EyeMo: A Solution for Individuals with Disabilities to Use a Computer Through Eye Movements

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Graphical/Tabular Abstract (Grafik Özet)

This study focuses on developing a computer control application using eye movements to assist individuals with neuromuscular diseases and spinal cord injuries. The application, utilizing a lightweight eyeglass frame and mini-USB camera, accurately detects the user's pupil. The user interface enables tasks like web browsing and video watching. / Bu çalışma, nöromüsküler hastalıkları ve omurilik yaralanması olan bireylere yardımcı olmak için göz hareketlerini kullanan bir bilgisayar kontrol uygulamasının geliştirilmesine odaklanmaktadır. Hafif bir gözlük çerçevesi ve mini-USB kamera kullanan uygulama, kullanıcının gözbebeğini doğru bir şekilde algılar. Kullanıcı arayüzü web'de gezinme ve video izleme gibi görevleri mümkün kılar.
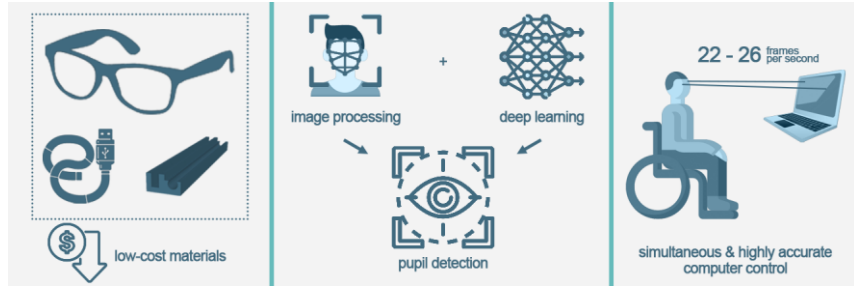
Figure A: EyeMo: A Solution for Individuals with Disabilities to Use a Computer Through Eye Movements / Şekil A: EyeMo: Dezavantajlı Bireylerin Göz Hareketleriyle Bilgisayar Kullanması İçin Bir Çözüm

Highlights (Önemli noktalar)

➢ *An application has been developed for disadvantaged individuals to use computers with their pupils. / Dezavantajlı bireylerin göz bebekleriyle bilgisayar kullanmaları için uygulama geliştirilmiştir.*
➢ *The developed application stands out with its low cost and the technology it uses. / Geliştirilen uygulama düşük maliyeti ve kullandığı teknolojisi ile öne çıkmaktadır.*
➢ *Traditional image processing methods and deep learning techniques were used together. 22-26 frames of image can be processed per second. / Geleneksel görüntü işleme yöntemleri ve derin öğrenme teknikleri birlikte kullanılmıştır. Saniyede 22-26 kare görüntü işlenebilmektedir. /*

Aim (Amaç): *This study aimed to develop a computer control application that uses eye movements to help individuals with neuromuscular diseases and spinal cord injuries navigate and interact with computers. / Bu çalışma, nöromüsküler hastalıkları ve omurilik yaralanması olan bireylerin bilgisayarlarda gezinmesine ve bilgisayarlarla etkileşime girmesine yardımcı olmak için göz hareketlerini kullanan bir bilgisayar kontrol uygulaması geliştirmeyi amaçlamıştır.*

Originality (Özgünlük): *A high-accuracy and low-cost solution was produced by using traditional methods and deep learning techniques together. / Geleneksel yöntemler ve derin öğrenme teknikleri birlikte kullanılarak yüksek doğruluklu ve düşük maliyetli bir çözüm üretilmiştir.*

Results (Bulgular): *The application offers functionalities like left-click, right-click, double-click, and scrolling, enabling users with motor function challenges to perform tasks from internet browsing to video watching. 22-26 images per second can be processed simultaneously. / Uygulama, sol tıklama, sağ tıklama, çift tıklama ve kaydırma gibi işlevler sunarak, motor fonksiyon zorlukları yaşayan kullanıcıların internette gezinmekten video izlemeye kadar görevleri gerçekleştirmesine olanak tanımaktadır. Saniyede 22-26 kare görüntü eş zamanlı olarak işlenebilmektedir.*

