BinoVFAR: An Efficient Binocular Visual Field Assessment Method using Augmented Reality Glasses

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ABSTRACT

Virtual Reality (VR)-based Visual Field Assessment (VFA) methods completely isolate the users from the real world, which results in nausea, eye strain, and lack of concentration and patience for the time-consuming test. In this paper, a robust binocular visual field assessment method based on novel Augmented Reality (AR) glasses is presented, namely, **BinoVFAR** that can simultaneously find the VF of both eyes. In this method, 60 stimuli in an arrangement of 6 rows and 10 columns randomly appear on a white background on the display of the AR glasses. These stimuli are displayed for 2 seconds that continuously change the intensities from light gray to black. Wearing the AR glasses and focusing on the central fixation point, the users are asked to click the clicker by seen a stimulus. The visible stimuli's intensities and positions are recorded in a 6×10 matrix based on the users' responses. A bi-cubic interpolation is applied to compute the binocular visual field map (as a 600×1000 matrix). A set of experiments (with an average accuracy of 99.93%), including repeatability and reproducibility tests (with an average Intra-class correlation coefficient (ICC) of 99.72%), are conducted to evaluate the BinoVFAR method.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; *Empirical studies in HCI*; • **Applied computing → Health informatics**; **Health care information systems**.

KEYWORDS

Augmented Reality, Binocular vision, Visual field, Visual field assessment, Vision pattern

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1 INTRODUCTION

Visual Field-Testing (VFT) is a significant part of regular eye care for people at risk of vision loss from diseases and related issues. Glaucoma [20], hyperthyroidism, stroke, and central nervous system-related patients need to get VF maps for assessing their conditions. People with diabetes and high blood pressure have a greater risk of developing blocked blood vessels in the optic nerves and retina. They may also need visual field testing to monitor the effects of these conditions on their vision. Subjects with the limited VF may not continue their daily activities, e.g. driving in busy roads [3, 17, 18, 22].

A traditional VF method conducts the confrontation visual field test [7]. In this test, for testing a single eye, another eye should be closed/covered, and the subjects/users have to focus on an object directly in front of them. Several objects/fingers have been shown in the peripheral (side) vision field, which is required to be seen by the subjects. Based on the subjects' responses, a physician can predict the visual field through their seen and unseen objects.

Automated perimetry test began around 1970 with the automated perimeter developed by Drs. John Lynn and George Tate [21] which is also famous for checking the eye problems and monitoring their progress [6]. In this method, a more detailed map represents the seen and unseen areas of the visual field. Subjects look into the center of a bowl-shaped instrument called a perimeter with one eye while the other is covered with a patch. The testing eye is placed on the lens prescribed position to ensure the best visualization. Subjects have to keep looking at a center target throughout the test. A stimulus (a small round shape with dim light) appears in different places throughout the bowl. Users press a button instantly whenever they can visualize the light of the stimulus. Subjects are generally allowed to blink during the test and pause if they feel a break is needed for a smooth examination. Due to looking straight ahead on the fixation point, the automated perimetry detects the lights away from the central area. Since glaucoma and other eye diseases affect peripheral vision, this test helps the ophthalmologist find vision loss outside the central visual field. A similar method was proposed in [14] called kinetic visual field testing. The blinking lights were replaced with light moving toward the target from the peripheral. The limitation of these methods is that testing both eyes separately are time-consuming, inconvenient, and stressful for elderly patients/subjects and children as they may not tolerate the restrictions of head movement and cannot easily keep their heads stable for a long time throughout the test. To overcome this limitation, Murray et al [13] proposed a VF testing system, including a personal computer, display, and eye tracker, based on

Humphrey Field Analyzer (HFA) Central-40 point screening in which the stimulus size and intensity are equal to Goldmann III and 14 decibels (dB), respectively. In this system, the visual field map was created by detecting and measuring the eye movement when the users focus on the displayed stimuli once they are visible for them. The whole test consists of three eye-tracking tests, i.e a 40-point binocular test and two 41-point tests for each eye. This system was designed and evaluated for both children (with an accuracy of 99.1%) and adults (with an accuracy of 99.2%). Although it achieved good performance, it has the limitation of measuring the VF map only within the range of 48 degrees.

According to a study carried out in 2008, the VF test is one of the problematic diagnostic tests performed in an ophthalmology office due to the requirement of the users' concentration and attention throughout the test [4]. Hence, providing an adaptable and comfortable platform for VF testing is vital, which can be realized by audio-visual-spatial technology of extended reality (XR) [9, 11]. XR covers three kinds of imaging: augmented reality (AR), virtual reality (VR), and mixed reality (MR). Although these concepts are more prevalent in games and entertainment and seem far from eye care, they are effectively utilized in VF testing by providing an interactive environment. In the last two decades, Virtual Reality (VR)-based visual field testing methods [5, 11, 12, 15, 19, 23, 24] have attracted much attention among researchers. Wroblewski et al. [24] proposed a compact eye-tracking perimeter (VirtualEye) mounted on the head, which was formed by two main modes. Its first mode was manually performed by the patients using a mouse. The second one was the visual grasp through which an eye tracker recognized the changes in gaze direction as the sign of the target acquisition. These modes were tested on 59 and 40 patients, respectively. Hotta et al. [5] proposed an active visual field testing (AVFT) using a VR head-mounted display (VR-HMD) eye tracker, which increases the test reliability by keeping a constant distance between the eyes and the camera independent from the head posture (eye gaze calibration was fixed during the test). This method was designed based on 76 stimuli in a radial pattern, and every test needs 5 minutes.

