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(12) **United States Patent**
Abou Shousha et al.

(10) **Patent No.: US 10,409,071 B2**
(45) **Date of Patent: Sep. 10, 2019**

(54) **VISUAL ENHANCEMENT FOR DYNAMIC VISION DEFECTS**

(71) Applicant: **UNIVERSITY OF MIAMI**, Miami, FL (US)

(72) Inventors: **Mohamed Abou Shousha**, Pembroke Pines, FL (US); **Ahmed Sayed**, Miami, FL (US); **Ozgur Gundogan**, Miami, FL (US)

(73) Assignee: **University of Miami**, Miami, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/367,687**

(22) Filed: **Mar. 28, 2019**

(65) **Prior Publication Data**

US 2019/0223716 A1 Jul. 25, 2019

Related U.S. Application Data

(63) Continuation-in-part of application No. 16/144,995, filed on Sep. 27, 2018.
(Continued)

(51) **Int. Cl.**

G02B 27/01	(2006.01)
A61B 3/113	(2006.01)
A61B 3/00	(2006.01)

(52) **U.S. Cl.**
CPC ***G02B 27/0172*** (2013.01); ***A61B 3/0091*** (2013.01); ***A61B 3/113*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G02B 27/0172; G02B 27/0179; G02B 2027/0187; G02B 2027/0178;
(Continued)

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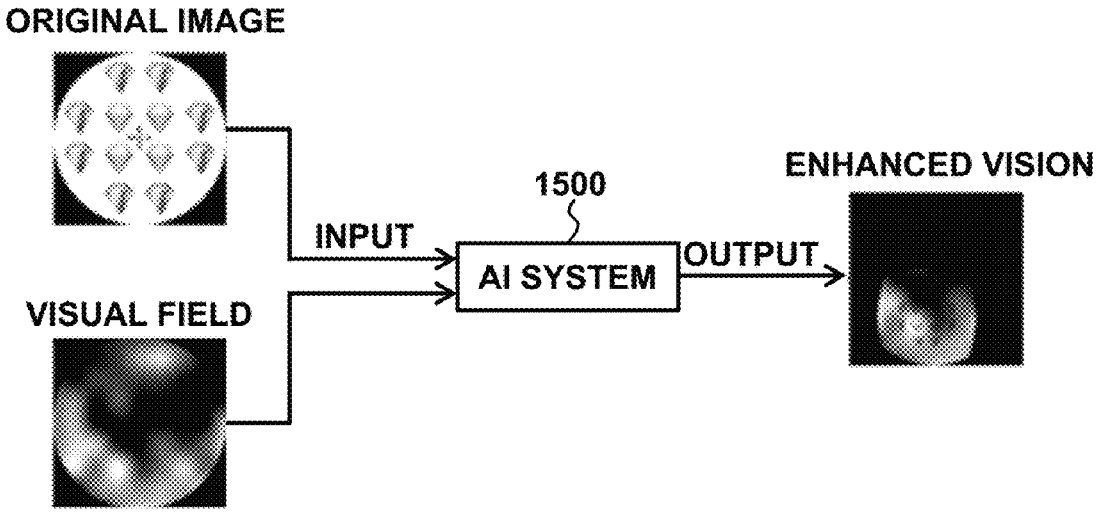
Primary Examiner — Maurice L. McDowell, Jr.
(74) *Attorney, Agent, or Firm* — Pillsbury Winthrop Shaw Pittman LLP

(57) **ABSTRACT**

In certain embodiments, live image data modifications may be facilitated for dynamic vision defects. In some embodiments, one or more eyes of a user may be monitored while a set of stimuli are displayed to the user. Feedback related to the set of stimuli may be obtained, where the feedback indicates (i) whether or how the user sees one or more stimuli of the set and (ii) one or more characteristics related to the eyes that occurred when such stimuli are displayed. A set of modification profiles associated with the user may be generated based on the feedback, where each modification profile of the set (i) is associated with eye-related characteristics and (ii) includes modification parameters to be applied to an image to modify the image for the user when eye-related characteristics of the user matches the associated eye-related characteristics.

20 Claims, 44 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/563,770, filed on Sep. 27, 2017.

(52) **U.S. Cl.**
CPC ***G02B 27/017*** (2013.01); ***G02B 27/0179*** (2013.01); *G02B 2027/014* (2013.01); *G02B 2027/0123* (2013.01); *G02B 2027/0138* (2013.01); *G02B 2027/0141* (2013.01); *G02B 2027/0178* (2013.01); *G02B 2027/0187* (2013.01)

(58) **Field of Classification Search**
CPC G02B 2027/014; G02B 2027/0138; G02B 2027/0141; G02B 27/017; G02B 2027/0123; A61B 3/0091; A61B 3/113
See application file for complete search history.

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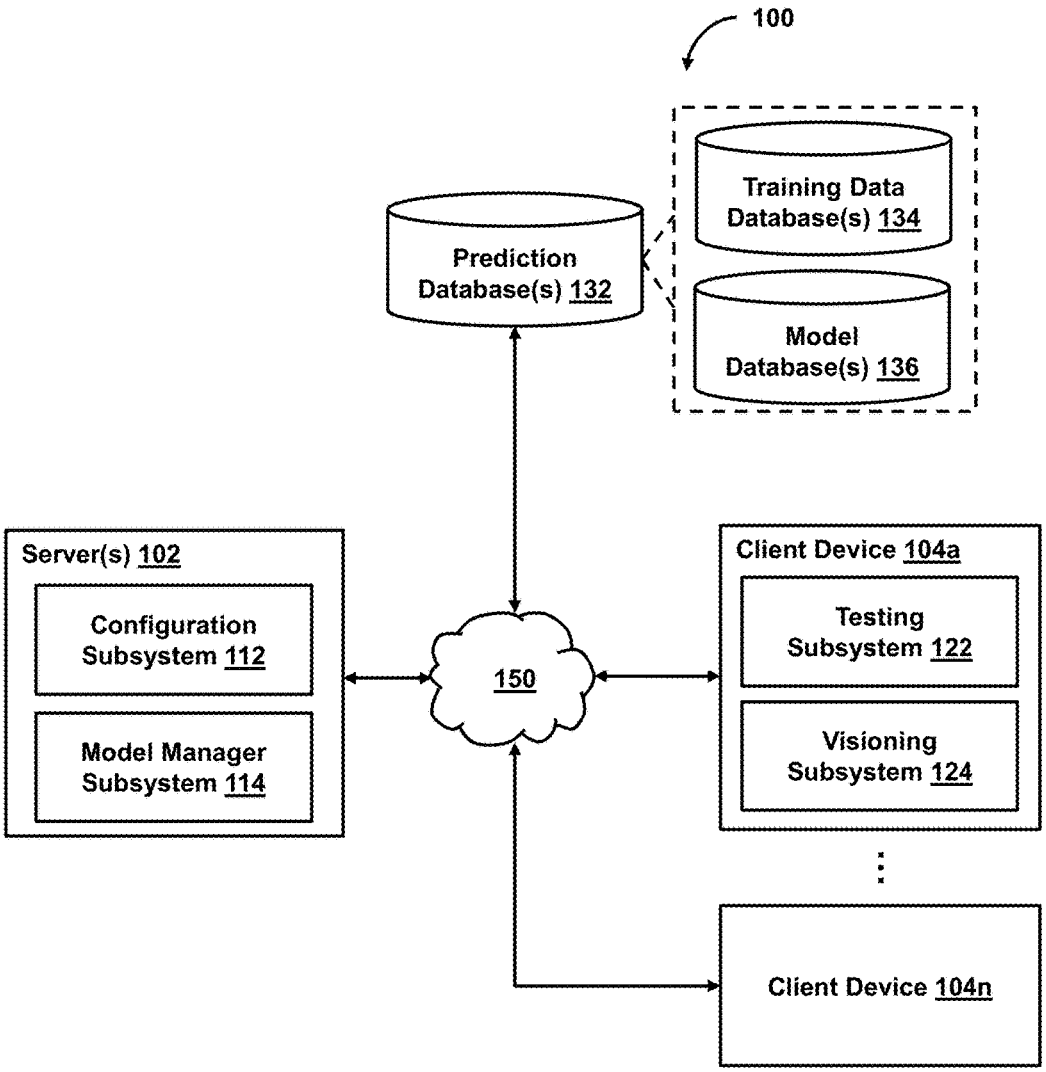

100
Training Data Database(s) 134
Prediction Database(s) 132
Model Database(s) 136
Server(s) 102
Configuration Subsystem 112
Model Manager Subsystem 114
150
Client Device 104a
Testing Subsystem 122
Visioning Subsystem 124
Client Device 104n

FIG. 1A

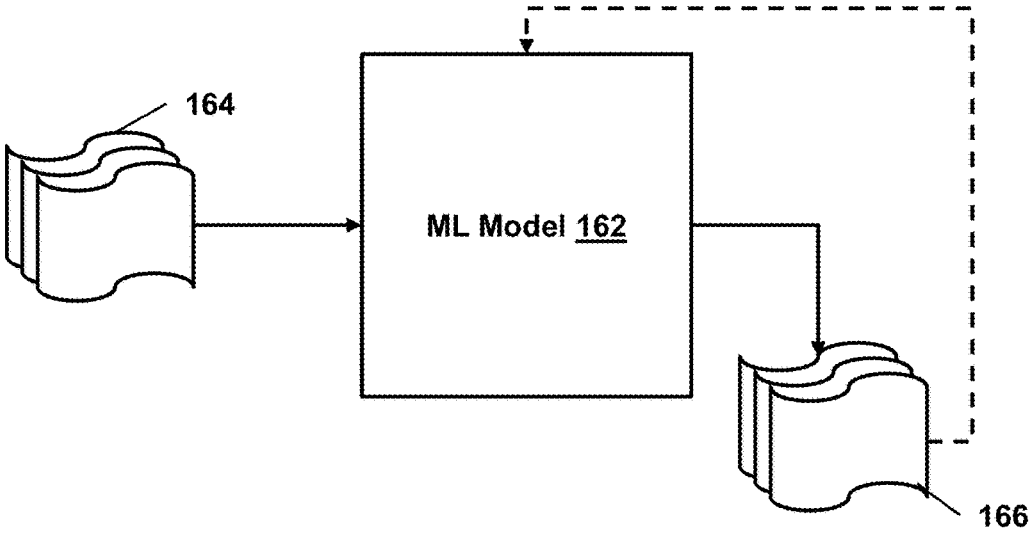


FIG. 1B

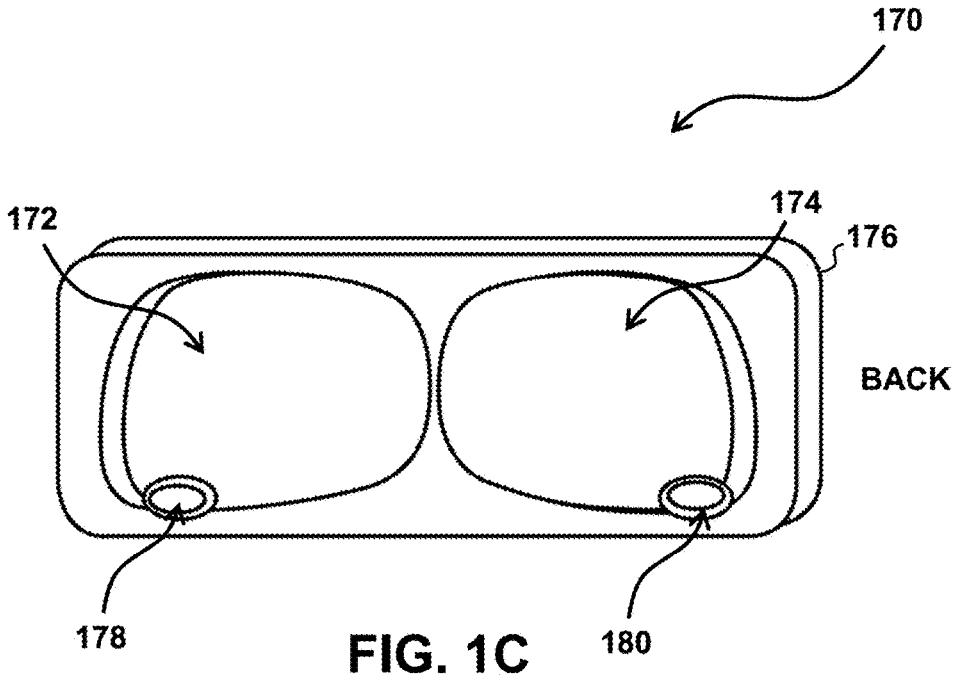


FIG. 1C

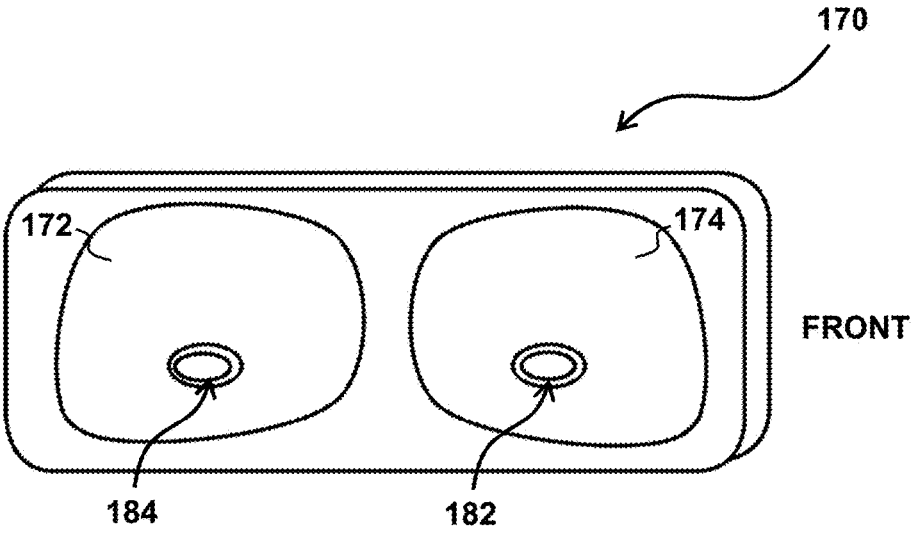


FIG. 1D

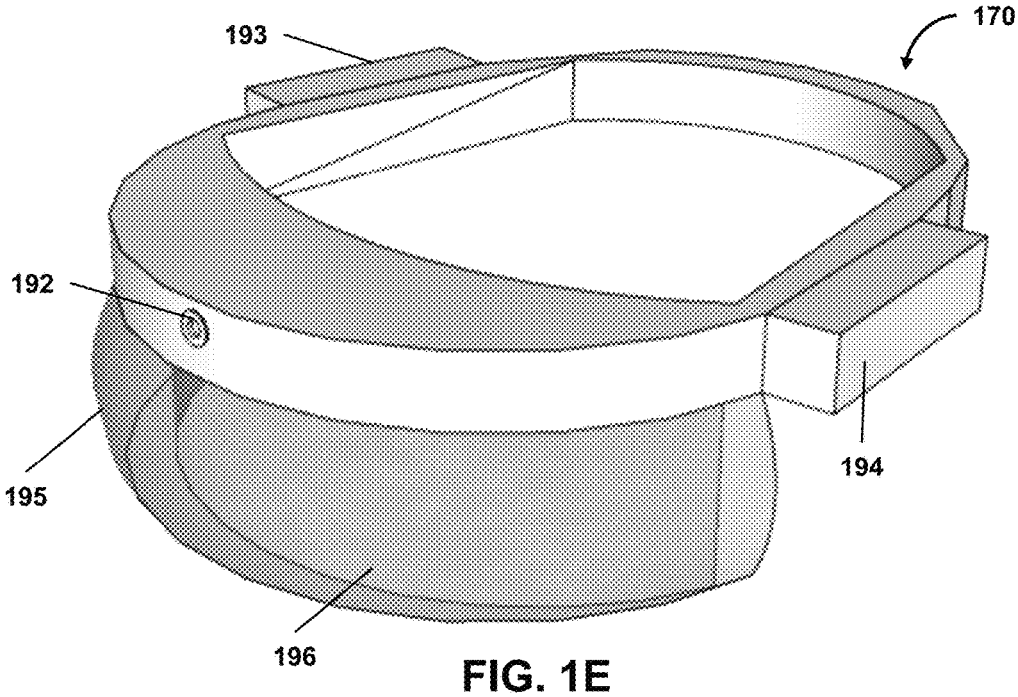


FIG. 1E

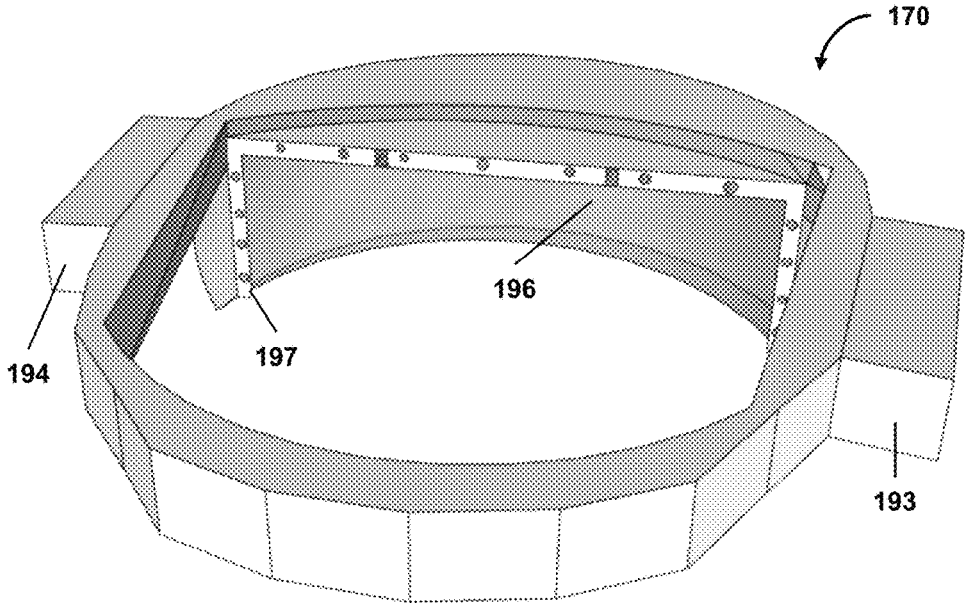


FIG. 1F

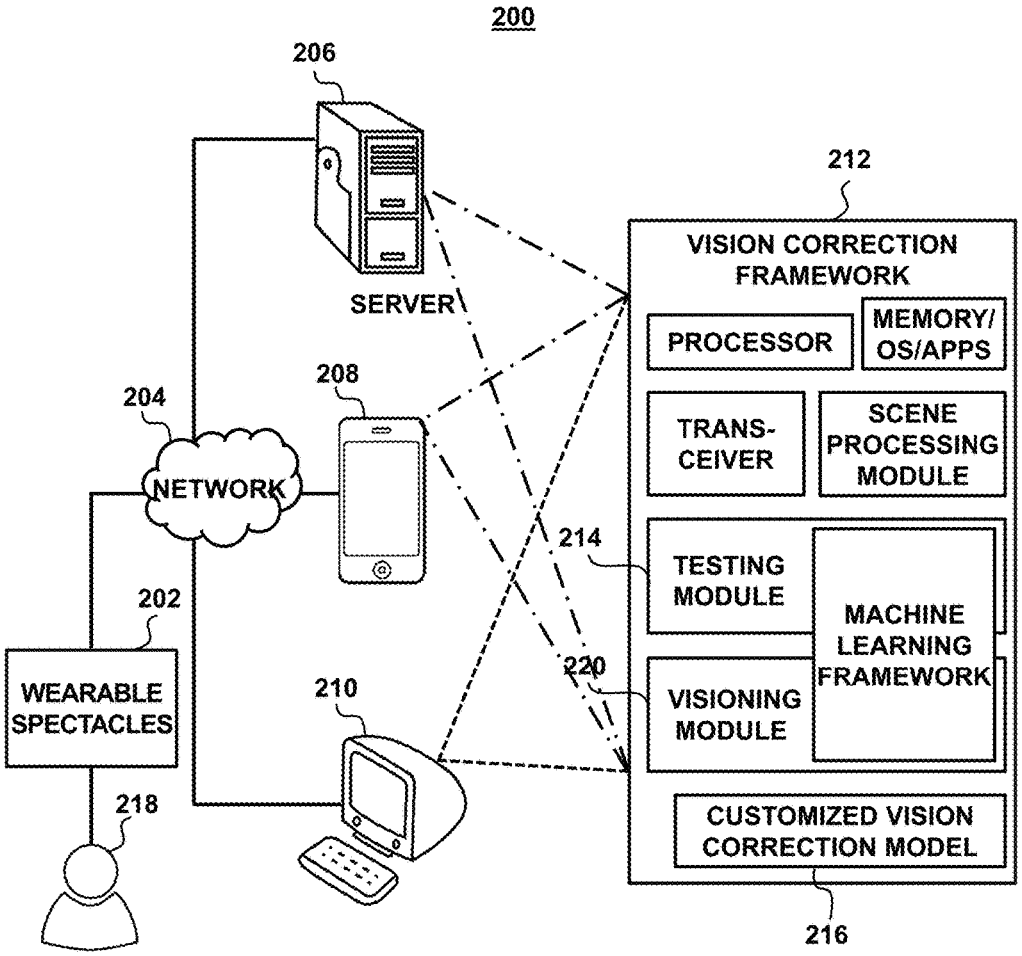

200
206
SERVER
212
VISION CORRECTION FRAMEWORK
PROCESSOR
MEMORY/ OS/APPS
TRANS-CEIVER
SCENE PROCESSING MODULE
208
204
NETWORK
214
TESTING MODULE
MACHINE LEARNING FRAMEWORK
202
220
VISIONING MODULE
WEARABLE SPECTACLES
210
218
CUSTOMIZED VISION CORRECTION MODEL
216

FIG. 2

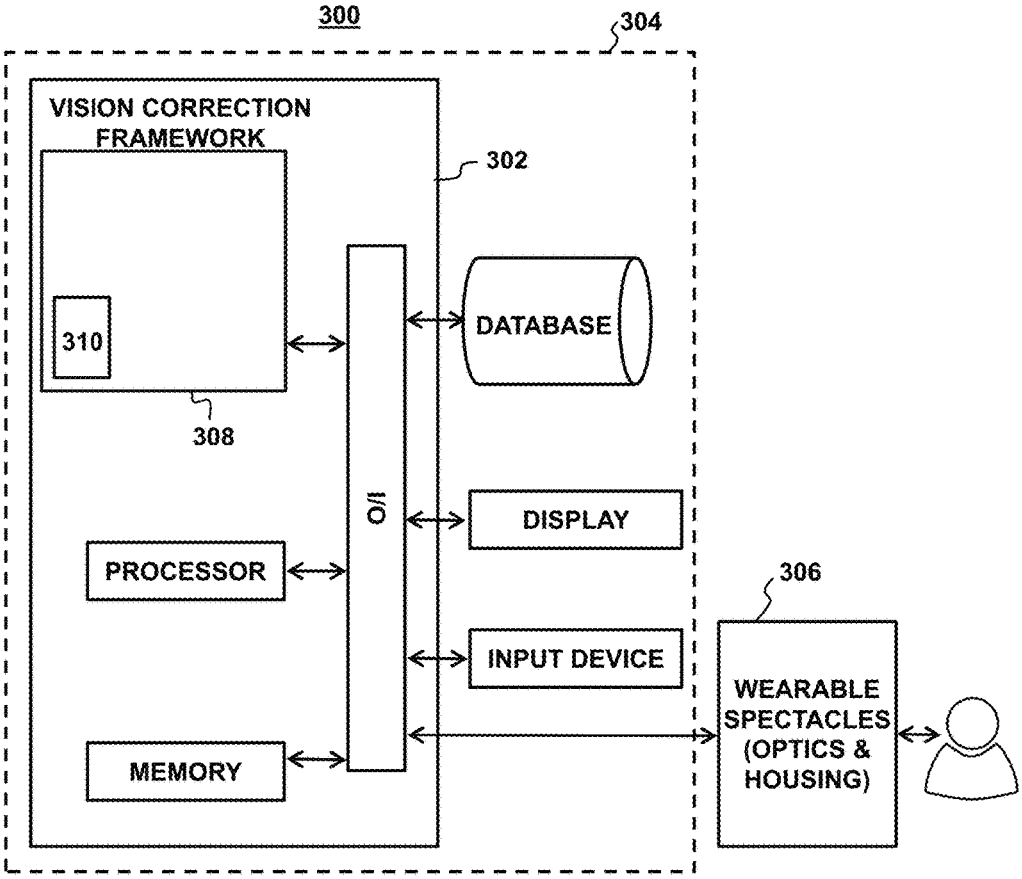

300
304
VISION CORRECTION FRAMEWORK
302
310
308
DATABASE
I/O
DISPLAY
PROCESSOR
306
INPUT DEVICE
WEARABLE SPECTACLES (OPTICS & HOUSING)
MEMORY

FIG. 3

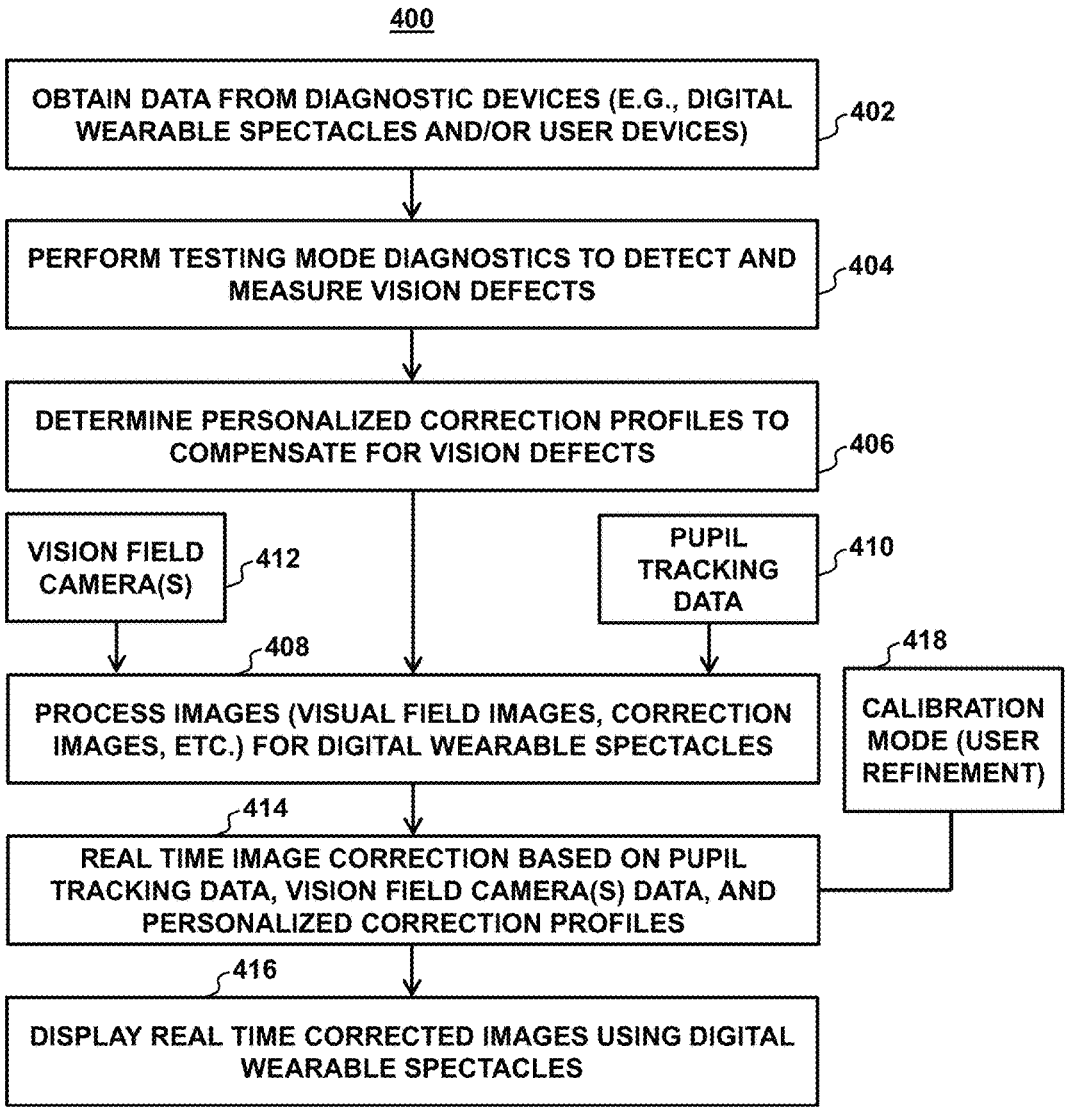

400
OBTAIN DATA FROM DIAGNOSTIC DEVICES (E.G., DIGITAL WEARABLE SPECTACLES AND/OR USER DEVICES)
402
PERFORM TESTING MODE DIAGNOSTICS TO DETECT AND MEASURE VISION DEFECTS
404
DETERMINE PERSONALIZED CORRECTION PROFILES TO COMPENSATE FOR VISION DEFECTS
406
VISION FIELD CAMERA(S)
412
PUPIL TRACKING DATA
410
408
418
PROCESS IMAGES (VISUAL FIELD IMAGES, CORRECTION IMAGES, ETC.) FOR DIGITAL WEARABLE SPECTACLES
CALIBRATION MODE (USER REFINEMENT)
414
REAL TIME IMAGE CORRECTION BASED ON PUPIL TRACKING DATA, VISION FIELD CAMERA(S) DATA, AND PERSONALIZED CORRECTION PROFILES
416
DISPLAY REAL TIME CORRECTED IMAGES USING DIGITAL WEARABLE SPECTACLES

