, and MQTT protocol if the brain and eye control of the disabled work normally.

Method. A non-invasive Sichiray TGAM brainwave EEG sensor kit captures signals and then transmit them via Bluetooth to the HC-05 module connected to the Arduino Mega microcontroller. Information about edge IoT devices is presented to the disabled on the LCD 1602 display wired to the same Arduino Mega. The disabled person chooses the option shown on display via the double blink that is detected if the quality of signal equals zero and low/mid gamma waves are less than ten in three consecutive Bluetooth packets. Control commands are sent from Arduino Mega (MQTT publisher) to the edge IoT devices (MQTT subscribers) that analyze them and start a specific operation like opening a door and turning the alarm on/off.

Results. Five females and five males of different ages from 8 to 59 years old examined the control of smart home appliances with the Sichiray TGAM brainwave sensor kit. Everyone successfully handled the Sichiray headset and showed satisfaction with the brain-to-thing system.

Conclusions. In this work, a smart home concept for immobilized people was developed using the brain-to-thing approach and the MQTT communication between the MQTT publisher, Sichiray TGAM brainwave EEG sensor kit connected via Bluetooth to the Arduino Mega microcontroller, and edge IoT devices total priced at USD 150. The most likely prospect of the presented work is to produce the sample that is ready to market.

KEYWORDS: brain-to-thing, immobilized people, EEG sensor, MQTT.

ABBREVIATIONS

AC is an air conditioner;
AI is artificial intelligence;
AMQP is an advanced message queuing protocol;
ASIC is an application specific integrated circuit;
BCI is a brain-computer interface;
BTC is a brain-to-thing communication;
CoAP is a constrained application protocol;
DDS is a data distribution service;
EEG is an electroencephalogram;
IIC is an inter-integrated circuit;
IoT is an Internet of Things;
LCD is a liquid-crystal display;
MAC is media access control;
MDP is a Markov decision process;
MQTT is a message queueing telemetry transport;
TGAM is ThinkGear ASIC module;
WBCI is a wireless brain-computer interface;
XMPP is an extensible messaging and presence protocol.

NOMENCLATURE

γ_L is a value of low gamma wave;
γ_M is a value of mid gamma wave;
$max_{\gamma L}$ is a maximum value of low gamma waves;
$max_{\gamma M}$ is a maximum value of mid gamma waves;
N is the number of IoT devices;
t is a current period of time.

INTRODUCTION

Disabled people without physical movement face additional barriers in almost all areas of life, including simple operations like turning the light on/off and controlling the AC. During the COVID-19 pandemic, they are disproportionately affected [1, 2] since regular transportation of medical and other support staff has got broken in some areas. For instance, public transport is suspended, and passengers may disembark from regional buses and trains but may not board in red zones under the Ukrainian adaptive quarantine regime [3]. Because of that and other factors, people without physical movement spend some time alone. The problem is getting more complicated for the disabled who are physically immobilized from neck to toes.

This paper presents a thought-managed smart home system based on BTC [4, 5] for people physically immobilized from neck to toes whose brain and eye control work normally. A non-invasive WBCI Sichiray TGAM brainwave EEG sensor kit is proposed to capture EEG signals. The EEG signals are transmitted via Bluetooth to the HC-05 module connected to the Arduino Mega board. The information about edge IoT devices [4–19] is pre-

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sented to the disabled on the LCD 1602 display with an IIC adapter wired to the same Arduino Mega microcontroller. The double blink is used to detect an event where the disabled person chooses the option shown on display. Control commands are sent from Arduino Mega (MQTT publisher) to the edge IoT devices (MQTT subscribers) that analyze them and start a specific operation like opening a door and turning the light on/off. The operation's confirmation is shown on the LCD 1602 display. To support the personalized usage of the BTC system with an AI touch, a combination of MDP [20] and Q-Learning (Q–L) [21] is proposed to identify the personalized suggestion flow directly. The BTC system has been examined by five males and five females of different ages between 8 and 59 years. Everyone successfully handled the BCI headset and showed satisfaction with the BTC system.

The object of study is the brain-to-thin communication that manages smart home appliances by immobilized people.

Three types of BCIs, active, reactive, and passive, describe possible communication pathways between the human brain and external devices [14]. Over twenty companies produce EEG devices that can derive the brain signals in several non-overlapping frequency bands, e.g., Alpha, Beta, Delta, Gamma, and Theta. The Sichiray TGAM brainwave EEG sensor kit with a separate Bluetooth board [15, 16] has an advantage over alternatives because of its low price of USD 50.

The subject of study is the non-invasive Sichiray TGAM brainwave EEG sensor kit that captures signals transmitted via Bluetooth to the HC-05 module connected to the Arduino Mega board. In this soft-/hardware complex, the information about edge IoT devices is presented to the disabled person on the LCD 1602 display wired to the same Arduino Mega microcontroller.

Analysis of the concepts and soft-/hardware solutions presented in [4–16] shows that none of them implement WBCI to control smart home appliances using IoT data protocol(s) along with budget EEG-based brain kit(s). The perspective approach is the WBCI based on the low-cost brainwave EEG sensor such as Sichiray TGAM and lightweight publish/subscribe IoT data protocol such as MQTT.

The purpose of the work is to develop the brain-to-thin communication of affordable price to control the smart home appliances by immobilized people.

1 PROBLEM STATEMENT

Over a billion people live with some form of disability around the world [1] and this number is dramatically increasing nowadays because of the COVID-19 and other pandemics. Military conflicts and world economic stagnation reduce the financial support of social activities, including assistive devices and support staff for immobilized people. None of the existing devices is of the price at USD 150 which is the aim of this work.

2 REVIEW OF THE LITERATURE

Many papers released were related to the case when the brain and eye control of immobilized people work normally and can be employed to manage the smart home. The BCI with EEG non-invasive electrodes and a headset installation is broadly applied to manage smart home appliances using IoT techniques [4–16]. It is also important to personalize smart home interactions to help disabled people improve their daily life routines through solutions based on AI. For instance, the menu options can be shown in a different order in accord with previous selections, i.e., rates/ranks of the options, of the disabled. Here, a good solution may be giving suggestions to save time while interacting with the smart home environment.

Edge IoT devices exchange data via IoT protocols such as MQTT, CoAP, XMPP, DDS, AMQP [17] using WiFi, Bluetooth, and Ethernet networking technologies. On a short distance of up to 10 m, most IoT hardware employs Bluetooth classes 2 or 3 to be connected directly [18]. WiFi and Ethernet connections are mainly applied for longer distances. MQTT IoT software can be executed on thin clients like Arduino Uno since it takes approximately 10 KB of random-access memory. MQTT brokers reliably work with 100,000 publishers and 100 subscribers [19] that satisfies the smart and intelligent home network requirements.

