Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Design and implementation of a portable device for visual field testing

Görme alanı testi için taşınabilir bir cihaz tasarımı ve uygulaması

Kerim Özkara[1], Aeshah Basim Younus Al-Bayatı[1], Ahmet Reşit Kavsaoğlu[1]*

[1]Department of Biomedical Engineering, Faculty of Engineering and Natural Sciences, Karabuk University, Karabuk, Türkiye.
kerim.ozkara@sinop.edu.tr, sdam99as@gmail.com, kavsaoglu@karabuk.edu.tr

Received/Geliş Tarihi: 09.08.2025 Revision/Düzeltme Tarihi: 12.11.2025 doi: 10.65206/pajes.98444
Accepted/Kabul Tarihi: 26.11.2025 Research Article/Araştırma Makalesi

Abstract

Inspired by the Humphrey Field Analyzer (HFA) device used in the diagnosis and monitoring of diseases such as glaucoma that cause vision loss, this study developed a low-cost, portable device application that is integrated with existing devices and has a design that facilitates patient use. The system design consists of mechanical, hardware, and software components. The mechanical design includes a visual stimulus box integrated with a special chin rest to ensure user ergonomics and reliable results. The hardware component features an LED-based visual stimulus circuit designed in a 24/2 pattern and controlled by an Arduino Mega microcontroller. The functionality of the hardware has been verified using Proteus simulation software. On the software side, a user interface has been developed using MATLAB Appdesigner, which enables two-way communication with the Arduino Mega microcontroller via a serial port. The developed visual field-testing system is a low-cost, easy-to-install, portable, and reliable system that does not require specialized technical personnel. Compared to commercial devices, the design eliminates motor noise associated with stimulus projection in HFA devices, making it quieter and less distracting for users. This study offers a cost-effective, user-friendly, and portable alternative to traditional visual field-testing devices for potential clinical diagnosis and patient education applications.

Keywords: Visual field test, Glaucoma Diagnosis, Low-Cost Medical Device, Humphrey Field Analyzer

Öz

Görme alanı kaybına neden olan glokom gibi hastalıkların teşhisi ve takibinde kullanılan Humphrey Alan Analizörü'nden (HFA) esinlenilen makale çalışmasında mevcut cihazlara uyum sağlayan ve hasta kullanımını kolaylaştıran tasarım ile düşük maliyetli ve taşınabilir bir cihaz uygulaması geliştirilmiştir. Sistem tasarımı mekanik, donanım ve yazılım bileşenlerinden oluşmaktadır. Mekanik tasarım, kullanıcı ergonomisini ve güvenilir sonuçları sağlamak için özel bir çene desteği ile entegre edilmiş bir görsel uyaran kutusu içerir. Donanım bileşeni, bir Arduino Mega mikrodenetleyici tarafından kontrol edilen 24/2 deseninde tasarlanmış LED tabanlı bir görsel uyaran devresine sahiptir. Donanımın işlevselliği Proteus simülasyon yazılımı kullanılarak doğrulanmıştır. Yazılım tarafında, seri port üzerinden Arduino Mega mikrodenetleyici ile çift yönlü iletişime olanak sağlayan MATLAB Appdesigner kullanılarak bir kullanıcı arayüzü geliştirilmiştir. Geliştirilen görme alanı test sistemi, uzman teknik personel gerektirmeyen, düşük maliyetli, kurulumu kolay, taşınabilir ve güvenilir bir sistemdir. Tasarım ticari cihazlarla karşılaştırıldığında, HFA cihazlarındaki uyaran projeksiyonuyla ilişkili motor gürültülerini ortadan kaldırarak sessiz çalışmasıyla kullanıcılar için daha az dikkat dağıtıcı hale gelmektedir. Bu çalışma, potansiyel klinik tanı ve hasta eğitimi uygulamalarıyla, geleneksel görme alanı test cihazlarına uygun maliyetli, kullanıcı dostu ve taşınabilir bir alternatif sunmaktadır.

Anahtar kelimeler: Görme alanı testi, Glokom Tanısı, Düşük Maliyetli Tıbbi Cihaz, Humphrey Alan Analizörü

1 Introduction

The visual field is the area a person can see at any given time without moving their head or eyes relative to the fixation point. The extent of a person's visual field is a critical aspect of visual function, as restricted visual fields can negatively impact daily activities and overall quality of life [1]. Visual field testing, or perimetry, is a diagnostic tool used to measure and map the retina's sensitivity within the visual field. It plays a vital role in diagnosing and monitoring conditions such as glaucoma, which can lead to progressive visual field loss [2]. Traditional perimetry devices, such as the Humphrey Field Analyzer (HFA), have been widely used for over two decades. However, these systems are often expensive, require specialized personnel, and may not be accessible in low-resource settings. This study aims to address these limitations by designing a low-cost, portable, and automated static perimetry system that simulates the 24-2 test pattern of the HFA.

Perimetry is based on contrast sensitivity, which refers to the ability to detect a light stimulus or shape against a darker or lighter background [2]. Automated static perimetry, such as the HFA, uses this principle to create a detailed retinal sensitivity map within the visual field. While the HFA and similar devices are highly effective, their high cost and complexity limit their accessibility. This work proposes an alternative system that leverages modern hardware and software technologies to provide a cost-effective solution for visual field testing. The system is designed to be user-friendly, portable, and capable of delivering reliable results without requiring specialized technical personnel.

The proposed system comprises three main components: mechanical, hardware, and software. The mechanical design includes a visual stimulus box integrated with a specialized chin rest to ensure user comfort and accurate results. The hardware component features an LED-based visual stimulus circuit arranged in a 24-2 pattern controlled by an Arduino Mega microcontroller. The functionality of the hardware was validated using Proteus simulation software. On the software side, a user interface was developed using MATLAB Appdesigner, enabling bidirectional communication with the Arduino Mega microcontroller via a serial port. This interface allows for real-time control of the stimulus presentation and data collection.

*Corresponding author/Yazışılan Yazar

The developed system offers several advantages over traditional perimetry devices. It costs approximately $1038, significantly more affordable than commercial systems. Its portable and embedded design makes it suitable for clinical and non-clinical settings. Additionally, the system operates quietly, eliminating the motor noises associated with traditional devices, which can distract patients. These features make the system particularly suitable for training elderly patients who may struggle with conventional perimetry devices.

Considering the reasons mentioned above, this paper presents the design of a low-cost automated static perimetry system that simulates the 24-2 test pattern of the Zeiss HFA3 device. A visual field testing system, as illustrated in Fig. 1, has been developed to achieve this goal. The system provides an affordable, portable, and user-friendly alternative to traditional perimetry devices, making visual field testing more accessible in various clinical and non-clinical settings.