FIG. 4

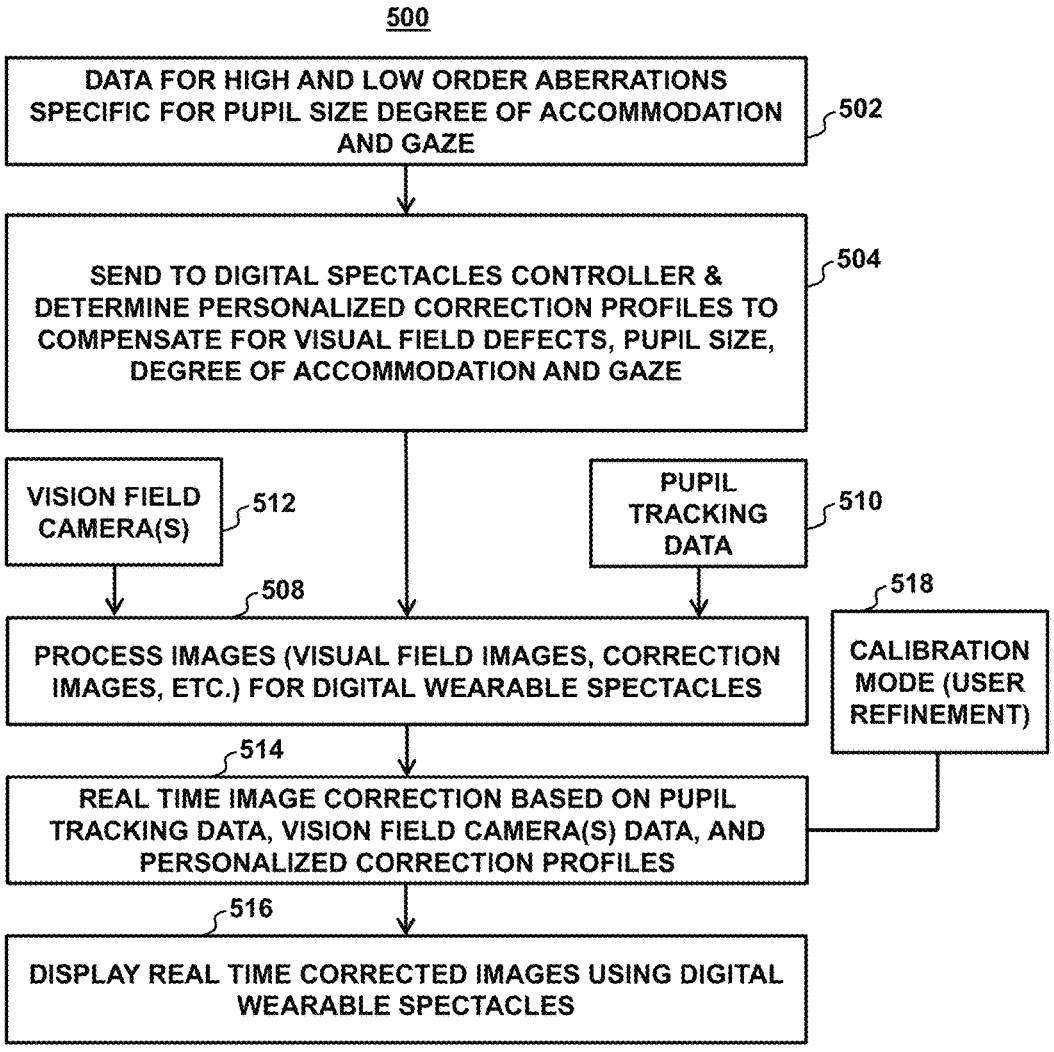

500
DATA FOR HIGH AND LOW ORDER ABERRATIONS SPECIFIC FOR PUPIL SIZE DEGREE OF ACCOMMODATION AND GAZE
502
SEND TO DIGITAL SPECTACLES CONTROLLER & DETERMINE PERSONALIZED CORRECTION PROFILES TO COMPENSATE FOR VISUAL FIELD DEFECTS, PUPIL SIZE, DEGREE OF ACCOMMODATION AND GAZE
504
VISION FIELD CAMERA(S)
512
PUPIL TRACKING DATA
510
508
518
PROCESS IMAGES (VISUAL FIELD IMAGES, CORRECTION IMAGES, ETC.) FOR DIGITAL WEARABLE SPECTACLES
CALIBRATION MODE (USER REFINEMENT)
514
REAL TIME IMAGE CORRECTION BASED ON PUPIL TRACKING DATA, VISION FIELD CAMERA(S) DATA, AND PERSONALIZED CORRECTION PROFILES
516
DISPLAY REAL TIME CORRECTED IMAGES USING DIGITAL WEARABLE SPECTACLES

FIG. 5

FIG. 6A

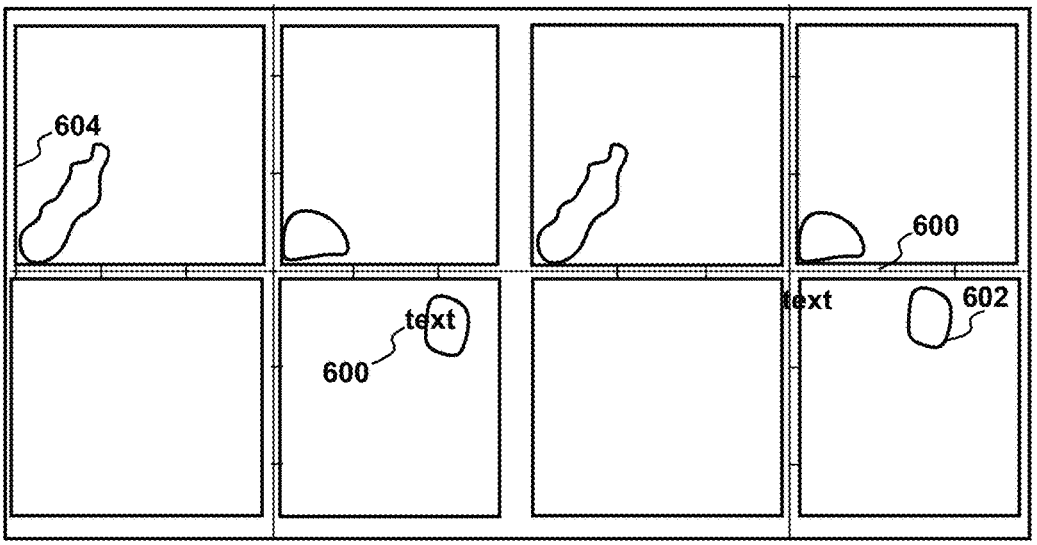


FIG. 6B

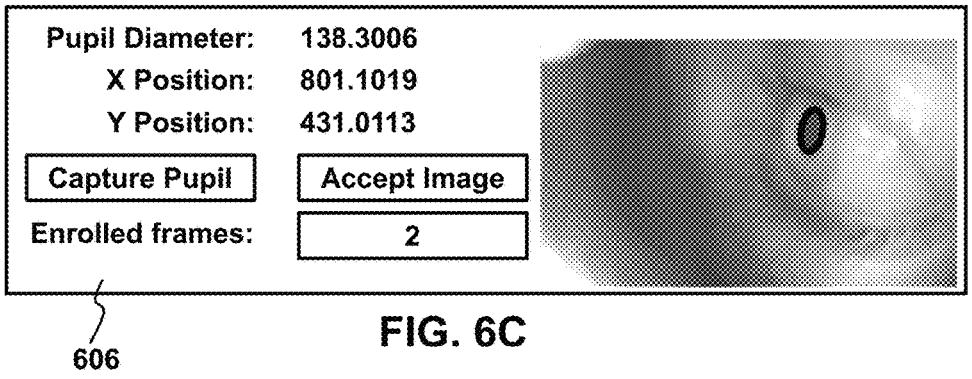


FIG. 6C

FIG. 7A

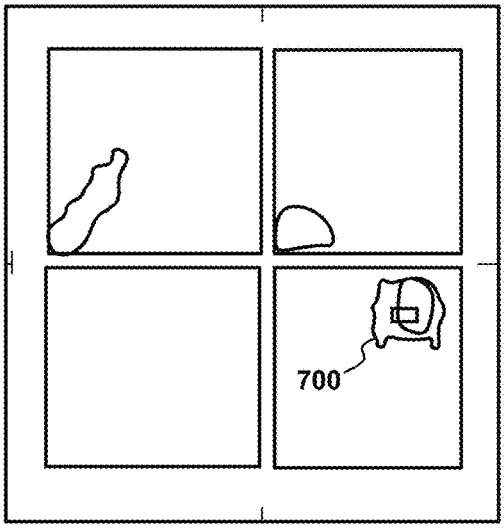
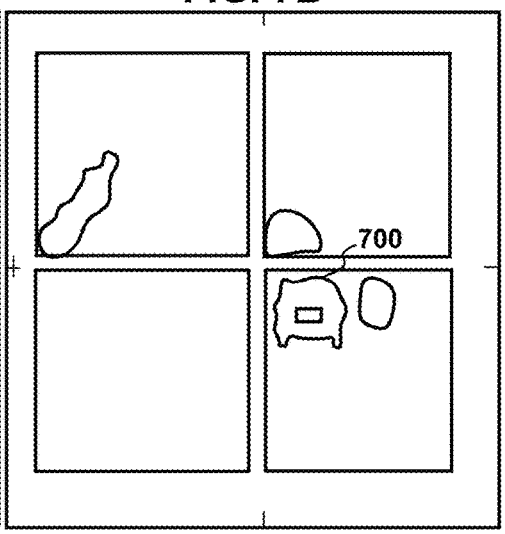


FIG. 7B



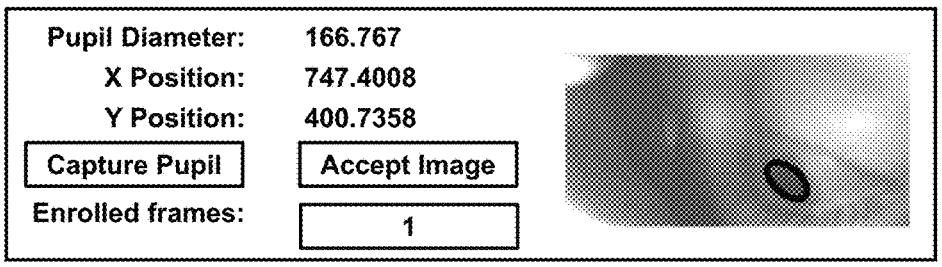


FIG. 7C

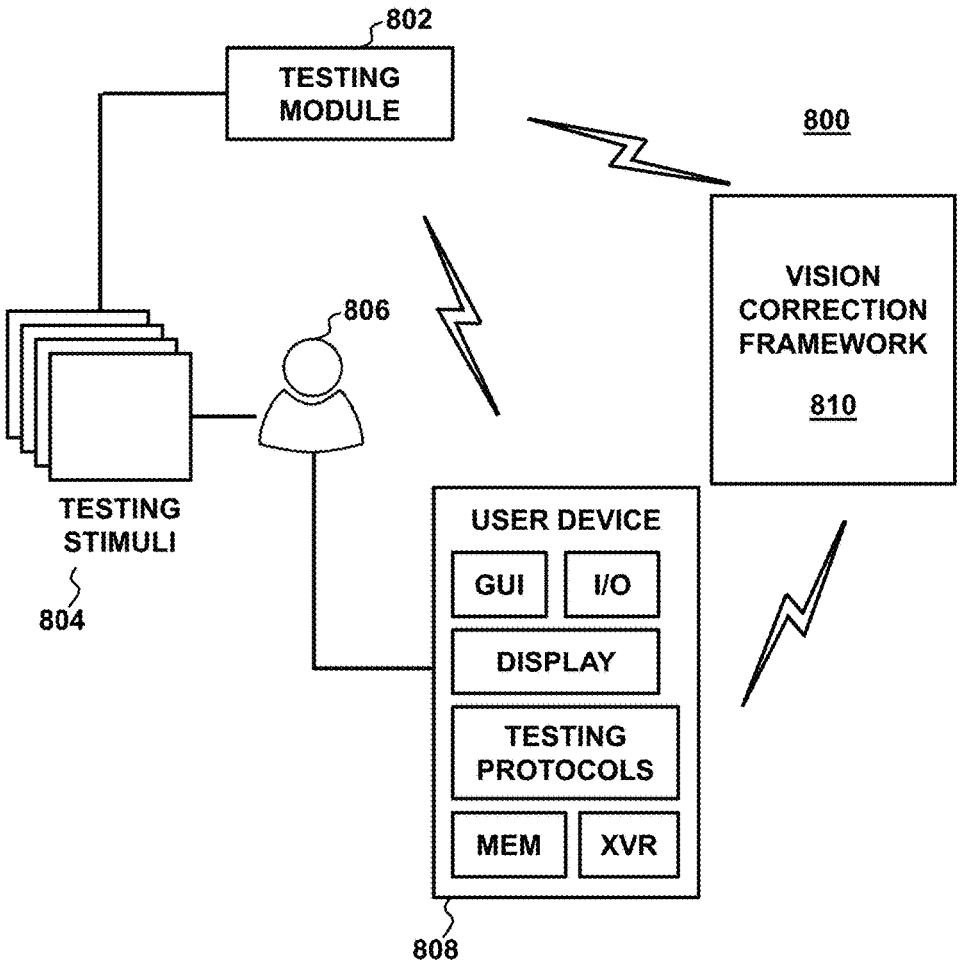

802
TESTING MODULE
800
VISION CORRECTION FRAMEWORK
810
806
TESTING STIMULI
804
USER DEVICE
GUI
I/O
DISPLAY
TESTING PROTOCOLS
MEM
XVR
808

FIG. 8

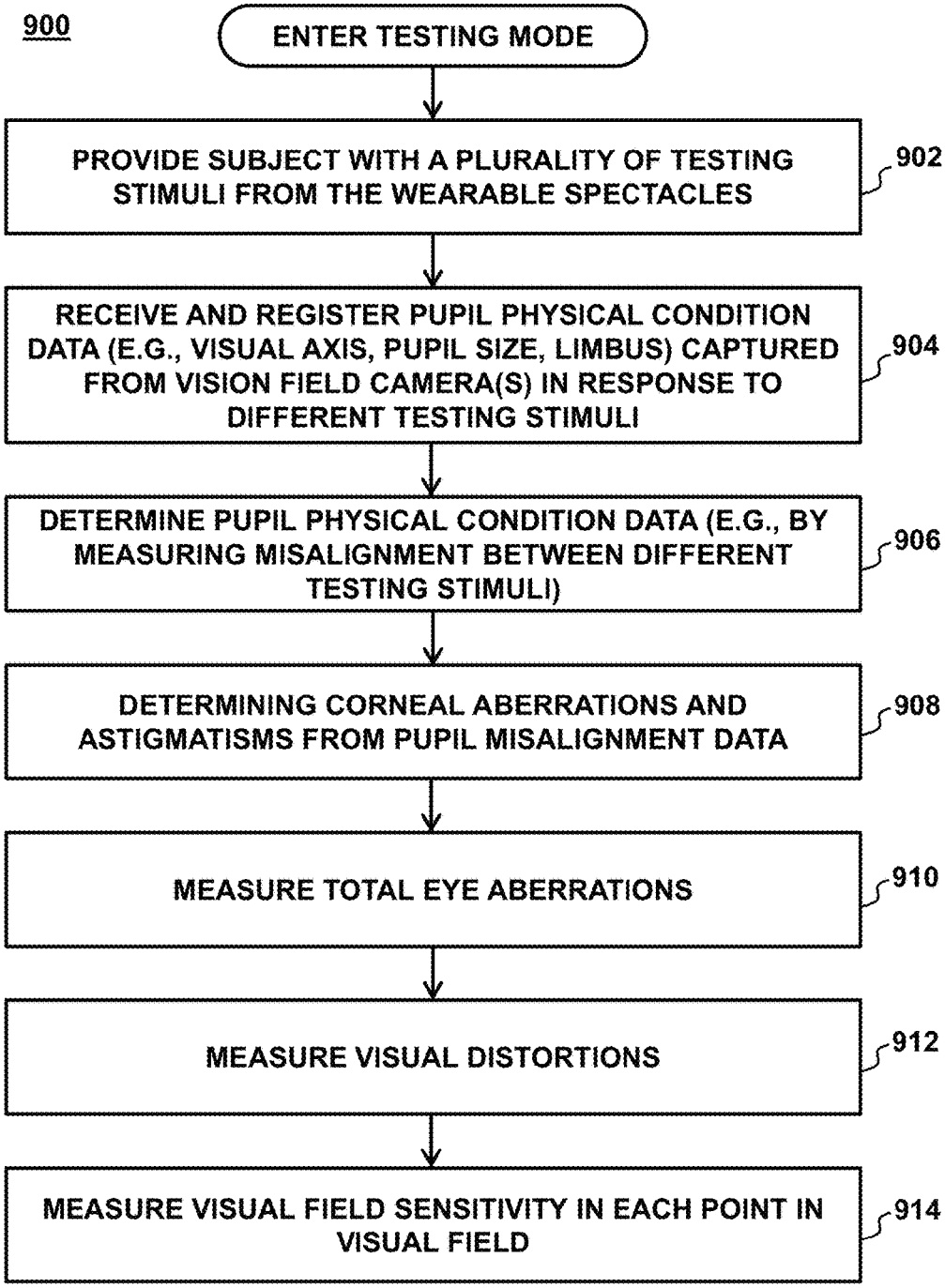

900
ENTER TESTING MODE
PROVIDE SUBJECT WITH A PLURALITY OF TESTING STIMULI FROM THE WEARABLE SPECTACLES
902
RECEIVE AND REGISTER PUPIL PHYSICAL CONDITION DATA (E.G., VISUAL AXIS, PUPIL SIZE, LIMBUS) CAPTURED FROM VISION FIELD CAMERA(S) IN RESPONSE TO DIFFERENT TESTING STIMULI
904
DETERMINE PUPIL PHYSICAL CONDITION DATA (E.G., BY MEASURING MISALIGNMENT BETWEEN DIFFERENT TESTING STIMULI)
906
DETERMINING CORNEAL ABERRATIONS AND ASTIGMATISMS FROM PUPIL MISALIGNMENT DATA
908
MEASURE TOTAL EYE ABERRATIONS
910
MEASURE VISUAL DISTORTIONS
912
MEASURE VISUAL FIELD SENSITIVITY IN EACH POINT IN VISUAL FIELD
914

FIG. 9

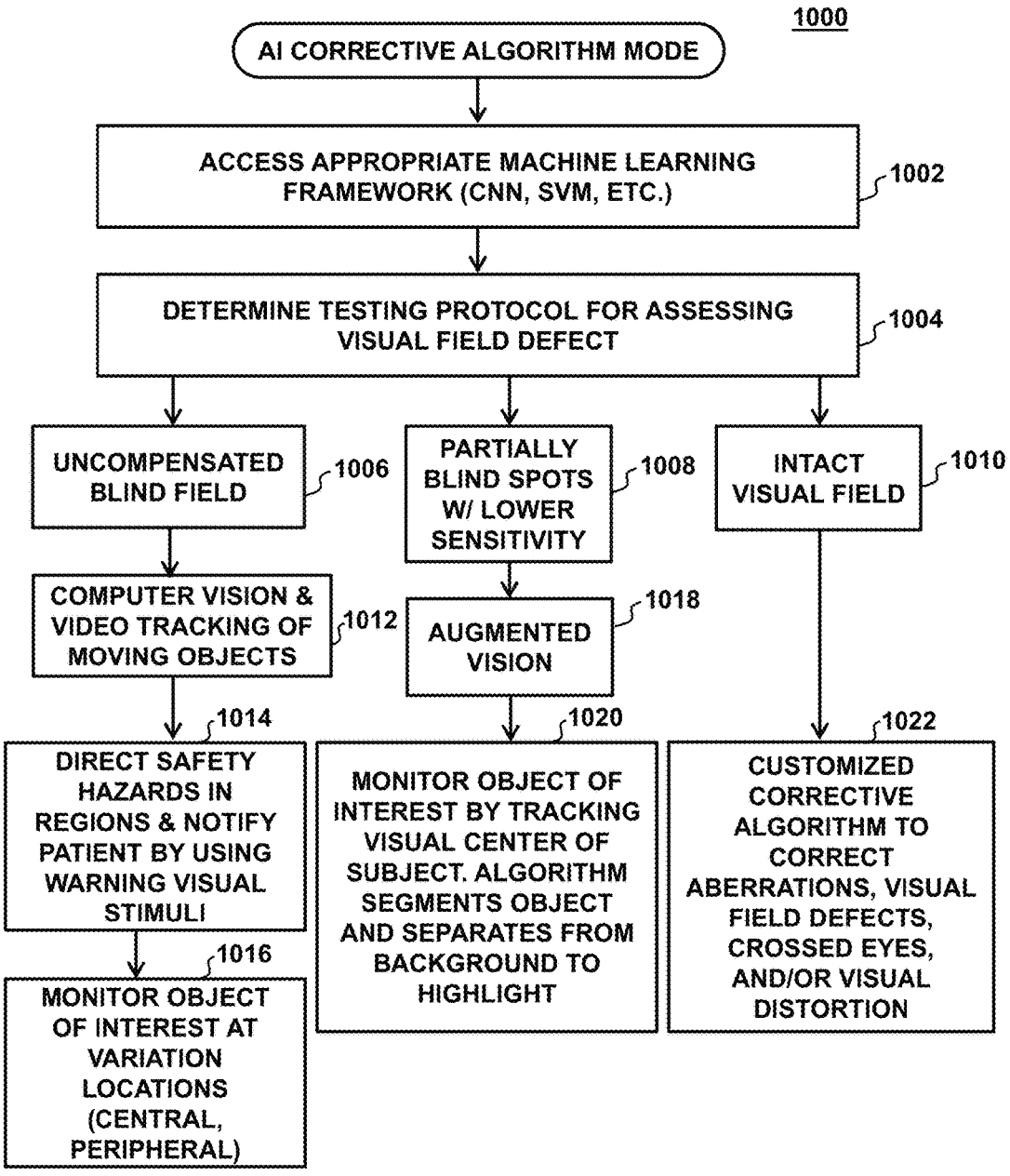

1000
AI CORRECTIVE ALGORITHM MODE
ACCESS APPROPRIATE MACHINE LEARNING FRAMEWORK (CNN, SVM, ETC.)
1002
DETERMINE TESTING PROTOCOL FOR ASSESSING VISUAL FIELD DEFECT
1004
UNCOMPENSATED BLIND FIELD
1006
PARTIALLY BLIND SPOTS W/ LOWER SENSITIVITY
1008
INTACT VISUAL FIELD
1010
COMPUTER VISION & VIDEO TRACKING OF MOVING OBJECTS
1012
AUGMENTED VISION
1018
1014
DIRECT SAFETY HAZARDS IN REGIONS & NOTIFY PATIENT BY USING WARNING VISUAL STIMULI
1020
MONITOR OBJECT OF INTEREST BY TRACKING VISUAL CENTER OF SUBJECT. ALGORITHM SEGMENTS OBJECT AND SEPARATES FROM BACKGROUND TO HIGHLIGHT
1022
CUSTOMIZED CORRECTIVE ALGORITHM TO CORRECT ABERRATIONS, VISUAL FIELD DEFECTS, CROSSED EYES, AND/OR VISUAL DISTORTION
1016
MONITOR OBJECT OF INTEREST AT VARIATION LOCATIONS (CENTRAL, PERIPHERAL)

FIG. 10

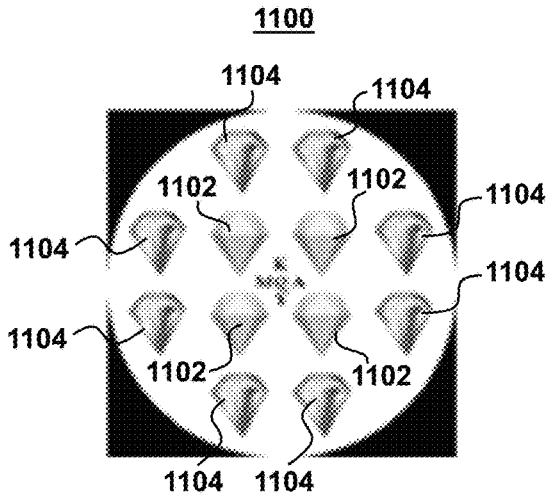

1100
1104
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FIG. 11

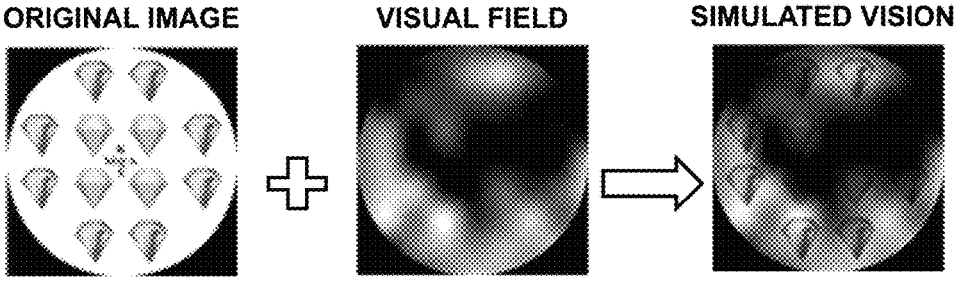
ORIGINAL IMAGE
VISUAL FIELD
SIMULATED VISION

FIG. 12

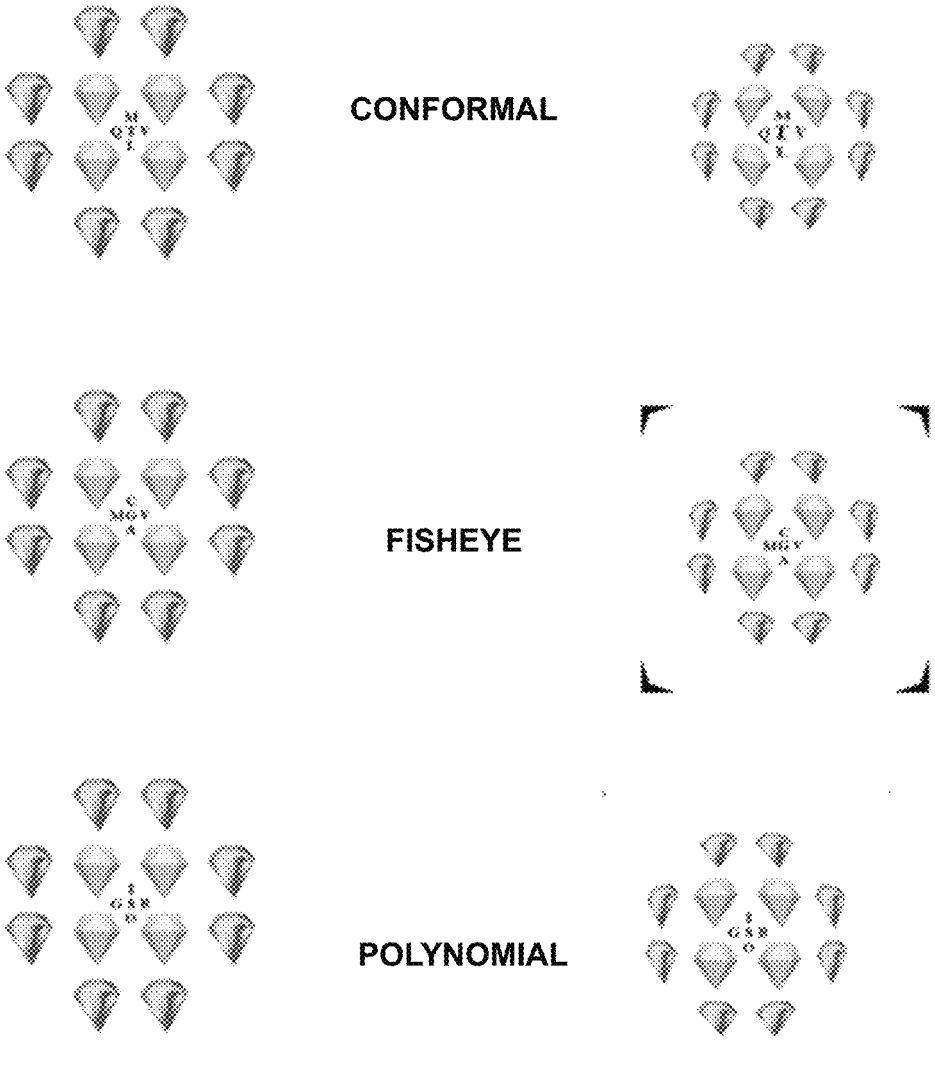

FIG. 13

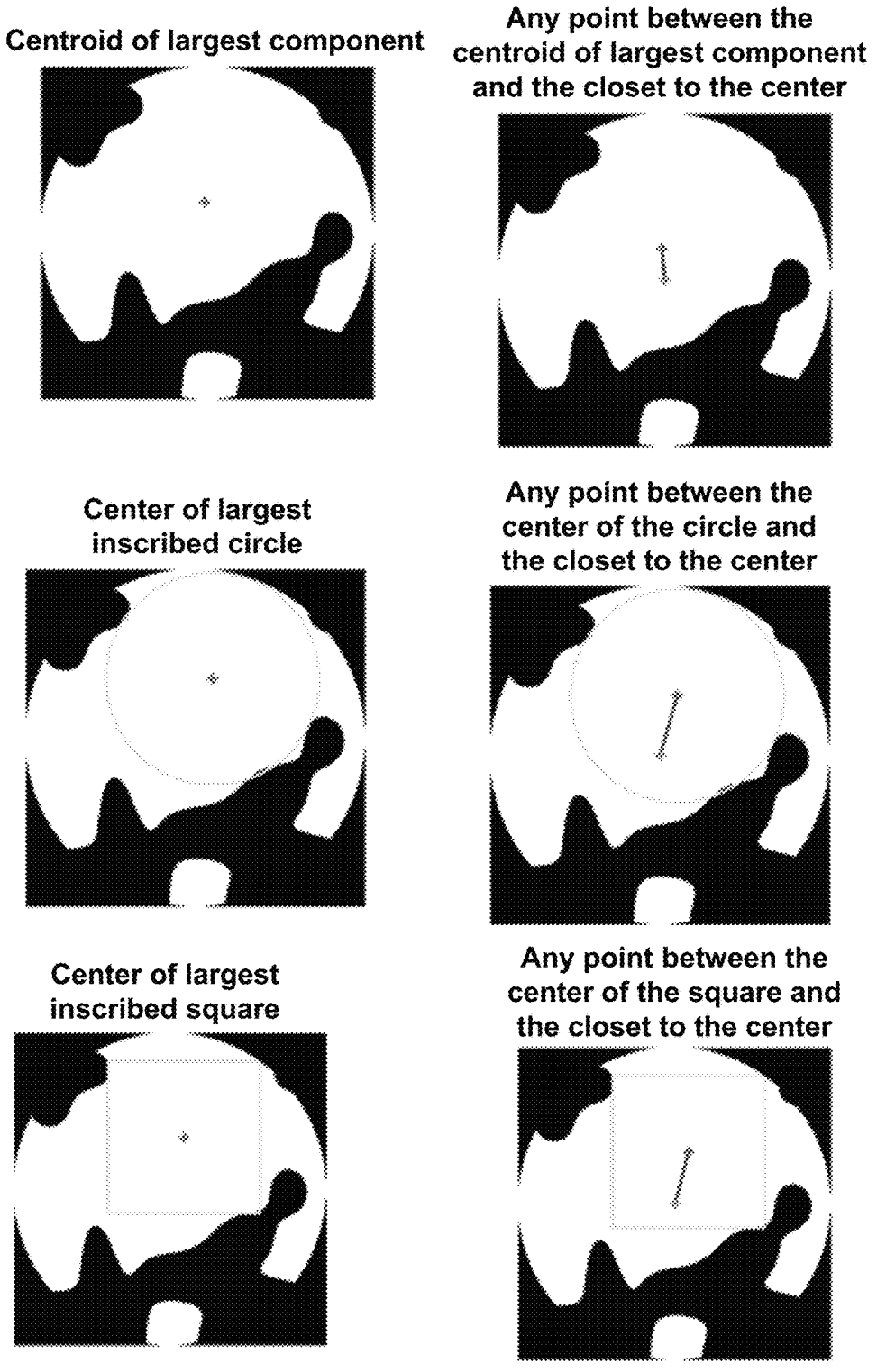
Centroid of largest component
Any point between the centroid of largest component and the closet to the center
Center of largest inscribed circle
Any point between the center of the circle and the closet to the center
Center of largest inscribed square
Any point between the center of the square and the closet to the center