3 MATERIALS AND METHODS

In this research work, smart home appliances are wirelessly controlled via the NodeMCU ESP8266 ESP-12 modules [22] with 3.3 V relays [23] (5 V relays can be used as well), MQTT subscribers, that receive control commands through the MQTT IoT data protocol from Arduino Mega microcontroller, the MQTT publisher. Ethernet shield connects Arduino Mega to the smart home network, as well as the MQTT broker is started on the Lenovo G510 laptop with Windows 10 in this project. LCD 1602 display presents information about edge IoT devices (e.g., light, door, and AC), it is wired to the Arduino Mega board. Sichiray TGAM brainwave EEG sensor kit captures EEG signals and then transmits them to the HC-05 Bluetooth module [16] connected to the Arduino Mega. C programs were developed in Arduino IDE for Arduino Mega and NodeMCU ESP8266 ESP-12 boards. The various parts involved in the design of the BTC system for controlling smart home devices are shown in Fig. 1.

During the EEG recording, the eye blinking can generate bioelectric signals with the amplitude ten times larger/smaller than some previous values [24]. Hence, double blinking is used to select an option shown on the LCD 1602 display in this project. It is detected if the following dependencies appear in three Bluetooth packets [16] in a row:

1. Quality of signal equals 0.
2. $Y_L[t] < \max_{Y_L}$, $Y_M[t] < \max_{Y_M}$, $\max_{Y_L} = 10$, $\max_{Y_M} = 10$. Maximum values 10 for $\max_{\gamma L}$ and $\max_{\gamma M}$ are proposed for the experienced users in this project.

Gamma waves are applied to detect the double blink event in this project since they are the only type of brain waves that affect the entire brain [25, 26].

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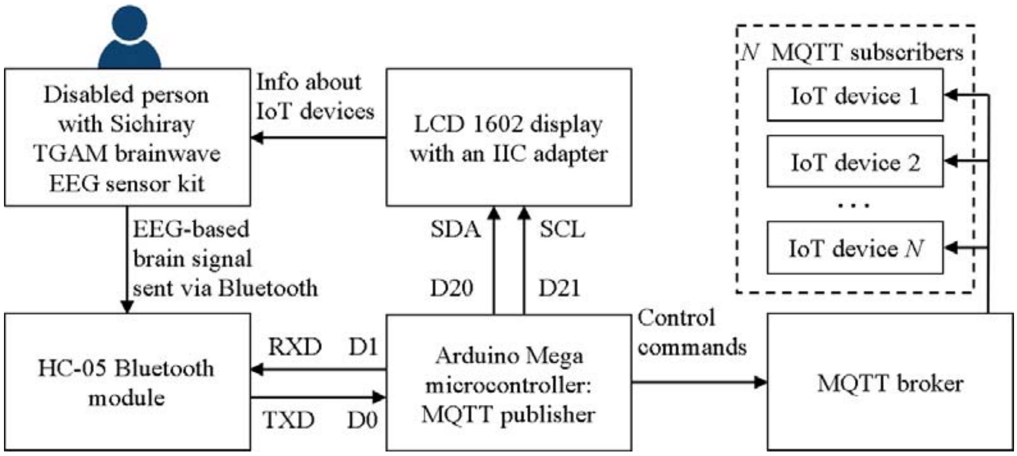

Figure 1 – Block diagram of the brain-controlled smart home with Sichiray TGAM brainwave EEG sensor kit and MQTT IoT data protocol

Then, three Bluetooth packets are skipped since two above-stated dependencies may be repeated, and hence the duplication of the double blink can be detected again that is wrong.

Boards with static IP addresses are connected via the router (two routers, TP-Link TL-WR940N and TL-MR3020, were successfully tested). Additional MAC filtering can optionally be applied to improve the security of the BTC system.

Like a similar WBCI system [6], the proposed BTC project employs a single dry EEG sensor to prevent the inconvenience of wearing many EEG electrodes, making the device completely wearable. The low power consumption with 3 V and 5 V supplies and recharging ability adds to its flexibility. Therefore, the proposed BTC is a comprehensive system in terms of functionality and design which provides independence and ease of its use for disabled people without physical movement.

For the long-term exploitation, the BTC system is proposed to employ MDP and Q-L techniques to run reinforcement learning for detecting optimum rewards of actions so it will personalize the order of menu options in future use cases.

4 EXPERIMENTS

The outcomes of the proposed BTC system for controlling a smart home for immobilized people are achieved using two parts, headset and edge wireless IoT devices.

In the headset part, the information on IoT devices is displayed and brain signals are sent to the HC-05 Bluetooth module connected to the Arduino Mega (MQTT publisher).

Sichiray TGAM brainwave EEG sensor kit and an example of its installation on the head are shown in Fig. 2. It safely measures and transfers signals such as human attention and meditation, Alpha, Beta, Delta, Gamma, and Theta waves via the Bluetooth slave module. The kit consists of an EEG electrode, two ear clips with ground electrodes, TGAM and Bluetooth modules, and a 2xAAA battery holder with a switch. An additional bandage is needed to rest the EEG electrode on the forehead above the eyes. The baud rate of 57600 bits/sec is used in this project [16].

The receiving part consists of the Arduino Mega board wired with the HC-05 Bluetooth master module (see Fig. 3), where HC-05 TXD and RXD pins are wired with Arduino Mega RX(D0) and TX(D1) pins, respectively. These pins must be disconnected during the Arduino sketch uploading into the Arduino Mega board. In this project, the logic level converter [16] is not used.

Arduino Brain Library is the most known way to parse data from Neurosky-based EEG headsets [27] nowadays. The standard test, the Arduino sketch BrainSerialTest.ino, shows only errors in the data received by the HC-05 module [16]; hence, the solution is the analysis of the Bluetooth packets sent by the Sichiray Bluetooth module.