Conclusion (Sonuç): *With this study, a low-cost and high-accuracy application that performs simultaneous pupil detection has been developed. / Bu çalışma ile eş zamanlı göz bebeği tespiti yapan, düşük maliyetli ve yüksek doğruluklu bir uygulama geliştirilmiştir.*

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Abstract

The maintenance of an upright posture and the execution of desired movements by individuals necessitate the seamless and harmonious functioning of the muscular and skeletal systems. Neuromuscular diseases, spinal cord injuries, and related conditions can adversely impact individuals' motor functions, leading to a loss of muscle strength and, in severe cases, paralysis. Such health challenges may result in social isolation and detachment from one's social life. This study is focused on the development of a computer control application utilizing eye movements to aid users in navigating and interacting with computers. The system utilizes a lightweight eyeglass frame and a mini-USB camera to accurately capture images of the user's pupil. Pupil detection is achieved through a combination of traditional image processing and deep learning techniques, ensuring high accuracy under diverse conditions. The user interface incorporates functionalities such as left-click, right-click, double-click, and scrolling, empowering users to perform tasks ranging from internet browsing to video watching. After the development of the application, a request for research permission was submitted to the local institution to allow volunteers to test the application, adhering to ethical standards. Following the approval of ethical clearance, the application was made available for use by volunteers, and feedback was systematically collected. Upcoming versions of the application have the potential for integration with smart home systems. Additionally, the developed application can be used in games and for educational purposes.

EyeMo: Dezavantajlı Bireylerin Göz Hareketleriyle Bilgisayar Kullanması İçin Bir Çözüm

Öz

Bireylerin dik duruşu sürdürmesi ve istenilen hareketleri yapabilmesi kas ve iskelet sistemlerinin kusursuz ve uyumlu çalışmasını gerektirmektedir. Nöromüsküler hastalıklar, omurilik yaralanmaları ve benzer durumlar bireylerin motor fonksiyonlarını olumsuz yönde etkileyerek kas gücü kaybına ve ciddi vakalarda felce yol açabilir. Bu tür sağlık sorunları kişinin sosyal izolasyonuna ve sosyal hayatından kopmasına neden olabilir. Bu çalışma, kullanıcıların bilgisayarda gezinmesine ve bilgisayarla etkileşime girmesine yardımcı olmak için göz hareketlerinden yararlanan bir bilgisayar kontrol uygulamasının geliştirilmesine odaklanmaktadır. Geliştirilen yazılım, kullanıcının gözbebeğinin görüntülerini doğru bir şekilde yakalamak için hafif bir gözlük çerçevesi ve bir mini USB kamera kullanır. Gözbebeği tespiti, geleneksel görüntü işleme ve derin öğrenme tekniklerinin bir kombinasyonu yoluyla gerçekleştirilir ve çeşitli koşullar altında yüksek doğruluk sağlanır. Kullanıcı arayüzü, sol tıklama, sağ tıklama, çift tıklama ve kaydırma gibi işlevleri barındırarak kullanıcıların internette gezinmekten video izlemeye kadar çeşitli görevleri gerçekleştirmesine olanak tanır. Uygulamanın geliştirilmesinin ardından, gönüllülerin uygulamayı etik standartlara bağlı kalarak test etmeleri için yerel etik kuruldan araştırma etik kurulu alınmıştır. Etik onayın alınmasının ardından uygulama gönüllülerin kullanımına sunulmuş ve sistematik olarak geri bildirimler toplanmıştır. Uygulamanın gelecek versiyonları akıllı ev sistemleriyle entegrasyon potansiyeline sahiptir. Ayrıca geliştirilen uygulama oyunlarda ve eğitim amaçlı da kullanılabilir.

