# Development of a Communication and Control System Using Eye Tracking for Physically Disabled People

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ABSTRACT

This study aims to provide opportunities for physically disabled individuals (paralysis, limb deficiencies, Parkinson's, ALS, etc.) to meet specific needs independently in daily life, to communicate, to inform about emergency; and facilitate their care. The system was developed with Python programming language. Commands are on the home page and classified as house control and needs. The system was tested with a house prototype which consisted of servo motors, an LED and a fan controlled by Raspberry Pi.

**Key words**: *Barrier-free technologies, eye tracking system, image processing, Python, Raspberry Pi*

## 1 Introduction

Congenital or acquired physical disabilities have negatively affected people's lives for centuries and have caused them to encounter various difficulties. Such physical disabilities affect large number of people when their loved ones who help them are considered as well.

There are many different definitions of disability in the literature due to the difficulty of defining it. However, considering the common points of these definitions, disability can be explained as "the need for additional support due to various disabilities, congenital or acquired as a result of different reasons, that negatively affect one's life" (Yumuşak, 2014).

Disabled people form a large part of the population of society. According to OECD-Eu data, there are 1.559 billion disabled people in the world population of 7.78 billion. This corresponds to approximately 15% of the world's population (Association for Living Without Obstacles, 2018).

Researches on the difficulties faced by disabled people show that the most common problems in their lives are unemployment and financial difficulties, the lack of proper arrangement of the physical environment and lack of communication with the society (Yumuşak, 2014).

The concept of Human Computer Interaction (HCI) has emerged with the need for systems that are easier to use. Human Computer Interaction is an interdisciplinary concept that includes both humans and technology. Human Computer Interaction, which provides easy usability, has many advantages. These advantages can be listed as being pleasing and efficient, easy to learn and remembered even if it is not used for a long time, and minimizing user error (Çağıltay, 2016). Computer use, which has a high prevalence rate as a result of the solutions it offers, is done via computer input devices such as keyboard, mouse and touchpad. However, people with mobility impairments cannot make physical contact with computer input devices, therefore cannot use a computer and benefit the advantages of Human Computer Interaction (Dönmez & Çağıltay, 2016).

In this study, a home control and communication system that uses image processing-based eye tracking system was introduced as a solution for disabled individuals who cannot live independently in their home environment where they spend most of their lives and cannot communicate comfortably in their homes due to their physical limitations. The developed system meets the need for support that will bring disabled people into society and make their lives easier by bringing a solution to the difficulties they experience, which are the physical environment not being properly arranged and lack of communication with the community.

## 2 Method

In this study, the design-based research method was used. This method was developed to further the interaction of design, theory and practice. In this study, the design-based research steps created by R. C. Reeves, Ron Oliver and Jan Herrington (2004) were followed. The preferred method consists of two main topics and four stages: the predictive and developmental research steps. (Reeves, Oliver, & Herrington, 2004).

Studies concerned about the disabled individuals were analyzed. The founder of the barrier-free informatics platform, also an information technology specialist; a company official that develops technological support products for disabled people, and three people who are experts in the field of information technologies and who work on platforms related to solutions for people with disabilities were interviewed. In the meeting, the needs of disabled people, commercially developed technological products and the feedbacks made about the use of these products, and solution proposals for the development of existing technological systems were discussed. It was decided to develop a home automation system that can be controlled with an eye tracking system that will facilitate the lives of the disabled and increase their independence.

The basis of this study is the concept of "Computer Vision". Computer vision, which is a branch of computer science, makes it possible for computers to produce an appropriate output by performing many operations on the given image (Postacı, 2020). In this study, computer vision was applied via Python programming language. The Opencv (Open Source Computer Vision) library was used for image processing, which forms the basis of this study. In addition to the Opencv library, the Dlib library containing machine learning algorithms to perform operations such as recognition, the Mouse library that can receive and imitate user inputs to control the mouse cursor on the screen, the Tkinter and Pillow libraries for the design of the interface, the Pygame library for the playback of audio files. Additionally, the Smptlib library for sending e-mails to the relatives of the users and Ctypes library is for detecting whether the user is using the systemand the Rpi GPIO library for controling the prototype using Raspberry Pi was used.

The developed program first detects the faces in the camera with the face detection function of the "Dlib" library, and then determines the eye, mouth, eyebrow and nose elements on the face with the "facial mapping" method (Figure 3). In this study, only the points that give the position of the eyes were focused on, among the items found, since eye tracking will be performed (Fig. 1).

**Fig. 1:** "Facial mapping" diagram

First, a function was defined to detect whether the eye is blinking or not. This function draws a horizontal line between the rightmost and leftmost points of the eye, and a vertical line passing through the middle of the upper and lower two points, using the points determined by "facial mapping". When the eye is blinked, the horizontal length remains the same, while the vertical length decreases and the obtained ratio increases. The program counts this decrease as the user blinked. Mouse library is used to simulate clicking the mouse cursor when the eye blinks (Fig. 2).

