Pamukkale Univ Muh Bilim Derg, 28(5), 632-642, 2022

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

A human-computer interaction system based on eye, eyebrow and head movements

Göz, kaş ve baş hareketlerine dayalı bir insan-bilgisayar etkileşimi sistemi

Muhammed Oğuz TAS[1], Hasan Serhan YAVUZ[1]*

[1]Department of Elec.-Elect. Engineering, Faculty of Engineering-Architecture, Eskisehir Osmangazi Univ. Eskisehir, Turkey.
motas@ogu.edu.tr, hsyavuz@ogu.edu.tr

Received/Geliş Tarihi: 29.09.2020 Revision/Düzeltme Tarihi: 12.11.2021 doi: 10.5505/pajes.2022.10280
Accepted/Kabul Tarihi: 15.02.2022 Research Article/Araştırma Makalesi

Abstract

Devices like computers that require manual control are difficult to use by disabled people such as having multiple sclerosis (MS), amyotrophic lateral sclerosis (ALS), partial stroke, etc. These people have a very limited movement capability such that they can do most of the interaction with a limited movement of head and the eye. Assistive technologies are very important for people with disabilities not to be dependent on anyone in daily life. In this study, we present a human-computer interaction application that works based on analysis of the head and eye/eyebrow movements from real-time images captured by a visual camera. We propose Difference Between Eye and Eyebrow (DEEB) features to detect the action intention of the user and properly realize the computer keyboard and mouse actions based on eyebrow, eye and head movements. In addition, there are shortcut keys in the designed interface that facilitate access to Instagram, WhatsApp, YouTube etc. which are considered to make it easier for individuals with disabilities to communicate with their social environment. We obtained satisfactory results on the designed interface in the experimental study.

Keywords: Human computer interaction, Disabled person, Face detection, Eye and eyebrow detection, Eye and head controlled computer.

Öz

Manuel kontrol gerektiren bilgisayar gibi cihazların, Multipl Skleroz (MS), Amiyotrofik Lateral Skleroz (ALS), kısmi felç gibi engelli kişiler tarafından kullanılması zordur. Bu kişiler sınırlı hareket kabiliyetine sahip olduklarından çevresiyle iletişimlerinin çoğunu kısıtlı baş ve göz hareketleri ile gerçekleştirebilmektedirler. Engellilerin günlük hayatta kimseye bağımlı olmaması için yardımcı teknolojiler oldukça önemlidir. Bu çalışmada, görsel kamera ile elde edilmiş gerçek zamanlı görüntülerden baş ve göz/kaş hareketlerinin analizine dayalı çalışan bir insan-bilgisayar etkileşimi uygulaması sunulmaktadır. Kullanıcının eylem niyetini tespit etmek ve kaş, göz ve baş hareketlerine göre bilgisayar klavyesi ve fare eylemlerini doğru bir şekilde gerçekleştirmek için Göz ve Kaş Arasındaki Fark (DEEB) özniteliği önerilmiştir. Ayrıca tasarlanan arayüzde, engelli bireylerin sosyal çevreleriyle iletişim kurmasını kolaylaştırdığı düşünülen Instagram, WhatsApp, YouTube vb. sosyal platformlara erişimlerini kolaylaştıran kısayol tuşları da bulunmaktadır. Deneysel çalışmada tasarlanan arayüzde tatmin edici sonuçlar elde edilmiştir.

Anahtar kelimeler: İnsan bilgisayar etkileşimi, Engelli insan, Yüz tanıma, Göz ve Kaş tanıma, Göz ve Baş kontrollü bilgisayar.

1 Introduction

Disabled people with diseases such as stroke, MS or ALS that cause loss of motor abilities need special human-computer interfaces to communicate with the others. It is very difficult for people with severe motor impairments who cannot use their speech or sign language to perform basic things such as sending or receiving messages via the computer, using social media, checking e-mails, watching movies, etc. These people need special assistive technologies to increase their independence in daily lives and communication with the others.

With the rapid development of computer technology in recent years, studies in various fields such as artificial intelligence, computer vision, human computer interaction (HCI) have increased and the design of assistive tools has gained much attention and importance for people with physical disabilities [1]. People who have to live with diseases such as MS, ALS or stroke have difficulty using computer like devices due to the need for manual control of their peripherals such as mouse, keyboard, joystick, remote controller etc. Since these devices are difficult to use by people with disabilities, they do not benefit for their social lives. Therefore, many methods have been developed to enable these people to take a part in social life and communication, such as alternating interfaces, on-screen keyboards, moving the mouse with eyes, hand signs or marked gloves controlled mouse.

Every year, many people have difficulties in communicating effectively due to the loss of their motor and speech skills. This situation has led to the widespread use of computer-aided tools for disabled people in recent years and enables alternative communication methods to be developed for them. With these tools, a disabled individual can communicate with other people via the computer or any similar communication device. With the innovations in human-computer interaction technology, it is aimed to make the computer input devices such as keyboard, mouse, touch screen, touch pad requiring manual control easier to use [2]. There are several studies in the literature to control the mouse pointer including head control, eye control, EEG Control and fusing a few of them (hybrid) to enable people with physical disabilities to communicate with the computer. Following subsections summarize the related work.

1.1 Head-controlled systems

In head-controlled systems, gyroscopes, cameras, or devices containing transceiver signals are used to move the user's computer cursor, and only the head and neck need to move. In head-controlled systems, up-down head movements move the

*Corresponding author/Yazışılan Yazar

cursor in the direction of Y axis and right-left head movements are used to control the cursor in the direction of the X axis in general.

In [3], infrared light emitting diodes and photodetectors and a low cost head control joystick designed to determine the head position. In [4], a gyroscope is used to predict head orientation and a new contactless virtual mouse is proposed as an alternative to digital joysticks. In [5], a new technique for contactless writing is presented with head movements that allow any alphabet character to be reached in only three steps. Here, the authors propose a reduced interaction keyboard by eliminating many additional mechanisms required for head movement and selection process in many directions necessary for the use of the on-screen keyboard. In order to determine the head position, [6] uses two tilt sensors placed on the headset and the right-left and up-down positions of the head are detected, mouse movement is performed and a touch switch device is designed to touch the user's cheek for mouse clicks. Alhamzawi [7] presents a mouse cursor control system using the head movements of a user located in front of the computer. Images representing the position of the head are converted into mouse cursor coordinates after the reference point in the middle of the user's head is captured by the camera. Mouse click is performed by keeping the pointer in the desired position for the specified time.

1.2 Eye-controlled systems

The detection of the human face captures by the camera and the removal of eyebrows and eye points on the face is very important for the use of eye-controlled devices. Many actions, such as narrowing of the eyes, trimming, lifting eyebrows etc., can be performed by using features that can be defined in appropriate forms. There are many challenging situations in the eye detection process such as lighting, skin color, eye aperture, the condition of being glasses, hair blocking the eye and red eye effect due to photographic effect. In recent years, especially machine learning and deep learning architectures have been used to overcome these difficulties.