1. INTRODUCTION (GİRİŞ)

Individuals' movements are realized through the coordinated and collaborative functioning of many neuron groups. The control of these movements is generally provided by the central nervous system, which actively involves the brain and spinal cord. In particular, motor neuron groups are responsible for generating the signals required for the execution of movements and for completing the movement of the skeletal and muscular system according to the generated signal [1]. When motor neurons are unable to perform their function due to external factors such as diseases or trauma, movement restrictions may occur. Progressive loss of strength is a clinically prominent feature of motor neuron diseases. This loss forms the basis for a significant portion of the challenges faced by patients, and it is a major contributor to healthcare costs associated with this group of diseases. Functions such as eating, breathing, speaking, walking, and fine motor movements are all dramatically affected by changes in muscle strength [2], [3]. Neuromuscular diseases constitute a group of disorders that arise due to problems related to the structure or function of muscles. These diseases lead to the inability of muscles to perform their normal function, a decrease in muscle strength, and sometimes loss of muscle tissue. These diseases can be of genetic origin or may develop later in life [4], [5]. The spinal cord can lose its function due to pressure resulting from diseases or trauma. As a consequence, the damaged areas become unable to perform their communication function, leading to the loss of connection between the brain and organs below the damaged regions. This results in the occurrence of spinal cord paralysis [6]. Examples of such disorders include Amyotrophic Lateral Sclerosis (ALS/MND), Charcot Marie Tooth (CMT), Duchenne Muscular Dystrophy (DMD), various myopathies, muscular dystrophies, and tetraplegia due to spinal cord injury. According to the Annual Health Statistics of the Turkish Ministry of Health, 3.28% of deaths in our country are attributed to diseases of the nervous system and sensory organs. In Organisation for Economic Co-operation and Development (OECD) countries, deaths due to diseases of the nervous system and sensory organs account for 5% of total deaths [7]. The prevalence of ALS in our country is reported to be between 3.7-7.3 per 100,000, while the prevalence of DMD is reported to be between 15.9-19.5 per 100,000 [8], [9]. The global prevalence of motor neuron diseases is reported to be 3.37 per 100,000, while in our country, it is reported as 3.6 [10]. Most of these diseases lack a known effective treatment. Patients may experience difficulties in using their limbs, and respiratory and speech difficulties are also observed. This situation gradually weakens patients' interactions with their surroundings. These processes can be challenging for both patients and caregivers [11]. In the advanced stages of diseases, patients become dependent on the bed and caregivers, moving only their heads, and in the final stages, only their eye muscles. At this stage, patients rely on communication tools using their heads and eyes with physicians, caregivers, and families. Patients interact with their surroundings by using their heads and eyes [12]. Therefore, there is a need for alternative tools that patients can use to communicate with their heads and/or eyes.

It is a well-known fact that computers have been used as a means of communication for many years [13]. Especially with the existence of social media platforms, their impact on communication continues to grow. Individuals suffering from the aforementioned diseases use computers both to communicate with their environment and to spend time. However, for individuals who cannot use their hands and eventually only use their eyes, using a computer becomes quite challenging [14]. Various studies have been conducted to overcome this challenge, and one prominent area is the field of Augmentative and Alternative Communication (AAC). Eye-tracking systems are at the forefront of these studies, where infrared cameras are commonly used. In eye-tracking systems, infrared cameras are generally utilized. When the infrared rays are absorbed by the pupil, the pupil becomes darker, while other areas remain lighter in color. This creates a contrast between the pupil and other areas, making the pupil easily distinguishable. When an infrared sensor is not used, standard cameras are employed. With a set of defined rules and the identified pupil, the use of a computer mouse or keyboard can be facilitated [12], [15]–[21]. Additionally, there are studies that enable computer usage by tracking the movement of an individual's head [22]–[26].

Image processing plays a significant role in many aspects of modern technology. In fields such as medicine, security, automation, autonomous vehicles, and many more, image processing is utilized for tasks such as digital image analysis, object recognition, face recognition, object tracking, and similar functions. These tasks require the ability to mimic the complexity and speed of the human eye and mind. Deep learning provides the ability to learn from large datasets using artificial neural networks. In image processing, a deep learning model known as Convolutional Neural

Networks (CNNs) has become highly effective, especially for working with large and complex visual data. Research is also being conducted on the detection of the pupil using deep learning, and results show much higher accuracy compared to standard image processing methods [27]–[29].