Information about IoT devices is presented to the disabled on the LCD 1602 display with an IIC adapter wired via the SDA and SCL pins to the Arduino Mega microcontroller (D20 and D21 pins, respectively). In this project, LCD 1602 module shows the IoT device's name and state in the first line and the brain signals in the second one, a maximum of 16 characters in a line. The disabled person must double blink to choose a specific option. Options are changed every 10 sec. Examples are as follows:

– "Alarm": the option "Alarm" is shown to the disabled person;

– "Alarm ON": the option "Alarm ON" is shown to the disabled person;

– "Alarm OFF": the option "Alarm OFF" is shown to the disabled person;

– "Alarm ON +++++++": this text is the confirmation of the option "Alarm ON" selected by the disabled person;

– "Alarm OFF ------": this text is the confirmation of the option "Alarm OFF" selected by the disabled person.

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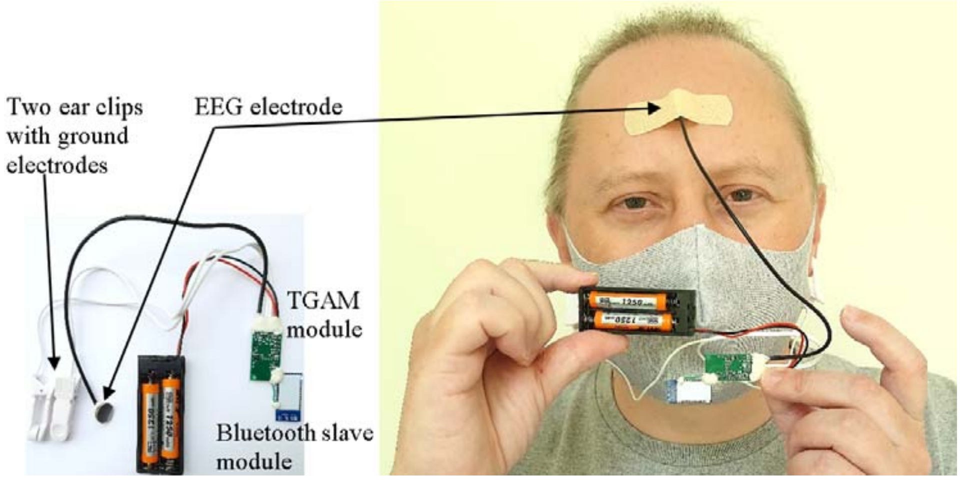

Figure 2 – Sichiray TGAM brainwave EEG sensor kit (on the left) and an example of its installation on the head (on the right)

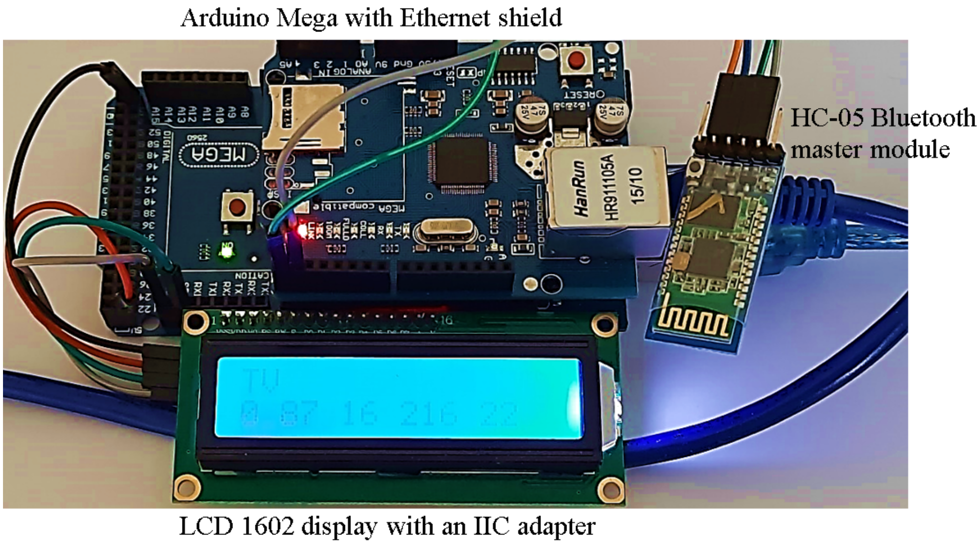

Figure 3 – Arduino Mega microcontroller with HC-05 Bluetooth module, LCD 1602 display, and Ethernet shield

The quality of signal and ten brain signals sent by the Sichiray TGAM brainwave EEG sensor kit are as follows: attention, meditation, delta wave, theta wave, low alpha wave, high alpha wave, low beta wave, high beta wave, low gamma wave, mid gamma wave. However, quality of the signal, attention, meditation, low gamma wave, and mid gamma wave are only shown in the second line of the LCD 1602 display since the first parameter is a selector that excludes Bluetooth packets with poor quality of signal, second and third parameters are the integrative ones because they are calculated using different brain waves, last two parameters are used to detect the double blink event in this project.

To manage the edge IoT devices via the MQTT IoT data protocol, the following control commands are applied:

– Alarm (static IP address 192.168.0.105): ON (control command "101"), OFF (control command "102");

– Light (static IP address 192.168.0.106): ON (control command "201"), OFF (control command "202");

– AC (static IP address 192.168.0.102): ON (control command "301"), OFF (control command "302");

– TV (television; static IP address 192.168.0.103): ON (control command "401"), OFF (control command "402");

– Door (static IP address 192.168.0.104): Open (control command "501"), Close (control command "502").

In this project, the MQTT broker and the MQTT publisher are assigned static IP addresses 192.168.0.100 and 192.168.0.101, respectively.

A flow chart of the flow of events in the BTC smart home for disabled people without physical movement is shown in Fig. 4.