Human-computer interaction based on eye perception has been studied since the early 1990s. In [8], eye movement-based interaction techniques are described that try to use eye movements as an input. In [9], the commands related to the menu option corresponding to the relevant location on the computer screen location were performed by calculating the approximate position of the user's eye at the Erica workstation. An algorithm is provided in [10] to control a computer screen cursor with the movement of the iris. In [11], optical flow method is used to perform various mouse operations. Here, the authors propose an approach to detect blinking. The study [12] provides a low-cost eye-based human computer interaction for people with disabilities that provides the functionality of an input device such as a mouse, passing through a series of image processing algorithms. An eye mouse that can be used by people with disabilities was introduced in [13]. Lin et al. [14] offer the development of eye tracking and virtual keyboard control system using a PC camera. Chen and Liu [15] provide an accurate and effective eye detection method using distinctive Haar features and a new efficient support vector machine. The system proposed in [16] enables certain features of the face to be detected by the HaarCascade method to take the view point of the camera to the eye and uses the integral projection method to reference the position of the pointer to get the position information of the eye movement and to select a word on the virtual keyboard. Attiah and Khairullah [17] proposes the use of eye blink-based virtual keyboard using 68 features on the face extracted with dlib [18]. Anaya and Yuce [19] proposes a new triboelectric sensor that tracks eye movements based on charge transfer between the eyelash and the Ecoflex™. Here the authors aimed that people with disabilities can use the keyboard with eye movements and write code in a specific Python integrated development environment. The HCI system proposed in [20] allows the configuration of an artificial neural network (ANN) to minimize mouse flickering from eye movements. The ANN finds the relationship between mouse cursor position based on gaze coordinates and multilayer sensor model. In recent studies, the human-machine interfaces based on eye tracking are expanded to be used in smart home applications for controlling and monitoring [21].

1.3 Brain-controlled systems

The direct use of computers' peripherals by people with disabilities whose mobility barriers are completely restricted may not be possible through eye tracking or head movements. Brain-human interaction systems, a special area of human computer interaction, are used for these people. Brain-Computer Interfaces (BCIs) are based on the use of brain signals for the communication of devices, without the need for any muscle activity. A typical BCI system recognizes the user's thinking intentions, performing the basic functions of a typical input device such as a mouse. A typical BCI interface usually includes the following steps: (1) signal preprocessing, where the input data is received, (2) suppression of unwanted signals, (3) the classification based on the signal information and (4) the feedback of the classification result [22].

In [23], a method based on computer mouse's directional control is proposed by the device using electro encephalographic (EEG) signals. In the article, the direction of movement of the cursor on the screen is created according to the frequency of oscillation in the brain of the user. The described approach uses a technique called operant conditioning, and in the simplest version it is based on comparing the signal magnitude in two narrow adjacent bands. A brain-computer interface (BCI) based on electroencephalography was developed to help people with disabilities in [24]. This interface allows accessing the internet, controlling the computer, enabling control of a robot arm to move objects. Also communication tool applications have been developed that enable people with severe disabilities to interact with other people using basic commands related to emotions and needs. Salih and Abdal [25] proposed keyboard control with the BCI system for people with physical disabilities and wrote 1.55-1.8 words per minute using the signals coming from the frontal lobe of the brain with the help of NeuroSky Mindwave headset. In [26], a code-modulated EEG-based brain-computer interaction system is provided that allows the user to work with Windows applications. EEG signals are used to move the cursor and press the keys with mental energy without using a physical pointing device and an optimized virtual keyboard is created in [27]. The design of the hBCI system based on the brain neural computer interface on both EEG and electrooculography (EOG) signals has been proposed in [28]. In [29], the researchers correctly addressed the actions of eye blinking, imagining moving left or right, or imagining foot movement by using machine learning algorithms to the signals captured from a 64-channel EEG equipped with electrodes to read the tensions at the contact points throughout the scalp.

1.4 Hybrid systems

Apart from the titles given in the subsections above, there are also systems created by using some combinations of these methods and used as hybrid. In [30], it is aimed to detect the head positions and eye conditions using image processing techniques and convolutional neural networks. In the proposed system, the user moves his head to move the mouse cursor to the desired coordinates, and then sends the appropriate commands by blinking. A control system using head pose prediction, eye detection and classification has been proposed in [31]. In this study, the values created by the head movement of the user were converted into mouse movements with the gyroscope. The NeuroSky headphone that reads EEG signals is used for mouse applications such as hard blinking and brow lift functions. In [32], virtual keyboard application based on gaze is proposed and mouth is used for selection process. In [33], a virtual keyboard design containing all the characters of the Latin alphabet was created. To select a command on the keyboard, the user points to the desired item from the perspective and selects it with five predefined hand gestures. In [34], a human-computer interface that provides hands-free mouse controls based on mouth tracking was presented. In the study, mouth movements for mouse movement and head shake movements for mouse clicking were used.

People with severe motor impairments may perform their operations on the computer using the computer keyboard and mouse with features such as gaze time, gaze position, head movement, and communicate with people with the help of human-computer interaction. In this study, a multi-functional HCI interface has been introduced for the use of people with disabilities and it is aimed that the operations on this interface can be easily used by these people. Unlike most of the studies in the literature, there is no wearable hardware requirement for the application apart from a simple visual camera. In the study, it was ensured that the keyboard and mouse functions were controlled by head, eye and eyebrow movements. At the same time, real-time testing of computer functions such as right-clicking, left-clicking, page navigation, typing with a virtual keyboard, navigating social media applications has been provided. Here, it is aimed to control the keyboard and mouse functions with head, eye and eyebrow movements. In order to detect the head and eye movements, we proposed a simple feature extraction methodology which can be realized by the current computer vision tools in real time. In the designed method, first of all, the face is detected and the direction of movement of the mouse is determined according to the head movement. Then, the action commands associated with the special gestures such as blinking, eyebrow lifting are realized. An individual-specific fine-tuning formulation was used to detect all these movements and commands. This adjustment allows the identification and use of mimics specific to individuals with partial mobility difficulties.

To summarize, the study includes the following contributions:

- An original Human-Computer Interface is presented. A keyboard design has been made in the interface and a two-stage and easy method, which we call the Fast-Slow Scan Process (FSSP), is proposed for the use of the designed keyboard,
- Navigation of the mouse cursor is provided with the head movements that are detected by using the distances between the center points of eyes (called as anchors),
- A new feature, called the Difference Between Eye and Eyebrow (DEEB) is presented to understand whether the eyebrows are lifted or not inspiring from the Eye-Aspect Ratio (EAR) feature [35] that indicates whether the eye is open or closed.

The rest of the paper is organized as follows: The second section introduces the methodology and the graphical user interface design; the third section presents the experimental studies, test results are discussed in fourth section and the last section gives the conclusion.

2 Proposed methodology

The computer contains many inputs such as keyboard, mouse, touch screen that require manual control, and these devices are very difficult to use by disabled people with motor impairments. Therefore, there is a need for the development of alternative forms of use. In this context, we aimed to design a cost effective human-computer interface to control the computer in real time regardless of the keyboard and mouse. The method we developed to realize the virtual mouse and keyboard, which can be controlled by head, eye and eyebrow movements, is fundamentally based on image processing and object detection algorithms captured from the visual camera. Different from other studies, we designed an original user interface and proposed new feature called as DEEB in this study. With this interface, we aimed to make it easier to run customized personal applications. The mouse cursor is moved by the head movement and the eyes' gaze. We assigned some special mimics made with eyes and eyebrows to activate the defined buttons. In order to detect these mimics, we have suggested a feature extraction framework to capture especially the eyebrow movements in real time. As a result, ordinary or disabled people can control their personal computers by moving the cursor with eye, eyebrow and head movements in the designed interface.