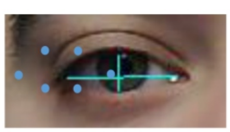
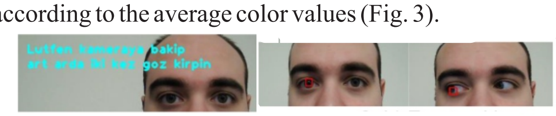


**Fig. 2:** Identifying points and drawing lines on the eye

Three methods were tried in the eye tracking step, and after the trials, the most suitable one was selected. The first method tried was using the contour finding method in the Opencv library. In this method, the eye image is separated from the camera image by applying a mask. "Gaussian blur", conversion to gray and tones and adaptive thresholding processes are applied on the obtained image. Then, contour finding function of Opencv library is run on the threshold eye image.

Since it was observed that the method used to determine the location of the pupil is affected by the environmental conditions, the use of the trackers in the Opencv library has been tried. In this method, the middle point of the user's eye is given to the tracker in the image when the user looks at the camera. However, after the experiments, it was observed that the determined point changed due to the trackers not being sensitive enough and the point is tracked according to the average color values (Fig. 3).




(a) (b)

**Fig. 3:** a) Configuration screen b) Eye tracking

Then, the third and the final method was tested. Using "facial mapping", the image where the eye is located is extracted and "median blur", "conversion to gray and tones and adaptive thresholding processes are performed respectively. The obtained image is divided into two equal parts, right and left, and the amount of white pixels is taken, the change in this amount is evaluated and the direction the eye looks at is determined. As long as the amount of white in the right half is above a certain amount, it is taken as looking to the left, as long as the amount of white in the left half is above a certain amount, it is considered as looking to the right. Using these directions, the mouse cursor is moved to right if looking to right, and to left if looking to left. This method has also been tried for up and down looking situations, but adequate results could not be obtained. Thereupon, it was decided that the mouse cursor would only move horizontally.

Tkinter and Pillow libraries were used in the interface design. Commands that are included in the program are door, air conditioner, light on/off, bed lowering/raising; medicine, water, requesting food, reporting the need for toilet, thanking, calling out and reporting an emergency. These commands are divided into two categories as "home control" and "needs", and the emergency notification command is placed in all program windows for quick access. A home page was created where the user can choose between two categories (Fig.4). Selected commands notify the user by giving an audible and visual warning.

In the first design of the interface, assuming that the place where the eye looks will be used, it was thought that a circular design would be more comfortable to use, and the commands were placed in the windows of the categories in this way (Fig.5).

**Fig. 4:** Homepage design

**Fig.5:** a) Home control window b) Requirement notification window

After it was decided to use only the horizontal direction of the eye, the interface design was rearranged in accordance with the horizontal mouse movement . In the continuation of the development process, the number of commands in the system was increased. A window open/close command was added to the home control category, and a calling command was added to the needs category. Since the increase of the number of buttons may cause difficulties for the users after the increase in the number of commands, the commands were rearranged in two rows and an up/down button has been added to enable the transition between the two rows (Fig. 6).

**Fig.6:** a) New home control window design b) New needs

The added up/down button works as a "Toggle button", it moves the mouse cursor down if it's up and up if it's down. The movement of the mouse cursor is performed by aligning the mouse cursor with the commands. For this movement, it was tried to use a blink for a certain period of time instead of a button. However, it was observed that the loop added for this purpose reduced the running speed of the program and it was decided to use the button. A return button was added to the home control and needs window, which the users can use when they want to return to the home page from the command window. In addition, it was observed in the experiments that users have difficulties in where they should look. To solve this problem, directional arrows were placed in all windows of the interface to show where they should look to move the mouse cursor, and a circle that shows where they should look to stop the mouse cursor. In addition to these improvements, the interface windows were made full screen (Fig. 7).

(a) (b) (c)

**Fig. 7:** a) New home page design b) New home control window design c) New needs window design

In the new interface design, it was taken into account that increasing the mouse movement may cause difficulties for the user to switch between the menus. To eliminate possible problems in this regard, the mouse cursor is automatically positioned to coincide with the commands of the user on the main page, and to coincide with the commands in the upper row in the command windows.

After reaching the current design of the interface, the development of the emergency notification system was worked on. Considering the possibility that the person to be notified may not be in the same place as the user at that time, the feature of notifying via e-mail was added to the system. With the addition of this feature, pressing the emergency notification button sends the message "Your relative has reported an emergency." To the relative of the user. In addition, considering that the user's condition may be too serious to use the button from the system, a message asking the user if they are okay is displayed if the system is not used for a certain period of time. The mouse cursor is automatically placed on the confirmation button on the message so that they can more easily press the button if there is not an emergency. If the user does not press the confirmation button on this message within a certain time, an e-mail saying "Your relative is not responding, there may be an emergency." is sent. A letter informing the user that their relative has been notified is shown to the user.

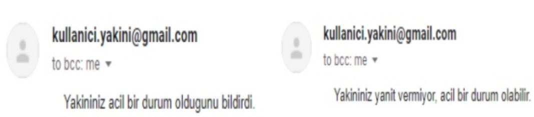



**Fig. 8:** Emails sent to the user's relatives

Informing the user's relatives via messaging, which is an easier-to-reach communication method is being worked on and will be added to the system in further improvements. In addition, work on customization of the commands is in progress.