During the examination of the literature on eye tracking systems, it is seen that for high sensitivity in eye tracking systems, the cameras that will detect the pupil must be positioned to detect the eye clearly. This is often achieved by using eyeglass frames or headbands. Particularly, the prices of infrared sensor cameras are higher than standard cameras. However, cameras modified to become infrared sensors tend to be heavier than usual, causing discomfort and earaches when worn on the head or glasses for extended periods. This study aims to develop software that allows individuals with disabilities to control the computer using their pupils. For this purpose, a standard lightweight mini-camera, eyeglass frame, and a glasses-camera holder were used to capture images of the pupil. The developed application was announced to relevant non-governmental organizations, and with their support, it was tested by users, and feedback was collected.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

2.1. Eyeglass Frame, Camera, And Holder
(Gözlük Çerçevesi, Kamera ve Tutucu)

In order to detect users' pupils accurately, the camera needs to be positioned as close to the eye as possible. To achieve this, a standard eyeglass frame that does not interfere with the user's vision and is readily available in the market has been selected. The chosen frame weighs 14 grams. For the camera, a readily available USB camera with a diameter of 3.9 mm was preferred. The cable of the camera is 120 cm long, and its weight is 48 grams. The cable is surrounded by a rigid wire, allowing it to bend as desired. Due to its small diameter, it does not obstruct the user's field of vision. To stably integrate the camera and eyeglass frame and allow easy detachment when needed, an eyeglass-camera holder has been designed. It has been 3D printed and made ready for use. The camera can be positioned on the right or left side as desired. If the user has their own glasses, the frame can be modified accordingly and reprinted. The holder is 6 cm long and weighs 2 grams. When the eyeglass frame, camera, and holder are assembled, images can be captured through the application. The total weight of the created module (including the camera cable)

is 64 grams. The assembled module is depicted in Figure 1.

Figure 1. Eyeglass frame, camera, and holder
(Gözlük çerçevesi, kamera ve tutucu)

2.2. Programming Environment (Programlama Ortamı)

The application is intended to run independently of the operating system. Therefore, Python 3.10 programming language has been preferred. PyCharm 2022 has been used as the programming environment. The application has been developed on a computer with an AMD Ryzen 7 processor and 16 GB of memory.

2.3. Collection Of User Feedback (Kullanıcılardan Geri Dönüşlerin Toplanması)

Before starting the development of the application, discussions were held with non-governmental organizations to introduce the purpose of the application and learn about their expectations. In this context, after developing the application, further discussions were conducted with non-governmental organizations to identify random voluntary individuals. Ethical approval was obtained from the Karabük University Social and Human Sciences Scientific Research and

Publication Ethics Board. After providing the necessary information to the volunteers, they were asked to use the developed application for a period and provide their opinions. Open-ended questions were asked to these individuals using interview methods. The interviews were conducted via phone calls.

## 3.DEVELOPED APPLICATION AND RESULTS (GELİŞTİRİLEN UYGULAMA VE SONUÇLARI)

3.1. Image Capture And Pupil Detection
(Görüntünün Alınması ve Göz Bebeğinin Tespit Edilmesi)

The camera used for simultaneous image transfer is a USB-connected plug-and-play camera. Therefore, it can directly operate on current operating systems without the need for any software installation. While the application is in use, the camera captures images at a resolution of 1280X720 and in the range of 22-26 frames per second (FPS). Precisely locating the image of the pupil in the captured frame is crucial for the accurate detection of the pupil. To achieve this, guidelines have been drawn on the window where the image is displayed in the application. By centering the pupil with these guidelines, continuous and highly accurate detection of the pupil is ensured (Figure 2a).

Additionally, aligning the user's forehead with the computer screen enhances the application's performance (Figure 2b). with the "line" formed from one side of the keyseat.