For a better presentation of the proposed HCI interface in this study, we give more details in the following subsections. We first introduce the user interface design and activating mimic actions. Then, we give face and fiducial points detection and the proposed feature extraction details. Finally, we define mouse cursor movement, keyboard operations and overall system management of the interface.

2.1 The user interface

In this study, we designed an interface where people can easily use. In the design, some applications which can be done by the user, such as social media applications, can be easily accessed so that especially the disabled people can keep in touch with others or meet their social needs comfortably. The interface given in Figure 1 basically includes the following sections: the text box and information area divisions, real-time viewer window, people to contact shortcuts, the keyboard region, quick commands section and social connection division. People can direct the cursor movements with the head and eyes to interact with their environment with this interface.

1. Text Box: The written texts appear in the text box. The written texts can be converted into sound by using text-to-speech button,
2. Person List: This section includes the information (e-mail addresses, phone numbers, social media user names, etc.) of primary 10 contacts. The user can send messages or e-mails to these people quickly. The user can edit or modify these entries any time.

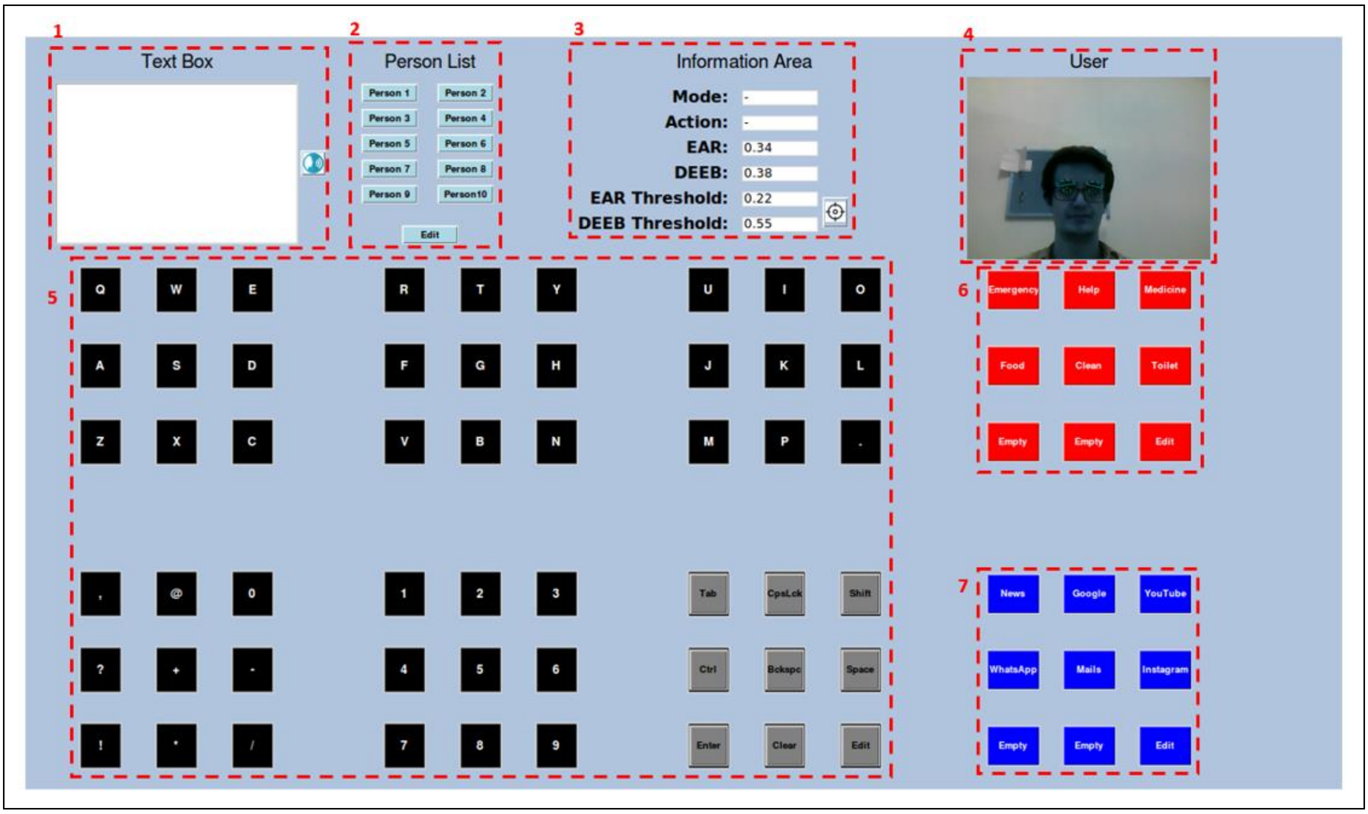

Figure 1. Designed user interface for the proposed method. Marked regions are 1: Text Box, 2: Person List, 3: Information Area, 4: User, 5: Keyboard, 6: Primary shortcut buttons, 7: Secondary shortcut buttons.

3. Information Area: This section displays some parameters and actions performed in any mode. Here, there is a calibration button that allows to adjust the threshold values which can be useful to work in accordance with the environment conditions,
4. User: This part displays the real time view of the user,
5. Keyboard: This region includes standard letters and numbers in QWERTY layout, some punctuation marks and special keys (space, backspace, enter, tab, caps lock, shift, ctrl and clear) on the keyboard,
6. Primary shortcut buttons: In this division there are 6 primary buttons that can activate some immediate actions (emergency, help, medication, food, cleaning and toilet) designed for especially the disabled people. The user can modify and change these primary shortcuts,
7. Secondary shortcut buttons: This division includes the access to frequently used social applications (e-mail, messaging, social media, news sites, video sites) for disabled people. The user can modify and change these primary shortcuts.

2.2 Activating mimic actions

Interaction between human and computer can be done as a series of facial gestures performing various actions. In this study, we matched the movement of the mouse with head movements, and approval/execution actions with some special eyebrow and eye movements. The list of mimics to perform some special actions is given in Table 1. More details about the operation modes of the system are given in section 2.5.

The first action given in the table, the keyboard mode, is activated when the eyes are narrowed by a certain amount. When both eyes are narrowed, the eye aspect ratio (EAR) value given in the information screen is far below the threshold value and when this mimic happens throughout the certain frame, the mode is entered. Similarly, in the case of right blinking, the EAR value for the right eye (or the EAR value for the left eye in the case of left blinking) are well below the corresponding threshold value. When this mimic is detected throughout the frame, the right click (or the left click) operation is performed. Exiting any mode is based on whether the eyebrows are lifted. If eyebrows are lifted along a certain frame while in a mode, the related mode is closed. Difference Between Eye and Eyebrow (DEEB) feature is used in the information screen to understand whether the eyebrows are lifted. When the eyebrows are lifted, the DEEB value is much above the threshold value. The calculation of EAR and DEEB values are given in the following subsections.

The eye closing action used to exit the program should be separated from the instant eye closings. In [16], the open or closed state of the eye for spontaneous and non-spontaneous conditions was evaluated as two classes as given in Table 2. The time taken for instant eye blink is less than 0.25 seconds while non-instant blink is greater than 0.25 seconds. Using this situation, the user closes his eyes in any mode for a certain period of time to close the program. Similarly, this table is used to prevent instant eyebrow lifts.

Table 1. Activating mimic actions and corresponding functions.