FIG. 14

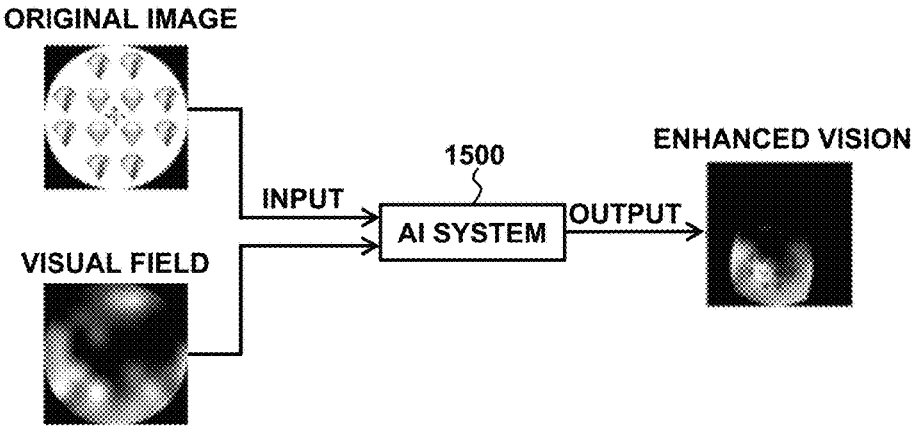
ORIGINAL IMAGE
VISUAL FIELD
INPUT
1500
AI SYSTEM
OUTPUT
ENHANCED VISION

FIG. 15

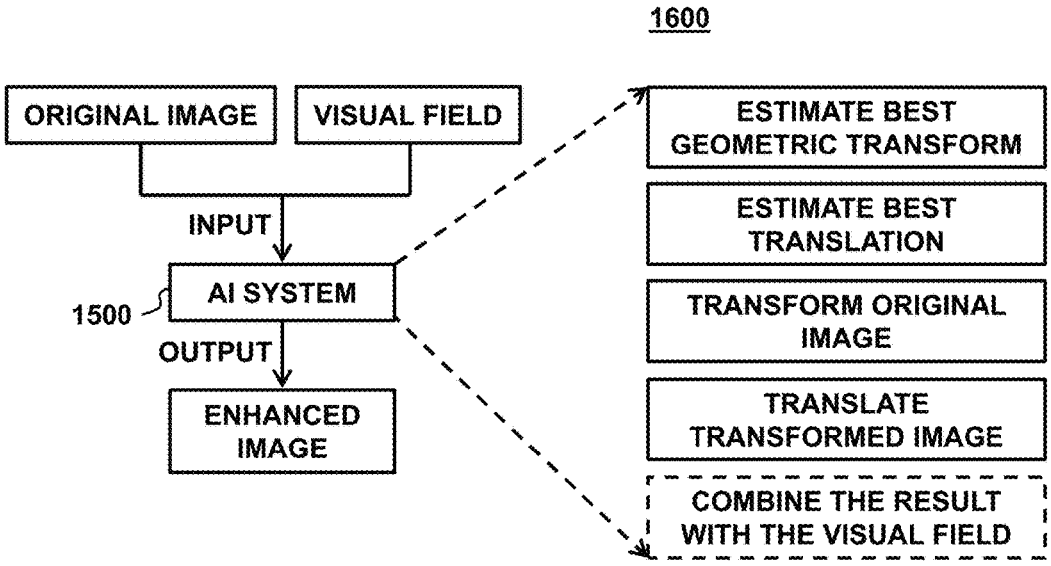
1600
ORIGINAL IMAGE
VISUAL FIELD
INPUT
1500
AI SYSTEM
OUTPUT
ENHANCED IMAGE
ESTIMATE BEST GEOMETRIC TRANSFORM
ESTIMATE BEST TRANSLATION
TRANSFORM ORIGINAL IMAGE
TRANSLATE TRANSFORMED IMAGE
COMBINE THE RESULT WITH THE VISUAL FIELD

FIG. 16

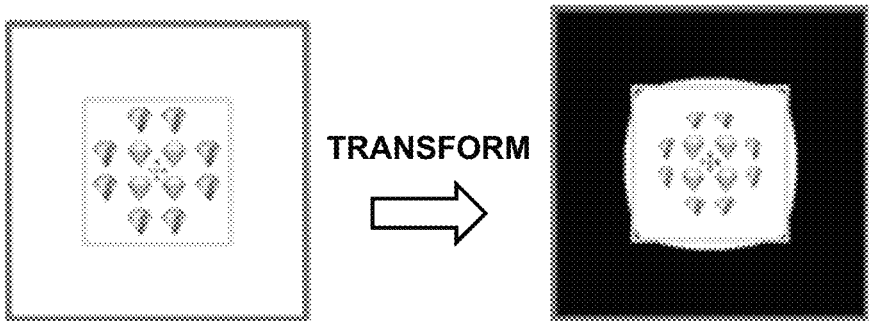

FIG. 17

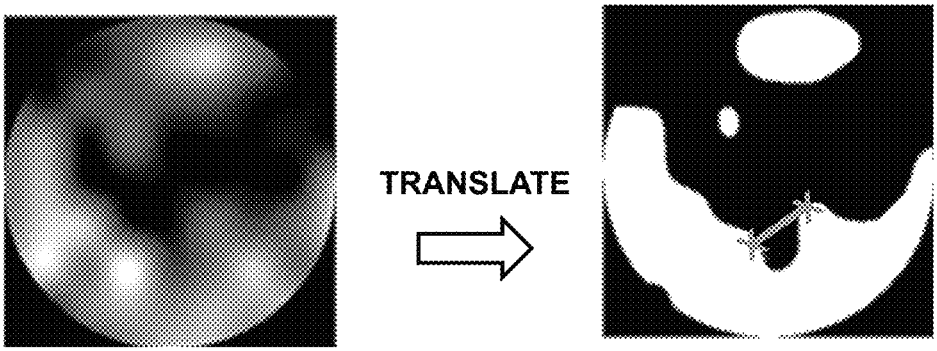

FIG. 18

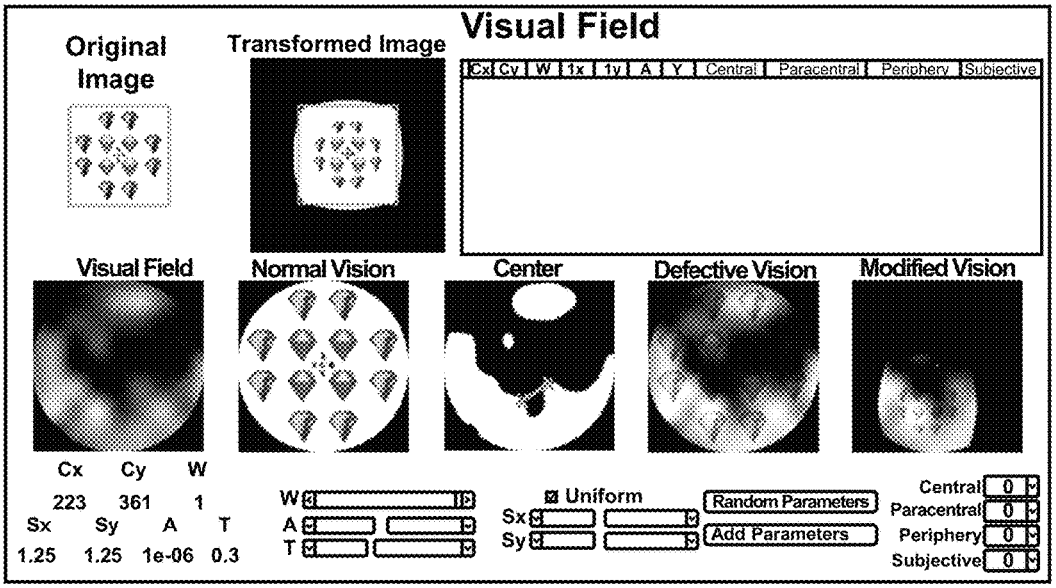
Original Image
Transformed Image
Visual Field
Cx Cy W 1x 1y A Y Central Paracentral Periphery Subjective
Visual Field
Normal Vision
Center
Defective Vision
Modified Vision
Cx Cy W
223 361 1
Sx Sy A T
1.25 1.25 1e-06 0.3
W
A
T
Uniform
Sx
Sy
Random Parameters
Add Parameters
Central 0
Paracentral 0
Periphery 0
Subjective 0

FIG. 19

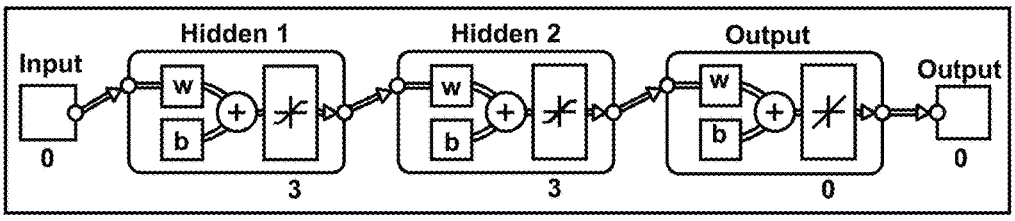

FIG. 20

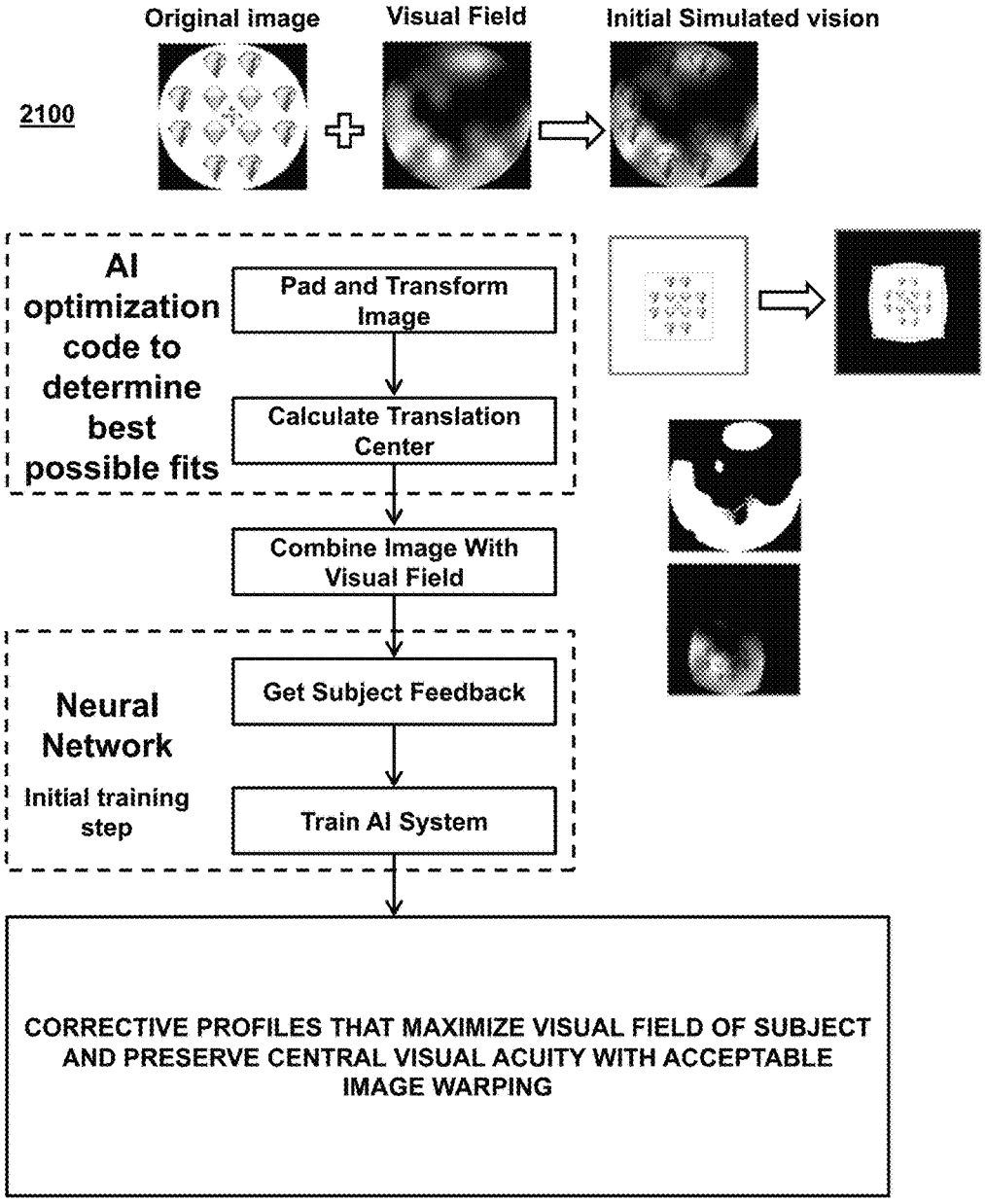
2100
Original image
Visual Field
Initial Simulated vision
AI optimization code to determine best possible fits
Pad and Transform Image
Calculate Translation Center
Combine Image With Visual Field
Neural Network
Initial training step
Get Subject Feedback
Train AI System
CORRECTIVE PROFILES THAT MAXIMIZE VISUAL FIELD OF SUBJECT AND PRESERVE CENTRAL VISUAL ACUITY WITH ACCEPTABLE IMAGE WARPING

FIG. 21

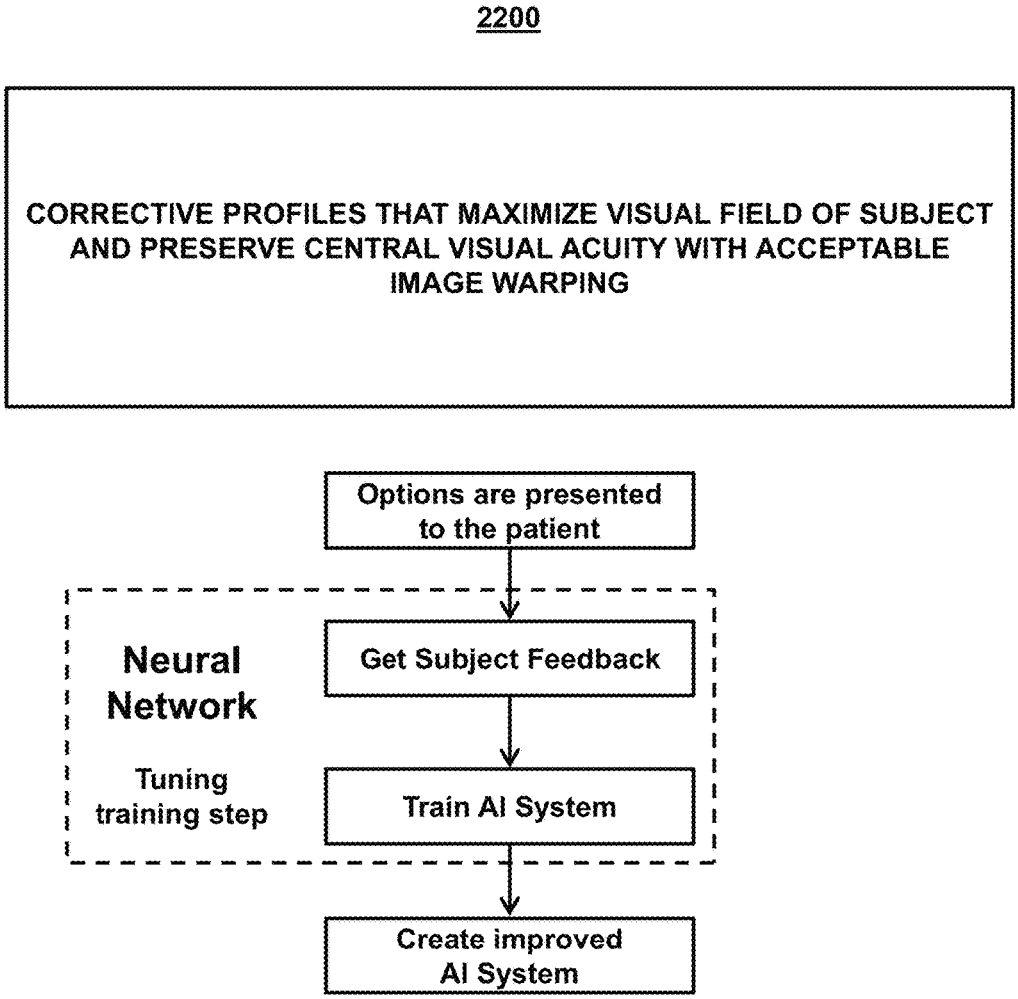
2200
CORRECTIVE PROFILES THAT MAXIMIZE VISUAL FIELD OF SUBJECT AND PRESERVE CENTRAL VISUAL ACUITY WITH ACCEPTABLE IMAGE WARPING
Options are presented to the patient
Neural Network
Tuning training step
Get Subject Feedback
Train AI System
Create improved AI System

FIG. 22

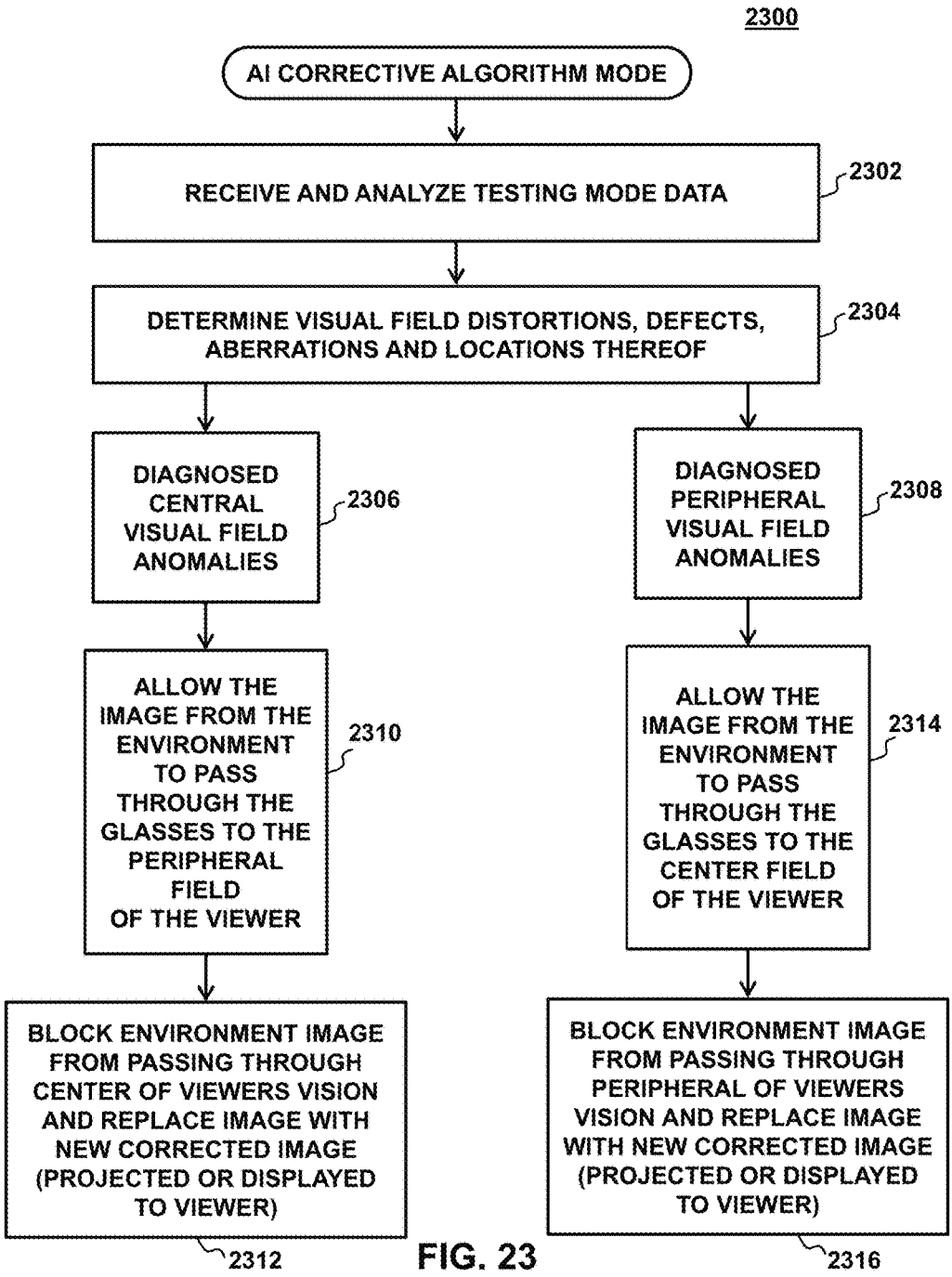
2300
AI CORRECTIVE ALGORITHM MODE
RECEIVE AND ANALYZE TESTING MODE DATA
2302
DETERMINE VISUAL FIELD DISTORTIONS, DEFECTS, ABERRATIONS AND LOCATIONS THEREOF
2304
DIAGNOSED CENTRAL VISUAL FIELD ANOMALIES
2306
DIAGNOSED PERIPHERAL VISUAL FIELD ANOMALIES
2308
ALLOW THE IMAGE FROM THE ENVIRONMENT TO PASS THROUGH THE GLASSES TO THE PERIPHERAL FIELD OF THE VIEWER
2310
ALLOW THE IMAGE FROM THE ENVIRONMENT TO PASS THROUGH THE GLASSES TO THE CENTER FIELD OF THE VIEWER
2314
BLOCK ENVIRONMENT IMAGE FROM PASSING THROUGH CENTER OF VIEWERS VISION AND REPLACE IMAGE WITH NEW CORRECTED IMAGE (PROJECTED OR DISPLAYED TO VIEWER)
2312
BLOCK ENVIRONMENT IMAGE FROM PASSING THROUGH PERIPHERAL OF VIEWERS VISION AND REPLACE IMAGE WITH NEW CORRECTED IMAGE (PROJECTED OR DISPLAYED TO VIEWER)
2316