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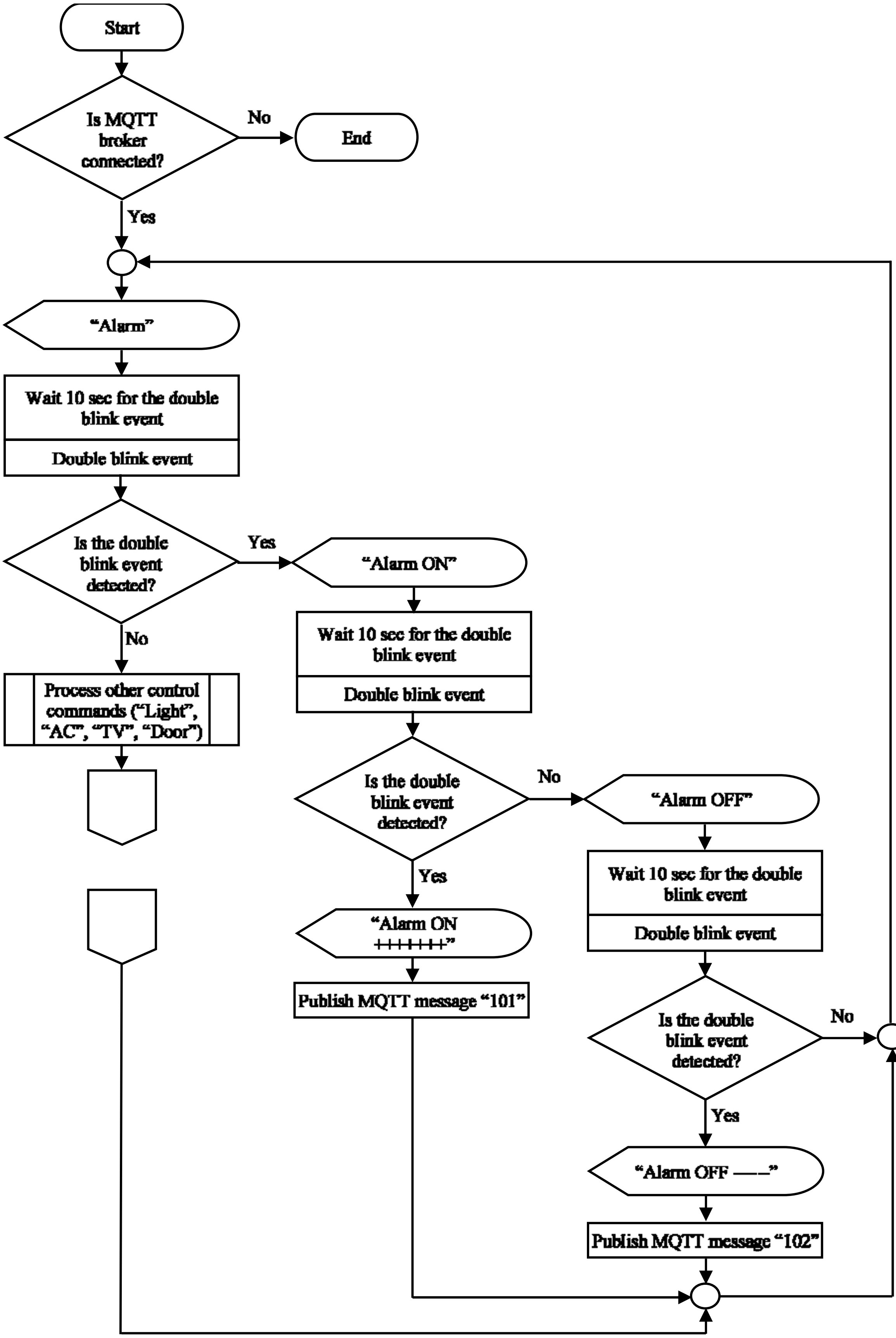

Figure 4 – A flow chart of event detection and control in the BTC smart home for disabled people without physical movement

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The Arduino sketch is based on the code [16] but the parts related to the Ethernet connection, MQTT IoT data protocol, LCD 1602 display, and detection of the double blink event were added.

In the part on the edge wireless IoT devices, the NodeMCU ESP8266 ESP-12 boards (MQTT subscribers) with relays implement control commands such as turning the light on/off and controlling the air conditioner.

Edge wireless IoT devices, MQTT subscribers, are controlled via the relays wired to the NodeMCU ESP8266 ESP-12 boards (see Fig. 5). Arduino sketch includes two libraries, ESP8266WiFi.h and PubSubClient.h, to program NodeMCU ESP8266 ESP-12 board and receive control commands via the MQTT IoT data protocol, respectively. Arduino relays [23] are controlled via the general-purpose input/output pin 16 (D0); they can work with the 10A–250V electrical equipment that satisfies requirements to the IoT devices in a smart home.

Eclipse Mosquitto version 1.4.11 [28] was installed on the Lenovo G510 laptop with Windows 10 in this project. This open-source software includes the MQTT broker mosquitto.exe, the MQTT publisher mosquitto_pub.exe, and the MQTT subscriber mosquitto_sub.exe. The administrator of the system can receive the control commands assigned to a specific topic, "/Blink" in this project (see Fig. 6; "–q" specifies the quality of service to use for the message from 0 to 2). In this project, quality of service level 1 is applied to deliver a message at least once to the receiver. The sender stores the message until it gets an acknowledgment packet from the receiver. MQTT passwords can be applied to the system improving its security if necessary.

Table 1 illustrates how the MQTT client publishes/subscribes messages under the topic "/Blink" and controls the relay connected to the AC with control commands "301" and "302". In Arduino IDE, NodeMCU 0.9 (ESP-12 Module) was selected to program the NodeMCU ESP8266 ESP-12 board. The cost of the custom hardware is about USD 150 for the following components: Sichiray TGAM brainwave EEG sensor kit, Arduino Mega, Ethernet shield, HC-05 Bluetooth module, LCD 1602 display, five relays, and NodeMCU ESP8266 ESP-12 boards.

5 RESULTS

Ten people of different ages and gender took part in the experiment on the control of smart home appliances with the Sichiray TGAM brainwave EEG sensor kit (their preferred values $max_{\gamma L}$ and $max_{\gamma M}$ are shown in parentheses): five female users of 8 (30, 70), 28 (30, 70), 43 (30, 70), 46 (10, 10), and 57 (20, 20) years old; five male users of 10 (30, 70), 37 (20, 20), 42 (20, 20), 47 (20, 20), and 59 (20, 20) years old. The male software developer has preferred values (10, 10). Everyone successfully handled the Sichiray TGAM brainwave EEG sensor kit and showed satisfaction with the BTC system.

6 DISCUSSION

New users noted that it is easy to control smart home appliances if low and mid gamma waves are greater than 10. However, false detections of the double blink event appear in this case. The solution is to adjust $max_{\gamma L}$ and $max_{\gamma M}$ in accordance with the distinctive features of the user(s). For some new users, frequent eye blinking is a way to replace the simple double blink.

Preparation for the experiment includes the acquaintance with the mobile application "Brainwave Visualizer" [29] (see Fig. 7) that changes the on-screen shapes morph and color depending on the state of mind. Also, two parameters, attention and meditation, are shown on the smartphone screen.

Three timeslots are taken into consideration in the statistical analysis:

1. Timeslot that is needed to teach new users how to use the Sichiray TGAM brainwave EEG sensor kit and the mobile application "Brainwave Visualizer" (about five minutes).
2. Timeslot that is needed to present the BTC system for the disabled people without physical movement by the developer/instructor (about ten minutes).
3. Timeslot that is needed to study how to use the BTC system for the disabled people without physical movement by the new users (about five minutes).