Action	Function
Narrowing both eyes	Activate Keyboard Mode
Right eye blinking	Right click
Left eye blinking	Left click
Downward head movement	Type character (Keyboard Mode), Fast forward / skip video (Youtube Mode), downward mouse movement or scroll down (other modes)
Upward head movement	Text to Speech (Keyboard Mode), Fast forward / skip video (Youtube Mode), upward mouse movement or scroll up (other modes)
Right directional head movement	Fast scanning (Keyboard Mode), taking screenshots (Google Mode and News Mode), right mouse movement (other modes)
Left directional head movement	Slow scanning (Keyboard Mode), save or print the pages (Google Mode and News Mode), left mouse movement (other modes)
Eyebrow lifting	Exit the current mode
Eyes closing	Close the program

Table 2. Spontaneous or non-spontaneous eye blinking classification.

Eye Blink Classification	Duration
Spontaneous	$\leq 0.25\ second$
Non-spontaneous	$> 0.25\ second$

In this study, we provide the cursor movement by the head movement. The center point of the eyes and the points of the nose between the eyes are used for the correct perception of head movements. Here, eye center points are fixed (as the anchor – the rest of paper eye center points referred as anchor points) and the direction of the head movement (+x, -x, +y, -y) is determined by using the changes between the nose point and the anchor points. The expressions given in the following equations are used to calculate the direction of the head movement. In the equations, $P_{LEC}\ (x_{lec}, y_{lec})$ denotes the location of the left anchor; $P_{REC}\ (x_{rec}, y_{rec})$ denotes the location of the right anchor; $P_{NP}\ (x_{np}, y_{np})$ denotes the nose point; $\boldsymbol{v}_{nl}$ denotes the vector from the nose point to the left eye anchor point; $\boldsymbol{v}_{nr}$ denotes the vector from the nose point to the right eye anchor point; c and k are the distance and angle constants; and $\cos\theta = \frac{\boldsymbol{v}_{nl} \cdot \boldsymbol{v}_{nr}}{\|\boldsymbol{v}_{nl}\| \times \|\boldsymbol{v}_{nr}\|}$.

$$left: \|P_{LEC} - \mathrm{P_{NP}}\| < \|P_{REC} - \mathrm{P_{NP}}\| + c \tag{1}$$

$$right: \|P_{REC} - \mathrm{P_{NP}}\| < \|P_{LEC} - \mathrm{P_{NP}}\| + c \tag{2}$$

$$up: \frac{(Y_{lec} - Y_{np}) + (Y_{rec} - Y_{np})}{2} > 0\ and\ \cos\theta > k \tag{3}$$

$$down: \frac{(Y_{lec} - Y_{np}) + (Y_{rec} - Y_{np})}{2} < 0\ and\ \cos\theta > k \tag{4}$$

These equations are used to discriminate the head movements. Figure 2 demonstrates the changes in the distance between the nose points and anchor points. In the figure, the black dots indicate the points of the eyebrows and eyes. The red line gives the distance vector between the nose point and the left anchor, the blue line gives the distance vector between the nose point and the right anchor.

When the user wants to write some text entry, it is necessary to scan the keyboard region with head movements and select letters to write the desired text. Here, fast and slow scanning are executed for the selection of letters. As shown in Figure 3, the keypad is composed of eight 3x3 blocks. The sequence of the eight blocks are formed by 2x4 matrix cells. When the head is rotated to right, fast scan process starts and cursor moves between eight primal buttons of each 3×3 blocks that is shown as green in Figure 3. When patient want the cursor to stay within the desired block, the head is rotated to the left and the slow scan starts by entering the nearest 3×3 block. During slow scanning process, if patient print to the desired letter people tilting head down and the letter closest to the cursor is printed on the screen. We call this scanning process as Fast-Slow Scan Process (FSSP). The full turn of fast scan takes 6 seconds, while any slow 9-button block section takes 8 seconds.

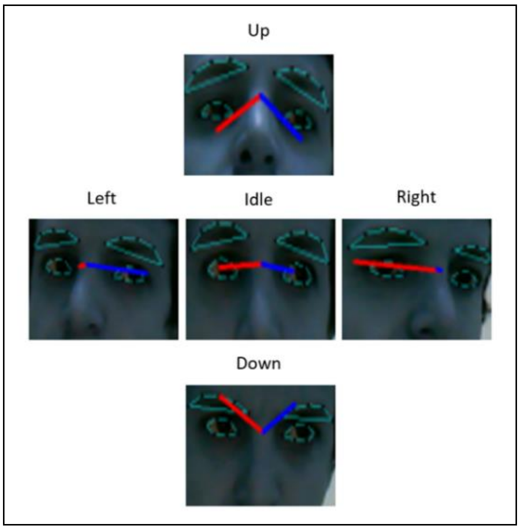

Figure 2. Head movements discrimination.

2.3 Face and fiducial points detection

The first stage of a proper interaction is the detection of the face and the fiducial points defining the actions. In the design, it is assumed that only one user will use the interface. Therefore, the face detection process is operated for one person. In case of more than one person in front of the camera, the individual in the image center is considered as an active user. The facial points in the study are used to calculate various aspect ratios. At the end of these operations, some certain actions such as whether the eyes are blinking, squinting, eyebrows are lifted or not are determined.