Smartphone-based VF testing systems using VR glasses have been popular in the recent five years to enable cost-effective and convenient remote VF screening with personal settings [11, 16, 19, 23]. In [23], Tsapakis et al. proposed a VF examination using smartphone-based VR glasses, which was evaluated on 20 eyes of 10 patients and achieved a high correlation coefficient between their results and those of Humphery perimeter. As their system was applied on a smartphone, it was lightweight, affordable, and portable. Motelongo et al. [11] proposed a VR-based platform (VisuALL) for visual field evaluation which was tested on six eyes of 3 subjects. As the VisuALL is a portable system and does not need any helps from experts, many patients with glaucoma can easily monitor their eyes with this system at home, especially those facing transportation difficulties. However, it suffers from the limitations of having a small sample size and single-center enrollment. Although some effective systems have been proposed based on VR for VF testing, these methods may not be able to test the wide visual field of the patient eyes due to the limited field of view of VR-based glasses. Besides, VR-based methods need to be completely isolated from the real world during the whole assessment that causes nausea and eye strain, and challenges patients' concentration and endurance in long time tests.

A binocular visual field assessment method using novel AR glasses, namely *BinoVFAR*, is proposed to overcome these problems. Total 60 stimuli are randomly displayed in different 100 degrees width and 60 degrees height visual field locations. The user responses have been recorded using a mouse clicker. A bi-cubic interpolation method is applied to expand 60 stimuli to a 600×1000 image representing the binocular visual field map based on the user responses. A set of experiments are conducted to evaluate the proposed method. Our method requires approximately 3-4 minutes to complete the VF test for each subject. In our *BinoVFAR* system, some unique and robust features are given below.

(1) The system uses a continuous intensity changing strategy for 60 stimuli that are displayed one by one with 2 seconds duration for each on a white background. It is ranging from $-50°$ to $50°$ in width and from $-30°$ to $30°$ in height for estimating a complete visual field map of $60° \times 100°$ in the binocular vision system. An additional 500 ms is required to start the next stimulus. Thus, our *BinoVFAR system* takes 3-4 minutes to complete the test, which is less than that of the other methods in the literature (e.g., monocular mean test time of 266.3 seconds in [11] and a single test time of 5 minutes in [5]).
(2) To monitor the fixation, our system uses a color point (red) in the center of the display scene. To ensure the user wears the AR glasses properly and calibrates them, eight light-green static points are created on the border of the visual field (four tops and four bottoms).
(3) To minimize the false negative, the missing stimulus randomly appears again without interruption and no need for the user or operator to take action.
(4) The variable stimuli presentation rate is adjusted to the subject's response time during the demonstration. There is minimal user interaction in our proposed method.
(5) Users are allowed to wear their prescribed glasses along with the AR glasses during the test.

2 BINOVFAR SYSTEM AND MATERIALS

2.1 System Design

For the binocular VF testing, 60 testing stimuli are presented in the proposed *BinoVFAR* system (using both eyes simultaneously) on the white background. These 60 stimuli appear on a rectangular plane with a width of $100°$ and a height of $60°$ in 60 predetermined cells (6 rows and 10 columns) as shown in Figure 1. The spatial testing resolution is designed in a way that there is a distance of $10°$ between the centers of each two adjacent stimuli. The design of these stimuli allowed for testing the usual blind spots at 15 degrees temporarily by the corresponding stimulus location (in case one eye of the subject/user). The diameter of each stimulus in the central area ranging from $-20°$ to $20°$ in both width and height is $2°$. Further from this area (i.e. from $\pm 20°$ to $\pm 50°$ in width and from $\pm 20°$ to $\pm 30°$ in height), the diameter of the stimuli is increased to $3°$. The reason behind increasing the diameter of the stimuli is overcoming the degraded visual acuity. In our method, each stimulus is presented as a dark dot whose intensity level is continuously changed from light gray to black (ranging from 192 to 0 gray-scale level in descending order) on a background with bright white illumination (intensity value of 255). This setup is arranged because it makes the VF testing easier for the subjects as the dark stimuli are easier to be distinguished in the white background.