New users admitted that sometimes it is much more convenient to select a specific option using the frequent eye blinking and slow eye blinking is working properly to avoid the double blinking event, as well as the explanation of the control commands helps to understand the BTC system. Also, they recommended replacing the small LCD 1602 display with the larger one.

The main objective of performing statistical analysis was to study that everyone could use this system and determine the stability and friendliness of the system. All participants admitted the stability and ease of using the proposed BTC system.

CONCLUSIONS

The urgent problem of the smart home affordable implementation for immobilized people was solved using the BTC EEG-based approach and the MQTT communication between the MQTT publisher, Sichiray TGAM brainwave EEG sensor kit connected via Bluetooth to the Arduino Mega microcontroller with Ethernet shield, and the MQTT subscribers, edge wireless IoT devices. The low-cost and reliable soft-/hardware priced at USD 150 assists people physically immobilized from neck to toes whose brain and eye control work normally.

The scientific novelty of obtained results that the method of the smart home management using low/mid gamma waves delivered from the Sichiray TGAM brainwave EEG sensor is firstly proposed. The double blink event is detected by the Sichiray TGAM brainwave EEG sensor if the quality of signal equals 0 and low/mid gamma waves less than 10 (this value is recommended for the experienced users; other values might be applied for new users) in three consecutive Bluetooth packets. This allows to implement the BTC smart home concept and reduces the workload on support staff.

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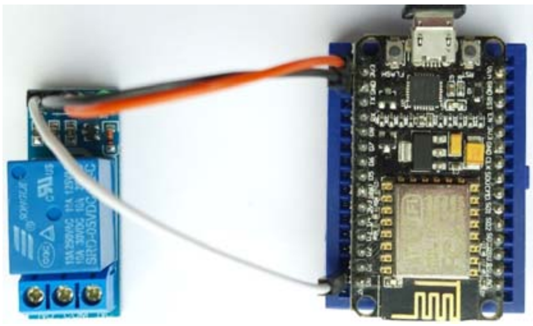

Figure 5 – NodeMCU ESP8266 ESP-12 board (on the right) with relay (on the left)

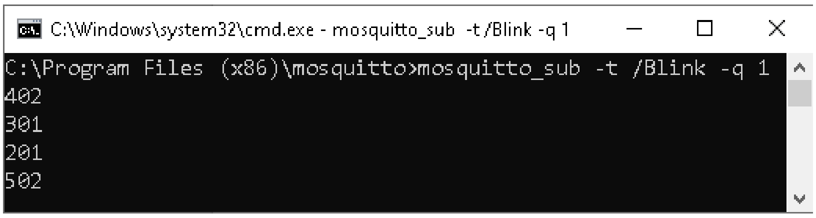

Figure 6 – Screenshot of the command-line interface window with the MQTT subscriber mosquitto_sub.exe: Control commands under the topic "/Blink" and the quality of service level 1

Table 1 – NodeMCU ESP8266 ESP-12 programming and its description: Publishing/subscribing MQTT messages under the topic "/Blink" and controlling the relay connected to the AC with control commands "301" and "302"

Microcontroller programming	Description
#include <ESP8266WiFi.h> #include <PubSubClient.h>	Include libraries to program NodeMCU ESP8266 board and work with MQTT IoT data protocol
String str;	Declare variable *str* of String type
byte server[] = { 192, 168, 0, 100 };	Declare array *server* with the IP address of the MQTT broker

void callback(char* topic, byte* payload, unsigned int length)
{ str = String((char*)payload);
if (str.indexOf("301") == 0) digitalWrite (16, HIGH);
else if (str.indexOf("302") == 0) digitalWrite (16, LOW);
}
	Function *callback* analyzes the Bluetooth payload and switches ON/OFF the relay

WiFiClient wifiClient; PubSubClient client(server, 1883, callback, wifiClient);	Declare WiFi and MQTT clients
const char* ssid = "SSID"; const char* password = "Password";	Declare constants for SSID and password
int Relay = 16;	Define the relay pin at D0
void setup() {	

WiFi.begin(ssid, password);
while (WiFi.status() != WL_CONNECTED)
delay(500);
	Connect NodeMCU ESP8266 ESP-12 board to the WiFi network

if (client.connect("arduinoAC")) client.subscribe("/Blink");	If MQTT client connected, subscribe messages under MQTT topic "/Blink"
pinMode(Relay, OUTPUT); }	Set pin D0 as output
void loop() { client.loop(); }	Check for new MQTT messages, topic "/Blink"

Figure 7 – Screenshot of the mobile application "Brainwave Visualizer" on the Samsung Galaxy SM-M315F/DSN smartphone, Android 11 OS

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The practical significance of obtained results is that the immobilized people can manage the smart home appliances via the double blink event to select an option shown on the LCD 1602 display with an IIC adapter using the low and mid gamma brain waves. This is achieved in two phases:

1. Headset part: Displaying information about edge IoT devices on LCD 1602 module and sending brain signals from the Sichiray TGAM brainwave EEG sensor kit to HC-05 Bluetooth board wired to the Arduino Mega with Ethernet shield (MQTT publisher).

2. Edge wireless IoT devices: NodeMCU ESP8266 ESP-12 boards with relays (MQTT subscribers).

The Arduino Mega microcontroller analyzes Bluetooth packets received from the Sichiray TGAM brainwave EEG sensor kit, and then sends control commands to the edge IoT devices via MQTT messages.

Ten people of different ages and gender took part in the experiment on the control of smart home appliances with the Sichiray TGAM brainwave EEG sensor kit: five female users of 8, 28, 43, 46, and 57 years old; five male users of 10, 37, 42, 47, and 59 years old. Everyone successfully handled the EEG headset and showed satisfaction with the BTC system.

Prospects for further research are as follows: development of the production sample of the BTC smart home for immobilized people that is ready to market; users of the BTC system recommended replacing the small LCD 1602 display with the larger one.