During the pupil detection process, traditional image processing methods were initially attempted; however, they exhibited low performance under different lighting conditions, varying pupil colors, and skin tones. Subsequently, deep learning-based methods were explored. The weights of the deep learning model used by Vera-Olmos et al. [28], based on the Google Inception deep learning network [30], were utilized. It was observed that the pupil was detected almost losslessly using this approach. In their study, Vera-Olmos et al. reported a 96% success rate in detecting the pupil with the developed model [28]. The weights and the deep learning network for this study were configured to process images from the camera simultaneously. As a result, as seen in Figure 2, the pupil can be detected with high accuracy in images captured by the camera. The pupil detection process is performed simultaneously without delay for each frame in the range of 22-26 frames per second obtained from the camera. Thus, 38-45 milliseconds are required to detect the pupil and perform the mouse function.
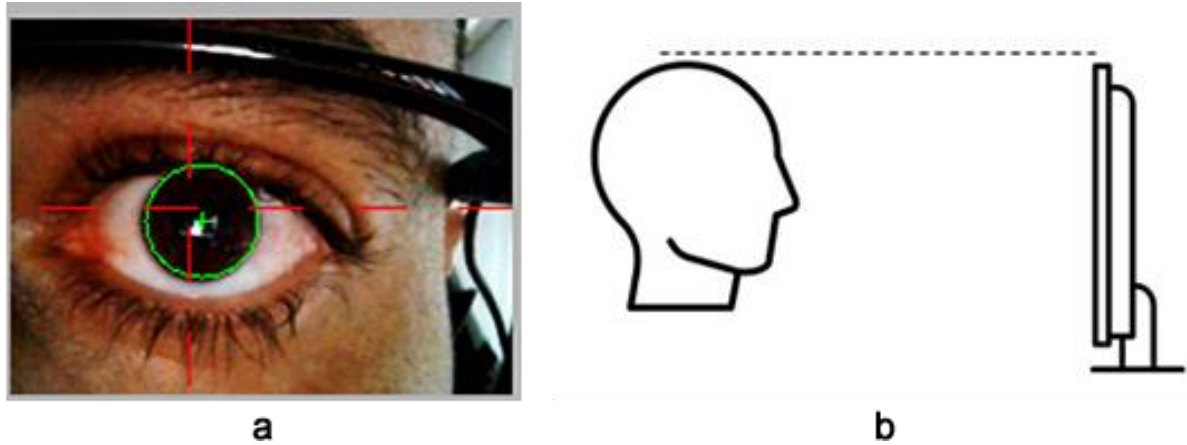

Figure 2. Alignment of guide lines and the pupil (a), alignment of the head with the screen (b) (Kılavuz çizgileri ve göz bebeğinin hizalanması (a), başın ekran ile hizalanması (b))

3.2. Calibration (Kalibrasyon Yapılması

Calibration is essential for the application to recognize the dimensions of the used screen. Therefore, calibration needs to be performed each time the application is restarted. When calibration is initiated, the calibration icon appears at a total of 9 points, starting from the middle of the page and clockwise from the bottom left corner, at three-

second intervals and sequentially. The calibration points and where these points appear are provided in Figure 3. To perform an accurate calibration, the user needs to keep their head steady and track the calibration points with their pupil. After calibration is completed, the cursor will become responsive to the movements of the pupil, allowing control through eye movements.
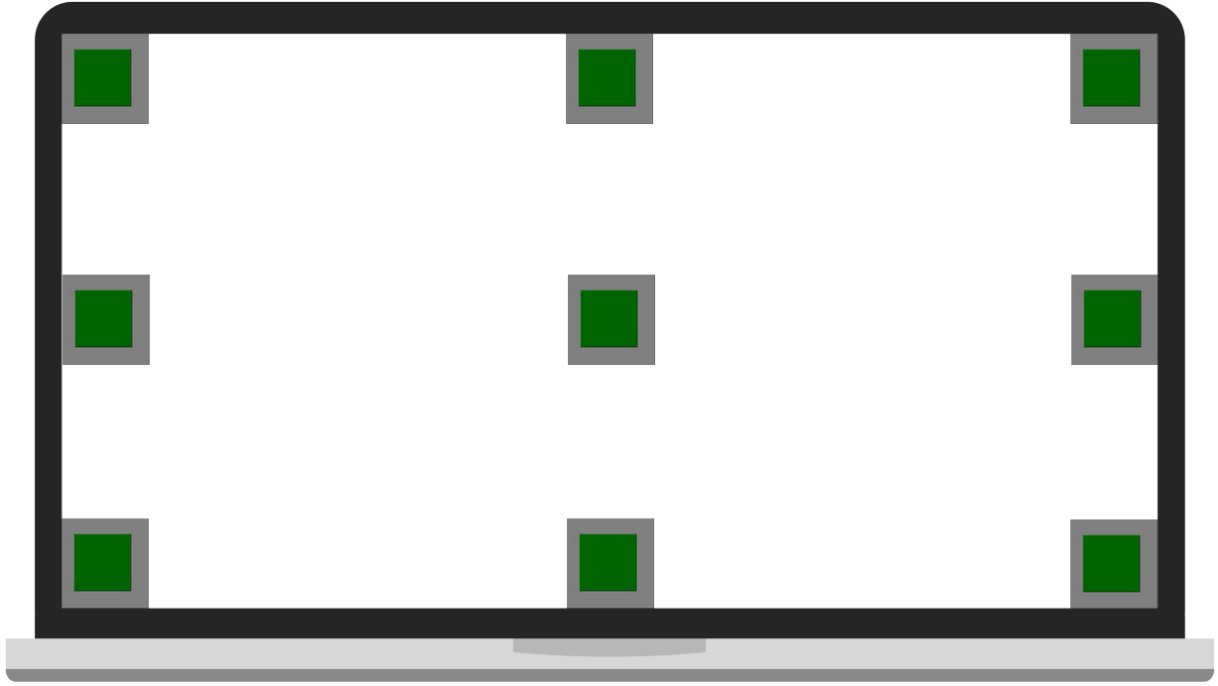
Figure 3. Calibration points and their display locations (Kalibrasyon için görünen noktalar ve görünme yerleri)