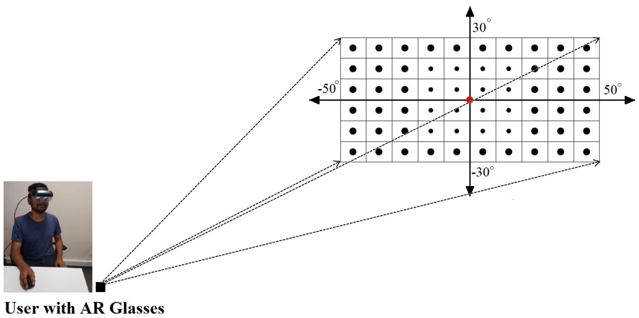

Figure 1: A set of stimuli displayed on 60 cells (6×10 matrix). The red circle represents the fixation point of the subject.

The stimuli are presented at a random position in each test. Each stimulus appears for 2 seconds (2000 ms). The fixed pre-stimulus delay period is 500 ms, followed by 2-seconds of stimulus presence. This 2-second fixed duration for each stimulus presence is determined empirically for healthy eyes (the average time during which the user with healthy eyes can see it and respond). The time between two stimuli is also altered through the control program based on the subject's/user's response speed, determined by the initial demonstration mode. Fig. 2 shows the full-timing cycle for two consecutive stimuli in the *BinoVFAR* system. During the appearance time of the stimulus, the users are required to click on a wireless mouse instantly if the stimulus is visible for them while they are focusing on the middle red point. The subjects'/users' responses are recorded once they click on the mouse. The recorded information includes the position of each clicked stimulus and the value of its intensity at which the subjects/users click. It is worth mentioning that as the present time of these stimuli is short, the user sometimes cannot click on time due to several reasons such as distractions. To avoid this limitation, minimize the false negative, and guarantee the accuracy of the results, if users do not respond to a visible stimulus, it is randomly repeated later during the test. The value of 0 is assigned if subjects do not see the stimulus at any intensity level during the VF test (even with one repetition for that specific stimulus).

2.2 Materials and Experimental Setup

2.2.1 Materials: The proposed *BinoVFAR* test is conducted using Dreamworld AR glasses and a USB compatible optical mouse on a PC with 32G RAM and i7 CPU (shown in Fig. 3). As illustrated in Fig. 4, AR glasses are portable light glasses with a 90° field of view, 2.5k resolution, 1080p front-facing RGB camera, built-in gesture control, three degrees of freedom (DOF) head tracker, and compatibility with both PCs and smartphones. They can connect to both PC and smartphone via USB-HDMI and USB type C cables, respectively. In our system, glasses are connected to the PC by using a USB cable and an HDMI cable simultaneously (shown in Fig. 3 (b)). The data relating to the stimuli are recorded by clicking on the optical mouse. This robust binocular VF testing system is designed and developed on Unity 3D Game Engine, and the final visual field map is obtained by applying the bicubic interpolation on MATLAB R2019b.

2.2.2 Experimental Setup: The overall flowchart of the proposed *BinoVFAR* system is illustrated in Fig. 5. As it is illustrated, in the first step, the subject/user is asked to wear the AR glasses. At the same time, introduction screen including a box for typing the subject's name, a start button, and 8 light-green static points on the border of the visual field, is displayed on the AR glasses and the PC screen. As the VR glasses should be worn properly (not too high or too low, not to be tilted and off center) by the user, these 8 static points (presented during the whole test) are created to calibrate the glasses and make sure the subject wears the AR glasses properly. Hence, it is asked from the subject to move his/her iris and look at each of the green circles. To cover the whole field of view, it is necessary for the subject to see all the eight points, otherwise, the glasses need to be adjusted on the eyes by the subject and then fixed with the head straps. Once, it is confirmed that the glasses are calibrated and the subject wears them properly, the subject's name is typed and the start button is clicked by the operator to start the test. During the whole test, the subject has to focus on the red fixation point at the center. In the next step, the subject clicks on the wireless mouse instantly the moment that the appearing stimulus is visible for him/her. Once the mouse is clicked by the user, the information of that stimulus (i.e. its intensity and position) is recorded. It continues until all 60 stimuli are displayed (the unclicked stimuli are automatically displayed twice). After completing the test, the final recorded data of the stimuli are presented by clicking on the "Show Result" button. In this step, the recorded intensity data of these 60 stimuli are extracted and saved in a 6×10 matrix in MATLAB. To achieve the final visual field map, this 6×10 matrix is resized to a 600×1000 matrix by applying bicubic interpolation. Bicubic interpolation, an extension of cubic interpolation [8], is a novel method for resampling discrete data to enlarge the images and achieve high-resolution images. As it is presented in Fig. 6, the bicubic interpolation calculates the interpolated intensity of the new pixel based on not only the influence of four adjacent points but also the influence factors of 16 points around the new interpolated pixel. W(x), the basic function of the bicubic interpolation is given as follows [2]:

$$W\left(x\right)=\begin{cases}\left(a+2\right)\left|x\right|^{3}-\left(a+3\right)\left|x\right|^{2}+1 & for\left|x\right|\leq 1\\ a\left|x\right|^{3}-5a\left|x\right|^{2}+8a\left|x\right|-4a & for 1<\left|x\right|<2\\ 0 & otherwise\end{cases}\qquad(1)$$