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REFERENCES

1. World Health Organization, Disability and Health, 2020 [Electronic resource]. Access mode: https://www.who.int/news-room/fact-sheets/detail/disability-and-health
2. COVID-19 and disabled people snapshot – March 2021 [Electronic resource]. Access mode: http://www.activityalliance.org.uk/how-we-help/research/5854-covid19-and-disabled-people-snapshot-september-2020
3. Ukraine: Authorities to tighten COVID-19 restrictions in Kyiv and Lviv March 20-April 9 /update 20, 2021 [Electronic resource]. Access mode: https://www.garda.com/crisis24/news-alerts/457186/ukraine-authorities-to-tighten-covid-19-restrictions-in-kyiv-and-lviv-march-20-april-9-update-20
4. Teles A., Cagy M., Silva F. et al.Using brain-computer interface and Internet of Things to improve healthcare for wheelchair users, *Mobile Ubiquitous Computing, Systems, Services, and Technologies: 11th international conference, Barcelona, 12–16 November 2017, proceedings*. Wilmington: IARIA XPS Press, 2017, pp. 92–94.
5. Zhang X. , Yao L. , Zhang S. et al.] Internet of Things meets brain-computer interface: A unified deep learning framework for enabling human-thing cognitive interactivity, *IEEE Internet of Things*, 2019, Vol. 6, pp. 2084–2092.
6. Jafri S.R.A., Hamid T., Mahmood R. et al. Wireless brain computer interface for smart home and medical system, *Wireless Personal Communications*, 2019, Vol. 106, pp. 2163–2177. DOI: 10.1007/s11277-018-5932-x
7. Lee W. T., Nisar H., Malik A. S. et al. A brain computer interface for smart home control, *Consumer Electronics: 17th IEEE international symposium, Hsinchu, 3–6 June 2013, proceedings.* Los Alamitos, IEEE, 2013, pp. 35–36. DOI: 10.1109/ISCE.2013.6570240
8. Qin L. Y., Nasir N. M. , Huq M. S. et al. Smart home control for disabled using brain computer interface, *International Journal of Integrated Engineering*, 2020, Vol. 12, No. 4, pp. 74–82.
9. Madoš B., Ádám N., Hurtuk J. et al. Brain-computer interface and Arduino microcontroller family software interconnection solution, *Applied Machine Intelligence and Informatics, 14th IEEE International Symposium, Herlany, 21–23 January 2016, proceedings.* NY, Curran Associates, 2016, pp. 217–221. DOI: 10.1109/SAMI.2016.7423010
10. Sharma V., Sharma A. Review on: Smart home for disabled using brain-computer interfaces, *Information Sciences and Computing Technologies,* 2015, Vol. 2, No. 2, pp. 142–146.
11. Kim M., Kim M.-K., Hwang M. et al. Online home appliance control using EEG-based brain-computer interfaces, *Electronics,* 2019, Vol. 8, No. 10: 1101, 13 p. DOI: 10.3390/electronics8101101
12. Nanda P., Kamath A. Survey on home automation system using brain computer interface paradigm based on auditory selection attention, *International Research Journal of Engineering and Technology*, 2019, Vol. 6, pp. 3100–3111.
13. Belkacem A. N., Jamil N., Palmer J. A. et al. Brain computer interfaces for improving the quality of life of older adults and elderly patients, *Frontiers in Neuroscience,* 2020, Vol. 14, No. 692, pp. 1–11. DOI: 10.3389/fnins.2020.00692
14. Gu X., Cao Z., Jolfaei A. et al. EEG-based brain-computer interfaces (BCIs): A survey of recent studies on signal sensing technologies and computational intelligence approaches and their applications, *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, 2021, Vol. 18, No. 5, p. 1645–1666. DOI: 10.1109/TCBB.2021.3052811
15. Wu Z. P., Zhang W., Zhao J. et al. Optimized complex network method (OCNM) for improving accuracy of measuring human attention in single-electrode neurofeedback system, *Computational Intelligence and Neuroscience*, 2019, Vol. 2019, No. 2167871. 10 p. DOI: 10.1155/2019/2167871
16. Irfan G., Zubov D. EEG-based brain-computer interface: connecting Sichiray brainwave sensor kit and Arduino Uno with HC-05 Bluetooth module, *Computer Intelligent Systems and Networks, 14th international conference, Kryvyi Rih, 23–25 March 2021, proceedings*. Kryvyi Rih, Kryvyi Rih National University, 2021, pp. 21–28.
17. Dizdarevic J. , Carpio F. , Jukan A. et al. Survey of communication protocols for Internet-of-Things and related challenges of fog and cloud computing integration, *ACM Computing Surveys*, 2019,Vol. 51, No. 6, Article 116, pp. 1–29. DOI: 10.1145/3292674
18. Trent M., Abdelgawad A., Yelamarthi K. et al. Gaggi O., Manzoni P., Palazzi C. et al. (Eds.) A smart wearable navi-

DOI 10.15588/1607-3274-2022-2-9

gation system for visually impaired, *Smart objects and technologies for social good*, *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*. Cham, Springer, 2017, Vol. 195, pp. 333–341. DOI: 10.1007/978-3-319-61949-1_35
19. ScalAgent Distributed Technologies: Benchmark of MQTT servers, ActiveMQ 5.10.0, Apollo 1.7, JoramMQ 1.1.3 (based on Joram 5.9.1), Mosquitto 1.3.5, RabbitMQ 3.4.2. ScalAgent Distributed Technologies, Échirolles, 2015 [Electronic resource]. Access mode: http://www.scalagent.com/IMG/pdf/Benchmark_MQTT_servers-v1-1.pdf
20. Tijms H., Boucherie R., Van Dijk N. M. (Eds.). One-step improvement ideas and computational aspects, *Markov decision processes in practice*. Cham, Springer, 2017, pp. 3–32. DOI: 10.1007/978-3-319-47766-4.
21. Watkins C. J., Dayan P. Technical Note: Q-Learning, *Machine Learning*, 1992, Vol. 8, pp. 279–292. DOI: 10.1023/A:1022676722315
22. Getting Started w/ NodeMCU ESP8266 on Arduino IDE © GPL3+ [Electronic resource]. Access mode: https://create.arduino.cc/projecthub/electropeak/getting-started-w-nodemcu-esp8266-on-arduino-ide-28184f
23. Guide for Relay Module with Arduino [Electronic resource]. Access mode: https://randomnerdtutorials.com/guide-for-relay-module-with-arduino/
24. Dawaga M.E. Automatic detection of eye blinking using the generalized Ising model: thesis ... master of science. London: University of Western Ontario, 2016, 54 p.
25. Jia X., Kohn A. Gamma rhythms in the brain, *PLOS Biology*, 2011, Vol. 9, No. 4, 4 p. DOI: 10.1371/journal.pbio.1001045
26. Brain Wave Frequencies [Electronic resource]. Access mode: https://nhahealth.com/brainwaves-the-language/
27. Arduino library for reading Neurosky EEG brainwave data [Electronic resource]. Access mode: https://www.pantechsolutions.net/blog/arduino-library-for-reading-neurosky-eeg-brainwave-data/
28. Eclipse Mosquitto™: An open-source MQTT broker [Electronic resource]. Access mode: http://mosquitto.org
29. Brainwave Visualizer (Android&iOS) [Electronic resource]. – Access mode: https://store.neurosky.com/products/brainwave-visualizer-1