FIG. 23

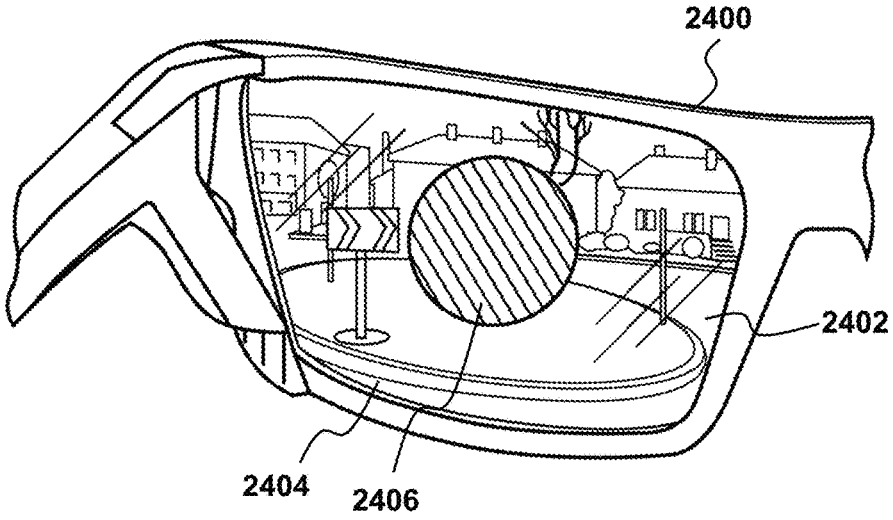

FIG. 24A

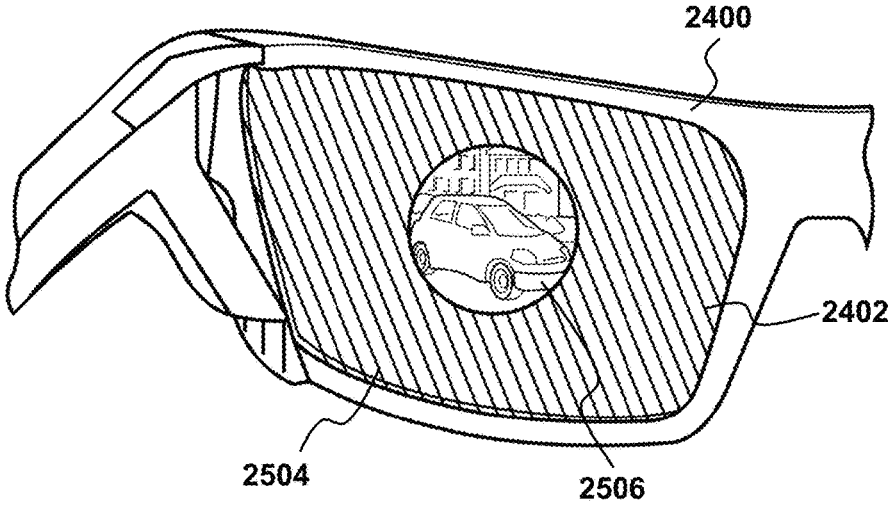

FIG. 24B

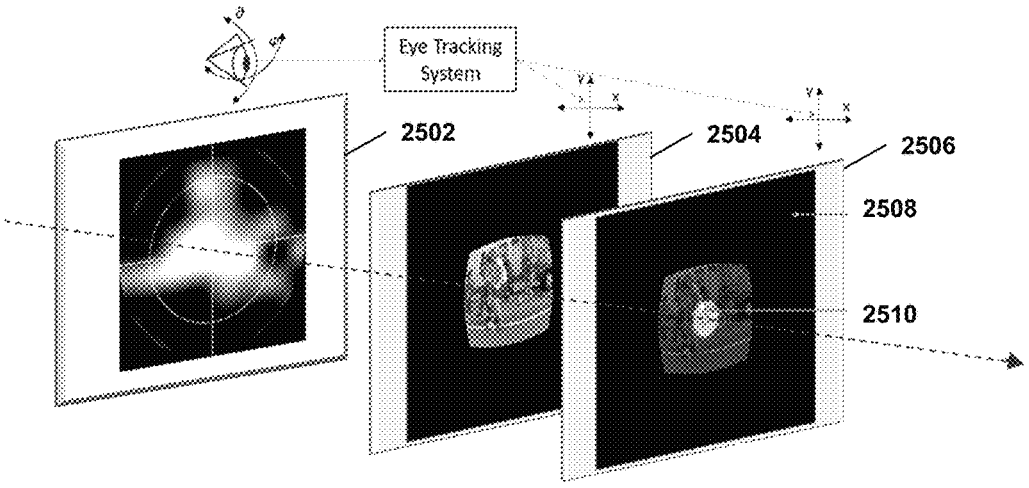

FIG. 25

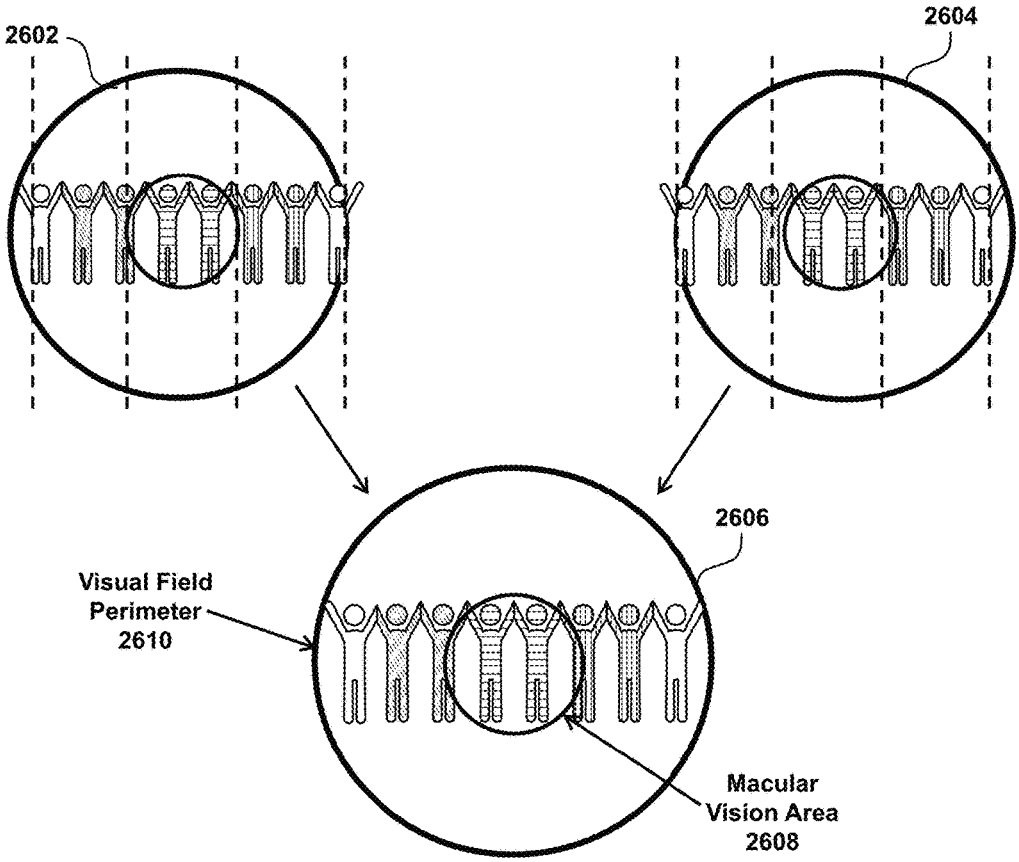
2602
2604
2606
Visual Field
Perimeter
2610
Macular
Vision Area
2608

FIG. 26

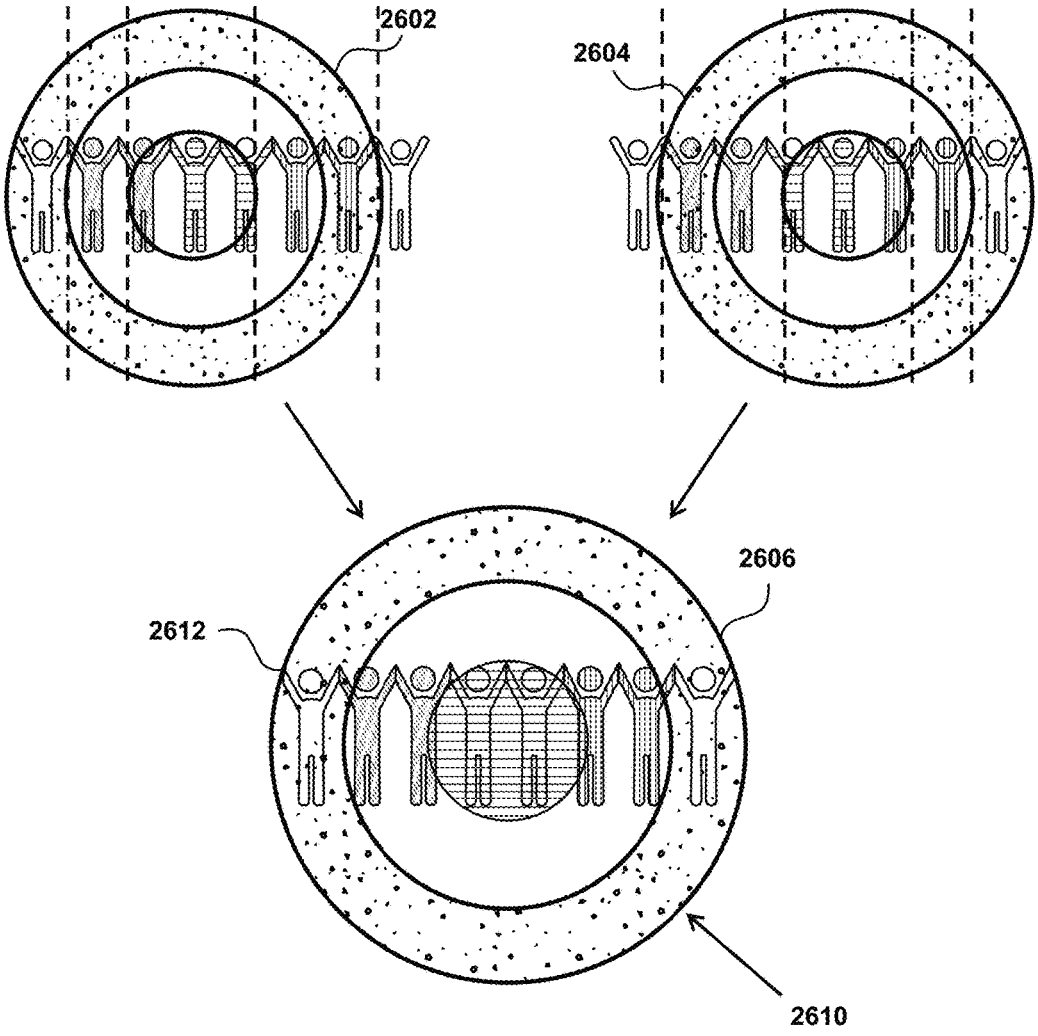

FIG. 27

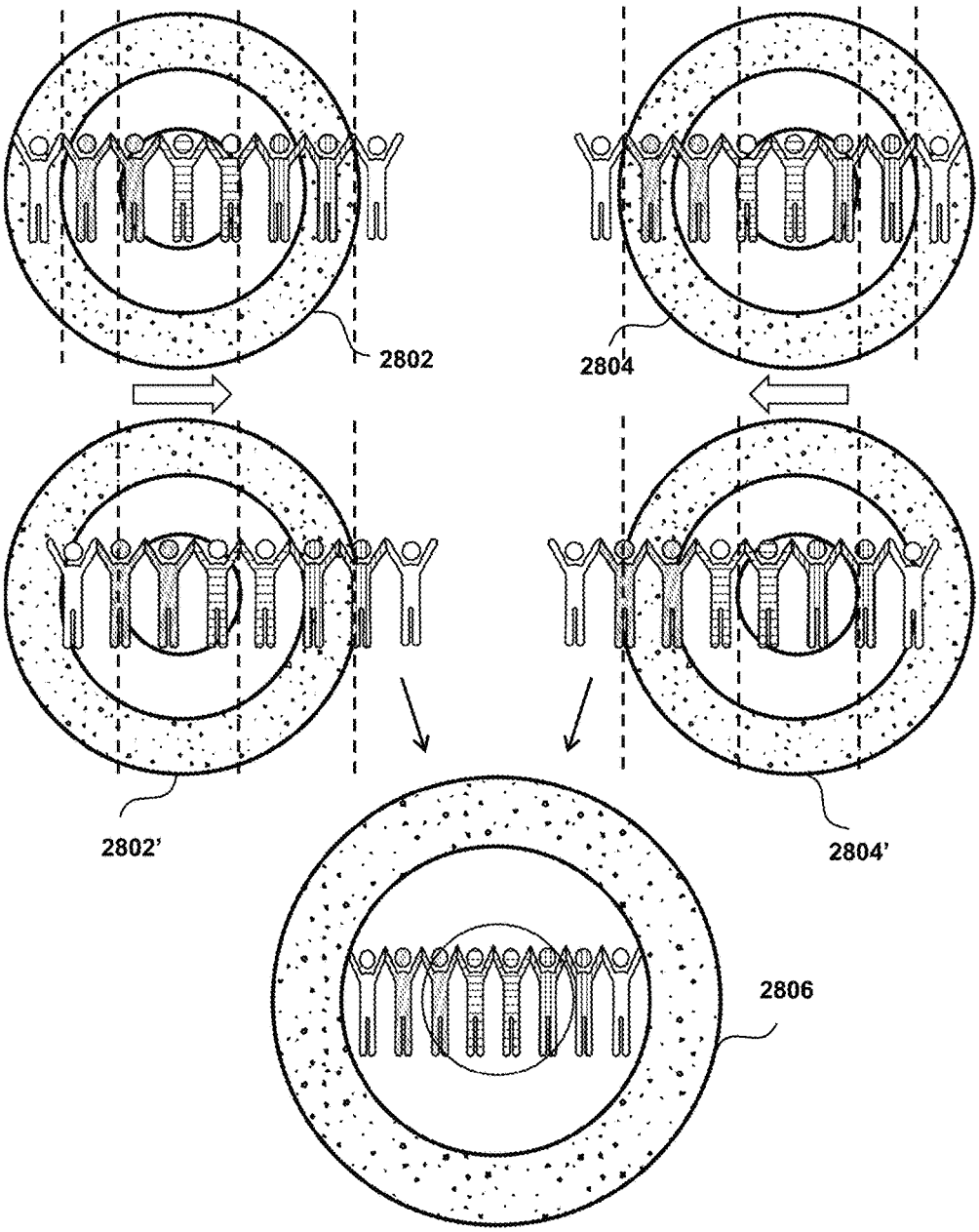

FIG. 28

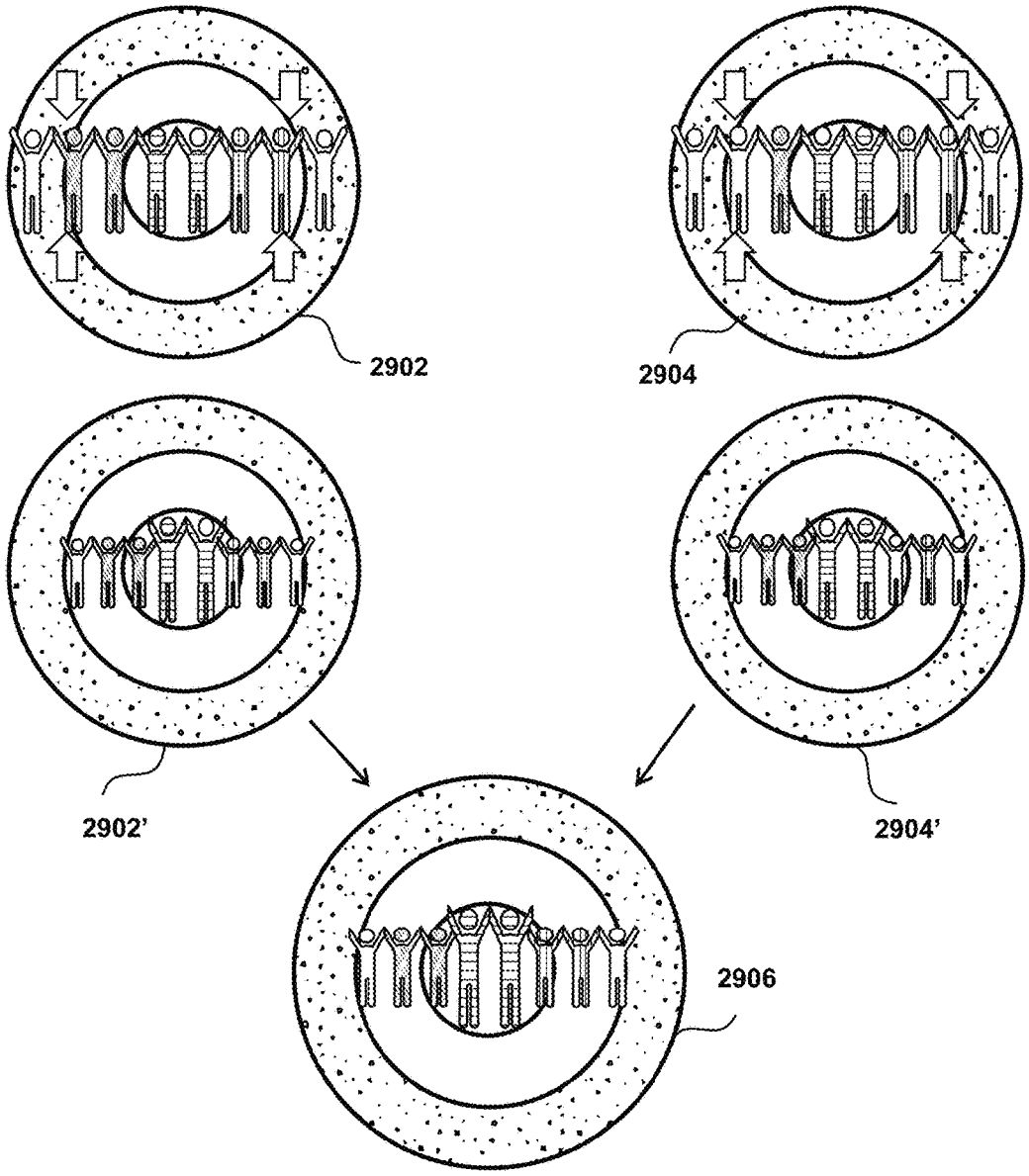

FIG. 29

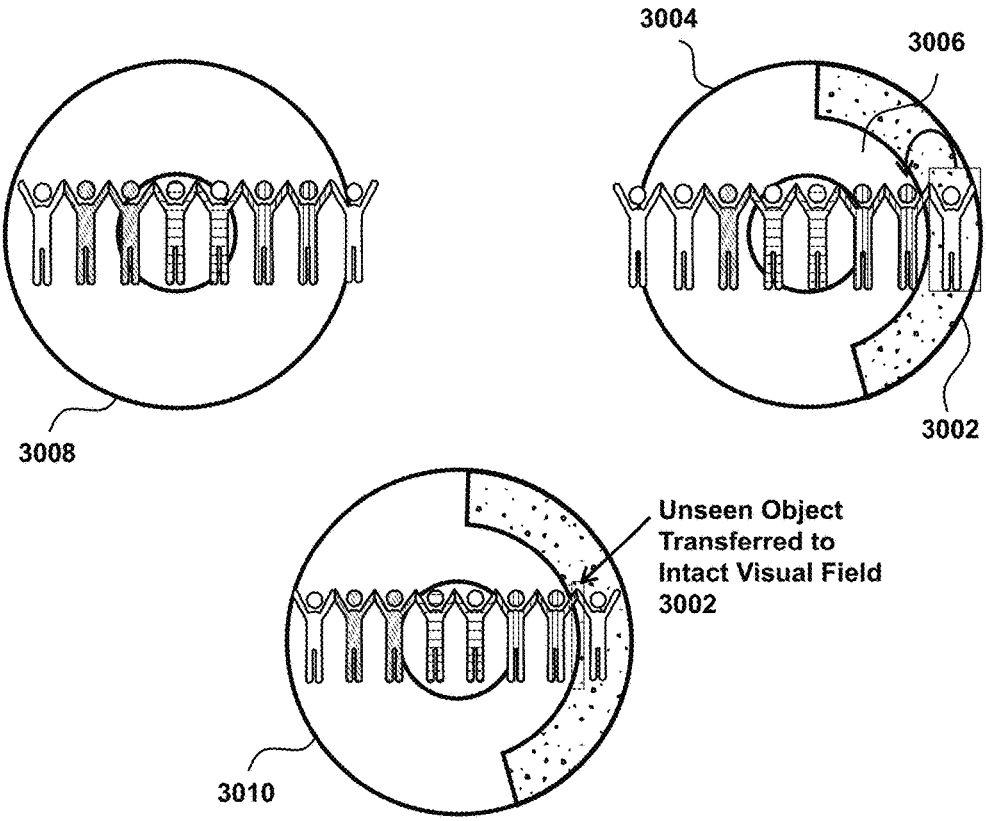
3004
3006
3008
3002
Unseen Object
Transferred to
Intact Visual Field
3002
3010

FIG. 30

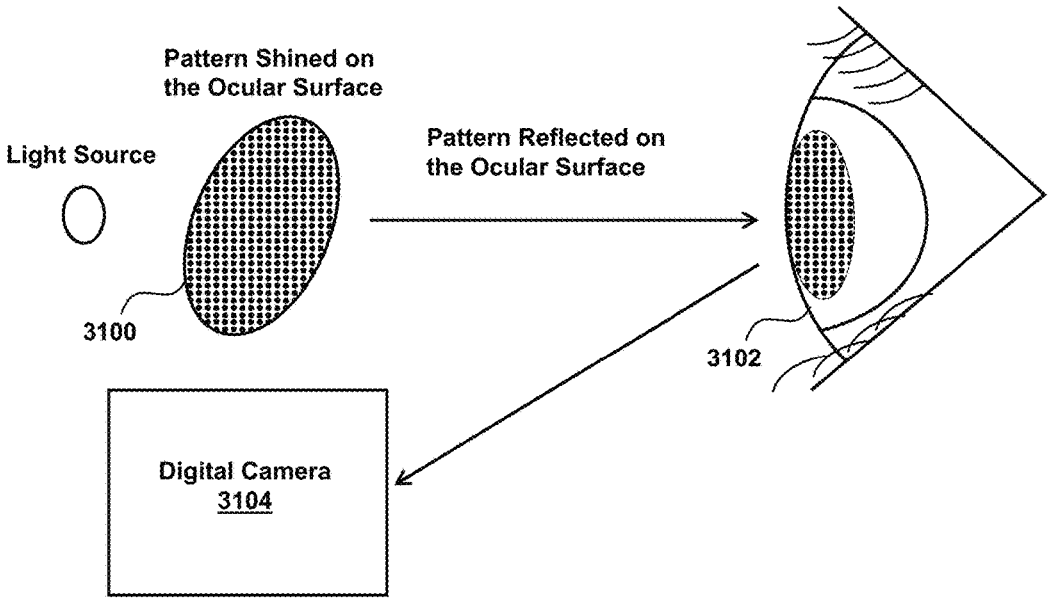
Pattern Shined on
the Ocular Surface
Light Source
Pattern Reflected on
the Ocular Surface
3100
3102
Digital Camera
3104

FIG. 31A

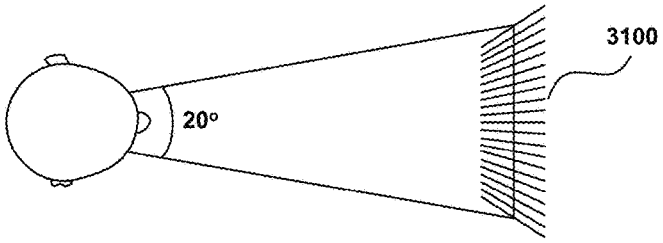

FIG. 31B

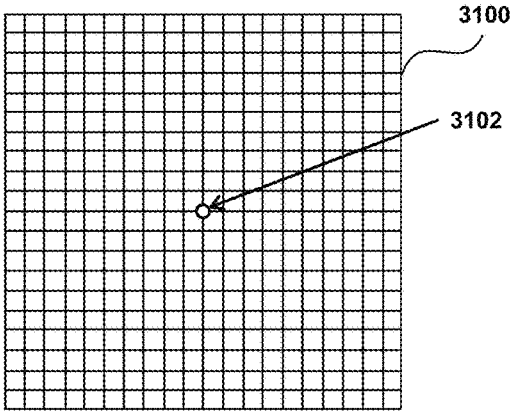

FIG. 31C

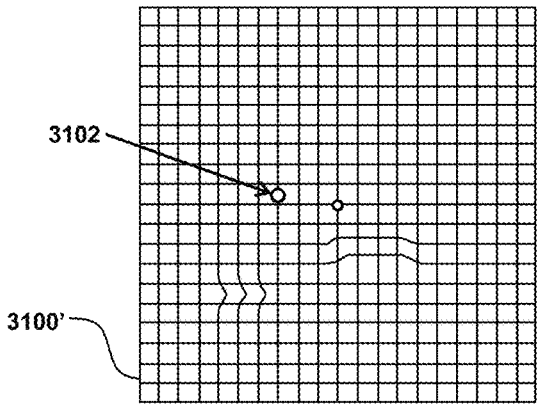

FIG. 31D

FIG. 31E

FIG. 31F

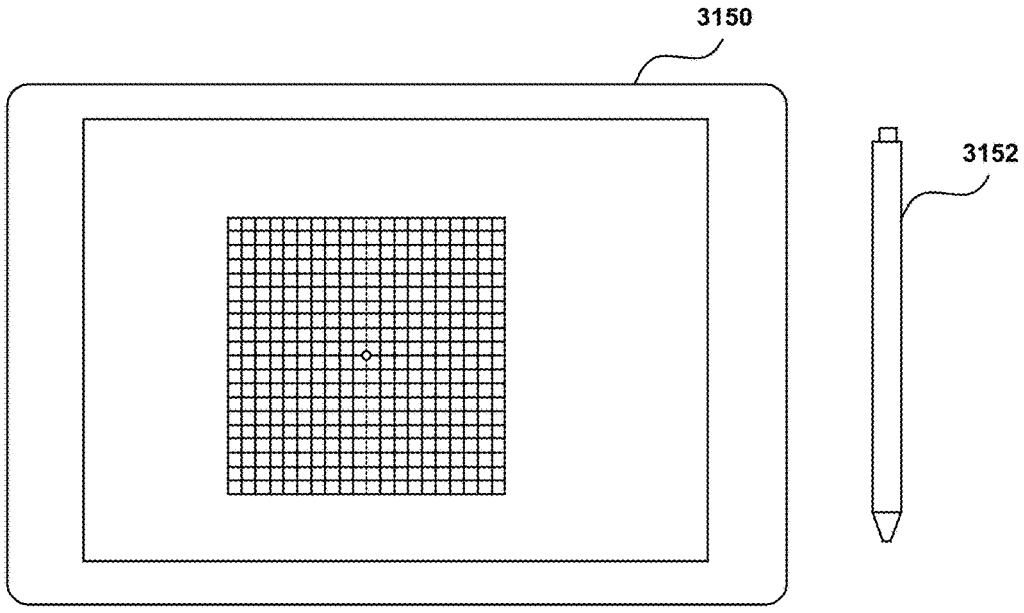

FIG. 31G

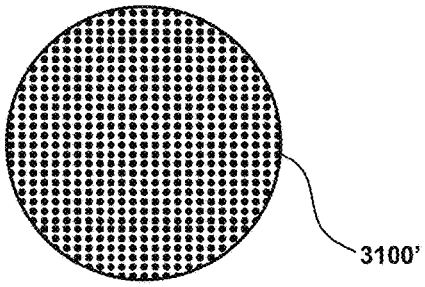

FIG. 33

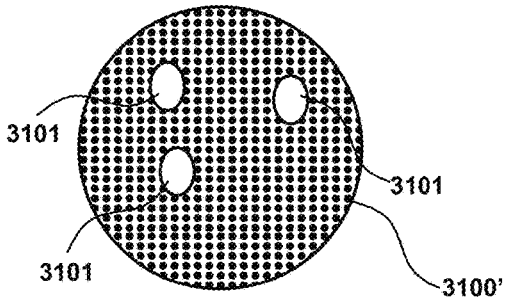

FIG. 34

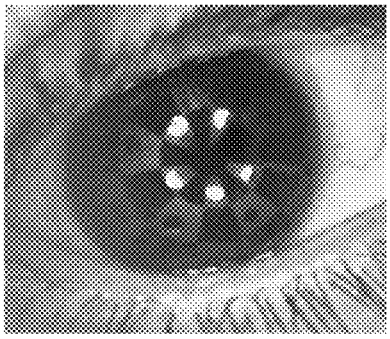

FIG. 32

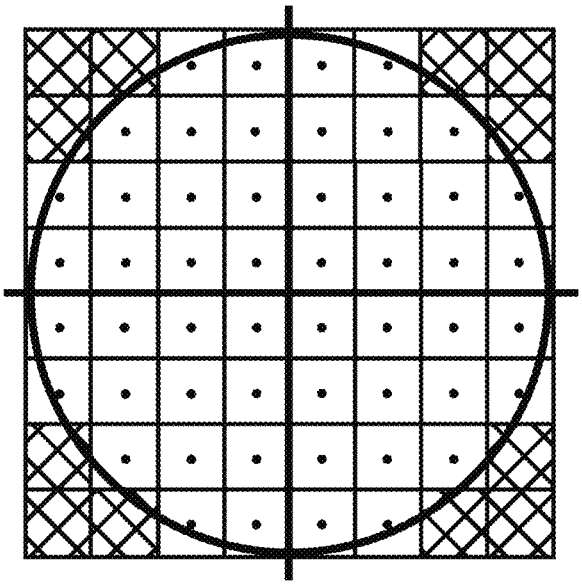

FIG. 35

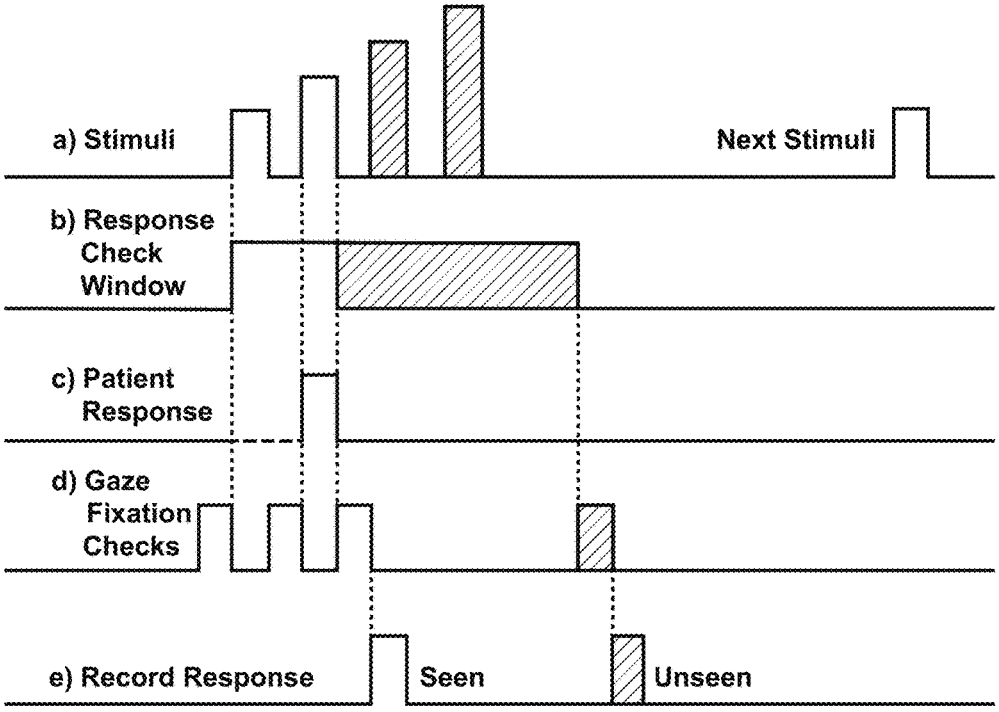
a) Stimuli
Next Stimuli
b) Response Check Window
c) Patient Response
d) Gaze Fixation Checks
e) Record Response
Seen
Unseen