K_{im} and K_{jn} are the horizontal and vertical distances between the interpolated pixel, $B\left(x,y\right)$ and the 16 pixels surrounding it as follows:

$$K_{i0}=1+\mu;K_{i1}=\mu;K_{i2}=1-\mu;K_{i3}=2-\mu;K_{j0}=1+v;K_{j1}=v;$$
$$K_{j2}=1-v;K_{j3}=2-v\qquad(2)$$

The weight coefficients are given as:

$$a_{mn}=W\left(K_{im}\right)W\left(K_{jn}\right)\qquad(3)$$

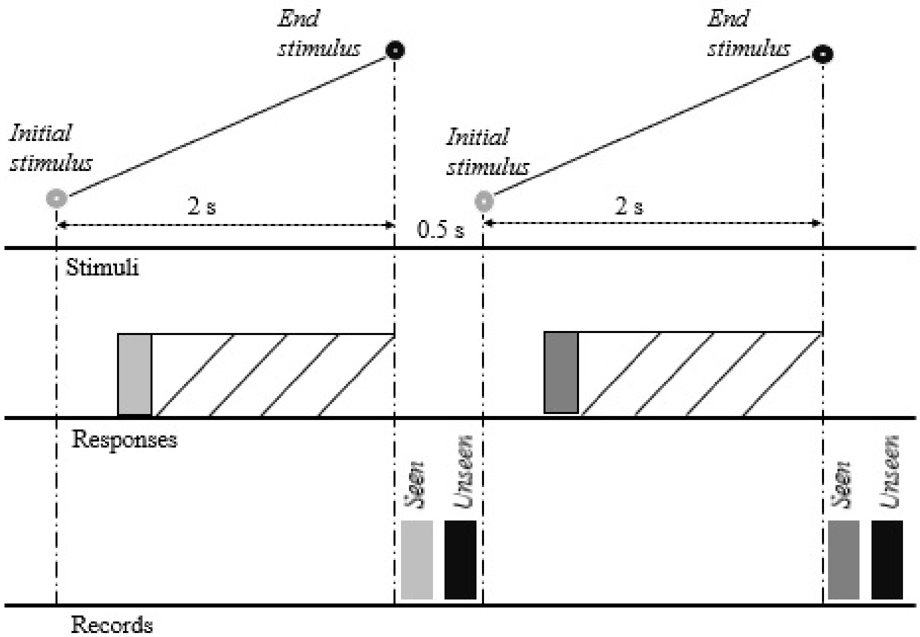

Figure 2: Timing of VF testing process for two consecutive stimuli that continuously repeated until the end of the test.

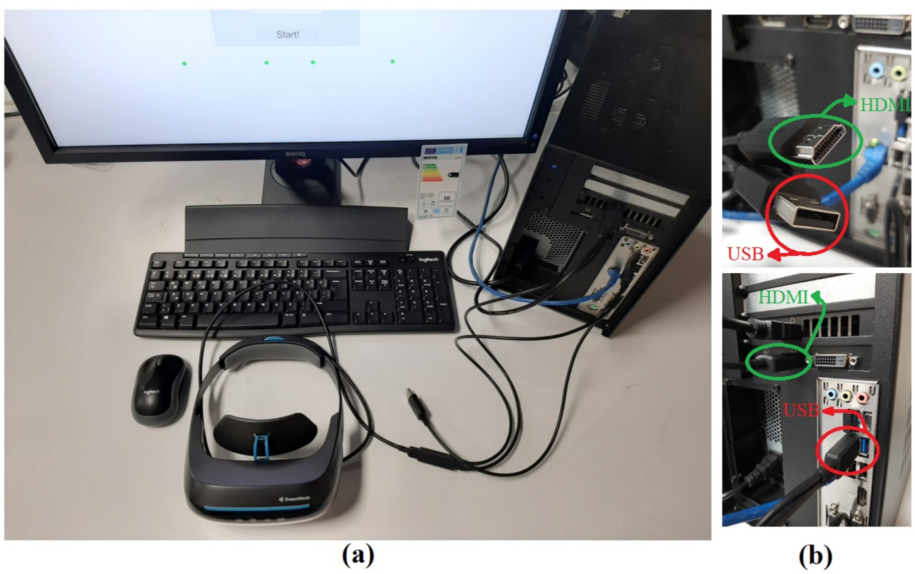

Figure 3: Experimental materials of the proposed binocular VF testing, a) computer setup, b) connection between the AR glasses and the computer.