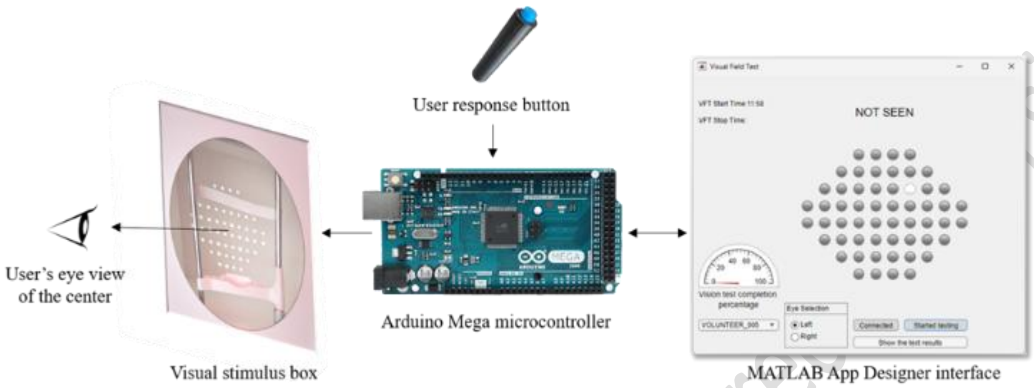


Figure 1. Visual field test system design block diagram.

The information flow between the Arduino Mega microcontroller and the MATLAB App Designer interface is bidirectional. The interface displays the percentage of completion of the testing process. In the "Eye Selection" section of the interface, the user selects the eye to be tested. The "Connected" button establishes the serial connection between the interface and the Arduino Mega, while the "Start Testing" button initiates the testing process. The volunteer results are displayed in a separate figure window for each test and saved in a .mat file named "VOLUNTEER_001." The start and end times of the visual field test are displayed in the "VFT Start Time" and "VFT Stop Time" labels, respectively. The "NOT SEEN" label on the interface changes to "SEEN" when the user presses the response button, allowing the user's responses to be monitored in real-time.

The interface includes 56 points represented by Lamp objects, arranged in 8 rows and 10 columns, corresponding to the LEDs in the visual stimulus box. Each Lamp object interacts directly with its corresponding LED in the stimulus box. When the left mouse button is clicked on any Lamp object, it turns white, and the corresponding LED in the stimulus box lights up at maximum brightness. Conversely, clicking the right mouse button turns the Lamp object dark gray and turns off the corresponding LED. This manual testing feature allows each of the 56 points to be individually verified. The visual field test begins automatically when clicking the "Start Testing" button. User feedback is collected via the response button, and upon completion, the test results, including the visual threshold values, are saved. These results can be displayed in a separate figure window by clicking the "Show the Test Result" button.

In the visual stimulus box, the row lines are connected to the cathode terminals of the LEDs. To activate a specific row, the corresponding I/O pins of the Arduino Mega are set to logic 0. The column lines are connected to the PWM-capable pins of the Arduino Mega, allowing the LEDs to emit light at the desired brightness levels. A headrest apparatus ensures the user remains stationary and focuses on the central red LED. The distance between the user's pupil and the central LED is 30 cm. The placement of the LEDs in the visual stimulus box, designed using SolidWorks, follows a 6° angular spacing to align with the visual field testing requirements.

This design ensures a low-cost, portable, and user-friendly visual field testing system that simulates the 24-2 test pattern of the HFA3 device. By integrating modern hardware and software technologies, the system provides reliable results while addressing the limitations of traditional perimetry devices, such as high cost and complexity.

Visual field testing is a standard method for assessing visual function and is critical for diagnosing and monitoring diseases such as glaucoma, which affects over 80 million people worldwide [9]. Traditional visual field tests, such as the Humphrey Field Analyzer (HFA), require patients to fixate on a central point while responding to light stimuli of varying intensities presented at different locations. These tests map the patient's sensitivity to light across the visual field, providing essential data for disease management [3] [4]. However, conventional methods like HFA are time-consuming and expensive and can cause patient fatigue, reducing cooperation and test accuracy [3] [5].

Recent advancements have introduced portable and cost-effective alternatives, such as virtual reality (VR)--based perimeters and tablet-based applications, which aim to address these limitations. For instance, VR headsets and digital displays have been used to perform visual field tests, offering the potential for home-based monitoring and reducing the burden on clinical resources [5] [6]. However, these methods often struggle with detecting early-stage glaucoma and may have higher false-positive rates, limiting their diagnostic accuracy [4] [7].

Studies have explored using devices like the iPad-based Visual Fields Easy (VFE) application, which, while portable and quick, has shown limited effectiveness in detecting early or moderate glaucoma compared to HFA [4] [7]. Similarly, VR-based perimeters like the PalmScan VF2000 and C3 Fields Analyzer (CFA) have demonstrated a high correlation with HFA in detecting visual field defects but face challenges in accurately classifying glaucoma severity and early-stage defects [5] [8] [9].

Another innovative approach is the Pattern Noise (PANO) perimeter, which uses contrast-based stimuli and a 15 Hz vibration pattern to assess visual field defects. PANO has shown promise in low-resource settings due to its affordability and portability, with studies reporting high sensitivity and specificity in detecting glaucoma compared to HFA [10] [11] [12]. However, further research is needed to validate its effectiveness in detecting early-stage defects and disease progression [12].

In addition to hardware advancements, machine learning, and deep learning algorithms have been integrated into visual field analysis. For example, 3D Convolutional Neural Networks (CNNs) have been used to predict visual field sensitivity from optical coherence tomography (OCT) scans, offering a more objective and reproducible method for glaucoma diagnosis and progression monitoring [13]. These computational approaches complement traditional perimetry and potentially improve diagnostic accuracy and efficiency.

Despite these advancements, HFA remains the gold standard for visual field testing due to its reliability and widespread validation. However, developing portable, cost-effective, and accurate alternatives is crucial for expanding access to visual field testing, particularly in low-resource settings.

2 Material and methods

2.1 Eye anatomy and glaucoma

The eyeball consists of three main layers: the outer layer (cornea and sclera), the middle layer (iris, pupil, and vessels that provide blood flow to the eye), and the inner layer (retina). The eye anatomy includes three sections in addition to these three main layers: the anterior chamber (between the cornea and iris), the posterior chamber (between the iris and lens), and the vitreous cavity (the space between the lens and retina). The vitreous cavity contains a thick gel-like substance through which light passes before reaching the optic nerve. The optic nerve transmits visual information to the brain, providing vision function. Any deterioration in the optic nerve and retina structures, critical for visual field testing, can directly affect the test results. The retina, one of the most crucial optical components of the eye, is a tissue that contains light-sensitive cells and sends electrical signals to the brain via the optic nerve. The retina contains rods and cones. Rod cells are effective in low light, while cones are effective in color and sharp vision. The macula region provides the sharpest vision for the area directly viewed, and the fovea, located within it, has the highest density of cone cells. During visual field testing, the health of the cells, especially in the macula and fovea region, is of great importance. Deteriorations in the macula can cause central vision loss, while damage throughout the retina can cause peripheral vision loss [14].