3.3. Using The Application (Uygulamanın Kullanılması)

After calibration, when the application starts capturing images from the camera, each selected function becomes active when waiting for the same duration as the waiting time set for all buttons on the interface (default waiting time is 2 seconds). When the waiting time is completed, the application plays a clicking sound, indicating that the function has been activated.

3.3.1. Application Interface (Uygulama Arayüzü)

The application has a window that does not take up much space on the screen and stays on top of all other windows continuously. Through this window, the functions of the application can be modified, and it is possible to monitor whether the pupil is detected or not (Figure 4). Details of the application interface are as follows:

1. File Menu: This menu includes the sub-menus for Settings and Exit.

2. Calibration Menu: Calibration must be performed each time the application is started to achieve high accuracy. Calibration can be initiated from this menu.

3. Connection Menu: Used to start the image stream from the selected camera.
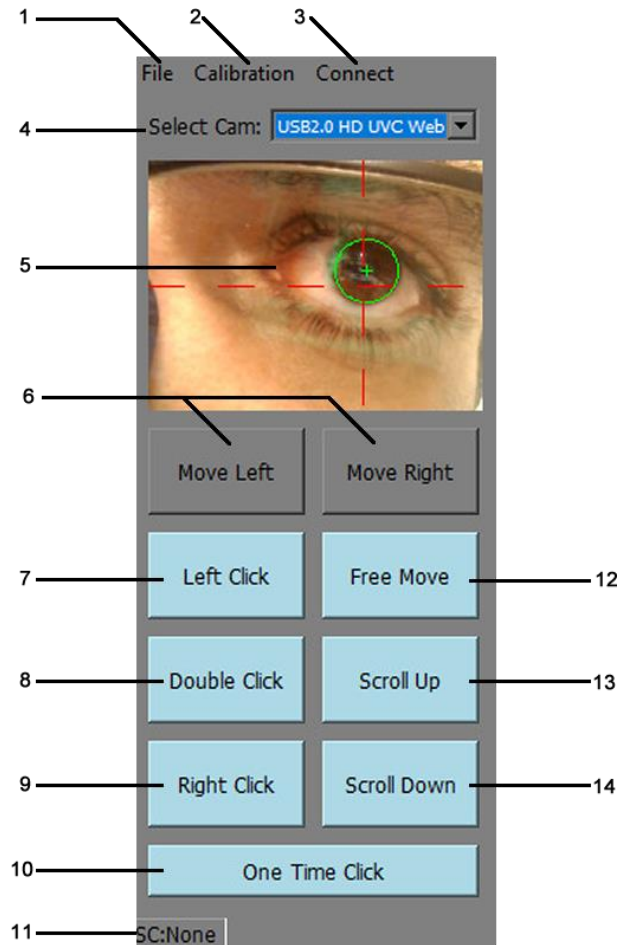
Figure 4. Application interface (Uygulama arayüzü)

4. Camera Selector: Plug-and-play cameras connected to your computer are listed here. You need to select the appropriate camera and start it from the "Connection" menu.