Employing these coefficients, the final interpolated image is obtained by:

$$B(x, y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} A(x_i, y_i) \tag{4}$$

where B is the interpolated image from the original image A, and i and j represent the row and column of 16 surrounding pixels, respectively. Applying this bicubic interpolation, the 6×10 matrix of the recorded stimuli is extended to a 600×1000 image as it is illustrated in the final step of Fig. 5. The highest intensity for the stimuli at the beginning of their appearance is 192 (light gray). Hence, having the color of light gray color in almost all pixels of the final visual field map means that the subject could successfully click on the mouse once the stimuli are appeared, which results in

Figure 4: Dreamworld AR glasses and their characteristics.

drawing the inference about the healthiness of the subject's eyes. Completely black areas on the visual field maps are the areas that the subject is not able to see them focusing on the fixation point.

It should be noted that before starting the main test, a demonstration as an instructional pattern is first presented to the subject/user. This demonstration follows the same procedure as that of the main binocular VF test. The purpose of this demonstration is familiarizing the subject with with the procedure of the test and no responses are recorded in this step. This training step also helps the operator to estimate the response speed of the subject.

3 EXPERIMENTAL RESULTS

3.1 Empirical user study

Being confronted with access limitations (such as Covid-19 restrictions) in getting access to the real patients in hospitals, our system is tested on healthy people by artificially blocking some areas of their visual field on the AR glasses. To do this, 16 different combinations are proposed for testing the binocular VF system as illustrated in Fig. 7(a). As presented in this figure from top left to bottom right, 16 combinations are as follows, respectively: healthy eyes (H), artificially blocking two columns from outer sides (2S), two rows from the top (2T), two rows from the bottom (2B), three columns from outer sides (3S), three rows from the top (3T), three rows from the bottom (3B), two rows from top and bottom (2T2B), two columns from outer sides and two rows from the top (2S2T), two columns from outer sides and three rows from the top (2S3T), two columns from outer sides and two rows from the bottom (2S2B), two columns from outer sides and three rows from the bottom (2S3B), three columns from outer sides and two rows from the top (3S2T), three columns from outer sides and three rows from the top (3S3T), three columns from outer sides and two rows from the bottom (3S2B), three columns from outer sides and three rows from the bottom (3S3B). In all these combinations, different areas are blocked so that the fixation red point is always visible for the user to focus on it during the whole test.

These 16 combinations have been showed and tested in the order presented in Fig. 7(a) from top left to bottom right for five different healthy subjects (normal vision). Before starting the test, all the subjects in this study filled and signed the written informed consent. Then, all the necessary instructions have been provided to the subjects by demonstration. All the subjects have asked to wear and adjust the AR glasses on their eyes by considering the eight calibration light-green points on the screen and focusing on the fixation redpoint during the testing process. Users were again informed that AR glasses do not harm their eyes or health. Three subjects out of five were wearing prescribed glasses, who were also allowed to wear them with the AR glasses during the test. The subjects have been supposed to click on the mouse clicker for seen stimulus. Unseen/unclicked stimuli have been temporarily stored in the memory to be displayed again to minimize the false-negative responses. The final recorded responses (shown for subject 1 in Fig. 7(b)) have been converted to 6×10 matrices which have been then extended to 600×1000 images as final VF maps by applying bicubic interpolation (shown for subject 1 in Fig. 7(c)). To complete a test, the subject may require approximately 3 - 4 minutes, depending on blocked areas and the number of unclicked/blocked stimuli (because they are repeated once more during the test). A 3-minute break time has been allocated between two tests to prevent subjects from getting tired and losing concentration in the following tests. Before conducting each test, it was asked from the users if attending the previous test had any side effects on them, such as headache. As no users had felt any side effects, all 16 tests were conducted with the predetermined 3-minute (not more) break time between each pair.

3.2 VF Test Results

The qualitative results of the proposed *BinoVFAR* system with 16 different combinations are illustrated for subject 1 in Fig. 7. The results for the other subjects are similar and not presented here to avoid duplication. As illustrated in this figure, a gray area refers to the areas in the subject's visual field, and black areas refer to the blocked areas and not in the subject's visual field. It should be mentioned that there are some dark gray spots in the final visual field maps that means the subjects can see them with delay. So, only pure black (not dark gray) areas are considered visual defects. In