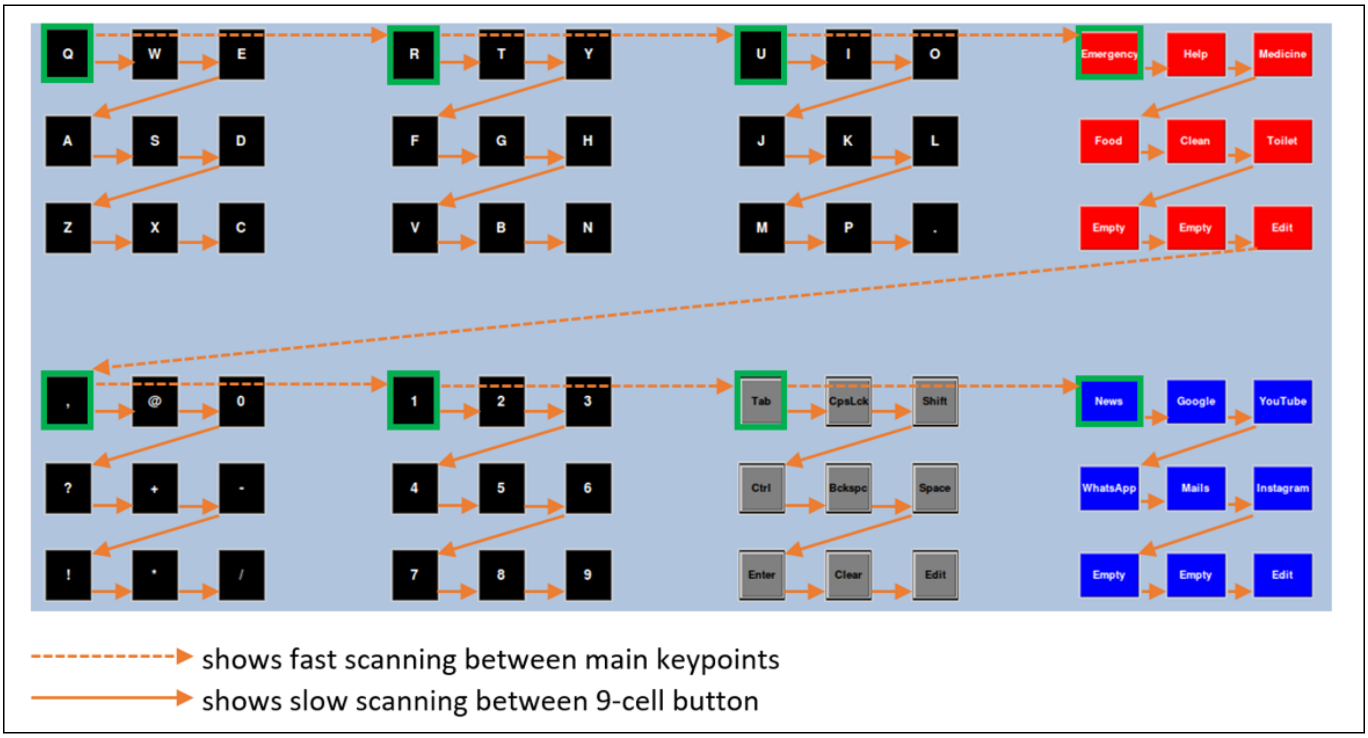

Figure 3. Scanning processes with head movements.

In addition, the mouse cursor is controlled by head movements using the point between the nose and the anchor points. For this reason, detection of fiducial points on the face is an important step.

Face and fiducial points detection process is a kind of object detection problem. It's not an easy problem due to negative effects such as illumination differences, different exposure patterns etc. [36]. In this study, since the user takes place in front of the screen, the detection problem is the frontal face detection. Face detection with frontal faces is partially easier than face detection under different posing schemes [37]. Some current deep learning based studies have made great contributions especially to face and fiducial points detections [38]-[40]. In addition, many researchers share their succesful pretrained models and software in the web. In this study, we used dlib models given in [19]. This model uses various state of the art convolutional networks and detects the face in a very short instance including the 68 fiducial points locations shown in Figure 4.

These fiducial points are used to localize eyes, eyebrows, nose, mouth and face boundaries for feature selection and extraction. Keen reader can refer to [19],[41] for more details.

2.4 Feature extraction

In this study, the actions given in Section 2.2 are performed by properly detecting the right, left, down, up movements of the head; opening and closing of the eyes and the up and down movements of the eyebrows. The Dlib library given in the bibliography [19] successfully finds the facial points given in Figure 4. Here, the points of the right eye are: 43, 44, 45, 46, 47, 48; points of the left eye: 37, 38, 39, 40, 41, 42; points of the right eyebrow: 23, 24, 25, 26, 27; the points of the left eyebrow: 18, 19, 20, 21, 22 and the point of the nose between the eyes: 28 are shown and their positions are known. We inspired from [35] to monitor and detect these gestures in real time.

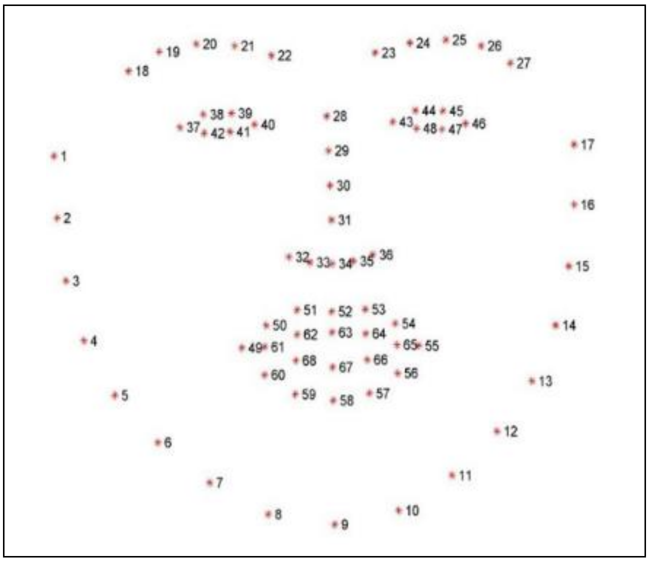

Figure 4. Location of 68 fiducial points on the face [19].

10 points related to eyebrow movements and 12 points related to eye movements were chosen to extract features. Distances between the relevant points were calculated by adapting the formulations given in [35] and some special ratios were used as the features. Using these features is both computationally eficient and effective in determining the appropriate gesture in real time.

The state of the eye (being open or closed and blinking) is determined by the eye aspect ratio (EAR) given in Equation (5) [35]. The values represented by p_i , $i = 1, \ldots, 68$ in the equation correspond to the positions of the i^{th} fiducial point of the respective eye shown in Figure 4. The EAR value generally remains constant when the eye is open; but it makes a sharp decrease through zero when the eye is closed as given in Figure 5.

$$EAR_{left} = \frac{\|p_{38} - p_{42}\| + \|p_{39} - p_{41}\|}{2\|p_{37} - p_{40}\|}$$

$$EAR_{right} = \frac{\|p_{44} - p_{48}\| + \|p_{45} - p_{47}\|}{2\|p_{43} - p_{46}\|} \quad (5)$$

$$EAR = \frac{EAR_{left} + EAR_{right}}{2}$$

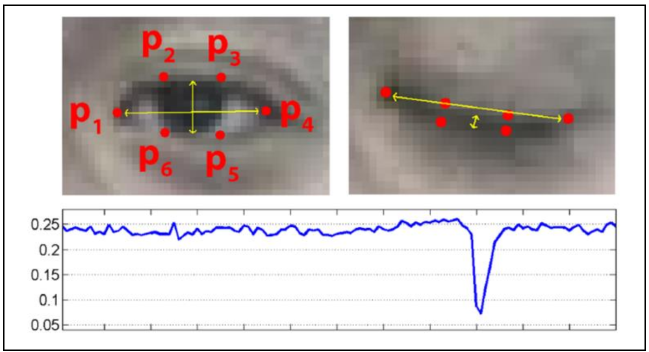

Figure 5. Change of EAR value over time when the eye is closed [35].

Inspired by the EAR feature, we define a new discriminative feature to detect the eyebrow lifting. As presented in Figure 6, we calculate four new feature points (left eye p_{69}, p_{70}, right eye p_{71}, p_{72}) that corresponds to the distance between the eye and eyebrow (DEEB). The DEEB feature can determine whether the eyebrows are lifted as given in Equation (6).

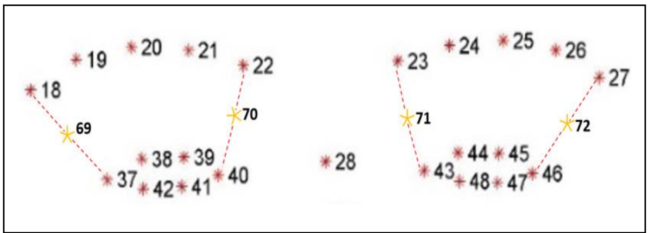

Figure 6. New feature points: 69-72.

$$DEEB_{left} = \frac{\|p_{19} - p_{38}\| + \|p_{21} - p_{39}\|}{4\|p_{69} - p_{70}\|}$$

$$DEEB_{left} = \frac{\|p_{24} - p_{44}\| + \|p_{26} - p_{45}\|}{4\|p_{71} - p_{72}\|} \quad (6)$$

$$DEEB = \frac{DEEB_{left} + DEEB_{right}}{2}$$

While the DEEB value is usually constant in normal conditions of the eyebrow, it increases sharply when the eyebrows are lifted. This ensures that the DEEB feature is used as a distinctive feature. The change of DEEB value over time is presented in Figure 7.