5. Image Area: Visible when image capture begins.

6. Left Edge, Right Edge: When the application is first opened, it appears in the middle of the screen. While using the application, you can position the application window to the left or right side of the screen. The selected side is highlighted in orange.

7. Left Click: Used to activate the left-click function of the mouse. When active, the button color turns green. To deactivate, move the mouse cursor over it and wait for the specified waiting time.

8. Double Click: Used to activate the double-click function of the mouse. When active, the button color turns green. To deactivate, move the mouse cursor over it and wait for the specified waiting time.

9. Right Click: Used to activate the right-click function of the mouse. When active, the button color turns green. To deactivate, move the mouse cursor over it and wait for the specified duration.

10. Single Click, Continuous Click: Can be selected to continue until the used mouse functions are canceled or to work once. If the button color is blue, the selected function works once. If you want the selected mouse function to work continuously, move over the button and wait for the specified duration. The button color turns green when continuous click mode is activated.

11. Calibration Information: Indicates the calibration status. When calibration is not performed, it shows "SC:N." When calibration is successfully done, it shows "SC:OK."

12. Free Move: Allows moving the mouse icon without any mouse click function. When active, the button color turns green. To deactivate, move the mouse cursor over it and wait for the specified duration.

13. Scroll Up: Scrolls up by the distance specified in the settings menu of a webpage or similar locations. When active, the button color turns green. To deactivate, move the mouse cursor over it and wait for the specified duration.

14. Scroll Down: Scrolls down by the distance specified in the settings menu of a webpage or similar locations. When active, the button color

turns green. To deactivate, move the mouse cursor over it and wait for the specified duration.

3.3.2. Settings Menu (Ayarlar Menüsü)

Under this menu, default values for the application can be modified. The visual representation of the Settings window (Figure 5) and details of its functions are provided below.
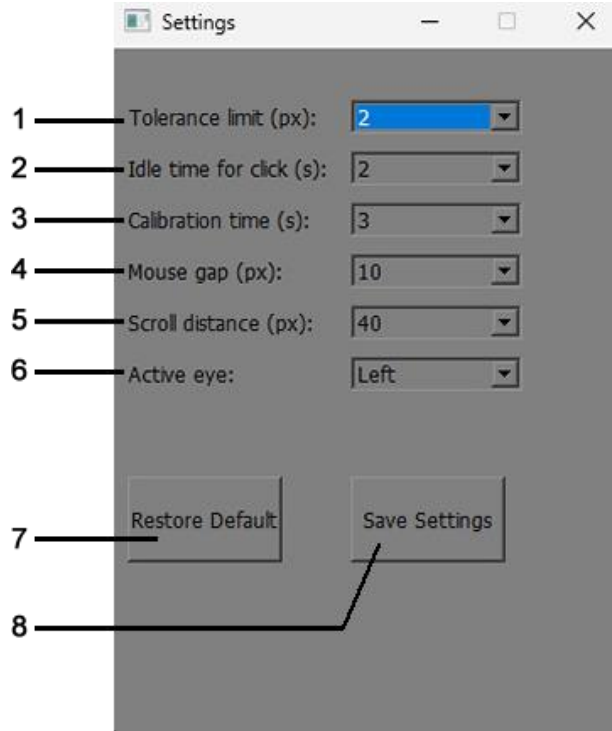
Figure 5. View of settings window (Ayarlar penceresinin görünümü)

1. Tolerance Limit: This setting is used to adjust the off-screen distance required to move the cursor left, right, up, and down. It ensures the cursor remains stationary while reading text or watching a video, and can be increased or decreased based on screen size.

2. Wait Time: When any cursor function is selected, this setting determines how long it takes for the function to be triggered. The function is activated when the cursor remains idle on any button for the duration specified here.

3. Calibration Time: Indicates how long the calibration points will be displayed on the screen.

4. Cursor Gap: Adjusts the distance the cursor moves left, right, up, and down with each gaze. Depending on the screen scaling used, this value can be decreased or increased. As this value decreases, the cursor moves more slowly, but its sensitivity increases.