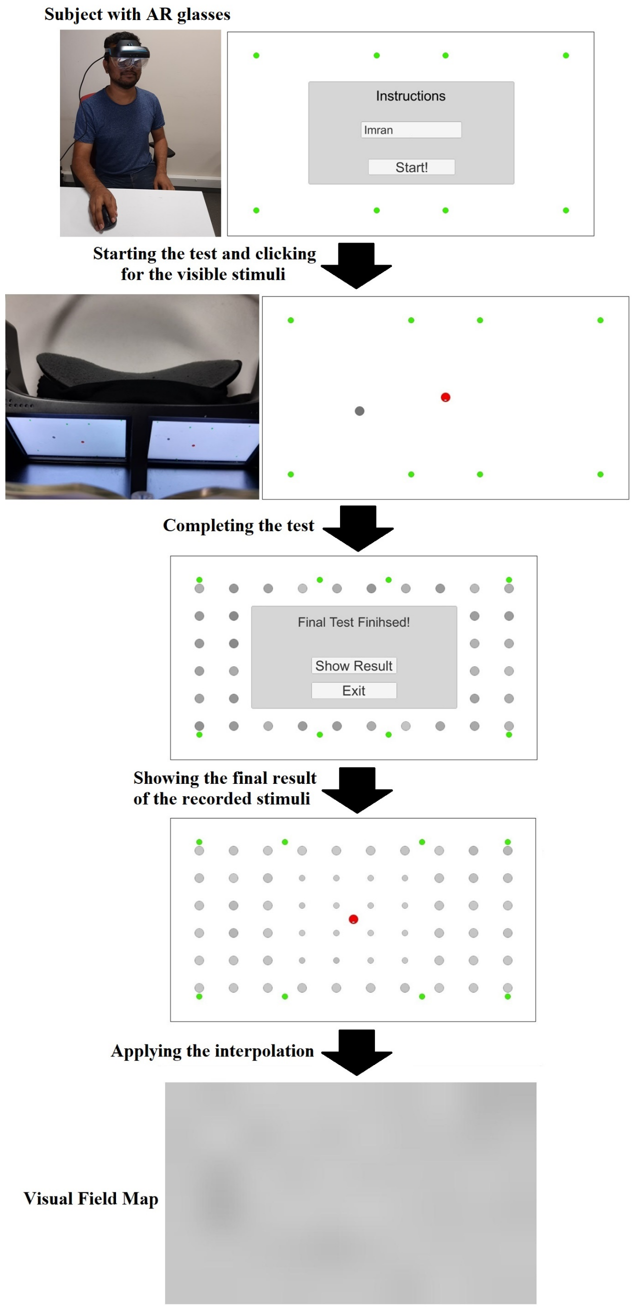

Figure 5: The overall flowchart of VF testing system on a subject using AR glasses.

this test, the displayed and blocked stimuli in every 16 combinations are real positive (P) and real negative (N) cases, respectively. Table 1 represents the quantitative results of each subject in each of 16 combinations in terms of accuracy rate ($AR = \frac{TP+TN}{P+N} \times 100$), where TP (true positive) is the number of displayed stimuli which are clicked by the subject, TN (true negative) is the number of blocked stimuli which are not clicked by the subject and $P + N = 60$. As

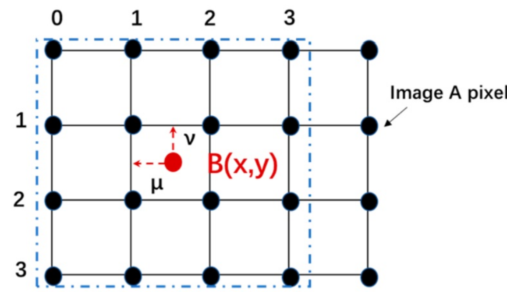

Figure 6: Principle of bicubic interpolation [2].

Table 1: The accuracy rates (AR in percentage) of binocular VF test for five different subjects in 16 combinations.

Category	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5
H	100	100	100	100	98.33
2S	100	100	100	100	100
2T	100	100	100	100	100
2B	100	100	100	100	100
3S	100	100	100	100	100
3T	100	100	100	100	100
3B	100	100	100	100	100
2T2B	100	100	100	100	100
2S2T	100	100	100	100	100
2S3T	100	100	100	100	100
2S2B	100	100	100	100	100
2S3B	100	100	100	100	100
3S2T	100	100	100	100	100
3S3T	100	100	100	100	100
3S2B	100	98.33	100	98.33	100
3S3B	100	100	100	100	100
Average	**100**	**99.89**	**100**	**99.89**	**99.89**

presented in this table, the ARs for subjects 1 and 3 are all 100%. For subjects 2 and 4, there is a wrong response in 3S2B out of 60 responses. There is also one wrong response for subject 5 but this time in the H case. Analysing the wrong answers, it is observed they are the stimuli on the furthest corners of the field of view which are not clicked by the subject, or the subject clicks them while they are blocked. These wrong responses mainly occurred because of distractions such as noise, the tension of the test, etc. The average AR of the results for five subjects is 99.93%, which shows the high performance of the proposed system.

Additionally, the confusion matrix for each of these five subjects are presented in Table 2 in terms of true positive rate ($TPR = \frac{TP}{P_t}$), true negative rate ($TNR = \frac{TN}{N_t}$), false negative rate ($FNR = \frac{FN}{P_t}$), and false-positive rate ($FPR = \frac{FP}{N_t}$). The sum of stimuli in all 16 combinations is 960, among which real positive cases (P_t) are 420, and real negative cases (N_t) are 540. FN and FP stand for false negative and false positive cases, respectively. FN means that the user can not see the displayed stimulus and does not click on the mouse even when that specific stimulus is repeated automatically.