FIG. 36

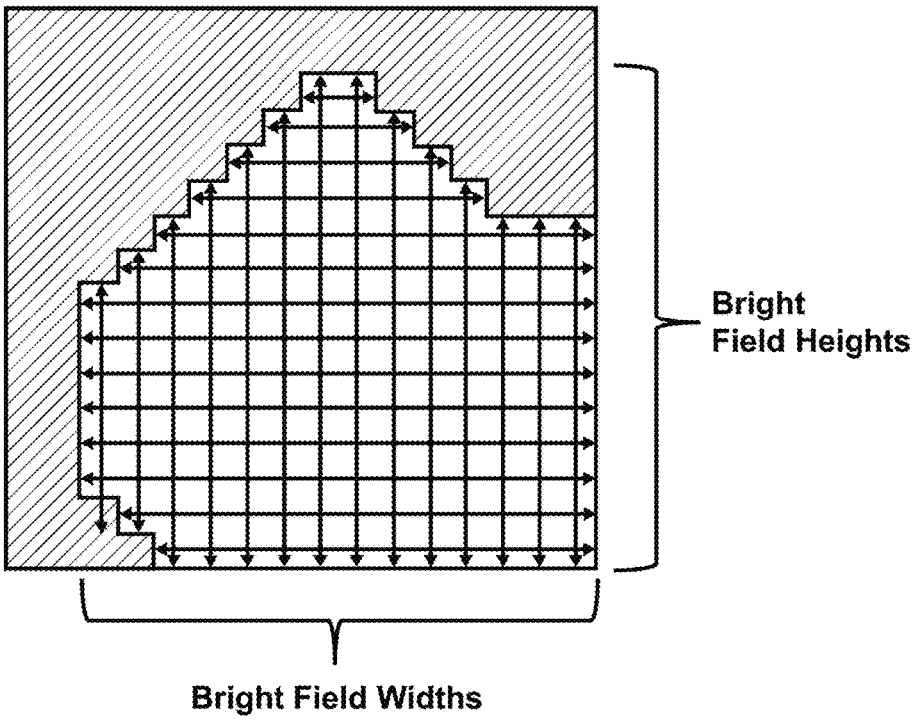

FIG. 37

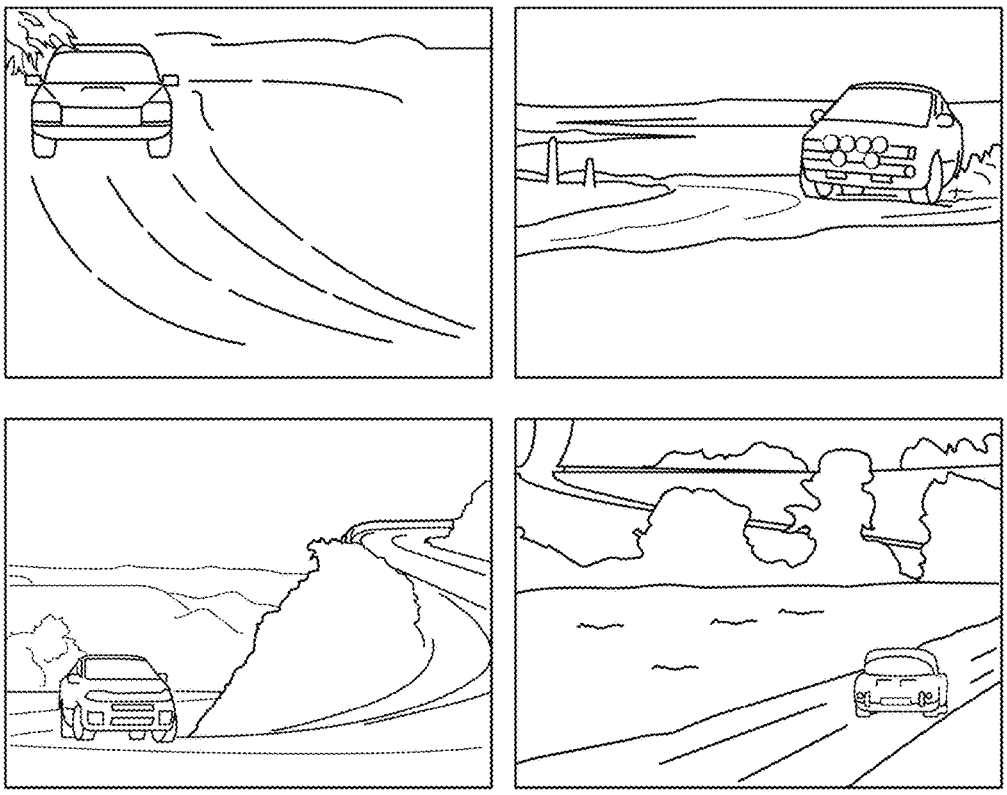

FIG. 38

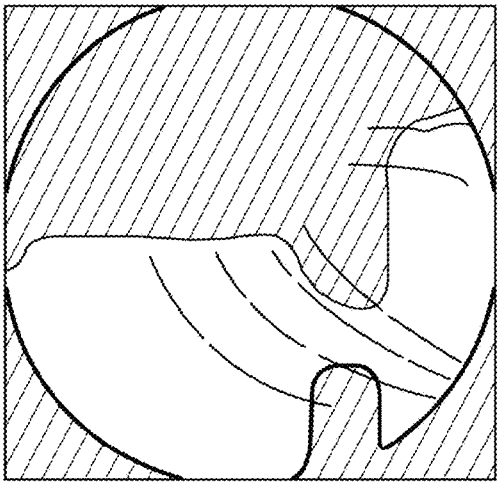

FIG. 39A

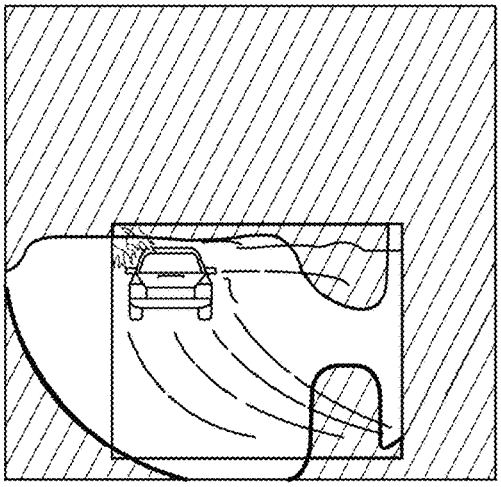

FIG. 39B

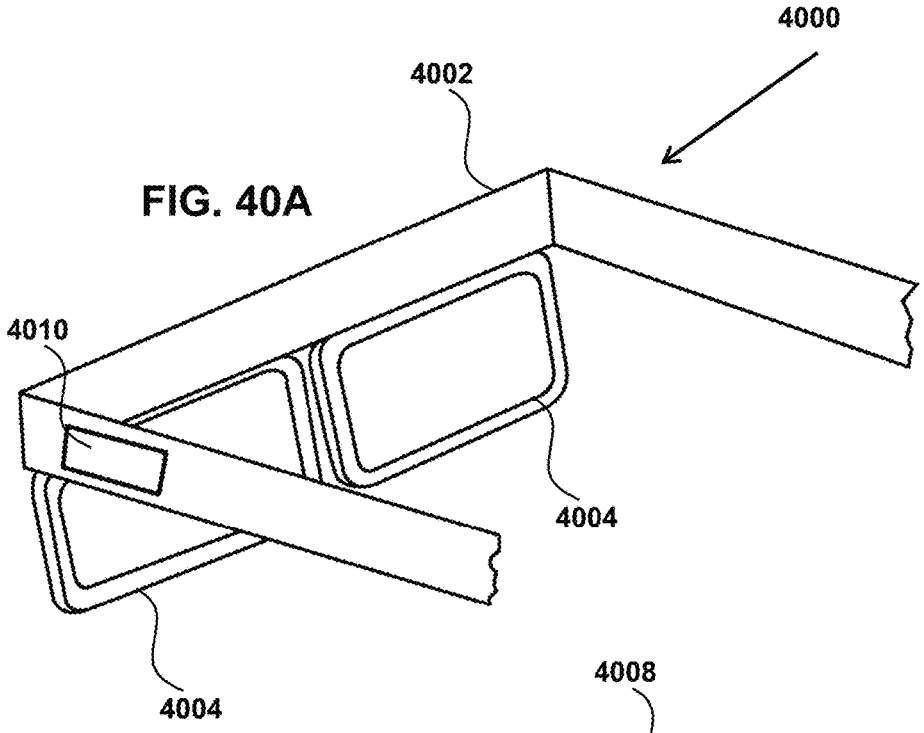

FIG. 40A

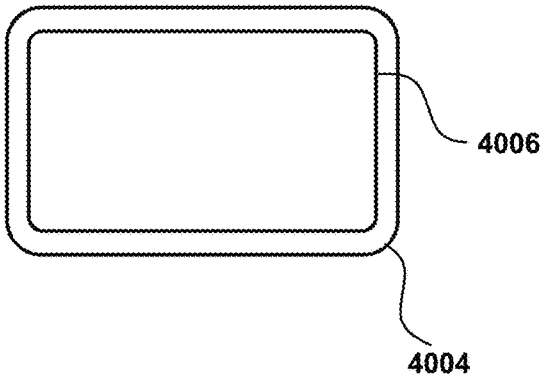

FIG. 40B

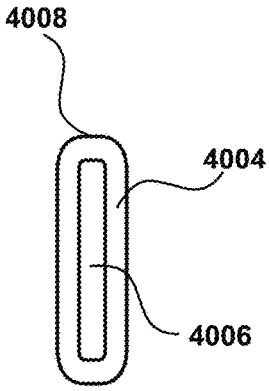

FIG. 40C

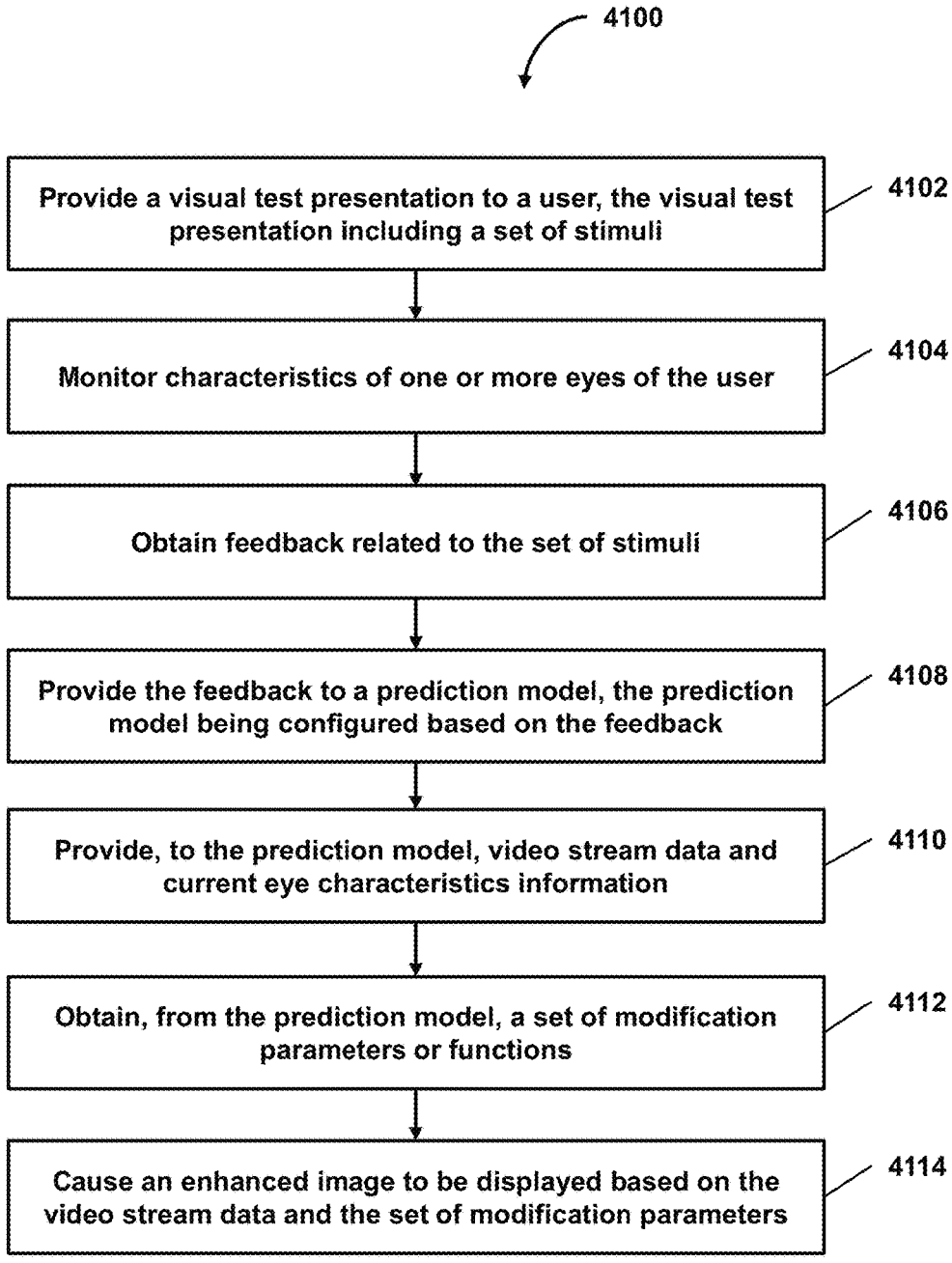
4100
Provide a visual test presentation to a user, the visual test presentation including a set of stimuli
4102
Monitor characteristics of one or more eyes of the user
4104
Obtain feedback related to the set of stimuli
4106
Provide the feedback to a prediction model, the prediction model being configured based on the feedback
4108
Provide, to the prediction model, video stream data and current eye characteristics information
4110
Obtain, from the prediction model, a set of modification parameters or functions
4112
Cause an enhanced image to be displayed based on the video stream data and the set of modification parameters
4114

FIG. 41

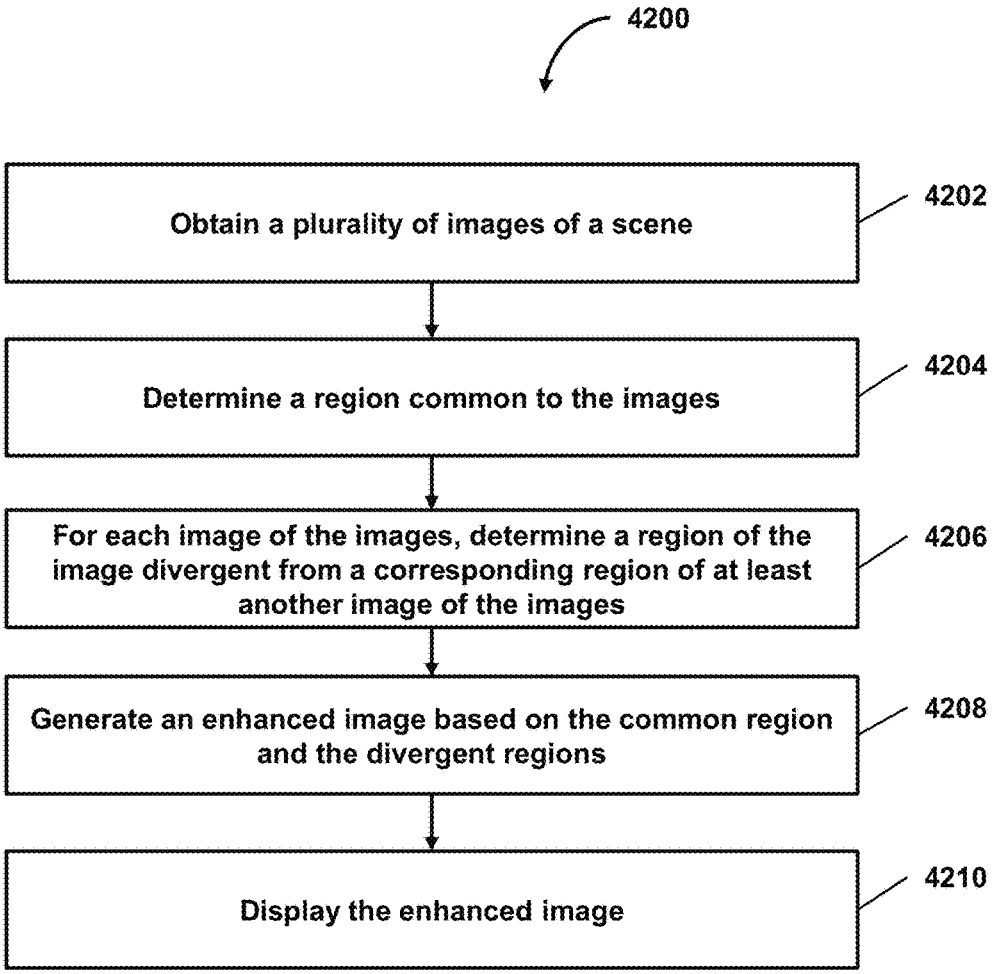
4200
Obtain a plurality of images of a scene
4202
Determine a region common to the images
4204
For each image of the images, determine a region of the image divergent from a corresponding region of at least another image of the images
4206
Generate an enhanced image based on the common region and the divergent regions
4208
Display the enhanced image
4210

FIG. 42

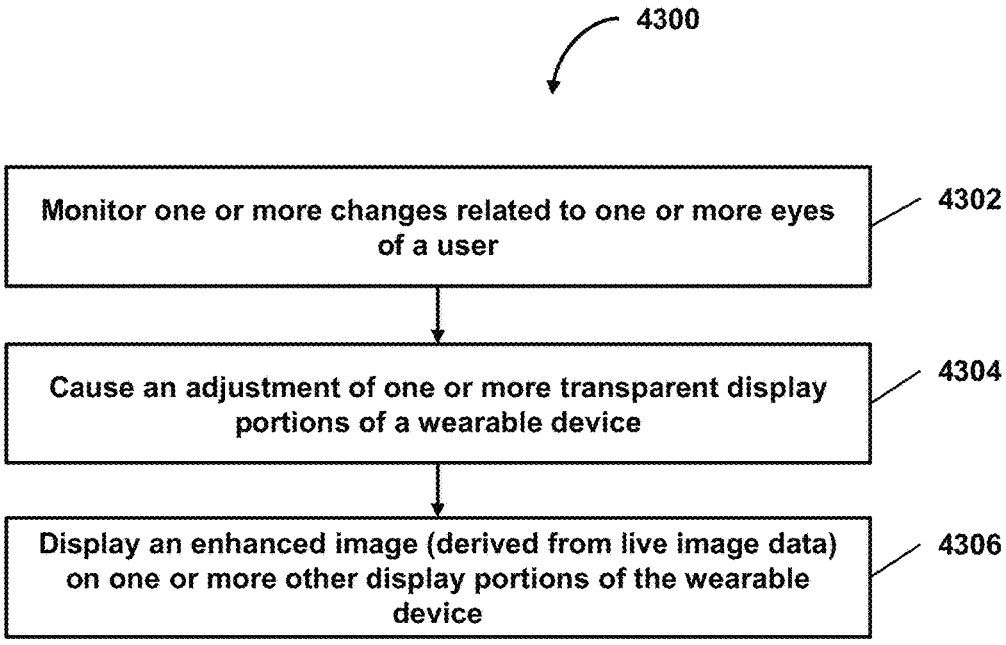
4300
Monitor one or more changes related to one or more eyes of a user
4302
Cause an adjustment of one or more transparent display portions of a wearable device
4304
Display an enhanced image (derived from live image data) on one or more other display portions of the wearable device
4306

FIG. 43

VISUAL ENHANCEMENT FOR DYNAMIC VISION DEFECTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. application Ser. No. 16/144,995, entitled "Digital Therapeutic Corrective Spectacles," filed Sep. 27, 2018, which claims the benefit of U.S. Provisional Application No. 62/563,770, entitled "Digital Therapeutic Corrective Spectacles," filed on Sep. 27, 2017, each of which is hereby incorporated by reference herein in its entirety.

This application is also related to (i) U.S. application Ser. No. 16/367,633, entitled "Vision Defect Determination and Enhancement," filed on even date herewith and (ii) U.S. application Ser. No. 16/367,751, entitled "Field of View Enhancement via Dynamic Display Portions," filed on even date herewith, each of which is also hereby incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

The invention relates to facilitating modification related to a vision of a user, including, for example, providing enhancement of a visual field or vision of the user via a wearable device.

BACKGROUND OF THE INVENTION

Although "smart glasses" and other wearable technologies to assist the visually impaired exist, typical wearable technologies do not adequately address a number of issues associated with traditional glasses and contact lenses. For example, typical wearable technologies fail to address issues faced by individuals who have higher order visual aberrations (e.g., errors of refraction that are not correctable by traditional glasses or contact lenses) or dynamic aberrations, which can change in relation the accommodation state of the eye and direction of gaze. These and other drawbacks exist.

SUMMARY OF THE INVENTION

Aspects of the invention relate to methods, apparatuses, and/or systems for facilitating modification related to a vision of a user, including, for example, providing enhancement of a visual field or vision of the user (e.g., correcting the visual field or vision of the user, augmenting the visual field or vision of the user, etc.), providing correction of visual aberrations of the user, or providing such enhancement or correction via a wearable device.

In some embodiments, feedback related to a set of stimuli displayed to a user may be obtained and used to determine one or more defective visual field portions of a user's visual field. In some embodiments, system **100** may provide an enhanced image or adjust one or more configurations of a wearable device based on the defective visual field portions. As an example, the feedback may include (i) an indication of a response of the user to one or more stimuli (e.g., an eye movement, a gaze direction, a pupil size change, etc.), (ii) an indication of a lack of response of the user to such stimuli, (iii) an eye image captured during the display of the stimuli (e.g., an image of a retina of the eye, an image of a cornea of the eye), or other feedback. As another example, an enhanced image (e.g., derived from live image data) may be generated or displayed to the user such that one or more given portions of the enhanced image (e.g., a region of the enhanced image that corresponds to a macular region of the visual field of an eye of the user or to a region within the macular region of the eye) are outside of the defective visual field portions. As another example, a position, shape, or size of one or more display portions of the wearable device, a brightness, contrast, saturation, or sharpness level of such display portions, a transparency of such display portions, or other configuration of the wearable device may be adjusted based on the determined defective visual field portions.

In some embodiments, enhancement of a field of view of a user may be facilitated via one or more dynamic display portions (e.g., transparent display portions on a transparent display, projecting portions of a projector, etc.). As an example, with respect to a transparent display, the dynamic display portions may include one or more transparent display portions and one or more other display portions (e.g., of a wearable device or other device). As an example, a user may see through the transparent display portions of a transparent display, but may not be able to see through the other display portions and instead sees the image presentation on the other display portions (e.g., around or proximate the transparent display portions) of the transparent display. In some embodiments, one or more changes related to one or more eyes of the user may be monitored, and the transparent display portions may be adjusted based on the monitoring. As an example, the monitored changes may include an eye movement, a change in gaze direction, a pupil size change, or other changes. One or more positions, shapes, sizes, transparencies, or other aspects of the transparent display portions may be automatically adjusted based on the monitored changes.

Various other aspects, features, and advantages of the invention will be apparent through the detailed description of the invention and the drawings attached hereto. It is also to be understood that both the foregoing general description and the following detailed description are exemplary and not restrictive of the scope of the invention. As used in the specification and in the claims, the singular forms of "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. In addition, as used in the specification and the claims, the term "or" means "and/or" unless the context clearly dictates otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a system for facilitating modification related to a vision of a user, in accordance with one or more embodiments.

FIG. **1**B illustrates a system implementing a machine learning model to facilitate modification related to a vision of a user, in accordance with one or more embodiments.

FIGS. **1**C-**1**F illustrate views of example spectacles devices, in accordance with one or more embodiments.

FIG. **2** illustrates an example vision system, in accordance with one or more embodiments.

FIG. **3** illustrates a device with a vision correction framework implemented on an image processing device and a wearable spectacles device, in accordance with one or more embodiments.

FIG. **4** illustrates an example process including a testing mode and a visioning mode, in accordance with one or more embodiments.

FIG. **5** illustrates an example process including a testing mode and a visioning mode, in accordance with one or more embodiments.

FIGS. **6**A-**6**C illustrate an example assessment protocol for a testing mode process including pupil tracking, in accordance with one or more embodiments.

FIGS. **7**A-**7**C illustrate an example assessment protocol for a testing mode process including pupil tracking, in accordance with one or more embodiments.

FIG. **8** illustrates a workflow including a testing module that generates and presents a plurality of visual stimuli to a user through a wearable spectacles device, in accordance with one or more embodiments.

FIG. **9** illustrates a testing mode process, in accordance with one or more embodiments.

FIG. **10** illustrates a process for an artificial intelligence corrective algorithm mode that may be implemented as part of the testing mode, in accordance with one or more embodiments.

FIG. **11** illustrates a test image, in accordance with one or more embodiments.

FIG. **12** illustrates development of a simulated vision image including overlaying an impaired visual field on a test image for presentation to a subject, in accordance with one or more embodiments.

FIG. **13** illustrates examples of different correction transformations that may be applied to an image and presented to a subject, in accordance with one or more embodiments.

FIG. **14** illustrates example translation methods, in accordance with one or more embodiments.

FIG. **15** illustrates an example of a machine learning framework, in accordance with one or more embodiments.

FIG. **16** illustrates a process of an AI system of a machine learning framework, in accordance with one or more embodiments.

FIG. **17** illustrates an example transformation of a test image, in accordance with one or more embodiments.

FIG. **18** illustrates an example translation of a test image, in accordance with one or more embodiments.

FIG. **19** is a graphical user interface illustrating various aspects of an implementation of an AI system, in accordance with one or more embodiments.

FIG. **20** illustrates a framework for an AI system including a feed-forward neural network, in accordance with one or more embodiments.

FIGS. **21**-**22** illustrate example testing mode processes of an AI system including an neural network and an AI algorithm optimization process, respectively, in accordance with one or more embodiments.

FIG. **23** illustrates an example process implementing testing and visioning modes, in accordance with one or more embodiments.

FIG. **24**A illustrates a wearable spectacles device comprising custom reality wearable spectacles that allow an image from the environment to pass through a transparent portion of the wearable spectacles' display, where the transparent portion corresponds to a peripheral region of the user's visual field, and where other portions of the wearable spectacles' display are opaque portions, in accordance with one or more embodiments.

FIG. **24**B illustrates a wearable spectacles device comprising custom reality wearable spectacles that allow an image from the environment to pass through a transparent portion of the wearable spectacles' display, where the transparent portion corresponds to a central region of the user's visual field, and where other portions of the wearable spectacles' display are opaque portions, in accordance with one or more embodiments.

FIG. **25** illustrates an alignment between visual field plane, a remapped image plane, and a selective transparency screen plane using eye tracking, in accordance with one or more embodiments.

FIG. **26** illustrates a normal binocular vision for a subject where a monocular image from the left eye and from the right eye are combined into a single perceived image having a macular central area and a peripheral visual field area surrounding the central area;

FIG. **27** illustrates a tunnel vision condition wherein a peripheral area is not visible to a subject;

FIG. **28** illustrates an image shifting technique to enhance vision or to correct a tunnel vision condition, in accordance with one or more embodiments.

FIG. **29** illustrates an image resizing transformation technique to enhance vision or preserve central visual acuity while expanding the visual field, in accordance with one or more embodiments.

FIG. **30** illustrates a binocular view field expansion technique, in accordance with one or more embodiments.

FIG. **31**A illustrates a technique for assessing dry eye and corneal irregularities including projecting a pattern onto the corneal surface and imaging the corneal surface reflecting the pattern, in accordance with one or more embodiments.

FIG. **31**B schematically illustrates presentation of a reference image comprising a grid displayed to a subject or projected onto a cornea or retina of the subject via wearable spectacles, in accordance with one or more embodiments.

FIG. **31**C illustrates an example grid for manipulation by a subject, in accordance with one or more embodiments.

FIG. **31**D illustrates an example manipulation of the grid illustrated in FIG. **31**C, in accordance with one or more embodiments.

FIG. **31**E illustrates a scene as it should be perceived by the subject, in accordance with one or more embodiments.

FIG. **31**F illustrates an example corrected visual field that when provided to a subject with a visual distortion determined by the grid technique results in that subject perceiving the visual field as shown FIG. **31**E, in accordance with one or more embodiments.

FIG. **31**G illustrates a display including a manipulatable grid onto which a subject may communicate distortions within a visual field, in accordance with one or more embodiments.

FIG. **32** is an image of a corneal surface reflecting a pattern projected onto the corneal surface, in accordance with one or more embodiments.

FIG. **33** illustrates an example of a normal pattern reflection, in accordance with one or more embodiments.

FIG. **34** illustrates an example of an abnormal pattern reflection, in accordance with one or more embodiments.

FIG. **35** illustrates a visual testing presentation including multiple contrast staircase stimuli and stimuli sequences at predetermined locations, in accordance with one or more embodiments.

FIG. **36** illustrates a timing diagram showing operations of a testing sequence at one stimulus location, in accordance with one or more embodiments.

FIG. **37** illustrates calculation of widths and heights of pixels bounding the largest bright field, in accordance with one or more embodiments.

FIG. **38** illustrate test images used to test four main quadrants of a visual field, in accordance with one or more embodiments.

FIG. **39**A illustrates an example visual field view prior to remapping, in accordance with one or more embodiments.

FIG. **39**B illustrates an example visual field view following remapping, in accordance with one or more embodiments.

FIGS. **40**A-**40**C illustrates an example custom reality spectacles device, in accordance with one or more embodiments.

FIG. **41** shows a flowchart of a method of facilitating modification related to a vision of a user via a prediction model, in accordance with one or more embodiments.