Retinal Photoreceptor Cells (Rods and Cones): The visual threshold depends on the health of the rod and cone cells in the retina. Loss of rod cells negatively affects night vision and peripheral vision, while deterioration in cone cells can affect central and color vision. These cellular losses in some regions of the retina lead to changes in threshold values in the visual field test [15][16].

Ganglion Cells and Optic Nerve: Ganglion cells in the retinal layer transmit signals to the optic nerve. Damage to ganglion cells or the optic nerve can cause loss in some visual field regions. For example, glaucoma can cause progressive damage to the optic nerve, narrowing the field of vision. Visual Pathways and Visual Cortex in the Brain: The brain's visual pathways and visual cortex process information from the optic nerve. Disorders such as strokes or tumors in the brain can cause regional deficits in the visual field test. Such lesions can cause deficits in the visual field even if the eye structures are intact [17].

Glaucoma is a group of eye diseases characterized by the death of retinal ganglion cells, resulting in vision loss and blindness. According to the World Health Organization (WHO), glaucoma is the leading cause of all blindness worldwide, secondary to cataracts, and is the leading cause of irreversible vision loss [18].

The clinical diagnosis of glaucoma depends on the results of various diagnostic methods, such as visual acuity examination, visual field tests, tonometry (measurement of pressure within the eye), dilated eye examination, optic nerve head photography, and semiautomatic optic nerve head imaging, including OCT. In a patient with glaucoma, these tests are repeated at regular intervals to assess disease progression. One of the most essential methods for early diagnosis of glaucoma is the visual field test. Also known as perimetry, this test plays a critical role in assessing visual function. The standard automatic perimetry (SAP) method is especially preferred in glaucoma patients. The HFA analyzer and Octopus perimeter are the most commonly used automatic perimetry devices [19].

2.2 Humphrey field analyzer device

The visual field test is performed using a device called HFA, as shown in Fig. 2. The patient's head is held steady with a forehead and chin support inside a large bowl-like device. The patient then looks at a light source directly in front of him with one eye while the other eye is closed, and random points of light with different intensities flash from the point of view corresponding to the visual field. The patient immediately presses a button each time he sees one of these lights. Performing a visual field test using HFA can be time-consuming, as it can take 10 minutes to an hour, depending on the patient's ability to maintain concentration [6].

Figure 2. Zeiss brand HFA device [20].

Research on the pricing of the Humphrey Visual Field Analyzer indicates that the cost of the device varies depending on the model and its condition. Specifically, the Zeiss Humphrey Field Analyzer 3 (HFA3) model is sold at an average price of around $14150 [21]. The brand-new HFA3 model, on the other hand, is available on the market at a price ranging between $10000 and $20000 [22][23].

Table 1. Actual dimensions of stimuli on the Goldmann perimeter [25].

Stimulus dimension	Nominal area (mm²)	Measured dimensions on the Copula		Actual measured area (mm²)
		Long axis (mm)	Short axis (mm)	
0	0.0625	0.33	0.23	0.059
I	0.25	0.67	0.47	0.249
II	1.0	1.34	0,94	0.97
III	4.0	2.68	1.89	3.89
IV	16.0	5.35	3.78	16.0
V	64.0	10.70	7.56	63.2

2.3 Mechanical design

This section provides a detailed description of the implemented visual field testing device's mechanical, hardware, and software designs. First, the external design and mechanical properties of the device are described. Second, the electronic circuit design and interfacing that constitute the hardware are described. The strategy used for programming and operating the device is described in the third section.

First, the visual stimulus box was designed using the SolidWorks 2021 program. The most commonly used Humphrey perimeter 24-2 pattern was considered when planning the box. The box dimensions were designed considering the distance between the patient's eye and the fixation point and the 6° angle between one stimulus (White LED light) and the other. One of the most critical functions in SolidWorks is to determine the distances between the stimuli, as shown in Figure 3.

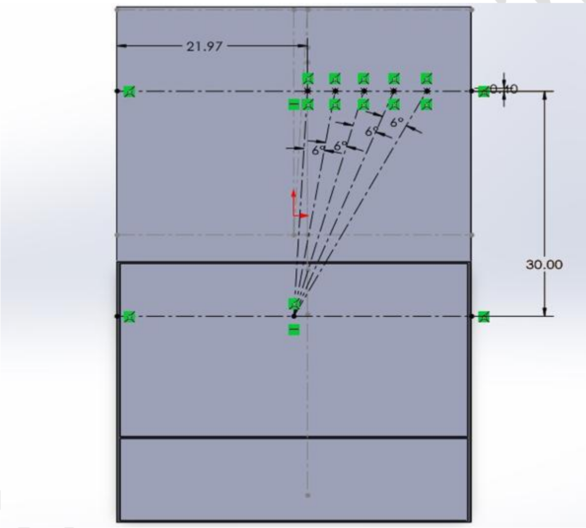


Figure 3. Visual stimulus box design implemented with SolidWorks.

The device is a box with internal dimensions of 40x40x40 cm, and the chin rest is placed so that the distance between the eye and the fixation point is 30 cm. To prevent the patient from seeing the source of the stimuli, the inside of the device is covered with a 180 gr paper layer that prevents reflection and scattering of light. The SolidWorks drawing and the actual view of the visual stimulus box are presented as shown in Figure 4.

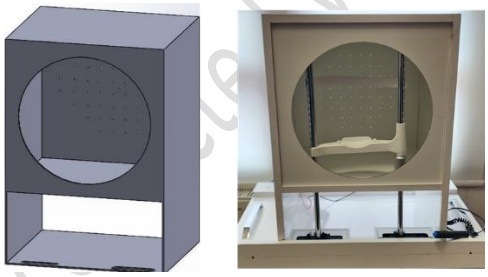


Figure 4. Visual stimulus box; 3D SolidWorks drawing and actual view.

The visual stimulus box interior illumination level was determined as 31 Lux due to the measurement made using the UNI-T UT383 portable luxmeter device on the Zeiss Perimetry device located in Karabük University Training and Research Hospital. The measurement result and the visual stimulus box interior illumination measurement images created in the study are shown in Figure 5.

Figure 5. Measurement made using UNI-T UT383 portable luxmeter device, a) Zeiss Perimetry device, b) designed visual stimulus box.

The white color of the stimulus and background was chosen as standard. The standard perimetric stimulus is white on a white background. This type of perimetry is usually called white-on-white perimetry or Standard Automatic Perimetry (SAP). White-colored stimuli offer the advantage of stimulating all different retinal cell types. As a result, white light allows visual field testing from early to advanced disease (i.e., provides a wide dynamic testing range). The traditionally used standard stimulus is a round 4 mm2 diameter Goldmann stimulus size III based on the definition of Professor Hans Goldmann [1][2][24].

In the visual stimulus box carried out in this thesis study, 3 mm diameter white LEDs were used. As a result of the 180-gr paper layer placed in front of it, which prevents the reflection and scattering of the light, the stimulus was formed with a diameter of 4 mm, as shown in Figure 6.