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ПРОТОТИП РОЗУМНОГО БУДИНКУ ДЛЯ ПАРАЛІЗОВАНИХ ЛЮДЕЙ: ВЗАЄМОДІЯ МОЗОК-РІЧ НА ОСНОВІ EEG/MQTT

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АНОТАЦІЯ

Актуальність. Паралізовані люди мають додаткові перешкоди в багатьох сферах життя, включаючи такі прості дії як вмикання/вимикання освітлення та керування повітряним кондиціонером. Мета роботи – розробка взаємодії мозок-річ в низькій ціновій категорії для контролю підсистем розумного будинку людьми, які паралізовані нижче шиї.

Метод. Неінвазивний прилад Sichiray TGAM вимірює активність мозку людей за допомогою датчика електроенцефалограми і потім передає інформацію через Bluetooth на модуль HC-05, який підключений до мікроконтролера Arduino Mega. Інформація щодо пристроїв розумного будинку показується паралізованій людині на екрані модуля LCD 1602, який підключений до того ж Arduino Mega. Паралізована людина вибирає опцію за допомогою подвійного моргання, що відображується в нульовому значенні якості сигналу та величинах нижніх і середніх гамма хвиль менше ніж десять в трьох послідовних Bluetooth пакетах. Команди керування надсилаються від Arduino Mega (MQTT-видавець) до пристроїв (MQTT-підписники) розумного будинку, які аналізують їх і виконують певну операцію, наприклад відкриття дверей та вмикання/вимикання сигналізації.

Результат. П'ять чоловіків і п'ять жінок віком від 8 до 59 років тестували комплекс керування підсистемами розумного будинку на базі приладу Sichiray TGAM. Результати показали успішне освоєння і зацікавленість у використанні системи мозок-річ.

Висновки. У даній роботі представлена концепція розумного будинку для паралізованих людей на базі принципу мозок-річ і MQTT взаємодії між MQTT-видавцем (прилад Sichiray TGAM з датчиком електроенцефалограми, який через Bluetooth підключений до мікроконтролера Arduino Mega) і пристроями розумного будинку загальною ціною близько USD 150. Перспективою подальшого розвитку є виробництво пристроїв готових до масового використання.

КЛЮЧОВІ СЛОВА: мозок-річ, паралізовані люди, датчик електроенцефалограми, MQTT.

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ПРОТОТИП УМНОГО ДОМА ДЛЯ ПАРАЛИЗОВАННЫХ ЛЮДЕЙ: ВЗАИМОДЕЙСТВИЕ МОЗГ-ВЕЩЬ НА ОСНОВЕ EEG/MQTT

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АННОТАЦИЯ

Актуальность. Парализованные люди встречают дополнительные препятствия во многих сферах жизни включая такие простые действия как включение/выключение освещения и управление воздушным кондиционером. Цель работы – разработка взаимодействия мозг-вещь в низкой ценовой категории для контроля подсистем умного дома людьми, которые парализованы ниже шеи.

Метод. Неинвазивный прибор Sichiray TGAM измеряет активность мозга людей при помощи датчика электроэнцефалограммы и затем передает информацию по Bluetooth на модуль HC-05, который подключен к микроконтроллеру Arduino Mega. Информация об устройствах умного дома показывается парализованному человеку на экране модуля LCD 1602, подсоединенному к тому же Arduino Mega. Парализованный человек выбирает показываемую опцию при помощи двойного моргания, что отражается в нулевом значении качества сигнала и величинах нижних и средних гамма волн меньше десяти в трех последовательных Bluetooth пакетах. Управляющие команды посылаются от Arduino Mega (MQTT-издатель) к устройствам (MQTT-подписчики) умного дома, которые анализируют их и выполняют определенную операцию, например открытие двери и включение/выключение сигнализации.

Результаты. Пять человек мужского и пять женского полов возрастом от 8 до 59 лет тестировали комплекс управления подсистемами умного дома на базе прибора Sichiray TGAM. Результаты показали успешное освоение и заинтересованность в использовании системы мозг-вещь.

Выводы. В данной работе представлена концепция умного дома для парализованных людей на базе принципа мозг-вещь и MQTT взаимодействия между MQTT-издателем (прибор Sichiray TGAM с датчиком электроэнцефалограммы, который через Bluetooth подсоединяется к микроконтроллеру Arduino Mega) и устройствами умного дома общей ценой около USD 150. Перспективой дальнейшего развития является производство изделия готового к массовому использованию.

КЛЮЧЕВЫЕ СЛОВА: мозг-вещь, парализованные люди, датчик электроэнцефалограммы, MQTT.