FIG. **42** shows a flowchart of a method of facilitating an increase in a field of view of a user via combination of portions of multiple images of a scene, in accordance with one or more embodiments.

FIG. **43** shows a flowchart of a method of facilitating enhancement of a field of view of a user via one or more dynamic display portions on one or more transparent displays, in accordance with one or more embodiments.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the embodiments of the invention. It will be appreciated, however, by those having skill in the art that the embodiments of the invention may be practiced without these specific details or with an equivalent arrangement. In other cases, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring the embodiments of the invention.

FIG. **1**A shows a system **100** for facilitating modification related to a vision of a user, in accordance with one or more embodiments. As shown in FIG. **1**A, system **100** may include server(s) **102**, client device **104** (or client devices **104***a*-**104***n*), or other components. Server **102** may include configuration subsystem **112**, model manager subsystem **114**, or other components. Client device **104** may include testing subsystem **122**, visioning subsystem **124**, or other components. Each client device **104** may include any type of mobile terminal, fixed terminal, or other device. By way of example, client device **104** may include a desktop computer, a notebook computer, a tablet computer, a smartphone, a wearable device, or other client device. Users may, for instance, utilize one or more client devices **104** to interact with one another, one or more servers, or other components of system **100**.

It should be noted that, while one or more operations are described herein as being performed by particular components of client device **104**, those operations may, in some embodiments, be performed by other components of client device **104** or other components of system **100**. As an example, while one or more operations are described herein as being performed by components of client device **104**, those operations may, in some embodiments, be performed by components of server **102**. It should also be noted that, while one or more operations are described herein as being performed by particular components of server **102**, those operations may, in some embodiments, be performed by other components of server **102** or other components of system **100**. As an example, while one or more operations are described herein as being performed by components of server **102**, those operations may, in some embodiments, be performed by components of client device **104**. It should further be noted that, although some embodiments are described herein with respect to machine learning models, other prediction models (e.g., statistical models or other analytics models) may be used in lieu of or in addition to machine learning models in other embodiments (e.g., a statistical model replacing a machine learning model and a non-statistical model replacing a non-machine-learning model in one or more embodiments).

In some embodiments, system **100** may provide a visual test presentation to a user, where the presentation including a set of stimuli (e.g., light stimuli, text, or images displayed to the user). During the presentation (or after the presentation), system **100** may obtain feedback related to the set of stimuli (e.g., feedback indicating whether or how the user sees one or more stimuli of the set). As an example, the feedback may include an indication of a response of the user to one or more stimuli (of the set of stimuli) or an indication of a lack of response of the user to such stimuli. The response (or lack thereof) may relate to an eye movement, a gaze direction, a pupil size change, or a user modification of one or more stimuli or other user input (e.g., the user's reaction or other response to the stimuli). As another example, the feedback may include an eye image captured during the visual test presentation. The eye image may be an image of a retina of the eye (e.g., the overall retina or a portion thereof), an image of a cornea of the eye (e.g., the overall cornea or a portion thereof), or other eye image.

In some embodiments, system **100** may determine one or more defective visual field portions of a visual field of a user (e.g., an automatic determination based on feedback related to a set of stimuli displayed to the user or other feedback). As an example, a defective visual field portion may be one of the visual field portions of the user's visual field that fails to satisfy one or more vision criteria (e.g., whether or an extent to which the user senses one or more stimuli, an extent of light sensitivity, distortion, or other aberration, or other criteria). In some embodiments, system **100** may provide an enhanced image or adjust one or more configurations of a wearable device based on the determination of the defective visual field portions. As an example, the enhanced image may be generated or displayed to the user such that one or more given portions of the enhanced image (e.g., a region of the enhanced image that corresponds to a macular region of the visual field of an eye of the user or to a region within the macular region of the eye) are outside of the defective visual field portion. As another example, a position, shape, or size of one or more display portions of the wearable device, a brightness, contrast, saturation, or sharpness level of such display portions, a transparency of such display portions, or other configuration of the wearable device may be adjusted based on the determined defective visual field portions.

In some embodiments, one or more prediction models may be used to facilitate determination of vision defects (e.g., light sensitivities, distortions, or other aberrations), determination of modification profiles (e.g., correction/enhancement profiles that include modification parameters or functions) to be used to correct or enhance a user's vision, generation of enhanced images (e.g., derived from live image data), or other operations. In some embodiments, the prediction models may include one or more neural networks or other machine learning models. As an example, neural networks may be based on a large collection of neural units (or artificial neurons). Neural networks may loosely mimic the manner in which a biological brain works (e.g., via large clusters of biological neurons connected by axons). Each neural unit of a neural network may be connected with many other neural units of the neural network. Such connections can be enforcing or inhibitory in their effect on the activation state of connected neural units. In some embodiments, each individual neural unit may have a summation function which

combines the values of all its inputs together. In some embodiments, each connection (or the neural unit itself) may have a threshold function such that the signal must surpass the threshold before it propagates to other neural units. These neural network systems may be self-learning and trained, rather than explicitly programmed, and can perform significantly better in certain areas of problem solving, as compared to traditional computer programs. In some embodiments, neural networks may include multiple layers (e.g., where a signal path traverses from front layers to back layers). In some embodiments, back propagation techniques may be utilized by the neural networks, where forward stimulation is used to reset weights on the "front" neural units. In some embodiments, stimulation and inhibition for neural networks may be more free-flowing, with connections interacting in a more chaotic and complex fashion.

As an example, with respect to FIG. **1**B, machine learning model **162** may take inputs **164** and provide outputs **166**. In one use case, outputs **166** may be fed back to machine learning model **162** as input to train machine learning model **162** (e.g., alone or in conjunction with user indications of the accuracy of outputs **166**, labels associated with the inputs, or with other reference feedback information). In another use case, machine learning model **162** may update its configurations (e.g., weights, biases, or other parameters) based on its assessment of its prediction (e.g., outputs **166**) and reference feedback information (e.g., user indication of accuracy, reference labels, or other information). In another use case, where machine learning model **162** is a neural network, connection weights may be adjusted to reconcile differences between the neural network's prediction and the reference feedback. In a further use case, one or more neurons (or nodes) of the neural network may require that their respective errors are sent backward through the neural network to them to facilitate the update process (e.g., backpropagation of error). Updates to the connection weights may, for example, be reflective of the magnitude of error propagated backward after a forward pass has been completed. In this way, for example, the prediction model may be trained to generate better predictions.

In some embodiments, upon obtaining feedback related to a set of stimuli (displayed to a user), feedback related to one or more eyes of the user, feedback related to an environment of the user, or other feedback, system **100** may provide the feedback to a prediction model, and the prediction model may be configured based on the feedback. As an example, the prediction model may be automatically configured for the user based on (i) an indication of a response of the user to one or more stimuli (of the set of stimuli), (ii) an indication of a lack of response of the user to such stimuli, (iii) an eye image captured during the visual test presentation, or other feedback (e.g., the prediction model may be personalized toward the user based on the feedback from the visual test presentation). As another example, the prediction model may be trained based on such feedback and other feedback from other users to improve accuracy of results provided by the prediction model. In some embodiments, upon the prediction model being configured (e.g., for the user), system **100** may provide live image data or other data to the prediction model to obtain an enhanced image (derived from the live image data) and cause the enhanced image to be displayed. As an example, a wearable device of system **100** may obtain a live video stream from one or more cameras of the wearable device and cause the enhanced image to be displayed on one or more displays of the wearable device. In some embodiments, the wearable device may obtain the enhanced image (e.g., a file or other data structure representing the enhanced image) from the prediction model. In some embodiments, the wearable device may obtain a modification profile (e.g., modification parameters or functions) from the prediction model, and generate the enhanced image based on the live video stream and the modification profile. In one use case, the modification profile may include modification parameters or functions used to generate the enhanced image from the live image data (e.g., parameters of functions used to transform or modify the live image data into the enhanced image). Additionally, or alternatively, the modification profile may include modification parameters or functions to dynamically configure one or more display portions (e.g., dynamic adjustment of transparent or opaque portions of a transparent display, dynamic adjustment of projecting portions of a projector, etc.).

In some embodiments, system **100** may facilitate enhancement of a field of view of a user via one or more dynamic display portions (e.g., transparent display portions on a transparent display, projecting portions of a projector, etc.). As an example, with respect to a transparent display, the dynamic display portions may include one or more transparent display portions and one or more other display portions (e.g., of a wearable device or other device). System **100** may cause one or more images to be displayed on the other display portions. As an example, a user may see through the transparent display portions of a transparent display, but may not be able to see through the other display portions and instead sees the image presentation on the other display portions (e.g., around or proximate the transparent display portions) of the transparent display. In one use case, live image data may be obtained via the wearable device, and an enhanced image may be generated based on the live image data and displayed on the other display portions of the wearable device. In some embodiments, system **100** may monitor one or more changes related to one or more eyes of the user and cause, based on the monitoring, an adjustment of the transparent display portions of the transparent display. As an example, the monitored changes may include an eye movement, a change in gaze direction, a pupil size change, or other changes. One or more positions, shapes, sizes, transparencies, or other aspects of the transparent display portions of the wearable device may be automatically adjusted based on the monitored changes. In this way, for example, system **100** may improve mobility without restriction (or at least reducing restrictions) on eye movements, gaze direction, pupil responses, or other changes related to the eye.

In some embodiments, system **100** may facilitate an increase in a field of view of a user via combination of portions of multiple images of a scene (e.g., based on feedback related to a set of stimuli displayed to the user or other feedback), system **100** may obtain a plurality of images of a scene. System **100** may determine a region common to the images, and, for each image of the images, determine a region of the image divergent from a corresponding region of at least another image of the images. In some embodiments, system **100** may generate or display an enhanced image to a user based on the common region and the divergent regions. As an example, the common region and the divergent regions may be combined to generate the enhanced image to include a representation of the common region and representations of the divergent regions. The common region may correspond to respective portions of the images that have the same or similar characteristics as one another, and each divergent region may correspond to a portion of one of the images that is distinct from all the other corresponding portions of the other images. In one scenario,

a distinct portion of one image may include a part of the scene that is not represented in the other images. In this way, for example, the combination of the common region and the divergent region into an enhanced image increase the field of view otherwise provided by each of the images, and the enhanced image may be used to augment the user's vision.

In some embodiments, system **100** may generate a prediction indicating that an object will come in physical contact with a user and cause an alert to be displayed based on the physical contact prediction (e.g., an alert related to the object is displayed on a wearable device of the user). In some embodiments, system **100** may detect an object in a defective visual field portion of a visual field of a user and cause the alert to be displayed based on (i) the object being in the defective visual field portion, (ii) the physical contact prediction, or (iii) other information. In some embodiments, system **100** may determine whether the object is outside (or not sufficiently in) any image portion of an enhanced image (displayed to the user) that corresponds to at least one visual field portions satisfying one or more vision criteria. In one use case, no alert may be displayed (or a lesser-priority alert may be displayed) when the object is determined to be within (or sufficiently in) an image portion of the enhanced image that corresponds to the user's intact visual field portion (e.g., even if the object is predicted to come in physical contact with the user). On the other hand, if the object in the defective visual field portion is predicted to come in physical contact with the user, and it is determined that the object is outside (or not sufficiently in) the user's intact visual field portion, an alert may be displayed on the user's wearable device. In this way, for example, the user can rely on the user's own intact visual field to avoid incoming objects within the user's intact visual field, thereby mitigating the risk of dependence on the wearable device (e.g., through habit forming) for avoidance of such incoming objects. It should be noted, however, that, in other use cases, an alert related to the object may be displayed based on the physical contact prediction regardless of whether the object is within the user's intact visual field.

In some embodiments, with respect to FIG. **1**C, client device **104** may include a spectacles device **170** forming a wearable device for a subject. In some embodiments, the spectacles device **170** may be a part of a visioning system as described herein. The spectacles device **170** includes a left eyepiece **172** and a right eyepiece **174**. Each eyepiece **172** and **174** may contain and/or associate with a digital monitor configured to display (e.g., provide on a screen or project onto an eye) recreated images to a respective eye of the subject. In various embodiments, digital monitors may include a display screen, projectors, and/or hardware to generate the image display on the display screen or project images onto an eye (e.g., a retina of the eye). It will be appreciated that digital monitors comprising projectors may be positioned at other locations to project images onto an eye of the subject or onto an eyepiece comprising a screen, glass, or other surface onto which images may be projected. In one embodiment, the left eye piece **172** and right eyepiece **174** may be positioned with respect to the housing **176** to fit an orbital area on the subject such that each eyepiece **172**, **174** is able to collect data and display/project image data, which in a further example includes displaying/projecting image data to a different eye.

Each eyepiece **172**,**174** may further includes one or more inward directed sensors **178**, **180**, which may be inward directed image sensors. In an example, inward directed sensors **178**, **180** may include infrared cameras, photodetectors, or other infrared sensors, configured to track pupil movement and to determine and track visual axes of the subject. The inward directed sensors **178**, **180** (e.g., comprising infrared cameras) may be located in lower portions relative to the eye pieces **172**, **174**, so as to not block the visual field of the subject, neither their real visual field nor a visual field displayed or projected to the subject. The inward directed sensors **178**, **180** may be directionally aligned to point toward a presumed pupil region for better pupil and/or line of sight tracking. In some examples, the inward directed sensors **178**, **180** may be embedded within the eye pieces **172**, **174** to provide a continuous interior surface.

FIG. **1**D illustrates a front view of the spectacles device **170**, showing the front view of the eye pieces **172**, **174**, where respective outward directed image sensors **182**, **184** comprising field of vision cameras are positioned. In other embodiments, fewer or additional outward directed image sensors **182**, **184** may be provided. The outward directed image sensors **182**, **184** may be configured to capture continuous images. The spectacles device **170** or associated vision system may be further configured to then correct and/or enhance the images, which may be in a customized manner based on the optical pathologies of the subject. The spectacles device **170** may further be configured to display the corrected and/or enhanced image to the subject via the monitors in a visioning mode. For example, the spectacles device may generate the corrected and/or enhanced image on a display screen associated with the eyepiece or adjacent region, project the image onto a display screen associated with the eyepiece or adjacent region, or project the image onto one or more eyes of the subject.

FIGS. **1**E-**1**F illustrate other examples of spectacles device **170**. With respect to FIGS. **1**E-**1**F, spectacles device **170** includes a high-resolution camera (or cameras) **192**, a power unit **193**, a processing unit **194**, a glass screen **195**, a see-through display **196** (e.g., a transparent display), an eye tracking system **197**, and other components.

In some embodiments, the spectacles device **170** may include a testing mode. In an example testing mode, the inward directed sensors **178**, **180** track pupil movement and perform visual axis tracking (e.g., line of sight) in response to a testing protocol. In this or another example, the inward directed sensors **178**, **180** may be configured to capture a reflection of a pattern reflected on the cornea and/or retina to detect distortions and irregularities of the cornea or the ocular optical system.

Testing mode may be used to perform a visual assessments to identify ocular pathologies, such as, high and/or low order aberrations, pathologies of the optic nerve such as glaucoma, optic neuritis, and optic neuropathies, pathologies of the retina such as macular degeneration, retinitis pigmentosa, pathologies of the visual pathway as microvascular strokes and tumors and other conditions such as presbyopia, strabismus, high and low optical aberrations, monocular vision, anisometropia and aniseikonia, light sensitivity, anisocorian refractive errors, and astigmatism. In the testing mode, data may be collected for the particular subject and used to correct captured images before those images are displayed, which may include projected as described herein, to the subject by the monitors.

In some examples, external sensors may be used to provide further data for assessing visual field of the subject. For example, data used to correct the captured image may be obtained from external testing devices, such as visual field testing devices, aberrometers, electro-oculograms, or visual evoked potential devices. Data obtained from those devices may be combined with pupil or line of sight tracking for

visual axis determinations to create one or more modification profiles used to modify the images being projected or displayed to a user (e.g., correction profiles, enhancement profiles, etc., used to correct or enhance such images).

The spectacles device **170** may include a visioning mode, which may be in addition to or instead of a testing mode. In visioning mode, one or more outward directed image sensors **182**, **184** capture images that are transmitted to an imaging processor for real-time image processing. The image processor may be embedded with the spectacles device **170** or may be external thereto, such as associated with an external image processing device. The imaging processor may be a component of a visioning module and/or include a scene processing module as described elsewhere herein.

The spectacles device **170** may be communicatively coupled with one or more imaging processor through wired or wireless communications, such as through a wireless transceiver embedded within the spectacles device **170**. An external imaging processor may include a computer such as a laptop computer, tablet, mobile phone, network server, or other computer processing devices, centralized or distributed, and may be characterized by one or more processors and one or more memories. In the discussed example, the captured images are processed in this external image processing device; however, in other examples, the captured images may be processed by an imaging processor embedded within the digital spectacles. The processed images (e.g., enhanced to improve functional visual field or other vision aspects and/or enhanced to correct for the visual field pathologies of the subject) are then transmitted to the spectacles device **170** and displayed by the monitors for viewing by the subject.

In an example operation of a vision system including the spectacles device, real-time image processing of captured images may be executed by an imaging processor (e.g., using a custom-built MATLAB (MathWorks, Natick, Mass.) code) that runs on a miniature computer embedded in the spectacles device. In other examples, the code may be run on an external image processing device or other computer wirelessly networked to communicate with the spectacles device. In one embodiment, the vision system, including the spectacles device, image processor, and associated instructions for executing visioning and/or testing modes, which may be embodied on the spectacles device alone or in combination with one or more external devices (e.g., laptop computer) may be operated in two modes, a visioning mode and a separate testing mode.

In some embodiments, with respect to FIG. **2**, system **100** may include vision system **200**, which includes a spectacles device **202** communicatively coupled to a network **204** for communicating with a server **206**, mobile cellular phone **208**, or personal computer **210**, any of which may contain a visional correction framework **212** for implementing the processing techniques herein, such as image processing techniques, which may include those with respect to the testing mode and/or visioning mode. In the illustrated example, the visional correction framework **212** includes a processor and a memory storing an operating system and applications for implementing the techniques herein, along with a transceiver for communicating with the spectacles device **202** over the network **204**. The framework **212** contains a testing module **214**, which includes a machine learning framework in the present example. The machine learning framework may be used along with a testing protocol executed by the testing module, to adaptively adjust the testing mode to more accurately assess ocular pathologies, in either a supervised or unsupervised manner. The result of the testing module operation may include development of a customized vision correction model **216** for a subject **218**.

A visioning module **220**, which in some embodiments may also include a machine learning framework having accessed customized vision correction models, to generate corrected visual images for display by the spectacles device **202**. The vision correction framework **212** may also include a scene processing module which may process images for use during testing mode and/or visioning mode operations and may include operations described above and elsewhere herein with respect to a processing module. As described above and elsewhere herein, in some embodiments, the spectacle device **202** may include all or a portion of the vision correction framework **212**.

In the testing mode, the spectacles device **170** or **202**, and in particular the one or more inward directed image sensors comprising tracking cameras, which may be positioned along an interior of the spectacles device **170** or **202**, may be used to capture pupil and visual axis tracking data that is used to accurately register the processed images on the subject's pupil and visual axis.

In some embodiments, with respect to FIG. **3**, system **100** may include a vision system **300**, which includes a vision correction framework **302**. The vision correction framework **302** may be implemented on an image processing device **304** and a spectacles device **306** for placing on a subject. The image processing device **304** may be contained entirely in an external image processing device or other computer, while in other examples all or part of the image processing device **304** may be implemented within the spectacles device **306**.

The image processing device **304** may include a memory **308** storing instructions **310** for executing the testing and/or visioning modes described herein, which may include instructions for collecting high-resolution images of a subject from the spectacles device **306**. In the visioning mode, the spectacles device **306** may capture real-time visual field image data as raw data, processed data, or pre-processed data. In the testing mode, the spectacles device may project testing images (such as the letters "text" or images of a vehicle or other object) for testing aspects of a visual field of a subject.

The spectacles device **306** may be communicatively connected to the image processing device **304** through a wired or wireless link. The link may be through a Universal Serial Bus (USB), IEEE 1394 (Firewire), Ethernet, or other wired communication protocol device. The wireless connection can be through any suitable wireless communication protocol, such as, WiFi, NFC, iBeacon, Bluetooth, Bluetooth low energy, etc.

In various embodiments, the image processing device **304** may have a controller operatively connected to a database via a link connected to an input/output (I/O) circuit. Additional databases may be linked to the controller in a known manner. The controller includes a program memory, the processor (may be called a microcontroller or a microprocessor), a random-access memory (RAM), and the input/output (I/O) circuit, all of which may be interconnected via an address/data bus. It should be appreciated that although only one microprocessor is described, the controller may include multiple microprocessors. Similarly, the memory of the controller may include multiple RAMs and multiple program memories. The RAM(s) and the program memories may be implemented as semiconductor memories, magnetically readable memories, and/or optically readable memo-

ries. The link may operatively connect the controller to the capture device, through the I/O circuit.

The program memory and/or the RAM may store various applications (i.e., machine readable instructions) for execution by the microprocessor. For example, an operating system may generally control the operation of the vision system **300** such as operations of the spectacles device **306** and/or image processing device **304** and, in some embodiments, may provide a user interface to the device to implement the processes described herein. The program memory and/or the RAM may also store a variety of subroutines for accessing specific functions of the image processing device **304** described herein. By way of example, and without limitation, the subroutines may include, among other things: obtaining, from a spectacles device, high-resolution images of a visual field; enhancing and/or correcting the images; and providing the enhanced and/or corrected images for display to the subject by the spectacles device **306**.

In addition to the foregoing, the image processing device **304** may include other hardware resources. The device may also include various types of input/output hardware such as a visual display and input device(s) (e.g., keypad, keyboard, etc.). In an embodiment, the display is touch-sensitive, and may cooperate with a software keyboard routine as one of the software routines to accept user input. It may be advantageous for the image processing device **304** to communicate with a broader network (not shown) through any of a number of known networking devices and techniques (e.g., through a computer network such as an intranet, the Internet, etc.). For example, the device may be connected to a database of aberration data.

In some embodiments, system **100** may store prediction models, modification profiles, visual defect information (e.g., indicating detected visual defects of a user), feedback information (e.g., feedback related to stimuli displayed to users or other feedback), or other information at one or more remote databases (e.g., in the cloud). In some embodiments, the feedback information, the visual defect information, the modification profiles, or other information associated with multiple users (e.g., two or more users, ten or more users, a hundred or more users, a thousand or more users, a million or more users, or other number of users) may be used to train one or more prediction models. In some embodiments, one or more prediction models may be trained or configured for a user or a type of device (e.g., a device of a particular brand, a device of a particular brand and model, a device having a certain set of features, etc.) and may be stored in association with the user or the device type. As an example, instances of a prediction model associated with the user or the device type may be stored locally (e.g., at a wearable device of the user or other user device) and remotely (e.g., in the cloud), and such instances of the prediction model may be automatically or manually synced across one or more user devices and the cloud such that the user has access to the latest configuration of the prediction model across any of the user devices or the cloud. In some embodiments, multiple modification profiles may be associated with the user or the device type. In some embodiments, each of the modification profiles may include a set of modification parameters or functions to be applied to live image data for a given context to generate an enhanced presentation of the live image data. As an example, the user may have a modification profile for each set of eye characteristics (e.g., a range of gaze directions, pupil sizes, limbus positions, or other characteristics). As further example, the user may additionally or alternatively have a modification profile for each set of environmental characteristics (e.g., a range of brightness levels of the environment, temperatures of the environment, or other characteristics). Based on the eye characteristics or environmental characteristics currently detected, the corresponding set of modification parameters or functions may be obtained and used to generate the enhanced presentation of the live image data.

Subsystems **112-124**

In some embodiments, with respect to FIG. **1**A, testing subsystem **122** may provide a visual test presentation to a user. As an example, the presentation may include a set of stimuli. During the presentation (or after the presentation), testing subsystem **122** may obtain feedback related to the set of stimuli (e.g., feedback indicating whether or how the user sees one or more stimuli of the set). As an example, the feedback may include an indication of a response of the user to one or more stimuli (of the set of stimuli) or an indication of a lack of response of the user to such stimuli. The response (or lack thereof) may relate to an eye movement, a gaze direction, a pupil size change, or a user modification of one or more stimuli or other user input (e.g., the user's reaction or other response to the stimuli). As another example, the feedback may include an eye image captured during the visual test presentation. The eye image may be an image of a retina of the eye (e.g., the overall retina or a portion thereof), an image of a cornea of the eye (e.g., the overall cornea or a portion thereof), or other eye image. In some embodiments, testing subsystem **122** may generate one or more results based on the feedback, such as affected portions of a visual field of the user, an extent of the affected portions, vision pathologies of the user, modification profiles to correct for the foregoing issues, or other results.

In some embodiments, based on feedback related to a set of stimuli (displayed to a user during a visual test presentation) or other feedback, testing subsystem **122** may determine light sensitivity, distortions, or other aberrations related to one or more eyes of the user. In some embodiments, the set of stimuli may include a pattern, and testing subsystem **122** may cause the pattern to be projected onto one or more eyes of the user (e.g., using a projection-based wearable spectacles device). As an example, the pattern may be projected onto a retina or a cornea of the user to determine defects affecting the retina or the cornea. In one use case, the projection pattern can be used to assess correct for dysmorphopsia in age-related macular degeneration and other retinal pathologies. As shown in FIG. **31**A, a digital projection of a pattern **3100** may be projected onto a subject's eye **3102**. The pattern may be digitally generated on a projector positioned on an interior of a spectacles device. A digital camera **3104** (e.g., an inward directed image sensor) may also be positioned on an interior side of the spectacles device to capture an image of the pattern **3100** reflected from the eye **3102**. For example, the image capture may be captured from the corneal surface of the eye, as shown in FIG. **32**. From the captured image of the pattern **3100**, testing subsystem **122** may determine if the pattern looks normal (e.g., as depicted in FIG. **33**) or exhibits anomalies (e.g., as depicted in FIG. **34** (**3101**)). The anomalies may be assessed and corrected for using one of the techniques described herein.

In some embodiments, testing subsystem **122** may cause a set of stimuli to be displayed to a user, obtain an image of one or more of the user's eyes (e.g., at least a portion of a retina or cornea of the user) as feedback related to the set of stimuli, and determine one or more modification parameters or functions to address light sensitivity, distortions, or other aberrations related to the user's eyes (e.g., lower or higher order aberrations, static or dynamic aberrations, etc.). Such

modifications may include transformations (e.g., rotation, reflection, translation/shifting, resizing, etc.), image parameter adjustments (e.g., brightness, contrast, saturation, sharpness, etc.), or other modifications. As an example, when a pattern (e.g., an Amsler grid or other pattern) is projected onto a retina or cornea of the user, the obtained image may include a reflection of the projected pattern with the aberrations (e.g., reflected from the retina or cornea). Testing subsystem **122** may automatically determine the modification parameters or functions to be applied to the pattern such that, when the modified pattern is projected onto the retina or cornea, an image of the retina or cornea (subsequently obtained) is a version of the pre-modified-pattern image without one or more of the aberrations. In one use case, with respect FIG. **31**C, when the pattern **3100** is projected onto a retina of the user, the obtained image may include the pattern **3100** with distortions (e.g., an inverse of the distortions depicted in modified pattern **3100'** of FIG. **31**D). A function (or parameters for such a function, e.g., that inverses the distortions in the obtained image) may be determined and applied to the pattern **3100** to generate the modified pattern **3100'**. When the modified pattern **3100'** is projected onto the user's retina, the reflection of the modified pattern **3100'** from the user's retina will include the pattern **3100** of FIG. **31**C without the prior distortions. To the extent that the reflection still includes distortions, testing subsystem **122** may automatically update the modified parameters or functions to be applied to the pattern to further mitigate the distortions (e.g., shown in the reflection of the retina).

In another use case, the eye image (e.g., the image of one or more of the user's eyes) capturing the projected stimuli (e.g., pattern or other stimuli) reflected from a retina or cornea may be used to determine a function (or parameters for the function) to correct for one or more other aberrations. Upon applying a determined function or parameters to the projected stimuli, and to the extent that the reflection of the modified stimuli still includes aberrations, testing subsystem **122** may automatically update the modified parameters or functions to be applied to the stimuli to further mitigate the aberrations (e.g., shown in the reflection). In a further use case, the foregoing automated determinations of the parameters or functions may be performed for each eye of the user. In this way, for example, the appropriate parameters or functions for each eye may be used to provide correction for Anisometropia or other conditions in which each eye has different aberrations. With respect to Anisometropia, for example, typical corrective glass spectacles cannot correct for the unequal refractive power of both eyes. That is because the corrective glass spectacles produced two images (e.g., one to each eye) with unequal sizes (aniseikonia) and the brain could not fuse those two images into a binocular single vision, resulting in visual confusion. That problem is simply because the lenses of glass spectacles are either convex, magnify the image or concave, minify the image. The amount of magnification or minification depends on the amount of correction. Given that the appropriate parameters or functions may be determined for each eye, the foregoing operations (or other techniques described herein) can will correct for Anisometropia (along with other conditions in which each eye has different aberrations), thereby avoiding visual confusion or other issues related to such conditions.