Figure 7: 16 different combinations of binocular VF testing and the correspondence qualatative results for subject 1, a) artificial blocking of the AR glasses, b) the results of the recorded clicked stimuli, c) the corresponding visual field maps.

Table 2: The confusion matrix of VF test for five subjects in all 16 combinations.

Subjects	TPR	TNR	FPR	FNR
Subject 1	1	1	0	0
Subject 2	0.9976	1	0	0.0023
Subject 3	1	1	0	0
Subject 4	1	0.9981	0.0018	0
Subject 5	0.9976	1	0	0.0023
Average	**0.9990**	**0.9996**	**0.0003**	**0.0009**

Table 3: Quantitative results of the reproducibilty assessment based on the calculated ICCs for all 12 pairs of VF maps achieved from four combinations tested on 3 subjects.

Subjects	2S	2T	2B	3S
Subject 1	99.91%	99.57%	99.87%	99.87%
Subject 2	99.88%	99.89%	99.86%	99.42%
Subject 3	99.76%	99.75%	99.18%	99.79%
Average	**99.72%**			

FP means that the user clicked on the mouse although the stimulus is blocked, and he/she cannot see that specific stimulus. As illustrated in Table 2, there is no FN or FP for subject 1 and 3. Subject 2 and 5 have one FN, and subject 4 has one FP. The average TPR, TNR, FPR, and FNR for five subjects are 0.9990, 0.9996, 0.0003, and 0.0009, respectively, which demonstrates the good performance of the proposed *BinoVFAR* system.

3.3 Repeatability Assessment

In this section, the repeatability and reproducibility assessment of the proposed *BinoVFAR* system is presented. To investigate the reproducibility, the test has been repeated twice (with the same setup and measurement parameters) for four first blocked combinations on three first subjects. The qualitative results are illustrated in Fig. 8 for three combinations. As presented in this figure, the VF map of the first try of every person is exceptionally similar to the VF map of their second try on the same test. To assess the reproducibility of the system quantitatively, the Intra-class Correlation Coefficient (ICC) is calculated between two results of the same test for the same person. This ICC is calculated based on the Pearson correlation coefficient, which is the covariance of the two arrays divided by the product of their standard deviations:

$$r_{xy} = \frac{1}{n-1} \sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{s_x}\right)\left(\frac{y_i - \bar{y}}{s_y}\right) \tag{5}$$

where r_{xy} is the related ICC, x_i and y_i are the individual sample points indexed with i, n is the sample size, and $\bar{x}$ and s are the sample mean and standard deviation, respectively. Calculating the ICC for all 12 pairs of VF maps (as summarized in Table 3), the average ICC is obtained as 99.72% which is statistically considered as an excellent reproducibility value for the proposed *BinoVFAR* system.

Another essential feature of our *BinoVFAR* system is its repeatability. In some of the tests, some users have made mistakes by unseen click and requested another test. As illustrated in Fig. 9 for two different tests, in the "3S2B" test, the user claimed that he saw the FN point recorded on his first try because he did not click on the mouse properly. In the "2S3B" test, the user felt the tension and clicked on the mouse while he did not see any stimulus on the screen of the AR glasses. So, one of the stimuli was recorded as FP on his first try. Repeating both tests for both users, they did the