People have different eye lengths, eyebrow length, eyebrow shape, distance between eyebrows and eyes. Apart from these, system operation may be adversely affected due to lighting differences in the environment and the distance between the user and the camera. In this study, EAR and DEEB features were provided to be calibrated for different individuals in order to work efficiently for different people. New threshold values for the EAR and DEEB can be determined by using the calibration button in the interface. Also these values are printed on the information area screen of the interface. The snapshot of the user is captured with the calibration button and EAR and DEEB (EAROpen-Eye, DEEBEyebrowLift) values are recorded. These values are user-specific fine settings. Standard threshold values were calculated as given in Equation 7. These values have been determined experimentally. Threshold values prior to calibration were experimentally set to $th_{EAR} = 0.22$ and $th_{DEEB} = 0.55$.

$$th_{EAR} = EAR_{OpenEye} - 0.10$$
$$th_{DEEB} = DEEB_{OpenEye} + 0.15 \quad (7)$$

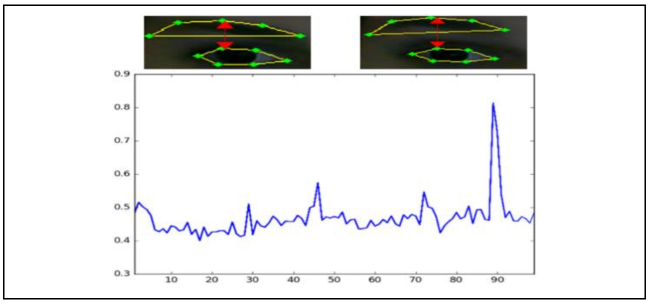

Figure 7. Change of the DEEB value over time. There exists a sudden increase when the eyebrow is lifted.

2.5 Operating modes

The designed interface can work in different modes in connection with some standard applications. Some applications have been adjusted to work with the interface initially but any other specific application can be assigned to the predefined empty slots in the interface. The following are the predefined modes of the designed interface.

KEYBOARD Mode: The user can use the keyboard with head movements. In this mode, by pressing the keyboard keys (except the connection keys), the user can write text in the text box and convert the text to the sound. Also, by pressing the connection keys, all other modes can be accessed with this mode.

WHATSAPP Mode: The user can send message via WebWhatsApp web application using head and eye movements. To do this faster, frequently contacted 10 people were added to the list. After the user writes the desired text in the text box, he switches to the WHATSAPP Mode and selects the person. Then the written message is sent to the person concerned.

E-MAIL Mode: The user can send e-mails via Hotmail using head and eye movements. To do this faster, frequently contacted 10 people were added to the address list. After the user type the desired text in the text box, he switches to MAIL Mode and selects the person. Then the e-mail is sent to the person concerned.

YOUTUBE Mode: The user can search and open any YouTube video by head and eye movements. Also, he/she can use special mimics to stop, fast forward, increase and decrease the video volume, change the video on YouTube. After the user types the desired search text in the text box, he can switch to YOUTUBE mode, select the desired video and watch it.

GOOGLE Mode: The user can search and navigate to any website using head and eye movements from Google. The user performs operations such as navigating the website with head movements, right-clicking and left-clicking with eye movements, taking the screenshot of the page, saving the page, printing the page. After the user types in the text box, he switches to GOOGLE mode.

INSTAGRAM Mode: The user can open Instagram application by using head and eye movements. The user performs operations such as navigating the page with head movements, right-clicking and left-clicking with eye movements, taking the screenshot of the page, saving the page. It can also send messages to previously identified people when he/she enters the INSTAGRAM mode after typing the desired keyword in the text box.

NEWS Mode: The user can read the news from NewYork Times using head and eye movements. The user performs operations such as navigating the news site with head movements, eye movements with right click and left click, taking the screenshot of the page, saving the page, printing the page,

QUIT Mode: The user can return from any current application mode to the initial state by lifting the eyebrows,

EXIT Mode: It allows the user to turn off the system in any mode when he/she closes his eyes for a while.

3 Experimental work

The performance of the designed interface for head, eye and eyebrow movements detection has been tested by experiments with different users. You can find the details about the participants, performance criteria and tests in the following subsections.

3.1 Participants

The participants are volunteers consisting of a total of 10 people (7 male and 3 female), who have different facial looks. All participants received a brief training related to the movements and actions before using the application. Participants are shown in Figure 8. Participants were seated in a chair at a distance of 40 to 80 cm in front of the computer screen, based on the 60 cm distance specified in [42].

Figure 8. Participants.

3.2 Equipment

Experimental study has been carried out on a personal laptop computer running on Ubuntu 16.04. The device has a 15.6-inch screen, 1920x1080 display resolution, 1GB NVIDIA GeForce GT 425M graphics card and Intel i5-1.8 GHZ CPU processor. In the study, we used the built in 1.3 megapixel webcam of the computer as the visual camera. The visual camera is the only necessary equipment in this study and there is no extra hardware device needed to work with the designed interface. Although the used computer is an old model, it can successfully execute the proposed software design in real time.

3.3 Tests

Two different tests were carried out in the study. The first experiment was conducted to determine how efficiently EAR and DEEB features work for different users. Here, the lighting conditions were also changed to measure the detection performance. In the second test, we measured the speed of printing some text by head and eye movements for a randomly selected (inexperienced) user.

In test-1, users have used the interface under bright and dark illuminations, with constant EAR (set to 0.22) and DEEB (set to 0.55) values and the user specific calibrated EAR and DEEB values calculated from Equation 7. In this test, we measured the following three motions: M1: narrowing the eyes (squinting); M2: eyebrow lifting; M3: head movements performances have been observed. The bright illumination was measured as 169 lux, the dark case is measured as 2 lux. Also, we used two different user-to-pc distances: 40 and 80 centimeters. Here, we defined three environment conditions. Environment-1: camera-to-human distance: 40 cm; illumination: 169 lux, Environment-2: camera-to-human distance: 80 cm; illumination: 169 lux, Environment-3: camera-to-human distance: 80 cm; illumination: 2 lux. In the tests, the users were asked to perform the above-mentioned movements under these environmental conditions. One observer followed the synchronization between the user movement and the cursor movement. If the synchronization problem has not occurred while the user is making the relevant action, the observer marked the relevant action as successful (✓). When there exists any discontinuity and/or the synchronization problem, the observer marked the relevant action as unsuccessful (✕). The results are given in Table 3.

In Test-2, we aimed to determine the speed of writing text by using head movements on the designed interface. This test was performed Environment-1: camera-to-human distance: 40 cm; illumination: 169 lux. In order to make this measurement, participants were asked to print the following sentences: Text-1: "Please Help Me" and Text-2: "I Need Medicine". Users send the printed text to Person-1 of the registered contact list shortcut via the WhatsAppWeb application. The observer measured the times elapsed for each user to write the expression. A shortcut button had also been defined corresponding to these two sentences. The time taken to select the keyword corresponding to the same sentence by using the shortcut button was also calculated. The same procedure has been repeated by using the mouse instead of the head movements. The average values of the calculations are presented in Table 4.