In some embodiments, with respect to FIG. **1**A, testing subsystem **122** may cause a set of stimuli to be displayed to a user and determine one or more modification parameters or functions (to address light sensitivity, distortions, or other aberrations related to the user's eyes) based on the user's modifications to the set of stimuli or other user inputs. In some scenarios, with respect to FIG. **31**C, the pattern **3100** may be a grid (e.g., an Amsler grid) or any known reference shape designed to allow for detecting a transformation needed to treat one or more ocular anomalies. That transformation may then be used to reverse-distort the image in real-time to allow better vision. In an example implementation of FIG. **8**, a vision system **800** may include a testing module **802**. The testing module **802** may be associated with wearable spectacles or may be executed in combination with an external device as described elsewhere herein. The testing module **802** may present testing stimuli comprising an Amsler grid to a subject **806**. The subject, via the user device **808** or other input device, may manipulate the image of the grid to improve distortions (e.g., by dragging or moving one or more portions of the lines of the grid). The visual correction framework **810** may present the Amsler grid for further correction by the subject. When the subject has completed their manual corrections (e.g., resulting in modified pattern **3100'**), the vision correction framework **810** may generate the modification profile of the subject to apply to visual scenes when they are using the spectacles device. As an example, the vision correction framework **810** may generate an inverse function (or parameters for such a function) that outputs the modified pattern **3100'** when the pattern **3100** is provided as input the function. The described workflow of vision system **800** may similarly be applicable to other testing mode operations described herein.

FIG. **31**B is a schematic illustration of the presentation of an Amsler grid **3100** (e.g., an example reference image) displayed as an image on a wearable spectacle (e.g., VR or AR headset). The Amsler grid **3100** may be displayed to or projected onto a cornea and/or retina of the subject. An example standard grid **3100** is shown in FIG. **31**C. The same grid pattern may be displayed on a user device. The subject may manipulate the lines of the grid pattern, particularly the lines that appear curved, utilizing a keyboard, mouse, touch screen, or other input on a user device, which may include a user interface. The subject can specify an anchor point **3102** from which to manipulate the image. After specifying the anchor point, the subject can use the user device (e.g., arrow keys) to adjust the specified line, correcting the perceived distortion caused by their damaged macula. This procedure may be performed on each eye independently, providing a set of two modified grids.

Once the subject completes the modification of the lines to appear straight, a vision correction framework takes the new grids and generate meshes of vertices corresponding to the applied distortions. These meshes, resulting from the testing mode, are applied to an arbitrary image to compensate for the subject's abnormalities. For example, each eye may be shown the modified image corresponding to the appropriate mesh, as part of confirmation of the testing mode. The subject can then indicate on the user device if the corrected images appear faultless which, if true, would indicate that the corrections were successful. For example, FIG. **31**E illustrates an actual scene, as it should be perceived by the user. FIG. **31**F illustrates a corrected visual field that when provided to a subject with a visual distortion determined by the Amsler grid technique, results in that subject seeing the visual field of FIG. **31**F as the actual visual field of FIG. **31**E.

Such correction may be performed in real time on live images to present the subject with a continuously corrected visual scene. The correction may be achieved real-time whether the spectacles device includes displays that generate the capture visual field or whether the spectacles device is

custom-reality based and uses a correction layer to adjust for the distortion, as both cases may utilize the determined corrective meshes.

In some examples, a reference image such as the Amsler pattern may be presented directly on a touch screen or tablet PC, such as **3150** (e.g., a tablet PC) shown in FIG. **31**G. The Amsler pattern is presented on a display of the device **3150**, and the subject may manipulate the lines that appear curved using a stylus **3152** to draw the corrections that are to be applied to the lines to make them appear straight. During the testing mode, after each modification, the grid may be redrawn to reflect the latest edit. This procedure may be performed on each eye independently, providing us a set of two modified grids. After the subject completes the testing mode modification, the tablet PC executes an application that creates and sends the mesh data to an accompanying application on the spectacles device to process images that apply the determined meshes.

Once the spectacles device receives the results of the testing mode modification, the spectacles device may apply them to an arbitrary image to compensate for the subject's abnormalities. The images that result from this correction may then be displayed. The display may be via an VR/AR headset. In one example, the display presents the images to the user via the headset in a holographical way. Each displayed image may correspond to the mesh created for each eye. If the corrected images seem faultless to the subject, the corrections may be considered successful and may be retained for future image processing. In some embodiments of the testing mode, instead of or in addition to presenting a single image modified according to the modified grids, a video incorporating the modifications may be presented. In one example, the video includes a stream of a camera's live video feed through the correction, which is shown to the subject.

In some embodiments, with respect to FIG. **1**A, testing subsystem **122** may determine one or more defective visual field portions of a visual field of a user (e.g., an automatic determination based on feedback related to a set of stimuli displayed to the user or other feedback). As an example, a defective visual field portion may be one of the visual field portions of the user's visual field that fails to satisfy one or more vision criteria (e.g., whether or an extent to which the user senses one or more stimuli, an extent of light sensitivity, distortion, or other aberration, or other criteria). In some cases, the set of stimuli displayed to the user includes at least one testing image of text or of an object. Defective visual field portions may include regions of reduced vision sensitivity, regions of higher or lower optical aberrations, regions of reduced brightness, or other defective visual field portions. In some cases, the set of stimuli may differ in contrast levels with respect to each other and with respect to a baseline contrast level by at least 20 dB. In some cases, the set of stimuli may differ in contrast levels with respect to each other and with respect to a baseline contrast level by at least 30 dB. In some cases, testing subsystem **122** may, in the testing mode, instruct a wearable spectacles device to display the set of testing stimuli to the user in a descending or ascending contrast.

In one use case, testing was performed on 4 subjects. A testing protocol included a display of text at different locations one or more display monitors of the spectacles device. To assess the subject's visual field of impaired regions, the word "text" was displayed on the spectacle monitors for each eye, and the subject was asked to identify the "text." Initially the "xt" part of the word "text" was placed intentionally by the operator on the blind spot of the subject. All 4 subjects reported only seeing "te" part of the word. The letters were then moved using software to control the display, specifically. The text "text" was moved away from the blind spot of the subject who was again asked to read the word. Subjects were able to read "text" stating that now the "xt" part of the word has appeared.

An example of this assessment protocol of a testing mode is shown in FIGS. **6**A-**6**C. As shown in FIGS. **6**A-**6**B, the code automatically detects the blind spots on a Humphrey visual field. The word "text" **600** is projected so that "xt" part of the word is in a blind spot **602** (FIG. **6**A). The subject was asked to read the word. The word "text" **600** was then moved away from the blind spot **602** (FIG. **6**B) and the subject was asked to read it again. The word "text" **600** can be displayed at different coordinates of the visual field of the subject, with the visual field divided into 4 coordinates in the illustrated example. This protocol allows for identification of multiple blind spots, including peripheral blind spot **604**. The text may be moved around over the entire visual field of the subject, with the subject being asked to identify when all or portions of the text is not visible or partially visible or visible with a reduced intensity.

The pupil tracking functionalities described herein may include pupil physical condition (e.g., visual axis, pupil size, and/or limbus), alignment, dilation, and/or line of sight. Line of sight, also known as the visual axis, is a goal that can be achieved by one or more of tracking the pupil, the limbus (which is the edge between the cornea and the sclera), or even track blood vessel on the surface of the eye or inside the eye. Thus, pupil tracking may similarly include limbus or blood vessel tracking. The pupil tracking may be performed utilizing one or more inward facing image sensors as described herein. In various embodiments, pupil tracking functionalities may be used for determination of parameters for registering the projected image on the visual field of the subject (FIG. **6**C).

With respect to FIG. **6**C, a GUI **606** display may be displayed to an operator. The GUI **606** may provide information related to the testing. For example, the GUI **606** shows measured visual field defects and the relative location of the image to the defects. The GUI **606** may be operable to allow automatic distribution of the images to the functional part of the visual field but may include buttons to allow the operator to override the automatic mode. The external image processing device may be configured to determine where this assessment text is to be displayed and may wirelessly communicate instructions to the digital spectacles to display the text at the various locations in the testing mode.

In another use case, with respect to FIGS. **7**A-**7**C, instead of "text" being used, the subject was tested to determine whether they could see a car **700** placed in different portions of the visual field, for pupil tracking and affected region determination. The pupil tracking functionality allows the vision system to register the projected image on the visual field of the subject.

In some embodiments, with respect to FIG. **1**A, testing subsystem **122** may determine one or more defective visual field portions of a visual field of a user based on a response of the user's eyes to a set of stimuli displayed to the user or lack of response of the user's eyes to the set of stimuli (e.g., eye movement response, pupil size response, etc.). In some embodiments, one or more stimuli may be dynamically displayed to the user as part of a visual test presentation, and the responses or lack of responses to a stimulus may be recorded and used to determine which part of the user's visual field is intact. As an example, if an eye of the user

responds to a displayed stimulus (e.g., by changing its gaze direction toward the displayed stimulus's location), the eye's response may be used as an indication that the eye can see the displayed stimulus (e.g., and that a corresponding portion of the user's visual field is part of the user's intact visual field). On the other hand, if an eye of the user does not respond to a displayed stimulus (e.g., its gaze direction does not move toward the displayed stimulus's location), the eye's lack of response may be used as an indication that the eye cannot see the displayed stimulus (e.g., and that a corresponding portion of the user's visual field is a defective visual field portion). Based on the foregoing indications, testing subsystem **122** may automatically determine the defective visual field portions of the user's visual field.

In some embodiment, the set of stimuli displayed to the user may include stimuli of different brightness, contrast, saturation, or sharpness levels, and the responses or lack of responses to a stimulus having a particular brightness, contrast, saturation, or sharpness level may provide an indication of whether a portion of the user's visual field (corresponding to the location of the displayed stimuli) has an issue related to brightness, contrast, saturation, or sharpness. As an example, if an eye of the user responds to a displayed stimulus having a certain brightness level, the eye's response may be used as an indication that the eye can see the displayed stimulus (e.g., and that a corresponding portion of the user's visual field is part of the user's intact visual field). On the other hand, if an eye of the user does not respond to a stimulus having a lower brightness level (e.g., that a normal eye would respond to) at the same location, the eye's lack of response may be used as an indication that a corresponding portion of the user's visual field has reduced brightness. In some cases, the brightness level for the stimulus may be incrementally increased until the user's eye responds to the stimulus or until a certain brightness level threshold is reached. If the user's eye eventually reacts to the stimulus, the current brightness level may be used to determine a level of light sensitivity for that corresponding virtual field portion. If the brightness level threshold is reached and the user's eye does not react to the stimulus, it may be determined that the corresponding virtual field portion is a blind spot (e.g., if the corresponding changes to one or more of contrast, saturation, sharpness, etc., to the stimulus also does not trigger an eye response). Based on the foregoing indications, testing subsystem **122** may automatically determine the defective visual field portions of the user's visual field.

In some embodiments, the location of a fixation point or the locations of the stimuli to be displayed to the user may be static during a visual test presentation. In some embodiment, a location of a fixation point and locations of the stimuli to be displayed to the user may be dynamically determined based on gaze direction or other aspect of the user's eyes. As an example, during a visual test presentation, both the fixation points and stimuli locations are dynamically represented to a patient relative to the patient's eye movement. In one use case, the current fixation point may be set to a location of the visual test presentation that the patient is currently looking at a particular instance, and a test stimulus may be displayed relative to that fixation point. In this way, for example, the patient is not required to fix his attention to a certain predefined fixation location. This allows the visual test presentation to be more objective, interactive, and reduce stress caused by prolonged fixation on a fixed point. The use of dynamic fixation points also eliminates patient errors related to fixation points (e.g., if the patient forgets to focus on a static fixation point).

As another example, a visual test presentation applying a fast thresholding strategy may utilize four contrasting staircase stimuli covering the central 40 degrees' radius using 52 stimuli sequences at predetermined locations, as illustrated in FIG. **35**. In other examples, different numbers of contrast stimuli, coverage, and stimuli locations may be used. In this example, the stimuli was located at the center of each cell shown in the FIG. **35**. The twelve corner cells, where the stimuli are not visible because of the circular display's lens, were not tested. The spacing between each stimulus location was approximately 10 degrees apart. Each stimuli sequence contained four consecutive stimuli at different contrast levels with respect to the background. Stimuli contrast ranged between 33 dB down to 24 dB in steps of 3 dB in a descending order between each contrast level. Threshold values were recorded at the last seen stimulus. If the patient did not see any stimulus contrast at a specific location, the location is marked unseen and was given a value of 0 dB.

The background had a bright illumination (100 lux) while the stimuli were dark dots with different contrast degrees. Therefore, the test was a photopic test rather than a mesopic one. In some embodiments, back ground may be dark and stimuli may comprise bright illumination dots. Each stimulus was presented for a time period of approximately 250 msec, followed by a response waiting time period of approximately 300 msec. These time periods were also made adjustable through a control program according to the subject's response speed, which, for example, may be adjusted prior to testing based on pre-test demonstration or dynamically during testing. Generally, a stimulus size of 0.44 degrees was used at the central 24 degrees' radius, which is equivalent to the standard Goldmann stimulus size III. The stimulus size at the periphery (between 24 and 40 degrees' radius) was doubled to be 0.88 degrees. The purpose of doubling the stimulus size in the peripheral vision was to overcome the degraded display lens performance at the periphery. This lens degradation effect was significant, as the normal human vision's acuity even deteriorates at the peripheral regions. The testing program also had the ability for the stimulus size to be changed for the different patient cases.

The fixation target (pattern) of FIG. **35** was located in the center of the screen for each eye tested. This target was designed as a multicolor point, rather than a unicolor fixation point as routinely used in the traditional Humphrey tests. This color changing effect helped grab the attention of the subject and made target focusing easier for them. The frequency of the color changes was asynchronous with the stimulus appearance, so that the subject would not relate both events together and falsely responds. The testing protocol also had the ability for the fixation target size to be changed according to the patient's condition. In addition, the eye/pupil tracking system may be used to check the subject's eye fixation at different time intervals. The eye tracking system transmits to the testing program the gaze vectors' direction, which informs the program if the subject is properly focused to the center or not.

Fixation checks were performed using the pupil/gaze data for each eye individually. Pupil/gaze data were acquired at different time instances and if the gaze direction vectors were at approximately 0 degrees then the subject is focusing on the center target, otherwise the program would pause waiting for fixation to restored. If the patient were out of fixation, no stimulus was shown and the test was halted until the participant gets back in fixation. Offset tolerance was allowed for minor eye movements at the fixation target. Fixation checks were performed for each stimuli's location

at mainly two time events; before showing each stimulus in the stimuli sequence (e.g., prior to each stimulus contrast level of the four levels mentioned earlier), and before recording a response, whether the response was positive (e.g., patient saw the stimulus) or negative (e.g., patient did not see the stimulus). Negative responses were recorded at the end of the stimuli sequence interval in addition to the allowed response time. Checking fixation before showing the stimuli sequence was to ensure the patient was focusing on the fixation target. If the subjects were out of fixation, no stimulus was shown and the test was halted until the participant gets back in fixation.

FIG. **36** shows a timing diagram showing operations of a testing sequence at one stimulus location. In one example, a pupil tracking device, which may be separate or a component of a vision system or device thereof, may include inward directed image sensors and be configured to provide data instructing the image display device, which may include a projector, to change the location of the stimulus being projected according to line of sight movement. In this way, even if the subject is looking around and not fixating, the stimuli may move with the eyes of the subject and will continue testing the desired location of the visual field. Therefore, rather than halting the stimuli sequence when the subject is determined to be focused outside of the fixation target, the stimuli sequence may continue with a modification of the stimuli to correspond with the intended location within the subject's visual field within the sequences as repositioned based on a determination of the subject's current fixation point.

For each subject, the visual field test started by orienting the subject of how the test goes. The spectacles device was fitted on the patient to ensure that the subject could see the fixation target clearly, and if necessary, target size was adjusted accordingly. Eye tracking calibration was performed at one point, the fixation target. Following that, a demonstration mode was presented to the subject. This mode follows the same sequence as the main test, but with only fewer locations, seven locations in this instance, and without recording any responses. The purpose of this mode was to train the subject on the test. Additionally, this training mode helps the program operator to check for the eye tracking system accuracy, patient response speed, and the patient eye's location with respect to the mounted headset, to make sure that no error or deviation would occur during the full test.

Normal blind spots were then scanned for, by showing suprathreshold stimuli at four different locations spaced by 1 degree in the 15-degree vicinity. This step was beneficial to avoid rotational misfits between the headset and the subject's eyes.

Next, the 52 stimuli sequences were presented to the patient at the pre-specified locations with random order. The subject indicated responses by either actuating an electronic clicker or gesturing in response to a stimuli. After recording the subject's responses at all locations, the "unseen" points' locations were temporarily stored. A search algorithm was then employed to find the locations of all "seen" points on the perimeter of the "unseen" points' locations. Those two sets of points were then retested, to eliminate random response errors by the participant, and ensure continuity of the visual field regions. False positive responses, false negative responses and fixation losses (if any) were calculated and reported by the end of the test. Consequently, all the 52 responses were interpolated using a cubic method to generate a continuous visual field plot of the tested participant.

The visual field test was tried on 20 volunteer subjects using simulated field defects, by covering parts of the inner display lens of the spectacles device. The results were assessed on point by point comparison basis with an image showing the covered areas of the display. The 52 responses were compared at the approximate corresponding locations in the covered headset's display image, as a measure of testing accuracy. Summary of the calculated errors are listed in Table 1.

TABLE 1

Error calculations for the 20 cases simulated defects visual field measurements.

	Left Eyes		Right Eyes		Total Error	
	Mean	SD	Mean	SD	Mean	SD
Error Points	1.600	1.698	1.500	1.396	1.550	1.535
Error Percentage	3.137%	3.329%	2.941%	2.736%	3.039%	3.009%

On the other hand, visual field tests for the 23 clinical patients were compared with the most recent Humphrey Field Analyzer (HFA) test routinely made by the subject during their visits. The common 24 degrees central areas were matched and compared between the two field testing devices. The comparison and relative error calculations were based again on a point by point basis at the common central 24 degrees areas, where areas beyond this region were judged through continuity with the central area and lack of isolated response points. Summary of the calculated errors are listed in table 2.

TABLE 2

Error calculations for 23 patients visual field measurements.

	Left Eyes		Right Eyes		Total Error	
	Mean	SD	Mean	SD	Mean	SD
Error Points	3.059	2.277	3.063	2.061	3.061	2.120
Error Percentage	7.647 %	5.692%	7.656%	5.039%	7.652%	5.301%

An image remapping process was then performed, which involved finding new dimensions and a new center for the displayed images to be shown to the patient. The output image fits in the bright visual field of a subject's eye by resizing and shifting the original input image.

The visual field was binarized by setting all seen patient responses to ones, and keeping the unseen responses to zeros, this resulted in a small binary image of 8×8 size. In other embodiments, smaller or larger binary images sizes may be used. Small regions containing at most 4 connected pixels, were removed from the binary visual field image. The

4 connected pixels represented a predetermined threshold value for determination of small regions, although larger or smaller threshold values may be used in some embodiments. Those small regions were not considered in the image fitting process. The ignored small regions represent either the normal blind spots, insignificant defects, or any random erroneous responses that might have occurred during the subject's visual field test.

Based on this interpolated binary field image, the bright field's region properties were calculated. Calculated properties for the bright regions included: 1) bright areas in units of pixels, 2) regions' bounding box, 3) weighted area centroid, and 4) a list of all pixels constituting the bright regions of the visual field. A bounding box was taken as the smallest rectangle enclosing all pixels constituting the bright region. A region's centroid was calculated as the center of mass of that region calculated in terms of horizontal and vertical coordinates. The values of this property correspond to the output image's new center, which corresponds to an amount of image shift required for mapping.

Using a list of pixels constituting the largest bright field, the widths and heights of all pixels bounding the bright field were calculated, as shown in FIG. **37**. For each row in the bright field, the two bounding pixels were found, and their vertical coordinates were subtracted to get the field's width BF_{widths} at that specific row. This width calculation was iterated for all rows establishing the considered bright field to calculate BF_{widths}. The same iteration process may be applied on a column basis to calculate $BF_{heights}$. Afterwards, either one of two scaling equations may be used to determine the new size of the mapped output image; $Width_{map}$ and $Height_{map}$, as shown in FIG. **37**.

The $Width_{map}$ may be calculated using resizing equation:

$$Width_{map1} = \frac{\text{median}(BF_{widths})}{50},$$

$$Height_{map1} - \text{median}(BF_{heights}),$$

where BF_{widths} and $BF_{heights}$ are the calculated bright field's bounding pixels' widths and heights, respectively. This scaling method calculates the new output image size as the median of the bright visual field size in each direction, centered at the new image center, found as above. The median measure was used rather than the mean value, to avoid any resizing skewness related to exceedingly large or small bright field dimensions. The mapping behavior of this method is to fit images within the largest possible bright area, but image stretching or squeezing could occur, as this method does not preserve the aspect ratio.

The $Height_{map}$ may be calculated using resizing equation:

$$Width_{map2} = \frac{\sum^{BF_{widths}}}{Isize^2} \times BX_{Width},$$

$$Height_{map2} = \frac{\sum^{BF_{heights}}}{Isize^2} \times BX_{height},$$

where I_{size} is the interpolated image size (output image size), BX_{widths}, $BX_{heights}$ are the bounding box width and height. The summations in the numerators of the equation approximate the bright field area calculated with respect to the horizontal and vertical directions, respectively. Therefore, dividing those summations by the square of the output image's size provided an estimate of the proportional image areas to be mapped in each direction. These proportions are then multiplied by the corresponding bounding box dimension that was previously calculated. The mapping behavior of this method is to fit images in the largest bright visual field while trying to preserve the output image's aspect ratio. Incorporating the bounding box's dimensions into the calculations helped this effect to happen. Yet, preservation of the aspect ratio may not result in all defective visual field patterns.

In one embodiment, the AI system may utilized the two equations and tens if not hundreds of the difference equations in a process of optimization to see which one will allow fitting more of the seeing visual field with the image. Based on the feedback of the operators the system may learn to prefer an equation more than the others based on the specific visual field to be corrected.

These remapping techniques were used in an identifying hazardous objects test. The remapping methods were tested on 23 subjects using test images that included a safety hazard, a vehicle in this test. The test images were chosen to test the four main quadrants of the visual field, as shown in FIG. **38**. A visual field example was used to remap the test images for display to the subject. The subject was tested by showing an image of an incoming car. The subject could not see the car before being shown the remapped image, as shown in FIG. **39**A illustrating the image as seen by the subject without remapping and in FIG. **39**B illustrating the image as seen after remapping. Our preliminary study demonstrated that 78% subjects (18 out of 23) were able to identify safety hazards that they could not do without our aid. Some subjects were tested on both eyes individually, so 33 eye tests were available. It was found that in 23 out of 33 eyes the visual aid was effective in helping the subject identify the simulated incoming hazard (P=0.023).

As indicated, in some embodiments, with respect to FIG. **1**A, testing subsystem **122** may determine one or more defective visual field portions of a visual field of a user based on a response of the user's eyes to a set of stimuli displayed to the user or lack of response of the user's eyes to the set of stimuli (e.g., eye movement response, pupil size response, etc.). In some embodiments, one or more moving stimuli may be dynamically displayed to the user as part of a visual test presentation, and the responses or lack of responses to a stimulus may be recorded and used to determine which part of the user's visual field is intact. As an example, in a kinetic part of the visual test presentation, recording of responses of a patient's eyes may begin after a stimulus is displayed in the visual test presentation and continues until the stimulus disappears (e.g., the stimulus may move from a starting point to a center point of the visual test presentation and then disappear). As another example, during the visual test presentation, the stimulus may be removed (e.g., disappear from the patient's view) when it is determined that the patient recognizes it (e.g., the patient's gaze direction changes to the current location of the stimulus). As such, the duration of the visual test presentation may be reduced and more interactive (e.g., the patient is provided with a feeling of playing a game rather than diagnosis of visual defects). Based on the foregoing indications (of responses or lack thereof to the set of stimuli), testing subsystem **122** may automatically determine the defective visual field portions of the user's visual field.

In some embodiments, testing subsystem **122** may determine one or more defective visual field portions of a visual field of a user, and visioning subsystem **124** may provide an

enhanced image or cause an adjustment of one or more configurations of a wearable device based on the determination of the defective visual field portions. As an example, the enhanced image may be generated or displayed to the user such that one or more given portions of the enhanced image (e.g., a region of the enhanced image that corresponds to a macular region of the visual field of an eye of the user or to a region within the macular region of the eye) are outside of the defective visual field portion. As another example, a position, shape, or size of one or more display portions of the wearable device, a brightness, contrast, saturation, or sharpness level of such display portions, a transparency of such display portions, or other configuration of the wearable device may be adjusted based on the determined defective visual field portions.

FIG. **4** illustrates a process **400** illustrating an example implementation of both a testing mode and a subsequent visioning mode. At a block **402**, in a testing mode, data is obtained from diagnostic devices like image sensors embedded within spectacles device and other user input devices, such as a cellular phone or tablet PC. At a block **404**, testing mode diagnostics may be performed to detect and measure ocular anomalies from the received data (e.g., visual field defects, eye misalignment, pupil movement and size, images of patterns reflected from the surface of the cornea or the retina, etc.). In an example, a control program and algorithms were implemented using MATLAB R2017b (MathWorks, Inc., Natick, Mass., USA). In various embodiments, a subject or tester may be provided with an option to select to test each eye individually, or test both eye sequentially in one run. In some embodiments, the testing mode may include an applied fast thresholding strategy including contrast staircase stimuli covering central radius of 20 degrees or more using stimuli sequences at predetermined locations. As an example, the testing mode may include an applied fast thresholding strategy include four contrast staircase stimuli covering the central 40 degrees' radius using 52 stimuli sequences at predetermined locations, as discussed herein regarding FIGS. **35-36**. As another example, the testing mode may include the automated determination of the visual defects (e.g., defective virtual field portions) based on one or more responses of the user's eyes to a set of stimuli displayed to the user or lack of such responses of the user's eyes to the set of stimuli (e.g., eye movement response, pupil size response, etc.) as described herein.

At a block **406**, the determined diagnostic data may be compared to a database or dataset that stores modification profiles for compensating for identifiable ocular pathologies (e.g., FIG. **16** and related discussions).

The identified modification profiles may then personalized to the individual, for example, to compensate for differences in visual axis, visual field defects, light sensitivity, double vision, change in the size of the image between the two eyes, image distortions, decreased vision.

The personalized profiles may be used by a block **408**, along with real-time data to process the images (e.g., using an image processor, scene processing module, and/or visioning module). The real-time data may include data detected by one or more inward directed image sensors **410**, providing pupil tracking data, and/or from one or more outward directed image sensors comprising one or more visual field cameras **412** positioned to capture a visual field screen. At a block **414**, real-time image correction may be performed and the images may be displayed (block **416**) on the spectacles device, either as displayed recreated digital images, as augmented reality images passing through the spectacles device with corrected portions overlaid, or as images projected into the retinas of the subject. In some examples, the operation of block **414** is performed in combination with a calibration mode **418** in which the user can tune the image correction using a user interface such as an input device that allows a user to control image and modification profiles. For example, users can displace the image of one eye to the side, up and down or cyclotorted to alleviate double of vision. In the above or another example, a user may fine tune the degree of visual field transformation (e.g., fish eye, polynomial, or conformal) or translation to allow enlarging the field of vision without negatively impact the functional vision or cause unacceptable distortions, fine tune the brightness, and contrast, or invert colors.

FIG. **5** illustrates another example process **500**, similar to that of process **400**, for implementation of a testing mode and visioning mode. At a block **502**, data for high and low order aberrations for pupil size, degree of accommodation, and gaze, are collected. In some embodiments, all or a portion of the data may be collected from an aberrometer or by capturing the image of a pattern or grid projected on the cornea and/or retina and comparing it to the reference image to detect aberrations of the cornea or the total ocular optical system. The collected data may be sent to a vision correction framework, which, at a block **504**, may determine personalized modification profiles similar to block **406** described above. Blocks **508-518** perform similar functions to corresponding blocks **408-418** in process **400**.

FIG. **8** illustrates a workflow **800** showing a testing module **802** that generates and presents a plurality of visual stimuli **804** to a user **806** through the spectacles device. The user **804** has a user device **808** through which the user may interact to provide input response to the testing stimuli. In some examples, the user device **808** may comprise a joystick, electronic clicker, keyboard, mouse, gesture detector/motion sensor, computer, phone such as a smart phone, dedicated device, and/or a tablet PC through which that the user may interfaces to provide input response to the testing stimuli. The user device **808** may also include an processor and memory storing instructions that when executed by the processor generate display of a GUI for interaction by the user. The user device **808** may include a memory, a transceiver (XVR) for transmitting and receiving signals, and input/output interface for connecting wired or wirelessly with to a vision correction framework **810**, which may be stored on an image processing device. The vision correction framework **810** may be stored on the spectacles device, on the user device, etc.—although in the illustrated example, the framework **810** is stored on an external image processing device. The framework **810** receives testing mode information from the testing module **802** and user input data from the user device **808**.

FIG. **9** illustrates a testing mode process **900**, as may be performed by the workflow **800**. At a block **902**, a subject is provided a plurality of testing stimuli according to a testing mode protocol. That stimuli may include images of text, images of objects, flashes of light, patterns such as grid patterns. The stimuli may be displayed to the subject or projected onto the retina and/or cornea of the subject. At a block **904**, a vision correction framework may receive detected data from one or more inward directed image sensors, such as data corresponding to a pupil physical condition (e.g., visual axis, pupil size, and/or limbus). The block **904** may further include receiving user response data collected from the user in response to the stimuli. At a block **906**, the pupil position condition may be determined across

different stimuli, for example, by measuring position differences and misalignment differences between different stimuli.