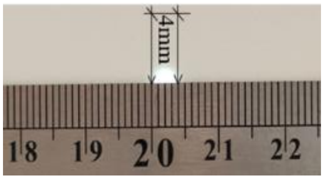


Figure 6. View of LED brightness diameter.

The actual dimensions of the stimuli on the Goldmann perimeter are shown in Table 1. The stimulus size used in this study is within the size IV standards according to this table.

2.4 Hardware

The circuit was designed using Proteus simulation software during the preliminary design phase. A 220 Ω resistor was added to each LED as a current limiter in the first step. As shown in Figure 7, the circuit is connected in rows and columns. The reason for using Row and Column lines in this way is to control many LED elements with a small number of microcontroller pins. Typically, an I/O pin must be used to control each LED independently. Figure 7, shows 56 white LEDs with a 24-2 pattern and one central red LED. This means that 57 I/O pins are needed on the microcontroller for 57 LEDs. In addition, if brightness adjustment is desired, these I/O pins must be PWM-enabled. Row and Column lines are used in a grid structure, 8 I/O pins for row lines and 10 PWM pins for column lines, making it possible to control 56 white color LEDs in a 24 2 pattern with a total of 18 pins. Column lines are connected to the PWM pins of the Arduino Mega microcontroller; thus, the brightness values of the LEDs can be adjusted. The PWM part is connected to the anode ends of the LEDs. Row lines are connected to the Digital I/O pins of the Arduino Mega microcontroller and the cathode ends of the LEDs. Therefore, the LEDs in the relevant row need to be activated for control, and this process is carried out by making that row Logic 0.

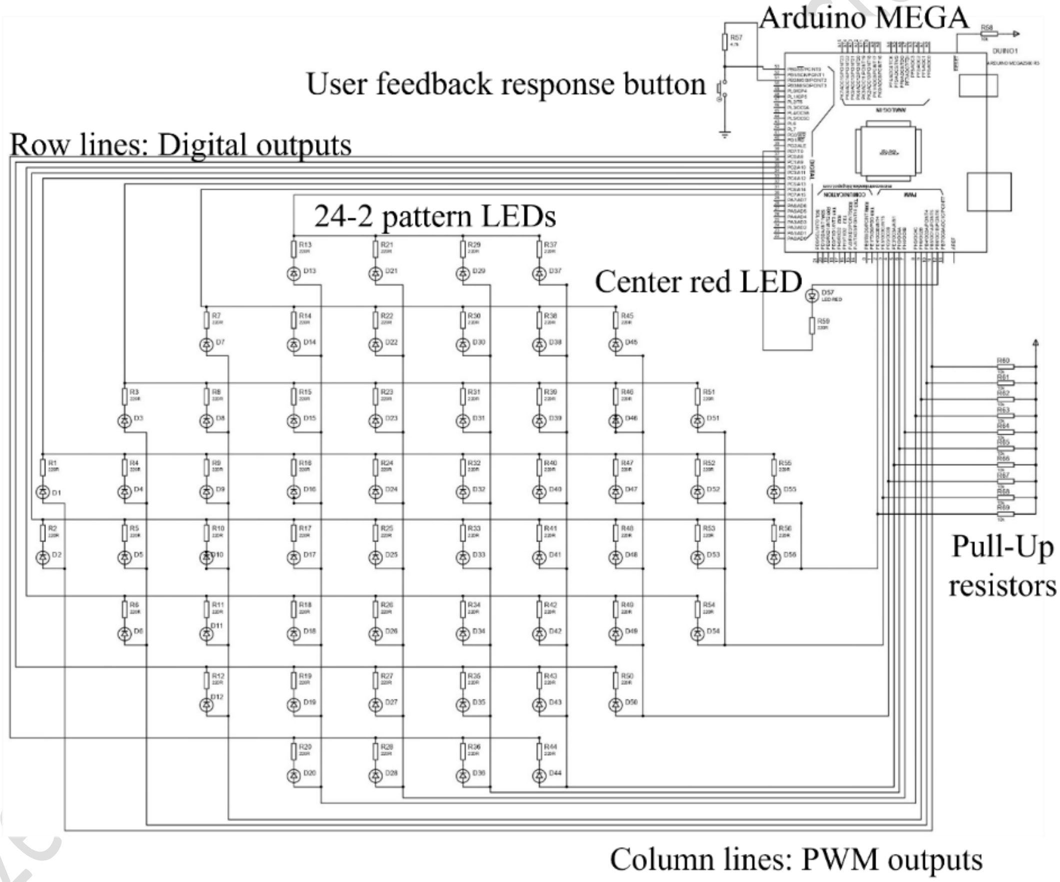


Figure 7. Electronic circuit design diagram with Proteus simulation software.

Arduino's pulse-width modulation (PWM) generates analog signals from digital pins. This technique is ideal for controlling analog values such as motor speed and speaker volume, and adjusting LED brightness. PWM creates square waves that turn on and off at a specific frequency. The duration that the square wave is "on" (pulse width) determines the average voltage. The higher the pulse width, the higher the average voltage. Pulse width can also be called duty time [26] [27].

In this study, 24 2-pattern LEDs were implemented using 56 white LEDs. In addition, a central red LED was used to ensure that the user focused on the center point during the visual field test. To adjust the brightness value of these LEDs used in the designed system, the column lines and the central red LED Anode tip shown in Figure 7 are connected to the PWM outputs on the Arduino Mega.

The user feedback response button circuit is designed as a Pull-Down type. When the button is pressed, the relevant pin drops from Logic 1 (+5V) to Logic 0 (0V). While detecting whether the button is pressed or not with the Arduino Mega microcontroller, measures have been taken to prevent fluctuations between Logic 1 and Logic 0 levels, called key bounce, in software. Thus, during the test, only 1 response was received when the user gave feedback with the response button. In addition, a reliable circuit connection against external interference was ensured by using the microphone cable of the button, in other words, by using a magnetically caged cable.

Finally, the visual stimulus box requires internal illumination to ensure that the surface containing the 24-2 pattern LEDs has a background luminance of 31.5 asb. For this purpose, white LED strips 40 cm in length and operating at a 12 V voltage level were installed inside the visual stimulus box, positioned to the right and left of the user's head support, directly facing the side where the 24-2 pattern LEDs are located. The LM2596 adjustable step-down power module provided the voltage supply for these LED strips. This study used this module to adjust the internal illumination intensity of the visual stimulus box.