ЛІТЕРАТУРА / ЛИТЕРАТУРА

1. World Health Organization, Disability and Health, 2020 [Electronic resource]. – Access mode: https://www.who.int/news-room/fact-sheets/detail/disability-and-health
2. COVID-19 and disabled people snapshot – March 2021 [Electronic resource]. – Access mode: http://www.activityalliance.org.uk/how-we-help/research/5854-covid19-and-disabled-people-snapshot-september-2020
3. Ukraine: Authorities to tighten COVID-19 restrictions in Kyiv and Lviv March 20–April 9 /update 20, 2021 [Electronic resource]. – Access mode: https://www.garda.com/crisis24/news-alerts/457186/ukraine-authorities-to-tighten-covid-19-restrictions-in-kyiv-and-lviv-march-20-april-9-update-20
4. Using brain-computer interface and Internet of Things to improve healthcare for wheelchair users / [A. Teles, M. Cagy, F. Silva et al.] // Mobile Ubiquitous Computing, Systems, Services, and Technologies: 11th international conference, Barcelona, 12–16 November 2017: proceedings. – Wilmington: IARIA XPS Press, 2017. – P. 92–94.
5. Internet of Things meets brain-computer interface: A unified deep learning framework for enabling human-thing cognitive interactivity / [X. Zhang, L. Yao, S. Zhang et al.] // IEEE Internet of Things. – 2019. – Vol. 6. – P. 2084–2092.
6. Wireless brain computer interface for smart home and medical system / [S.R.A. Jafri, T. Hamid, R. Mahmood et al.] // Wireless Personal Communications. – 2019. – Vol. 106. – P. 2163–2177. doi:10.1007/s11277-018-5932-x
7. A brain computer interface for smart home control / [W.T. Lee, H. Nisar, A.S. Malik et al.] // Consumer Electronics: 17th IEEE international symposium, Hsinchu, 3–6 June 2013: proceedings. – Los Alamitos : IEEE, 2013. – P. 35–36. DOI: 10.1109/ISCE.2013.6570240
8. Smart home control for disabled using brain computer interface / [L.Y. Qin, N.M. Nasir, M.S. Huq et al.] // International Journal of Integrated Engineering. – 2020. – Vol. 12, № 4 – P. 74–82.
9. Brain-computer interface and Arduino microcontroller family software interconnection solution / [B. Madoš, N. Ádám, J. Hurtuk et al.] // Applied Machine Intelligence and Informatics: 14th IEEE International Symposium, Herlany, 21–23 January 2016: proceedings. – NY: Curran Associates, 2016. – P. 217–221. DOI: 10.1109/SAMI.2016.7423010
10. Sharma V. Review on: Smart home for disabled using brain-computer interfaces / V. Sharma, A. Sharma // Information Sciences and Computing Technologies. – 2015. – Vol. 2, №. 2. – P. 142–146.
11. Online home appliance control using EEG-based brain-computer interfaces / [M. Kim, M.-K. Kim, M. Hwang et al.] // Electronics. – 2019. – Vol. 8, № 10: 1101. – 13 p. DOI: 10.3390/electronics8101101
12. Nanda P. Survey on home automation system using brain computer interface paradigm based on auditory selection attention / P. Nanda, A. Kamath // International Research

DOI 10.15588/1607-3274-2022-2-9

Journal of Engineering and Technology. – 2019. – Vol. 6. – P. 3100–3111.
13. Brain computer interfaces for improving the quality of life of older adults and elderly patients / [A.N. Belkacem, N. Jamil, J.A. Palmer et al.] // Frontiers in Neuroscience. – 2020. – Vol. 14, № 692. – P. 1–11. DOI: 10.3389/fnins.2020.00692
14. EEG-based brain-computer interfaces (BCIs): A survey of recent studies on signal sensing technologies and computational intelligence approaches and their applications / [X. Gu, Z. Cao, A. Jolfaei et al.] // IEEE/ACM Transactions on Computational Biology and Bioinformatics. – 2021. – Vol. 18, № 5. – P. 1645–1666. DOI: 10.1109/TCBB.2021.3052811
15. Optimized complex network method (OCNM) for improving accuracy of measuring human attention in single-electrode neurofeedback system / [Z.P. Wu, W. Zhang, J. Zhao et al.] // Computational Intelligence and Neuroscience. – 2019. – Vol. 2019, № 2167871. – 10 p. DOI: 10.1155/2019/2167871
16. EEG-based brain-computer interface: connecting Sichiray brainwave sensor kit and Arduino Uno with HC-05 Bluetooth module / G. Irfan, D. Zubov // Computer Intelligent Systems and Networks: 14th international conference, Kryvyi Rih, 23–25 March 2021: proceedings. – Kryvyi Rih: Kryvyi Rih National University, 2021. – P. 21–28.
17. Survey of communication protocols for Internet-of-Things and related challenges of fog and cloud computing integration / [J. Dizdarevic, F. Carpio, A. Jukan et al.] // ACM Computing Surveys. – 2019. – Vol. 51, № 6. – Article 116. – P. 1–29. DOI: 10.1145/3292674
18. Trent M. A smart wearable navigation system for visually impaired / [M. Trent, A. Abdelgawad, K. Yelamarthi et al.] // Smart objects and technologies for social good / [O. Gaggi, P. Manzoni, C. Palazzi et al.] (Eds.) // Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering. – Cham: Springer, 2017. – Vol. 195. – P. 333–341. DOI: 10.1007/978-3-319-61949-1_35
19. ScalAgent Distributed Technologies: Benchmark of MQTT servers: ActiveMQ 5.10.0, Apollo 1.7, JoramMQ 1.1.3 (based on Joram 5.9.1), Mosquitto 1.3.5, RabbitMQ 3.4.2. ScalAgent Distributed Technologies, Échirolles, 2015 [Electronic resource]. – Access mode: http://www.scalagent.com/IMG/pdf/Benchmark_MQTT_servers-v1-1.pdf
20. H. Tijms. One-step improvement ideas and computational aspects / H. Tijms // Markov decision processes in practice / R. Boucherie, N.M. Van Dijk (Eds.). – Cham: Springer, 2017. – P. 3–32. doi: 10.1007/978-3-319-47766-4.
21. Watkins C.J. Technical Note: Q-Learning / C.J. Watkins, P. Dayan // Machine Learning. – 1992. – Vol. 8. – P. 279–292. DOI: 10.1023/A:1022676722315
22. Getting Started w/ NodeMCU ESP8266 on Arduino IDE © GPL3+ [Electronic resource]. – Access mode: https://create.arduino.cc/projecthub/electropeak/getting-started-w-nodemcu-esp8266-on-arduino-ide-28184f
23. Guide for Relay Module with Arduino [Electronic resource]. – Access mode: https://randomnerdtutorials.com/guide-for-relay-module-with-arduino/
24. Dawaga M.E. Automatic detection of eye blinking using the generalized Ising model: thesis ... master of science / Dawaga Marwa Elsayh. London: University of Western Ontario, 2016. – 54 p.
25. Jia X. Gamma rhythms in the brain / X. Jia, A. Kohn // PLOS Biology. – 2011. – Vol. 9, № 4. – 4 p. DOI: 10.1371/journal.pbio.1001045
26. Brain Wave Frequencies [Electronic resource]. – Access mode: https://nhahealth.com/brainwaves-the-language/
27. Arduino library for reading Neurosky EEG brainwave data [Electronic resource]. – Access mode: https://www.pantechsolutions.net/blog/arduino-library-for-reading-neurosky-eeg-brainwave-data/
28. Eclipse Mosquitto™: An open-source MQTT broker [Electronic resource]. – Access mode: http://mosquitto.org
29. Brainwave Visualizer (Android&iOS) [Electronic resource]. – Access mode: https://store.neurosky.com/products/brainwave-visualizer-1

DOI 10.15588/1607-3274-2022-2-9