The prototype used in this study was first designed in 3D on the Tinkercad program (Fig.9a). After deciding on the design on the 3D model, the diagram of the circuit elements to be used was drawn through the Fritzing program. After the planning phase, the first prototype was developed. The developed prototype contains a fan representing the bed, door, light and air conditioner. Light and fan elements are connected to Raspberry Pi using Relay module relay. SG90 servo motors used in door and bed control are connected to Raspberry Pi by combining their positive ends. After the window control was added to the system, the prototype design was updated and a second prototype was created. The newly built prototype contains a fan representing the bed, door, light, window and air conditioner. The connection of the elements in the previous prototype was left the same, the servo motor used in the window control was also connected to the Raspberry Pi, as was the bed and the door (Fig. 9 a and b) .

**Fig.9:** a) 3D House Model b) Current prototype

The current version of the developed system has been tested with three users, and users' time to reach the desired commands, ease of use and effect of the distance from the camera on the system performance has been examined. The data of one of the trials are given in Table (1).

**Table 1:** Trial Data

| | | | Command | | | | | | | | | | | Total Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Light | Door | Window | Bed | Air Conditioner | Food | Water | Toilet need | Medicine | Thanks | Call Out | |
| 1. Person | Trial 1 – 30 cm | Success | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 162.4 s |
| | | Time (s) | 6.9 | 19.2 | 13.5 | 10.9 | 13.2 | 11 | 20.1 | 8.7 | 10.4 | 33.7 | 14.8 | Avg. : 14.8 s |
| | Trial 2 – 30 cm | Success | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 135 s |
| | | Time (s) | 8.7 | 7.8 | 12.9 | 9.8 | 22.5 | 9.8 | 10.2 | 7.2 | 7 | 19.2 | 19.9 | Avg. : 12.3 s |
| | Trial 3 – 40 cm | Success | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 110.5 s |
| | | Time (s) | 8.9 | 8 | 15.5 | 8.2 | 14 | 7.5 | 8 | 8.5 | 9.6 | 11 | 11.3 | Avg. : 10.1 s |
| | Trial 4 – 50 cm | Success | x | x | x | x | x | x | x | x | x | x | x | - |
| | | Time (s) | - | - | - | - | - | - | - | - | - | - | - | |

When the data shown in Table 1 are examined, it is seen that the user's speed of use increases in each trial. As for the distance of use, users have reported that they can move the mouse cursor more easily in a 40-centimeter setup. In other words, it can be said that the system works best at 40 centimeters, but does not give healthy results at longer distances such as 50 centimeters.

## 3 Discussion

It was seen that the system developed at the end of this study has the quality to increase the quality of lives of individuals with physical disabilities. The eye is one of the organs that loses its function the least in conditions such as paralysis and disability. Therefore, home automation developed with an eye tracking system both appeals to a wide audience around the world and increases the independence of disabled individuals in their daily lives by providing a comfortable use.

Studies based on computer vision-based eye tracking have been found in the literature. For example, the study titled "Design and Development of a Game Based Eye Training Program for Children with Low Vision" by Dönmez (2020) was conducted in the field of eye tracking systems and the target audience was children with low vision who could not be treated with glasses, lenses and eye surgery. The study aims to create an alternative to rehabilitation centers with low accessibility by offering visually impaired activities to children with low vision. As a result of the study, it shows that eye tracking technology is an effective and accessible way in terms of low vision exercise (Dönmez, 2020).

When these and similar studies are examined, computer vision promises potential both in facilitating the lives of the disabled and in the construction of exercises for rehabilitation purposes.

## 4 Conclusion

Disabled people, who make up 15% of the world's population, need supports that will make their lives easier. In this study, the physical limitations and miscommunication problems caused by the disability which are the largest problems for the disabled individuals after unemployment and financial were tried to be solved. In order to solve these problems, a home control and communication system has been developed using the eye tracking system.

The factors that were considered in the decision process of the product were that the designed product needed to be suitable for the user group and a reason was needed to be given to the users in order to use the product. Starting from this stage, the importance of suitability for the user group has been reinforced with this study and it has been understood how important it is.

The use of image processing technique in the study increased the program's dependence on environmental conditions. Although the proposed solution aims not to depend on environmental factors, at the end of the study, it has been observed that the image and therefore the image processing processes are affected by the physical factors such as light. A wearable system where the camera is attached on glasses can reduce the influence of environmental factors. In addition, a hybrid system can be developed to solve this problem. Since the perception of eye movements can be easily affected by environmental factors such as light, it is predicted that this system, which the user can control with head movements in addition to eye movements, will give better results. Head movements can be processed using a gyro sensor instead of computer vision to reduce dependence on environmental conditions.

The system and design presented in this study can also be applied to places that are frequently involved in daily life such as workplaces and schools in the future, and can be transformed in order to provide independence to individuals in different areas.

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