2.5 Software

The Ledcontrol (app, dB, number) function was created to perform a 24-2 visual field test. In this function, the dB parameter expresses the brightness of the LED in decibels. The number parameter indicates which of the 56 LEDs will be controlled. When we want to test the left eye, LEDs 1 and 2 are not used. When we want to test the right eye, LEDs 55 and 56 are not used. The ledcontrol function returns the information about whether the person being tested can see or not, as a value. The 24-2 visual field test starts with 25 dB and randomly selects center LEDs 15, 18, 39, or 42 (Figure 8). First, the visual threshold value for these LEDs is determined in dB. In this determination, the 4-2 ladder method is used. In each stage of this method, the latest status is recorded for the detection of the visual threshold, and the test is continued by selecting the center LEDs in a random order each time. The center LEDs with a known threshold value are not selected again. After the threshold values of all center LEDs are found in dB, they are stored in an array where the visual threshold values for all LEDs are stored. Continuing the visual field test, the other numbered LEDs, other than the center LEDs, in the 24-2 pattern are selected randomly. The initial threshold value of the other numbered LEDs is taken as the previously determined visual threshold values of the center LED closest to them. While the visual threshold dB values are found for all other LEDs, the latest status is recorded at each stage using the 4-2 ladder method, as in the case of the center LEDs. In this section, a randomly numbered LED is selected each time. With the 4-2 ladder method, the LEDs with the final threshold value are not selected again, and the test ends when the threshold values of all LEDs are found.

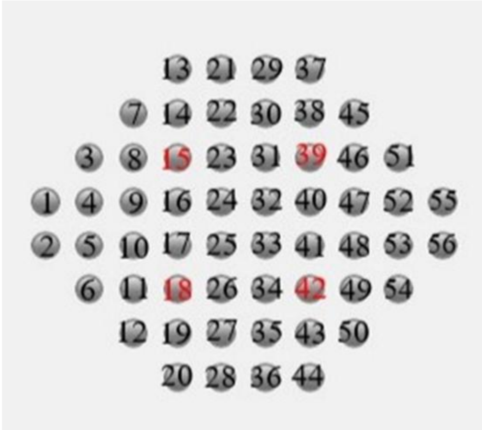


Figure 8. 24-2 pattern LEDs in the MATLAB AppDesigner interface

As shown in Figure 9, the program interface includes several elements. The most important one is the 24-2 LED pattern in the middle; this pattern simulates whether the LEDs used in the device give light or not, facilitating the task of the technical personnel monitoring the test from the software interface. The program interface includes the "Connected" button to provide the serial connection between MATLAB AppDesigner and Arduino, the "Start testing" button to start the test, and the eye selection buttons, Left and Right, to determine the left or right eye test selection, respectively. In addition, there is a drop-down object where volunteer patients are numbered to give a file name for saving the test result. There is also a counter showing the percentage of completion of the test. In the upper left corner of the interface are information labels named VFT Start Time and VFT Stop Time, respectively, to show the start and end times of the test. With the Show the test results button, the test results are shown in a separate figure window after the test of both eyes of the patient is completed.

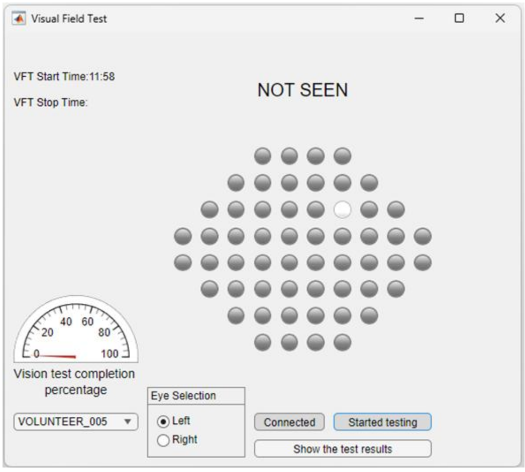


Figure 9. Visual field testing system interface.

When displaying the threshold sensitivity map and grayscale graph test results in the HFA device, 10 different grayscale graphs are used depending on different visual threshold dB value ranges. Figure 10, shows the grayscale symbols found in the HFA device corresponding to these 10 different grayscale graphs.

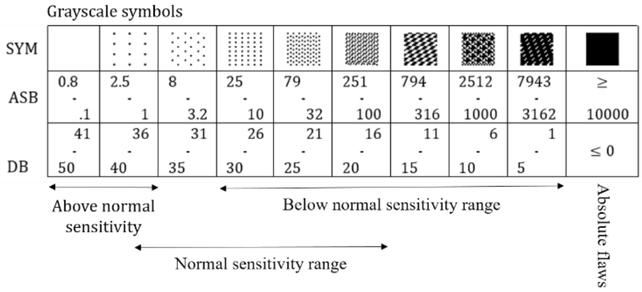


Figure 10. HFA grayscale symbols [28].

In this study, the visual field test system design shows the test results in a separate figure window. In contrast, the grayscale symbols in the grayscale graph are designed using the Special Character Editor in Windows. Nine different grayscale symbols, except the required space, can be defined as Special Characters in the Windows Special Character Editor, valid for all fonts. The result of this definition is displayed in the Windows Character Map window, as shown in Figure 11.

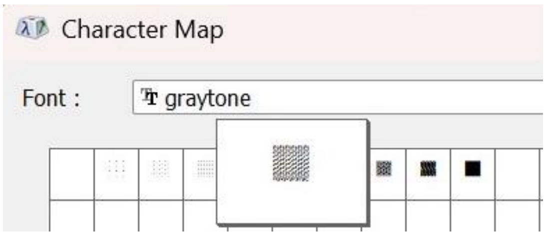


Figure 11. Appearance of grayscale symbols designed within the Windows character map.

2.6 Photometric calibration and verification

In the visual field test, the alert intensity is measured in decibels (dB), representing the light sensitivity of the retina. The brightness values of the LEDs are controlled by the PWM value. The PWM value relative to dB is calculated according to Equation 1.

$$PWM = 256^{\left(1-\frac{dB-10}{41}\right)} - 1 \qquad (1)$$

Lux values corresponding to PWM have been measured. The photometric calibration of the system was established through direct measurement. Luminance values in apostilbs (asb) were derived from the measured illuminance in lux (lx) using the conversion factor for a Lambertian surface.

$$L\ (asb) = E\ (lx) \times R \qquad (2)$$

Where R is the reflection coefficient of the display surface, for our system's diffuser, this coefficient was determined to be R = 3.14 asb/lx. Consequently, 1 lx corresponds to 3.14 asb under our specific measurement conditions [1].

The complete photometric calibration results are presented in Table 2, which shows the relationship between PWM duty cycle, measured illuminance (lux), calculated luminance (asb), and the corresponding stimulus intensity in dB.

The calibration procedure characterized the entire operational range of the device. The system's maximum stimulus luminance was calibrated to L_max = 659.4 asb (equivalent to 210 lx), which defines the 0 dB reference point. The background illumination was consistently maintained at 31 lx for all tests. The minimum achievable stimulus luminance above the background was 0 asb (0 lx). Therefore, the system provides a total dynamic range of 40 dB, spanning from 10 dB (659.4 asb) to 40 dB (effectively 0 asb, representing total loss).