4 Discussion

The results obtained for both tests are discussed separately as given in the following sub-sections.

4.1 Test 1: Feature perception performance

In this test, whether the participants' eye, eyebrow and head movements were perceived successfully or not was tested with three different movements for different environments. In this context, the performance of the EAR value with M1, the performance of the DEEB value with M2, and the performance of the proposed equations given in Equation (1) - Equation (4) with M3 were tested. The success criterion of this test is the detection of the action as successful (✓) or not (✕).

Table 3 shows that the interface designed under the first and second conditions works very successfully. Both conditions are tested under 169 lux illumination intensity, in the first case the user-camera distance is 40 cm and in the second case it is 80 cm. Under sufficient lighting intensity, we observed that the system operates successfully at distances between 40-to-80 cm and all movements are detected with 100% accuracy. The third condition is that the illumination intensity is minimum and the user-camera distance is maximum. In this case, there exists a decrease in detection performance due to insufficient illumination intensity, so we observed some discontinuities in the movement-response synchronizations. Readers may expect worse performance at 2 lux lighting environment. However, even if the environment is dark, the test success is at an acceptable level thanks to the light reflected from the computer screen. Test-1 results show that the detection and feature extraction processes of the designed interface should operate under at least an average illumination; not in the dark.

4.2 Test 2: Writing speed performance

In this test, participants were asked to write the specified texts in Environment 1 with the proposed keyboard control system. The success criterion of the test is specified as the number of characters written per minute (chars/min).

The results given in Table 4 shows that there is no big difference between using a mouse and using the head movements. Comparing the times elapsed to complete the job, users in the experiment spend at most three times of the time that they complete the same job by using a mouse. In the literature, Pathirana et al. [27] reports 6.61 characters/min, Nowosileski [5] reports 12-14 characters/min, Meena et al. [43] reports 17.22±4.54 letters/min, Cecotti et al. [33] reports 8.77±2.90 letters per minute speed by selecting the best gesture for each user, Saraswati et. al. [16] reports 4-character word were written in an approximately 67 seconds, Spüler [26] reports more than 20 error free characters per minute. When Table 4 is examined, the average typing speed obtained for Test 2 can be calculated as 7.00 characters/min. We should note that these measurements are the values of healthy contributors. Although people with disabilities may perform a slightly longer print times, we believe that the interface proposed in the study would make important contributions to facilitate the lives of these people.

5 Conclusion

In this study, a low-cost and real-time human-computer interaction application has been implemented for individuals with motor dysfunction, without requiring any wearable hardware or sensors.

In this study, a low-cost and real-time human-computer interaction application has been implemented for individuals with motor dysfunction, without requiring any wearable hardware or sensors, a new keyboard usage algorithm has been presented, and a new feature (DEEB) that distinguishes whether the eyebrows are lifted by measuring the distance between the eye and the eyebrow has been proposed.

Table 3. Test-1 results.

User ID	(th_{EAR}, th_{DEEB})	Environment-1			Environment-2			Environment-3		
		M1	M2	M3	M1	M2	M3	M1	M2	M3
User-1	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✗	✓
	(0.26, 0.58)	✓	✓	✓	✓	✓	✓	✓	✗	✓
User-2	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✗	✓
	(0.20, 0.57)	✓	✓	✓	✓	✓	✓	✓	✗	✓
User-3	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	(0.24, 0.61)	✓	✓	✓	✓	✓	✓	✓	✗	✓
User-4	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✗	✓
	(0.18, 0.61)	✓	✓	✓	✓	✓	✓	✓	✗	✓
User-5	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✗	✓
	(0.20, 0.53)	✓	✓	✓	✓	✓	✓	✓	✓	✓
User-6	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	(0.23, 0.64)	✓	✓	✓	✓	✓	✓	✓	✓	✓
User-7	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	(0.20, 0.62)	✓	✓	✓	✓	✓	✓	✓	✓	✓
User-8	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✗	✓
	(0.19, 0.68)	✓	✓	✓	✓	✓	✓	✓	✗	✓
User-9	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	(0.21, 0.55)	✓	✓	✓	✓	✓	✓	✓	✓	✓
User-10	(0.22, 0.55)	✓	✓	✓	✓	✓	✓	✓	✗	✓
	(0.26, 0.69)	✓	✓	✓	✓	✓	✓	✓	✗	✗
Correct Response (%)		100	100	100	100	100	100	100	40	95

Table 4. Test-2 results.

Text ID	Proposed Method		Hand Control	
	Keyboard	Keyword	Keyboard	Keyword
Text 1	14 chars / 123,94 secs	6,57 secs	14 chars / 17,71 secs	<1 secs
Text 2	15 chars / 124,63 secs	7,12 secs	15 chars / 15,55 secs	<1 secs

Here, the designed interface uses the built-in computer camera and eye, eyebrow and head movements of the users are detected in real time. In this way, it is aimed to make it easier for people with disabilities in hand or body coordination to use computers. The mouse cursor can be moved with head movements, and various commands can be activated with simple eye and eyebrow movements. Experimental work has shown that the designed system works successfully under sufficient illumination intensity. In dark environments, we observed some malfunctions in approval actions due to the difficulties in detection of the fiducial points on the face. The proposed application works successfully when the camera-user distance is in the range of 40-80 centimeters and under normal lighting intensities. This application, that we basically designed to facilitate the access of individuals with disabilities to various social media applications on computers, can be expanded to have more extended contents by revising for different mimics in future studies.

6 Author contribution statements

In the scope of this study, Muhammed Oğuz TAS in the formation of the idea, the design, and the literature review; Hasan Serhan YAVUZ in the examining the results, spelling, and checking the article in terms of content were contributed.

7 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared.

There is no conflict of interest with any person / institution in the article prepared.

8 References

[1] Rapp A, Cena F, Castaldo R, Keller R, Tirassa M. "Designing technology for spatial needs: Routines, control and social competences of people with autism." *International Journal of Human-Computer Studies*, 120, 49-65, 2018.

[2] Jacko JA. *Human Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications*, 3rd ed. London, England, Taylor and Francis Inc, 2012.

[3] Evans DG, Drew R, Blenkhorn P. "Controlling mouse pointer position using an infrared head-operated joystick". *IEEE Transactions on rehabilitation engineering*, 8(1), 107-117, 2000.

[4] Wook Kim Y, Hyun Cho J. "A novel development of head-set type computer mouse using gyro sensors for the handicapped". *In 2nd Annual International IEEE-EMBS Special Topic Conference on Microtechnologies in Medicine and Biology,* Madison, USA, 2-4 May 2002.

[5] Nowosielski A. "3-steps keyboard: reduced interaction interface for touchless typing with head movements". In *International Conference on Computer Recognition Systems*, Polanica Zdroj, Poland, 22-24 May 2017.

[6] Chen YL. "Application of tilt sensors in human-computer mouse interface for people with disabilities". *IEEE Transactions on neural systems and rehabilitation engineering*, 9(3), 289-294, 2001.

[7] Alhamzawi, HA. "Control Mouse Cursor by Head Movement: Development and Implementation". *Applied Medical Informatics*, 40(3-4), 39-44, 2018.

[8] Jacob RJ. "What you look at is what you get: eye movement-based interaction techniques". *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Seattle, USA, April, 1990.