5. Scroll Amount: Determines the amount of upward and downward scrolling achieved using the mouse. Increasing this value results in more significant scrolling.

6. Active Eye: Used to specify the eye within the camera's view.

7. Reset: Used to revert to default settings.

8. Save: Used to save the modified settings.

3.3.3. Using The Application (Uygulamanın Kullanılması)

After launching the application, the camera needs to be activated for the detection of the pupil. Subsequently, aligning the camera and the pupil prepares the application for use. At this stage, calibration is required to detect the boundaries of the screen used by the application and adjust them according to the pupil. Once calibration is completed, the cursor follows the pupil, enabling movement in left, right, up, and down directions. Depending on the selected function within the application, it allows left-click, right-click, double-click, scrolling down, and scrolling up. To deactivate the chosen function, the user needs to hover the cursor over the active function on the application or wait over the "free move" button. This way, the user can navigate through websites, type using a virtual keyboard, watch favorite videos, and engage with social media.

3.4. User Feedback (Kullanıcı Geridönüşleri)

Relevant non-governmental organizations were contacted and asked to select volunteers to try the application. Initially, five individuals were contacted, informed about the application, and provided with the voluntary consent form before handing over the application. Users were asked to use the application, share their opinions, and respond to open-ended questions. In response to the question "What are your thoughts on the benefits of this application?" the majority of users stated that it is particularly beneficial for individuals with disabilities, especially those who cannot move below the neck. When asked "What tasks can you accomplish using this application that you couldn't do on the computer before?" users responded with "I can browse the internet and watch videos." Regarding the question "What aspects of this application, if any, need improvement?" users generally mentioned that the frame of the glasses they were using tilted towards the direction where the camera was attached after a while. This caused the calibration to be disrupted, requiring recalibration. Users found this aspect not user-friendly. Another drawback mentioned was the need to look outside the screen in left, right, up, and down directions to move the cursor, leading to eye strain after a while. In response to the question "Would you consider using this application in the future?" users expressed that they would use it if the mentioned drawbacks were addressed. In their overall thoughts on the application, users conveyed that the application is necessary and beneficial but acknowledged that there are areas that need improvement.

4. CONCLUSIONS (SONUÇLAR)

In this study, an application was developed to enable individuals with disabilities to use a computer through eye movements. The developed application successfully detects the user's pupil, allowing simultaneous use of the pupil and the cursor. The application was tested by volunteer individuals and generally found to be successful.

Unlike many eye-tracking devices that are attached to the screen or table, the camera in this study is used with glasses frames and remains fixed on the head. This design contributes to a higher success rate in detecting the pupil when the direction and orientation of the head change.

Many eye-tracking systems on the market use infrared sensors, leading to increased costs. In this study, a standard camera operating in natural daylight was used, resulting in a lower system cost.

Traditional image processing methods can exhibit low success rates in pupil detection due to factors such as lighting conditions and eyeglass lenses. The use of deep learning-supported pupil detection in this study contributes to a high success rate.

In future studies, using built-in cameras above the screen with artificial intelligence support could prevent calibration disruption issues experienced by users compared to glasses-mounted cameras.

The application developed can find utility not only for individuals with disabilities but also in gaming, educational technologies, and the defense industry. Shortcuts assigned to the application can provide easier access to functions frequently used by individuals. Integration with smart home systems can enhance the comfort of individuals with disabilities, especially those living alone.

ACKNOWLEDGMENTS (TEŞEKKÜR)

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

Ethical approval was obtained from the Karabük University Social and Human Sciences Scientific Research and Publication Ethics Board to collect volunteer feedback in this study.

Bu çalışmadaki gönüllü geri dönüşlerinin toplanması için Karabük Üniversitesi Sosyal ve Beşeri Bilimler Bilimsel Araştırma ve Yayın Etiği Kurulu'ndan etik onay alınmıştır.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Hakan YILMAZ: He carried out the literature review, development of the application and writing of the article.

Literatür taramasını, uygulamanın geliştirilmesini ve makalenin üretimini gerçekleştirmiştir.

Mehmet ÖZDEM: He carried out the literature review, and writing of the article.

Literatür taramasını, makalenin üretimini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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