This comprehensive calibration ensures that the device operates within a standardized and clinically relevant range for accurate measurement of retinal sensitivity across the visual field.

Table 2. Photometric calibration values for LED stimulus.

dB	PWM	Lux	asb
40	3	1.00	3.14
39	4	2.00	6.28
38	5	3.00	9.42
37	6	3.80	11.93
36	7	4.60	14.44
35	8	5.40	16.96
34	9	6.20	19.47
33	10	7.00	21.98
32	12	8.60	27.00
31	14	10.20	32.03
30	16	11.80	37.05
29	19	14.20	44.59
28	21	15.80	49.61
27	25	19.00	59.66
26	28	21.40	67.20
25	33	25.40	79.76
24	38	29.40	92.32
23	43	33.40	104.88
22	50	39.00	122.46
21	57	44.60	140.04
20	65	51.00	160.14
19	75	59.00	185.26
18	86	68.24	214.27
17	98	78.32	245.92
16	113	90.40	283.86
15	129	103.36	324.55
10	255	210.00	659.40

3 Results

In this study, we developed a low-cost device design similar to the Zeiss HFA, which is widely regarded as the gold standard for visual field testing. To perform the 24-2 test, the most commonly used assessment for glaucoma and other eye diseases, we used LEDs as stimuli at 56 locations for both eyes. The user interface was designed using MATLAB App Designer, and we implemented a strategy akin to the full-threshold algorithm. While the HFA device has a maximum brightness of 0 dB at 10,000 asb and a minimum brightness of 51 dB at 0.08 asb, the visual field testing system we developed achieved a maximum brightness of 10 dB at 660 asb and a minimum brightness of 40 dB at 3.14 asb. The cost breakdown of the visual field testing system implemented in this study is in Table 3.

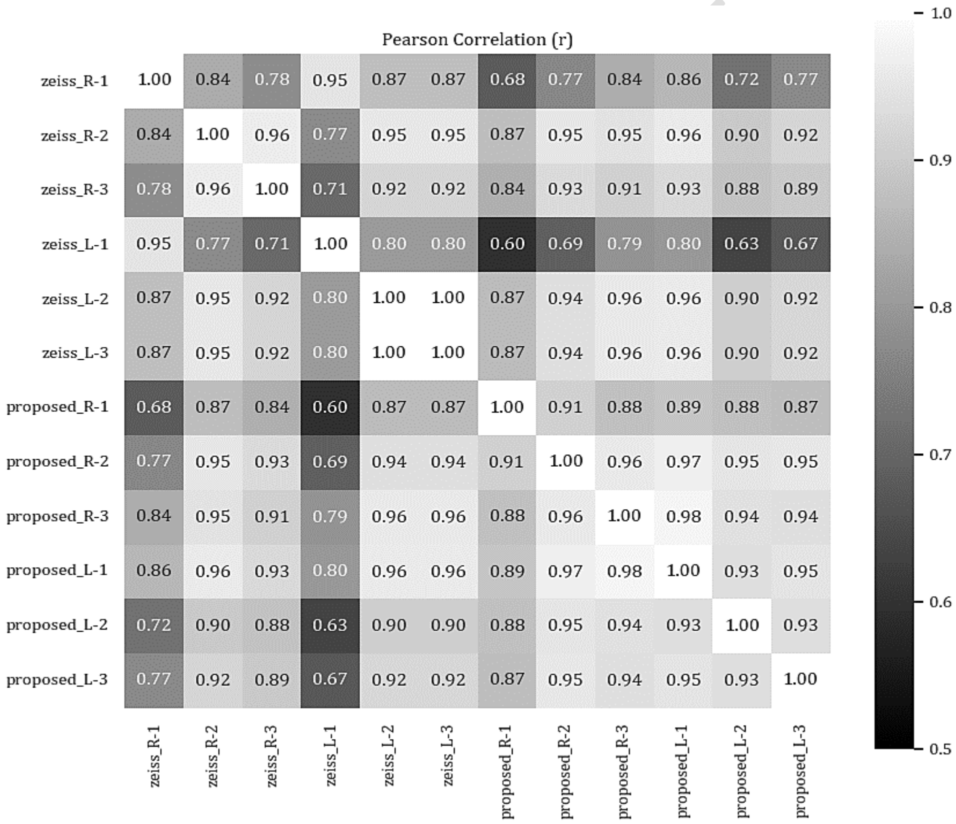
Table 3 Visual field system cost.

Components	Price
Arduino Mega 2560	18 $
15.6'' Touch screen	190 $
Chin rest apparatus	200 $
Enclosure	50 $
NVIDIA Jetson nano artificial intelligence kit	540 $
Electronic components	40 $
Total	**≈ 1038 $**

Table 4 shows a comparison chart between commercial devices available on the market and the visual field test system design implemented in this study in terms of features such as the type of test performed, whether the stimulus location is precise or not, gaze tracking, algorithm, stimulus source, origin, and price.

In this study, to show that the designed visual field test system can obtain similar results with the HFA device, the 24-2 test results, were obtained with the Zeiss brand HFA device located in Karabük Education and Research Hospital. In Figure 12, the threshold sensitivity map and the corresponding grayscale graph at 54 points for each eye as the right eye (OD Oculus Dexter) and left eye (OS - Oculus Sinister) are shown in the parts indicated by the red rectangle. The threshold sensitivity map and grayscale graph obtained with the Zeiss brand HFA device are shown in closer detail in Figure 13. It is seen that the threshold sensitivity dB values for the right eye vary between 28 dB and 35 dB outside the blind spot, and are <0 dB in the blind spot. And, it is seen that the threshold sensitivity dB values for the left eye vary between 25 dB and 36 dB outside the blind spot, and are <0 dB in the blind spot. The threshold sensitivity map and grayscale graph obtained with the visual field test system implemented in this study are shown in Figure 14, which shows that the threshold sensitivity dB values for the right eye vary between 25 dB and 35 dB outside the blind spot and are <0 dB in the blind spot. And, it is seen that the threshold sensitivity dB values for the left eye vary between 21 dB and 36 dB outside the blind spot and are <0 dB in the blind spot. These results demonstrate that the designed visual field test system yields similar results to those obtained with the Zeiss brand HFA device.

Test-retest trials were conducted using both the Zeiss brand device and the designed device, and the results are presented in Figure 12. As can be seen in Figure 12 the Pearson correlation coefficient for the Zeiss brand device ranged from a minimum of 0.67 to a maximum of 1.00, with an average correlation coefficient (r) of 0.89. In contrast, when the values obtained with the designed device were examined, the Pearson correlation coefficient ranged from a minimum of 0.68 to a maximum of 0.98, with an average correlation coefficient (r) of 0.94. The p-values for all 12 tests were $p<0.001$, indicating that the tests were highly significant. Furthermore, when comparing the tests of the two devices, it is evident from the correlation values that the tests are consistent despite the device difference.