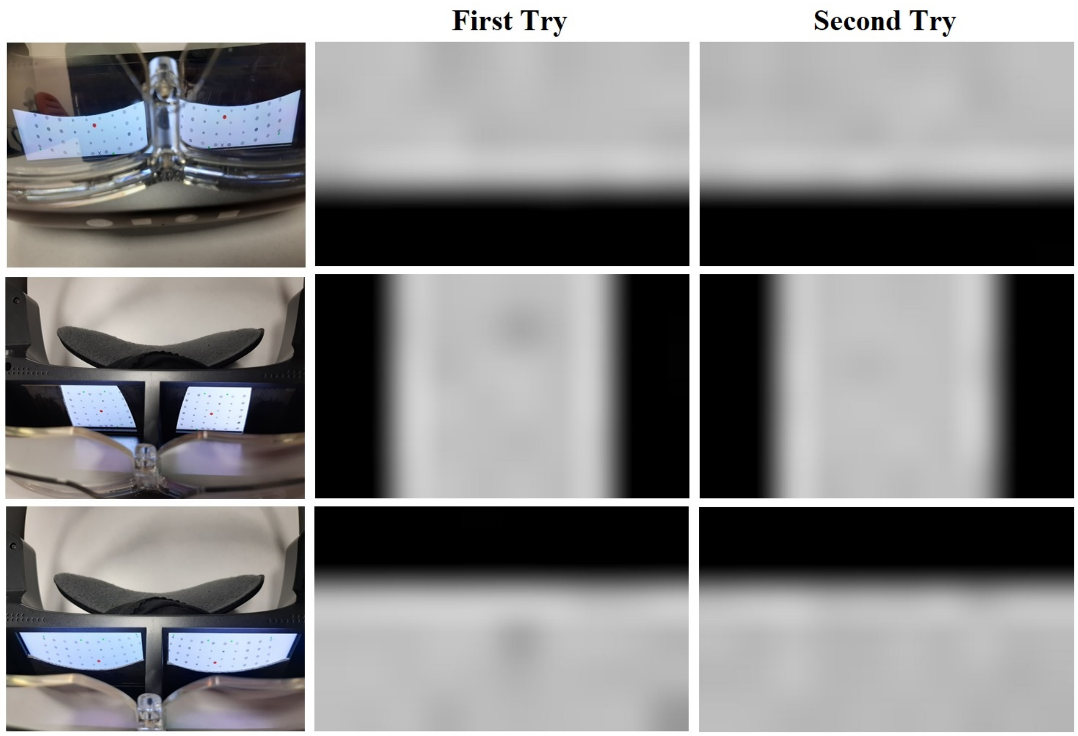

Figure 8: Qualitative results of the reproduciblity assessment for three combinations.

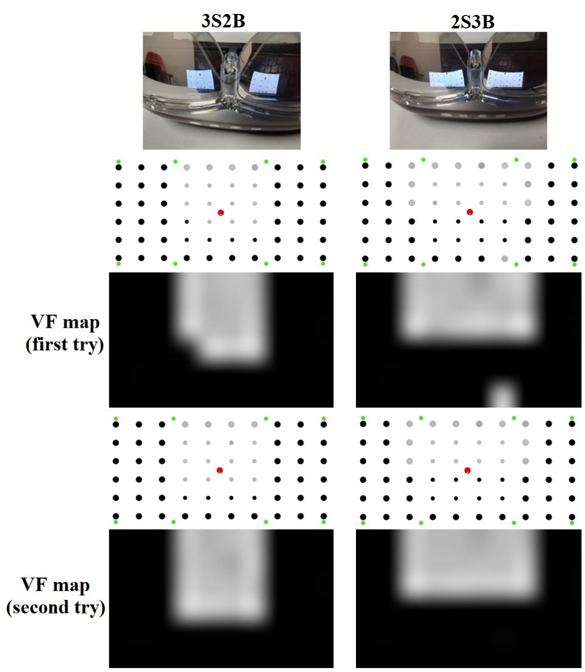

Figure 9: Two samples of the repeatability assessment for two combinations.

whole tests accurately without any mistakes, which shows that our system is highly repeatable, and it can be repeated for the users when they made some mistakes due to anxiety and those mistakes are not related to their vision defects.

3.4 Limitations

Our *BinoVFAR* system has some inevitable limitations. Firstly, this system relies on the subjects to focus on the fixation point during the VF testing. Subjects can change their focus and move their irises toward the position of each stimulus during the test. Possibly, iris/gaze detection and tracking system [1, 10] can deal with this limitation. Secondly, as the final visual field map is created based on the recorded data from the test on a different platform (MATLAB), this discontinuity may increase the time of the experiment. Applying the interpolation step and the test itself on the Unity 3D Game Engine can reduce the time of the whole experiment and increase the system's coherence.

4 CONCLUSIONS

In this paper, an automatic robust binocular VF testing system called *BinoVFAR* was proposed to find the visual field maps, particularly of the subjects with vision problems (e.g., glaucoma). In this system, 60 stimuli were created and displayed randomly in 60 cells arranged in a $60^\circ \times 100^\circ$ visual field. The intensity of each stimulus continuously changed from light gray to black for 2 seconds. A predefined 500 ms was allocated to start the next stimulus. Focusing on the fixation point through AR glasses, the subjects were asked to click on a wireless mouse once a stimulus was visible for them. The intensities of the stimuli were recorded based on the subjects' responses in 6×10 matrices, which were then interpolated to create the final 600×1000 visual field maps. The proposed system was evaluated by conducting experiments on five subjects (15 artificially blocked cases with one healthy case) and received an average accuracy of 99.93%. Achieving the average ICC of 99.72%, it demonstrated that our proposed system had strong repeatability and reproducibility. Once the restrictions of Covid-19 are removed, the proposed method will be tested on actual patients through clinics. The simulated binocular VF test will also be implemented and tested by blocking the areas according to the real visual field defects (e.g. Unilateral anopia, Bitemporal hemianopia, Homonymous hemianopia, etc). As our future work direction, we will improve the robustness of our proposed system by applying iris/gaze detection and tracking techniques. Additionally, the whole system will be performed on one platform to increase the test speed and the applicability of the system. Due to the extensive availability of smartphones, it will also be more effective if our proposed system works in smartphones. Moreover, to make the users' responses more valid and prevent the false answers recorded due to delayed clicking, another kind of user response such as voice feedback can be added to indicate the presence of the stimulus.

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