[9] Hutchinson TE, White KP, Martin WN, Reichert KC, Frey LA. "Human-computer interaction using eye-gaze input". *IEEE Transactions on Systems, Man, and Cybernetics*, 19(6), 1527-1534, 1989.

[10] Nasor M, Rahman KM, Zubair MM, Ansari H, Mohamed F. "Eye-controlled mouse cursor for physically disabled individual". *In 2018 Advances in Science and Engineering Technology International Conferences (ASET)*, Abu Dhabi, United Arab Emirates, 6 February-5 April 2018.

[11] Singh H, Singh J. "Real-time eye blink and wink detection for object selection in HCI systems". *Journal on Multimodal User Interfaces*, 12(1), 55-65, 2018.

[12] Hegde VN, Ullagaddimath RS, Kumuda S. "Low cost eye based human computer interface system (Eye controlled mouse)". *In 2016 IEEE Annual India Conference (INDICON)*, Bangalore, India, 16-18 December 2016.

[13] Kocejko T, Bujnowski A, Wtorek J. "Eye-mouse for disabled". *Human-Computer Systems Interaction*, Uppsala, Sweden, August 24-28, 2009.

[14] Lin CS, Lin CH, Lay YL, Yeh MS, Chang HC. "Eye-Controlled virtual keyboard using a new coordinate transformation of long and narrow region". *Optica Applicata*, 38(2), 481-489, 2008.

[15] Chen S, Liu C. "Eye detection using discriminatory Haar features and a new efficient SVM". *Image and Vision Computing*, 33, 68-77, 2015.

[16] Saraswati VI, Sigit R, Harsono T. "Eye gaze system to operate virtual keyboard". *International Electronics Symposium (IES)*, Denpasar, Indonesia, 29-30 September 2016.

[17] Attiah, A, Khairullah, E. F. Eye-Blink Detection System for Virtual Keyboard. *IEEE 2021 National Computing Colleges Conference (NCCC)*, Taif, Saudi Arabia, 27-28 March 2021.

[18] King D, "dlib-models". https://github.com/davisking/dlib-models, (27.09.2020)

[19] Anaya DFV, Yuce MRA. "Hands-Free human-computer-ınterface platform for paralyzed patients using a teng-based eyelash motion sensor". *42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, Montreal, Canada 20-24 July 2020.

[20] Sesin A, Adjouadi M, Cabrerizo M, Ayala M, Barreto A. "Adaptive eye-gaze tracking using neural-network-based user profiles to assist people with motor disability". *The Journal of Rehabilitation Research and Development*, 45(6), 801-818, 2008.

[21] Bissoli A, Lavino-Junior D, Sime M, Encarnação L, Bastos-Filho T. "A human–machine interface based on eye tracking for controlling and monitoring a smart home using the ınternet of things". *Sensors*, 19(4), 859-884, 2019.

[22] Lee JC, Tan DS. "Using a low-cost electroencephalograph for task classification in HCI research". *In Proceedings of the 19th Annual ACM Symposium on User Interface Software and Technology*, Montreux, Switzerland, 15-18 October 2006.

[23] Knězík J, Drahanský M. "Simple EEG driven mouse cursor movement". *Computer Recognition Systems,* 2, 526-531, 2007.

[24] Blasco JS, Iánez E, Ubeda A, Azorín JM. "Visual evoked potential-based brain-machine interface applications to assist disabled people". *Expert Systems with Applications*, 39(9), 7908-7918, 2012.

[25] Salih, T. A, Abdal, Y. M. Brain computer interface based smart keyboard using neurosky mindwave headset. *Telkomnika*, 18(2), 919-927, 2020.

[26] Spüler M. "A Brain-Computer Interface (BCI) system to use arbitrary Windows applications by directly controlling mouse and keyboard". *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Milan, Italy, 25-29 August 2015.

[27] Pathirana S, Asirvatham D, Johar MGM. "Designing virtual keyboards for brain-computer ınterfaces". *IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*, Colombo, Sri Lanka, 6-8 December 2018.

[28] Hosni SM, Shedeed HA, Mabrouk MS, Tolba MF. "EEG-EOG based virtual keyboard: Toward hybrid brain computer interface". *Neuroinformatics*, 17, 323-341, 2018.

[29] Alomari MH, AbuBaker A, Turani A, Baniyounes AM, Manasreh A. "EEG mouse: A machine learning-based brain computer interface". *International Journal of Advanced Computer Science and Applications,* 5(4), 193-198, 2014.

[30] Abiyev RH, Arslan M. "Head mouse control system for people with disabilities". *Expert Systems*, 37(3), 1-14, 2019.

[31] Castillo A, Cortez G, Diaz D, Espíritu R, Ilisastigui K, O'Bard B, George K. "Hands free mouse". *IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN)*, San Francisco, USA, 14-17 June 2016.

[32] Soundarajan S, Cecotti H. "A gaze-based virtual keyboard using a mouth switch for command selection". *40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Honolulu, USA, 18-21 July 2018.

[33] Cecotti H, Meena YK, Prasad G. "A multimodal virtual keyboard using eye-tracking and hand gesture detection". *40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC),* Honolulu, USA, 18-21 July 2018.

[34] Naizhong Z, Jing W, Jun W. "Hand-Free head mouse control based on mouth tracking". *10th International Conference on Computer Science & Education (ICCSE)*, Cambridge, United Kingdom, 22-24 July 2015.

[35] Soukupova T, Cech J. "Eye blink detection using facial landmarks". *21st Computer Vision Winter Workshop*, Rimske Toplice, Slovenia, 3-5 February 2016.

[36] Cevikalp H, Yavuz HS, Edizkan R, Gündüz H, Kandemir CM. "Comparisons of features for automatic eye and mouth localization". *International Symposium on Innovations in Intelligent Systems and Applications*, Istanbul, Turkey, 15-18 June 2011.

[37] Yavuz HS, Çevikalp H, Edizkan R. "Automatic face recognition from frontal images". *21st IEEE Signal Processing and Communications Applications Conference*, Girne, Turkish Republic of Northern Cyprus, 24-26 April 2013.

[38] Kawulok M, Celebi ME, Smołka B. *Advances in face detection and facial image analysis*, 1st ed. New York, USA, Springer Publishing Company, 2016.

[39] Su J, Gao L, Li W, Xia Y, Cao N, Wang R. "Fast face tracking-by-detection algorithm for secure monitoring". *Applied Sciences*, 9(18), 3774-3793, 2019.

[40] Peng C, Bu W, Xiao J, Wong K, Yang M. "An improved neural network cascade for face detection in large scene surveillance". *Applied Sciences*, 8(11), 2222-2235, 2018.

[41] Sagonas C, Tzimiropoulos G, Zafeiriou S, Pantic M. "300 faces in-the-wild challenge: The first facial landmark localization challenge". *In Proceedings of the IEEE International Conference on Computer Vision Workshops*, Sydney, Australia, 2-8 December 2013.

[42] T.C. Aile, Çalışma ve Sosyal Hizmetler Bakanlığı. "Ekranlı Araçlarla Çalışmalarda İş Sağlığı ve Güvenliği Rehberi". https://www.ktu.edu.tr/dosyalar/isgb_2333a.pdf (11.11.2021).

[43] Meena YK, Cecotti H, Wong-Lin K, Prasad G. "A novel multimodal gaze-controlled hindi virtual keyboard for disabled users". *IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, Budapest, Hungary, 9-12 October 2016.