Legend

Test Name	Device Name	Eye-Test Number
zeiss_R-1	Zeiss	Right - 1
zeiss _R-2	Zeiss	Right - 2
zeiss _R-3	Zeiss	Right - 3
proposed_R-1	Proposed	Right - 1
proposed _R-2	Proposed	Right - 2
proposed _R-3	Proposed	Right– 3
zeiss _L-1	Zeiss	Left - 1
zeiss _L-2	Zeiss	Left - 2
zeiss _L-3	Zeiss	Left - 3
proposed _L-1	Proposed	Left - 1
proposed _L-2	Proposed	Left - 2
proposed _L-3	Proposed	Left– 3

Figure 12. Pearson Correlation Matrix for all tests.

Table 4. Comparison between our study and commercial devices on the market.

Product	Types of Tests Performed	Stimulus Location Not Clear	Gaze Tracking	Algorithm	Stimulus Source	Origin	Price
HFA [20]	24-2 30-2 10-2 GHT	√	√	SITA	Optical projection LED	ABD	≈15000 $
Glaufield Lite AP901 [29]	24-2 30-2 10-2 GHT	×	√	Private	Fixed LED	India	≈9900 $
PANO [10]	24-2 30-2 10-2 GHT	√	×	Private	Laptop screen	Germany	Uncertain
Our design	24-2	√	×	Private	Fixed LED	Türkiye	≈1038 $

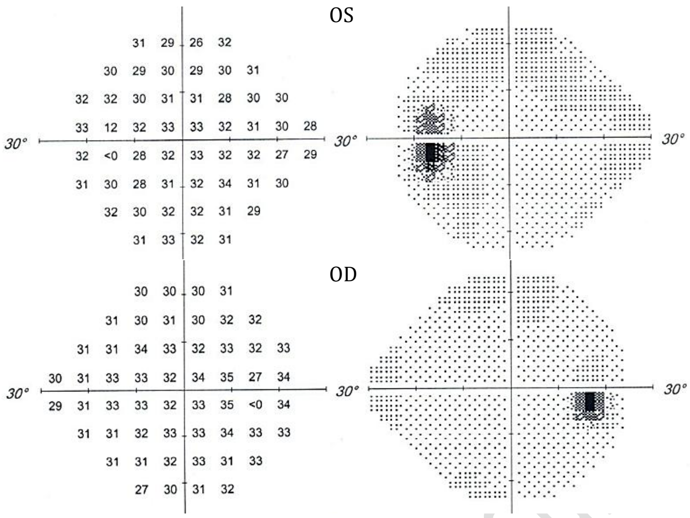


Figure 13. Threshold sensitivity map and grayscale graph with Zeiss brand HFA device for OS and OD.

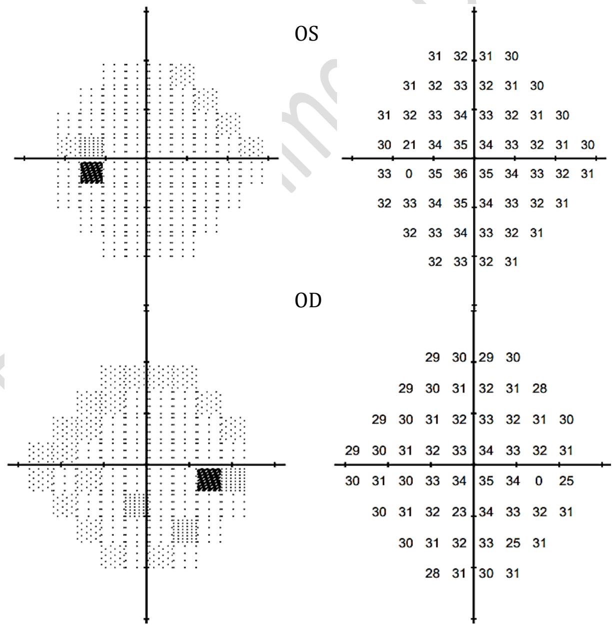


Figure 14. The threshold sensitivity map and grayscale graph obtained with the visual field test system design for OS and OD

4 Discussion and Conclusions

The visual field test system design carried out in this study is thought to contribute to the literature with its advantages such as performing the 24-2 test in a similar way to the HFA device on the market, being very low in terms of price cost at approximately $1038, being easily portable, being simple to install and not requiring technical stuff to use, being silent and not distracting in terms of not having motor sounds that provide the stimulus projector movement in HFA devices.

This study operates within a range of 40 dB to 10 dB, due to the type of LED used and the 8-bit driver, and covers the normal sensitivity range (38-16 dB), as shown in Figure 10. It can be used for the detection and tracking of residual functional visual fields within the normal range. To improve this, the sensitivity of the LEDs can be increased by using LEDs with a larger brightness range and a 10-12 bit PWM driver, although this may increase the cost.

We reduced the duration of each test session, reminding participants to gaze continuously at the fixation point in the centre, and provided intermittent central stimuli (control flashes). This method allows for the indirect monitoring of fixation loss. The study was conducted in a laboratory setting with experienced volunteers. This group can provide more stable fixation compared to the clinical population.

The absence of the eye-tracking module may introduce measurement uncertainty into the results. However, in other HFA devices some results indicate disabled feature, and the test performs as expected with it disabled. Therefore, in future versions, we could add a low-cost camera module to the system and develop a fixation tracking algorithm via the blind spot as a module, which would enhance test reliability by monitoring the fixation position in real-time and strengthen direct comparability with clinical devices.

The visual field testing device designed in this study operates via a computer interface. Therefore, instead of computer costs, an NVIDIA Jetson Nano artificial intelligence kit and a 15.6" touch screen were included as infrastructure for mobility and future AI-based analyses.

This study's visual field test system can be used primarily to educate elderly patients who have difficulty adapting to and getting used to it. It can also be used to inform those working on HFA; thus, it can be a good alternative for reducing density in eye clinics and diagnosing glaucoma in poor countries.

5 Recommendations

To overcome the limitations of the HFA device's response button, particularly the delayed reflexes in elderly patients, future work will focus on developing an autonomous visual field test. This system will replace manual input with human-computer interaction [30] and simultaneous EEG signal acquisition, eliminating dependence on user-operated buttons.

It is recommended to work on a system approach that integrates human-computer interaction capabilities achieved through EEG [31, 32, 33] into visual field testing devices, thereby facilitating device adaptation, ease of access, and cost-effectiveness for elderly patients, while enabling equivalent assessment to HFA devices. For this purpose, a visual field test software can be designed using a large computer screen and the Unity game programming environment. With this system, appropriate EEG signal recording can be obtained simultaneously, eye movement detection and visualisation can be determined, and test results can be verified within a validated system. Additionally, with this system, the stimulus size can be adjusted, and the stimulus brightness can be achieved within the desired dynamic range.

6 Authorship contribution statement

Author-1: Conceptualization, writing–original draft, investigation, methodology.

Author-2: Methodology, validation, funding acquisition, investigation.

Author-3: Corresponding author, Conceptualization, writing–original draft methodology, investigation, validation.

7 Ethics committee approval and conflict of interest statement

"The research title of this works was decided to be ethically appropriate by xxxxxxx University Rectorate Non-Interventional Clinical Research Ethics Committee with the Decision No. xxxxxxx/xxxxx in terms of its purpose, justification, approach and method-related explanations. "

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

"This study was supported by xxxxx University Scientific Research Projects Coordination Unit. Project Number: xxx."

8 References

[1] Racette L, Fischer M, Bebie H, Holló G, Johnson CA, Matsumoto CA. *Visual field digest: A guide to perimetry and the octopus perimeter*. Köniz, Switzerland, Haag-Streit AG, 2017.

[2] Yalvaç I. Glokomda Humphrey Görme Alanı. https://www.todnet.org/glokom/Humphrey.htm (03.01.2024)

[3] Bülbül, E. Visual field testing using forecasting and virtual reality. MSc Thesis, Middle East Technical University, Ankara, Turkey, 2022.

[4] Ichhpujani P, Thakur S, Sahi R. K, & Kumar S. "Validating tablet perimetry against standard Humphrey Visual Field Analyzer for glaucoma screening in Indian population". *Indian Journal of Ophthalmology*, 69(1), 87, 2021.

[5] Tsapakis S, et al. "Visual field examination method using virtual reality glasses compared with the Humphrey perimeter". *Clinical Ophthalmology*, 11, 1431, 2017.

[6] Selvaraj D, Vance J, Gilbert S. Using Google Cardboard to perform a visual field screening test. MSc Thesis, Iowa State University. Ames, Iowa. 2018.

[7] Johnson CA, Thapa S, Kong, YXG & Robin AL. "Performance of an iPad application to detect moderate and advanced visual field loss in Nepal". *American Journal of Ophthalmology*, 182, 147–154, 2017.

[8] Shetty V, et al. "Diagnostic performance of the PalmScan VF2000 virtual reality visual field analyzer for identification and classification of glaucoma". *Journal of Ophthalmic & Vision Research*, 17(1), 33, 2022

[9] Mees L, et al. "Validation of a head-mounted virtual reality visual field screening device". *Journal of Glaucoma*, 29(2), 86–91, 2020.

[10] Prechtl TechSolutions. Perimeter PANO. https://www.prechtl-techsolutions.com/perimeter-pano (07.05.2024)

[11] El-Khoury S, Hannen T, Dragnea DC, Ngounou F & Preußner PR. "Pattern noise (PANO): A new automated functional glaucoma test". *International Ophthalmology*, 38(5), 1993–2003, 2018.

[12] Hannen, T, El-Khoury S, Patel R, Ngounou F & Preußner PR. "Comparison of the automated pattern–noise (PANO) glaucoma test with the HFA, an FDT stimulus, and the fundus area cup-to-disk ratio". *Journal of Current Glaucoma Practice*, 15(3), 132, 2021.

[13] CHEN Z. Deep Learning for Glaucoma Diagnosis and Monitoring and for Video Processing. PhD Thesis. New York University Tandon School of Engineering. New York, America. 2024.

[14] Sebastian E. The complexity and origins of the human eye: A brief study on the anatomy, physiology, and origin of the eye. Senior Honors Theses. 2010

[15] American Academy of Ophthalmology. Retina. https://www.aao.org/eye-health/anatomy/retina-103 (11.07.2024)

[16] Hanes E. The anatomy of the retina. Verywell Health. https://www.verywellhealth.com/retina-anatomy-4800793 (11.07.2024)

[17] Kolb H. Simple anatomy of the retina. WEBVISION The Organization of the Retina and Visual System. https://webvision.med.utah.edu/book/part-i-foundations/simple-anatomy-of-the-retina/ (11.07.2024)

[18] Friedman DS. "Prevalence of open-angle glaucoma among adults in the United States". *Archives of Ophthalmology*, 122(4), 532, 2004.

[19] Kummet C. Statistical modeling to improve the detection of glaucoma progression. Diss., University of Iowa, 2013.

[20] ZEISS Medical Technology. ZEISS Humphrey Perimeters. https://www.zeiss.com/meditec/en/products/perimetry.html (20.05.2024)

[21] MedicalPriceOnline. HUMPHREY 750 field analyzer. https://www.medicalpriceonline.com/medical-

equipment/humphrey/humphrey-750-field-analyzer/ (01.08.2024)

[22] OphthalmicMart. Zeiss Humphrey field analyzer 3 Visual Field-Testing System. https://www.ophthalmicmart.com/product/humphrey-field-analyzer-3/ (01.08.2024)

[23] Nava Ophthalmic. Carl Zeiss Humphrey Field Analyzer 3 (HFA3). https://navaophthalmic.com/product/zeiss-hfa3/ (01.08.2024)

[24] Webeye Ophthalmology Archive. 1990 Perimetry Standards. https://web.archive.org/web/20180703025201/http://webeye.ophth.uiowa.edu/ips/GEN-INFO/standards/IPS90.HTM (03.01.2024)

[25] Greve EL. "Single and multiple stimulus static perimetry in glaucoma; the two phases of perimetry". Documenta Ophthalmologica (Vol. 36). 1-346 1973

[26] Arduino Documentation. Secrets of Arduino PWM. https://docs.arduino.cc/tutorials/generic/secrets-of-arduino-pwm/ (19.06.2024)

[27] Arduino Forum. Code for PWM signals to H bridge. https://forum.arduino.cc/t/code-for-pwm-signals-to-h-bridge/6474 (19.06.2024)

[28] Walsh TJ. *Visual Fields Examination and Interpretation (3rd ed.).* Oxford University Press, USA, 2011

[29] Appasamy Associates Empowering Vision. Appa Auto Perimeter AP901 CTS Glaufield Lite Swap. https://www.appasamy.com/ophthalmology-optometry/glaufield-lite-swap (08.05.2024)

[30] Tas M, Yavuz M. "*İnsan-Bilgisayar Etkileşiminde BCI kullanımı (göz/kaş/baş hareketleriyle)*". PAJES - Pamukkale University Journal of Engineering Sciences, 2022.

[31] Aygun, A. B. ,Kavsaoglu, A. R., "*An innovative P300 speller brain–computer interface design: Easy screen*", Biomedical Signal Processing and Control, Volume 75, 2022, 103593, https://doi.org/10.1016/j.bspc.2022.103593

[32] Küçükakarsu M, Kavsaoğlu AR, Alenezi F, Alhudhaif A, Alwadie R, Polat K. "*A Novel Automatic Audiometric System Design Based on Machine Learning Methods Using the Brain's Electrical Activity Signals*". Diagnostics. 2023; 13(3):575. https://doi.org/10.3390/diagnostics13030575

[33] Nazli B, Kavsaoğlu AR. "*Brain-Computer interfaces with auditory stimuli: A review study*". Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi. 2025;31:633–647.