At a block **908**, astigmatism determinations may be made throughout the field of vision, which may include analysis of pupil misalignment data and/or eye aberrations (e.g., projecting references images on the retina and cornea and comparing the reflected images from the retinal or corneal surfaces to reference images). At a block **910**, total eye aberrations may be determined (e.g., by projecting reference images onto the retina and/or cornea and then comparing the reflected images from the retinal or corneal surfaces to reference images, such as described in FIGS. **31**A, **32-34** and accompanying discussion). At a block **912**, visual distortions, such as optical distortions such as coma, astigmatism, or spherical aberrations or visual distortions from retinal diseases, may be measured throughout the field of vision. At a block **914**, the visual field sensitivity may be measured throughout the field of vision. In various embodiments of the process of FIG. **9**, one or more of blocks **904-914** may be optional.

In some examples, the vision systems herein can assess the data from the testing mode and determine the type of ocular anomaly and the type of correction needed. For example, FIG. **10** illustrates a process **1000** comprising an artificial intelligence corrective algorithm mode that may be implemented as part of the testing mode. A machine learning framework is loaded at a block **1002**, example frameworks may include, dimensionality reduction, ensemble learning, meta learning, reinforcement learning, supervised learning, Bayesian, decision tree algorithms, linear classifiers, unsupervised learning, artificial neural networks, association rule learning, hierarchical clustering, cluster analysis, deep learning, semi-supervised learning, etc.

At a block **1004**, a visual field defect type is determined. Three example field defects are illustrated: uncompensated blind field **1006**, a partially blind spot with lower sensitivity **1008**, and an intact visual field **1010**. The block **1004** determines the visual field defect and then applies the appropriate correction protocol for the visioning mode. For example, for the uncompensated blind field **1006**, at a block **1012**, a vision correction framework tracks vision, such as through pupil tracking using inward directed image sensors and does video tracking of a moving object in the visual field (e.g., through outward directed image sensors such as external cameras). In the illustrated example, at a block **1014**, safety hazards in regions of blind spots or that are moving into the regions of blind spots are detected by, for example, comparing the position of the safety hazard to a mapped visual field with defects as measured in the testing mode. At a block **1016**, an object of interest may be monitored at various locations including a central location and a peripheral location.

In the example of a partially blind spot **1008**, an augmented vision visioning mode may be entered at a block **1018**, from which an object in the visual field is monitored by tracking a central portions of the visual field. At a block **1020**, an image segmentation algorithm may be employed to separate the object from the visual field. An augmented outline may also be applied to the object and displayed to the user wherein the outline coincides with identified edges of the segmented object. With respect to the intact visual field **1010**, at a block **1022**, a customized corrective algorithm may be applied to correct aberrations, visual field detects, crossed eyes, and/or visual distortion.

In some embodiments, testing subsystem **122** may determine multiple modification profiles associated with a user (e.g., during a visual test presentation, while an enhanced presentation of live image data is being displayed to the user, etc.). In some embodiments, each modification profile may include a set of modification parameters or functions to be applied to live image data for a given context. As an example, the user may have a modification profile for each set of eye characteristics (e.g., a range of gaze directions, pupil sizes, limbus positions, or other characteristics). As further example, the user may additionally or alternatively have a modification profile for each set of environmental characteristics (e.g., a range of brightness levels of the environment, temperatures of the environment, or other characteristics).

Based on the eye-related or environment-related characteristics currently detected, the corresponding set of modification parameters or functions may be obtained and used to generate the enhanced presentation of the live image data. As an example, the corresponding set of modification parameters or functions may be obtained (e.g., to be applied to an image to modify the image for the user) based on the currently-detected eye-related characteristics matching a set of eye-related characteristics associated with the obtained set of modification parameters or functions (e.g., the currently-detected eye-related characteristics fall within the associated set of eye-related characteristics). In some embodiments, the set of modification parameters or functions may be generated based on the currently-detected eye characteristics or environmental characteristics (e.g., ad-hoc generation of modification parameters, adjustment of a set of modification parameters or functions of a currently-stored modification profile associated with the user for the given context, etc.).

In one use case, a wearable device (implementing the foregoing operations) may automatically adjust brightness of the enhanced presentation of the live image data for one or more eyes of the user based on the respective pupil sizes (e.g., where such adjustment is independent of the brightness of the surrounding environment). As an example, subjects with anisocoria have unequal pupil size, and those subjects have light sensitivity from a single eye, which cannot tolerate the light brightness tolerated by the healthy eye. In this way, the wearable device enables automatic adjustment of brightness for each eye separately (e.g., based on the detected pupil size of the respective eye).

In another use case, the wearable device may detect pupil size, visual axis, optical axis, limbus position, line of sight, or other eye accommodation state (e.g., including changes to the foregoing) and may change a modification profile based on the detected states. As an example, for subjects with higher order aberrations (e.g., errors of refraction that are not correctable by spectacles nor contact lenses), the subject's aberrations are dynamic and change according to the pupil size and the accommodation state of the eye. The wearable device may detect the state of accommodation by detecting the signs of the near reflex (e.g., miosis (decrease the size of the pupil) and convergence (inward crossing of the pupil)). Additionally, or alternatively, the wearable device may include a pupil and line of sight tracker to detect the direction of gaze. As another example, aberrations of the eye change according to the size and position of the aperture of the optical system and can be measured in relation to different pupil sizes and positions of the pupil and visual axis. The wearable device may, for example, measure the irregularities on the cornea to determine the higher order aberrations (e.g., based on the measurements) and calculate the modification profile to address the higher order aberrations. For different sizes and positions of the pupil and visual

axis (or other eye accommodation states), different modification profiles may be created and stored for future use to provide real-time enhancements. One or more of these detected inputs enable the wearable device to use the appropriate modification profile (e.g., set of modification parameters or functions) to provide enhancements for the user.

As another example, the wearable device may be used to correct for presbyopia by automatically performing autofocus of the images displayed to the user to provide near vision. To further augment and enhance near vision, the wearable device may detect where the user is trying to look at a near target (e.g., by detecting the signs of the near reflex, such as miosis (decrease in pupil size and convergence (inward movement of the eye)) and perform autofocusing for a region of an image corresponding to the target that the user is looking (e.g., the portion of the display that the user is looking, the proximate area around an object at which the user is looking, etc.). Additionally, or alternatively, the wearable device may determine how far the target is (e.g., a target object or area) by quantifying the amount of the near reflex exerted by the subject and distance of the target from the eye (e.g., via sensors of the wearable device) and provide the adequate correction based on the quantified amount and target distance.

As another example, the wearable device may be used to correct for double vision (e.g., related to strabismus or other conditions). The wearable device may monitor the user's eyes and track the user's pupils to measure the angle of deviation to displace the images projected for each eye (e.g., in conjunction with detecting strabismus or other conditions). Because double vision is typically dynamic (e.g., the double vision increases or decreases towards one or more gazes), the wearable device may provide the appropriate correction by monitoring the user's pupils and the user's line of sight. For example, if the user has an issue in moving the user's right pupil away from the user's nose (e.g., toward to edge of the user's face), then the user's double vision may increase when the user is looking to the right and may decrease when the user is looking to the left. As such, the wearable device may display an enhanced presentation of live image data to each eye such that a first version of the enhanced presentation displayed to one of the user's eyes reflects a displacement from a second version of the enhanced presentation displayed to the user's other eye (e.g., where the amount of displacement is based on the pupil position and gaze direction) to dynamically compensate for the user's condition (e.g., strabismus or other condition) and, thus, prevent double vision for all potential gaze directions.

Although prisms can be applied to shift image in front of the crossed eye (e.g., caused by strabismus or other condition) to correct for double vision, prisms are unable to produce torsion of the image and, thus, not useful in correcting for double vision resulting from conditions that cause images to appear tilted or cyclotorted (e.g., cyclotropia is a form of strabismus which causes images received from both eyes to appear tilted or cyclotorted). In some use cases, the wearable device may monitor the user's eyes to measure the degree of strabismus (e.g., including cyclotorsion) by detecting the pupil, limbus, line of sight, or visual axis of both eyes in relation to each other. Additionally, or alternatively, the wearable device may perform such measurements by obtaining images of retinas of both eyes and comparing the structures of the retina and nerve in relation to each other. In doing so, the wearable device may detect and measure the relative location of those eye structures and any torsion displacement. Such measurements may be provided to a prediction model to predict modification parameters for the live image processing to correct for the defect and alleviate the double vision. Continuous feedback may be obtained from sensors of the wearable device (e.g., pupil tracker, gaze tracker, tracker based on retina image, etc.) may be used to change the modification profile applied to live image data in real-time. In further use cases, the user may also fine tune the correction. As an example, an image may be displayed to the user on a user interface, and the user may move the image (or an object represented by the image) until that image cross in front of one eye and rotate the object until the object overlaps with the image seen by the other eye.

As with other forms of strabismus, the resulting displacement caused by cyclotropia changes in real-time based on the intended direction of action of the paralyzed (or partially paralyzed) muscle associated with the cyclotropia and when such a patient is looking towards one side or the other. By tracking the eye characteristics, the wearable device can dynamically compensate for the user's condition by displaying an enhanced presentation of live image data to each eye such that a first version of the enhanced presentation displayed to one of the user's eyes reflects a displacement from a second version of the enhanced presentation displayed to the user's other eye (e.g., where the amount of displacement is based on the pupil position and gaze direction).

In some embodiments, with respect to FIG. **1**A, upon obtaining feedback related to a set of stimuli (displayed to a user during a visual test presentation), feedback related to one or more eyes of the user, feedback related to an environment of the user, or other feedback, testing subsystem **122** may provide the feedback to a prediction model, and the prediction model may be configured based on the feedback. In some embodiments, testing subsystem **122** may obtain a second set of stimuli (e.g., during the visual test presentation). As an example, the second set of stimuli may be generated based on the prediction model's processing of the set of stimuli and the feedback related to the set of stimuli. The second set of stimuli may be additional stimuli derived from the feedback to further test one or more other aspects of the user's visual field (e.g., to facilitate more granular correction or other enhancements for the user's visual field). In one use case, testing subsystem **122** may cause the second set of stimuli to be displayed to the user (e.g., during the same visual presentation), and, in response, obtain further feedback related to the second set of stimuli (e.g., the further feedback indicating whether or how the user sees one or more stimuli of the second set). Testing subsystem **122** may then providing the further feedback related to the second set of stimuli to the prediction model, and the prediction model may be further configured based on the further feedback (e.g., during the visual test presentation). As an example, the prediction model may be automatically configured for the user based on (i) an indication of a response of the user to one or more stimuli (e.g., of the set of stimuli, the second set of stimuli, or other set of stimuli), (ii) an indication of a lack of response of the user to such stimuli, (iii) an eye image captured during the visual test presentation, or other feedback (e.g., the prediction model may be personalized toward the user based on the feedback from the visual test presentation). In one use case, for example, the feedback indicates one or more visual defects of the user, and the prediction model may be automatically configured based on the feedback to address the visual defects. As another example, the prediction model may be trained based on such feedback and other feedback from other users to improve accuracy of results provided by the prediction model (e.g., trained to provide modification

profiles described herein, trained to generate an enhanced presentation of live image data, etc.).

In some embodiments, visioning subsystem **124** may provide live image data or other data (e.g., monitored eye-related characteristics) to the prediction model to obtain an enhanced image (derived from the live image data) and cause an enhanced image to be displayed. In some embodiments, the prediction model may continue to be configured during the display of the enhanced image (derived from the live image data) based on further feedback continuously provided to the prediction model (e.g., on a periodic basis, in accordance with a schedule, or based on other automated triggers). As an example, a wearable device may obtain a live video stream from one or more cameras of the wearable device and cause the enhanced image to be displayed on one or more displays of the wearable device (e.g., within less than a millisecond, less than a centisecond, less than a decisecond, less than a second, etc., of the live video stream being captured by the cameras of the wearable device). In some embodiments, the wearable device may obtain the enhanced image from the prediction model (e.g., in response to providing the live image data, monitored eye-related characteristics, or other data to the prediction model). In some embodiments, the wearable device may obtain modification parameters or functions from the prediction model (e.g., in response to providing the live image data, monitored eye-related characteristics, or other data to the prediction model). The wearable device may use the modification parameters or functions to generate the enhanced image from the live image data (e.g., parameters of functions used to transform or modify the live image data into the enhanced image). As a further example, the modification parameters may include one or more transformation parameters, brightness parameters, contrast parameters, saturation parameters, sharpness parameters, or other parameters.

In an example, a vision correction framework having a machine learning framework with an AI algorithm may be used to create automatic personalized modification profiles by applying transformation, translation, and resizing of the field of view to better fit it to the remaining functional visual field. The machine learning framework may include one or more of data collection, visual field classification, and/or regression models. To facilitate recording of participant responses, quantitative scores, and feedback, a graphical user interface (GUI) and data collection program may be used.

With respect to transformations applied to images in the visioning mode, example transformations of the machine learning framework may include one or more of: 1) conformal mapping, 2) fisheye, 3) custom 4th order polynomial transformation, 4) polar polynomial transformation (using polar coordinates), or 5) rectangular polynomial transformation (using rectangular coordinates) (e.g., FIG. **13**).

With respect to translations applied to images in the visioning mode, examples may include one or more of the following. For the center detection, weighted averaged of the best center and the closest point to the center may be used. For example, the closest point may be determined by finding the nearest point to the center location. The best center may be determined by one or more of the following: 1) the centroid of the largest component, 2) the center of the largest inscribed circle, square, rhombus, and/or rectangle, or 3) the center of the local largest inscribed circle, square, rhombus, and/or rectangle (e.g., FIG. **14**). For example, the framework may search for the largest shape but alliteratively to avoid getting far from the macular vision region, the framework may substitute this by the weighted average of the closest point with the methods.

In various embodiments, the AI algorithm may be initially trained using simulated visual field defects. For example, to train the AI algorithm, a dataset of visual field defects may be collected. For example, in one experimental protocol, a dataset of 400 visual field defects were obtained from patients with glaucoma. The dataset may be used to create simulated visual field defects on virtual reality glasses for presentation to normal subjects for grading. The resulting feedback obtained from the grading may then be used to train the algorithm.

For example, an AI algorithm that automatically fits an input image to areas corresponding to the intact visual field pattern for each patient individually may be used. In various embodiments, the algorithm may include at least three degrees of freedom to remap the images, although more or less degrees of freedom may be used. In one example, the degrees of freedom include transformation, shifting, and resizing. The added image transformation may preserve the quality of the central area of the image corresponding to the central vision, where acuity is highest, while condensing the peripheral areas with an adequate amount of image quality in the periphery. This may be applied such that the produced overall image content would be noticeable to the patient.

The image transformations included in the AI algorithm may include one or more of conformal, polynomial or fish eye transformations. In some embodiments, other transformations may be used. The machine learning techniques may be trained on a labeled dataset prior to performing their actual task. In one example, the AI algorithm may be trained on a visual field dataset that incorporates different types of peripheral defects. For example, in one experiment, the dataset included 400 visual field defect patterns. The training phase was then guided by normal participants to quantitatively score the remapped images generated by the AI algorithm.

FIG. **11** shows an image **1100** of a test image (stimuli) according to one example. The test image **1100** may be designed to measure the acuity, the paracentral vision and/or the peripheral vision. The illustrated test image displays five letters at the central region, four internal diamonds **1102** at the paracentral region, and eight external diamonds **1104** at the peripheral region as shown in FIG. **11**.

To be able to train the AI system, a volume of data is needed, as introduced above. As an initial step, defective binocular visual fields may be used to simulate binocular vision of patients as shown in FIG. **12**. Next, the simulated vision may be presented to subjects through the spectacles device. In this way, the input image can be manipulated using different image manipulations then presented again to the subject to grade the modified vision. The corrected image may be further corrected and presented to the subject in a continually corrective process until an optimized corrected image is determined. FIG. **13** illustrates examples of different correction transformations that may be applied to the image and presented to the user. FIG. **14** illustrates an example of different translation methods (shifting the image to fit it in the intact visual field). The intact visual field is white and blind visual field is black.

The AI system may be designed using machine learning models such as artificial neural networks and Support Vector Machines (SVM). In some examples, the AI system is designed to produce an output comprising an estimate of the best image manipulation methods (e.g., geometric transformation and translation) through an optimization AI system. The vision system, in a visioning mode, may presents

images manipulated according to the output image manipulation methods to the patient through a headset such that the patient experiences the best possible vision based on his defective visual field. The machine learning framework (also termed herein "AI System") of the vision correction framework may trained using the collected data, (e.g., as described herein). A block diagram of an example AI system **1500** is shown in FIG. **15**.

A process **1600** of the AI system **1500** is shown in FIG. **16**. The input to the system **1500** includes a test image and a visual field image. The AI system **1500** estimates the best geometric transform for the test image such that more details can be presented through the visual field. Then, AI system **1500** estimates the best translation for the test image such that the displayed image covers major parts of the visual field. Then, the test image is transformed and translated as shown in FIG. **17**. and FIG. **18**, respectively. Finally, the image is combined with the visual field again in case of the training only for the simulation purpose, but it is displayed directly to the patient in the testing phase. A screenshot of graphical user interface presenting a summary of visual field analysis, which may include a final implementation of the visual field AI system including parameters of the image transformation and translation to be applied to the image, is shown in FIG. **19**.

In example an implementation, an artificial neural network model was used to implement the machine learning framework ("AI system") on the vision correction framework. The AI system takes as the visual field image converted to a vector. The AI system gives as output the prediction of the parameters of the image transformation and the translation to be applied to the scene image. Then, the scene image is manipulated using these parameters. The AI system includes two hidden layers wherein each hidden layer includes three neurons (i.e., units) and one output layer. One such example AI system model is shown FIG. **20**. This AI system may also extend to convolutional neural network model for even more accurate results, in other examples. FIGS. **21** and **22** illustrate example processes **2100** and **2200** of a testing mode application of a neural network and an AI algorithm optimization process using a neural network, respectively.

In some embodiments, with respect to FIG. **1**A, upon obtaining feedback related to a set of stimuli (displayed to a user during a visual test presentation), feedback related to one or more eyes of the user, feedback related to an environment of the user, or other feedback, testing subsystem **122** may provide the feedback to a prediction model, and the prediction model may be configured based on the feedback. In some embodiments, further feedback may be continuously obtained and provided to the prediction model (e.g., on a periodic basis, in accordance with a schedule, or based on other automated triggers) to update the configuration of the prediction model. As an example, the configuration of the prediction model may be updated while one or more enhancements of live image data are being displayed to the user.

In some embodiments, visioning subsystem **122** may monitor characteristics related to one or more eyes of the user (e.g., gaze direction, pupil size, limbus position, visual axis, optical axis, eyelid position, or other characteristics) and provide the eye characteristic information to the prediction model during an enhanced presentation of live image data to the user. Additionally, or alternatively, visioning subsystem **122** may monitor characteristics related to an environment of the user (e.g., brightness level of the environment, temperature of the environment, or other characteristics). As an example, based on the eye or environmental characteristic information (e.g., indicating the monitored characteristics), the prediction model may provide one or more modification parameters or functions to be applied to the live image data to generate the enhanced presentation of the live image data (e.g., the presentation of one or more enhanced images derived from the live image data to the user). In one use case, the prediction model may obtain the modification parameters or functions (e.g., stored in memory or at one or more databases) based on the currently-detected eye characteristics or environmental characteristics. In another use case, the prediction model may generate the modification parameters or functions based on the currently-detected eye characteristics or environmental characteristics.

In some embodiments, with respect to FIG. **1**A, visioning subsystem **122** may facilitate enhancement of a field of view of a user via one or more dynamic display portions on one or more transparent displays (e.g., based on feedback related to a set of stimuli displayed to a user or other feedback). As an example, the dynamic display portions may include one or more transparent display portions and one or more other display portions (e.g., of a wearable device or other device). In some embodiments, visioning subsystem **122** may cause one or more images to be displayed on the other display portions (e.g., such that the images are not displayed on the transparent display portions). As an example, a user may see through the transparent display portions of a transparent display, but may not be able to see through the other display portions and instead sees the image presentation on the other display portions (e.g., around or proximate the transparent display portions) of the transparent display. That is, in some embodiments, a dynamic hybrid see-through/opaque display may be used. In this way, for example, one or more embodiments can (i) avoid the bulky and heavy weight of typical virtual reality headsets, (ii) make use of a user's intact vision (e.g., making use of the user's good acuity central vision if the user has intact central vision but a defective peripheral visual field, making use of the user's intact peripheral vision if the user has intact peripheral vision but a defective central visual field, etc.), and (iii) mitigate visual confusion that would otherwise be caused by typical augmented reality technology that has an overlap effect between the see-through scene with the internally displayed scene.

As an example, live image data may be obtained via the wearable device, and an enhanced image may be generated based on the live image data and displayed on the other display portions of the wearable device (e.g., display portions of a display of the wearable device that satisfy an opaque threshold or fail to satisfy a transparency threshold). In some embodiments, visioning subsystem **122** may monitor one or more changes related to one or more eyes of the user and cause, based on the monitoring, an adjustment of the transparent display portions of the transparent display. As an example, the monitored changes may include an eye movement, a change in gaze direction, a pupil size change, or other changes. One or more positions, shapes, sizes, transparencies, brightness levels, contrast levels, sharpness levels, saturation levels, or other aspects of the transparent display portions or the other display portions of the wearable device may be automatically adjusted based on the monitored changes.

In one use case, with respect to FIG. **24**A, a wearable device **2400** may include a transparent display **2402** dynamically configured to have a transparent peripheral portion **2404** and an opaque central portion **2406** such that the light from the user's environment can directly pass through the

transparent peripheral portion **2404**, but does not pass through the opaque central portion **2406**. For patients with diagnosed central visual field anomalies **2306**, the foregoing dynamic configuration enables such patients to use their intact peripheral visual field to view the actual un-corrected view of the environment and be presented with a corrected rendition of the central region on the opaque central portion **2406**.

In another use case, with respect to FIG. **24**B, the wearable device **2400** may include the transparent display **2402** dynamically configured to have an opaque peripheral portion **2504** and a transparent central portion **2506** such that the light from the user's environment can directly pass through the transparent central portion **2506**, but does not pass through the opaque peripheral portion **2504**. For patients with peripheral visual field anomalies, the foregoing dynamic configuration enables such patients to use their intact central visual field to view the actual un-corrected view of the environment and be presented with a corrected rendition of the peripheral region on the opaque peripheral portion **2504**. In each of the foregoing use cases, with respect to FIGS. **24** and **25**, one or more positions, shapes, sizes, transparencies, or other aspects of the transparent display portions **2404**, **2506** or the opaque display portions **2406**, **2504** may be automatically adjusted based on changes related to one or more eyes of the user that are monitored by the wearable device **2400** (or other component of system **100**). Additionally, or alternatively, one or more brightness levels, contrast levels, sharpness levels, saturation levels, or other aspects of the opaque display portions **2406**, **2504** may be automatically adjusted based on changes related to one or more eyes of the user that are monitored by the wearable device **2400**. In some cases, for example, to dynamically accommodate for areas of the user's visual field that have reduced brightness, the user's pupil and line of sight (or other eye characteristics) may be monitored and used to adjust the brightness levels of parts of the opaque display portions **2406**, **2504** (e.g., in addition to or in lieu of increasing the brightness levels of parts of the enhanced image that correspond to the reduced brightness areas of the user's visual field).

As an example, with respect to FIG. **25**, based on a determination of a user's visual field (e.g., including defective visual field portions, intact visual field portions, etc., as represented by visual field plane **2502**), an enhanced image may be generated (e.g., as represented by the remapped image plane **2504**) as described herein. The enhanced image may be displayed to the user on one or more opaque display portions in the opaque area **2508** of a display (e.g., as represented by selective transparency screen plane **2506**) such that the displayed enhanced image augments the user's view of the environment through the transparent area **2510** of the display.

In one use case, with respect to FIG. **25**, the selective transparency screen plane **2506** may be aligned with the other planes **2502** and **2504** via one or more eye tracking techniques. As an example, an eye tracking system (e.g., of wearable device **2400** or other device) may be calibrated for a user to ensure proper image projections according to the user's personalized intact visual field. The eye tracking system may continuously acquire gaze coordinates (e.g., on a periodic basis, in accordance with a schedule, or other automated triggers). A coordinates transformation may be performed to convert the eye movements spherical coordinates (θ, φ) into the display's Cartesian coordinates (x, y). As such, the device's controller may determine the central position of the images to be displayed. Camera images will be truncated and shifted to match the acquired gaze vector direction (e.g., FIG. **25**). The same Cartesian coordinates may be sent to the selective transparency screen controller to make the area corresponding to macular vision at the current gaze direction transparent and allow usage of the central visual acuity. In some cases, low pass filtering may be performed on the gaze data to remove micro-eye movements (e.g., micro-eye movements caused by incessantly moving and drafting that occur even at fixations because the eyes are never completely stationary) that may otherwise cause shaky images to be displayed to the user.

As indicated above, in some embodiments, the wearable device may be configured to selectively control transparency of a display area of a monitor, such as a screen, glass, film, and/or layered medium. FIG. **23** illustrates an example process **2300** implementing testing and visioning modes and the use of a custom-reality spectacles device, which may use a macular (central) versus peripheral vision manipulation.

In some examples, the custom reality spectacles device (e.g., FIGS. **40**A-**40**C) include transparent glasses for overlaying corrected images onto a visible scene. The glasses may comprise a monitor comprising a screen having controllably transparency onto which images may be projected for display. In one example, the display comprises a heads-up display. In various embodiments, a custom reality spectacles device includes glasses having controllable layers for overlaying corrected images onto a scene visible through the glasses. The layers may comprise glass, ceramic, polymer, film, and/or other transparent materials arranged in a layered configuration. The controllable layers may include one or more electrically controlled layers that allow for adjusting the transparency over one or more portions of the visual field, for example, in pixel addressable manner. In one embodiment, may include pixels or cells that may be individually addressable (e.g., via an electric current, field, or light). The controllable layers may be layers that may be controlled to adjust contrast of one or more portions of the visual field, color filtering over portions, the zooming in/zooming out of portions, focal point over portions, transparency of the spectacles device surface that display the image to block or allow the light coming from the environment at a specific location of the visual field. If there is a portion of field of view (e.g., a portion of the peripheral vision or a portion of the macular vision or a portion, part of it is macular and part of it is peripheral) for manipulation to augment a subject's vision, then the transparency of that portion of the glass may be lowered to block the view of the environment through that portion of glass and to allow the patient to see more clearly the manipulated image displayed along that portion of the glass. In various embodiments, vision system or custom reality spectacles device may dynamically control transparency regions to allow a subject to naturally view the environment when redirecting eyes by eye movement rather than just head movement. For example, pupil tracking data (e.g., pupil and/or line of sight tracking) may be used to modify the portion of the glass having decreased transparency such that the decreased transparency region translates relative to the subject's eye.

For example, the transparency of the glass in the spectacles device comprising custom-reality glasses may be controllably adjusted to block light from that portion of the visual field corresponding to where image correction is performed (e.g., at a central region or a peripheral region). Otherwise subject may see the manipulated image and see through it and perceive the underling actual visual field in that region. Such light blocking can be achieved by a photochromic glass layer within the spectacles device.

Moreover, the spectacles device may change the position of the area where the glass transparency is reduced by measuring for eye (pupil) movement using inward directed image sensors, and compensating based on such movement by processing in the vision correction framework. In one example, the display screen of the monitor includes pixels or cells including electric ink technology and that may be individually addressed to cause an electric field to modify the arrangement of ink within a cell to modify transparency and/or generate a pixel of the display. In an example implementation, FIG. **40**A shows custom-reality glasses **4000** formed for a frame **4002** and two transparent glass assemblies **4004**. As shown in FIGS. **40**B and **40**C, the transparent glass assemblies **4004** have embedded, electronically controllable correction layers **4006** that may be controllable from fully transparent to fully opaque, that may be digital layers capable of generating a correction image to overlay or supplant a portion of the field of view of the glasses **4004**. The correction layers **4006** may be connected, through an electrical connection **4008**, to an image processing device **4010** on the frame **4002**.

With specific reference to the process **2300** of FIG. **23**, at a block **2302** testing mode data may be received by a vision correction framework, and at a block **2304** visual field distortions, defects, aberrations, and/or other ocular anomalies may be determined, along with their locations.

For diagnosed central visual field anomalies **2306**, at a block **2308** the custom reality spectacles device may allow the image from the environment to pass through the glass thereof to a peripheral field of the user (e.g., FIG. **24**A). As shown, custom reality spectacles device **2400** may have a multi-layered glass viewfinder **2402**. A peripheral region **2404** may be set as transparent to allow light passage there through, allowing the subject to view the actual un-corrected environment. At a block **2312**, a central region **2406** of the environment may be made opaque by the spectacles device **2400** and a corrected rendition of the central region may be presented by display to the user, for example, using corrections such as those of FIGS. **13**, **14**, **17**, and **18**.

For diagnosed peripheral visual field anomalies **2308**, at a block **2314** a central region **2506** (e.g., FIG. **25**B) of the environment is allowed to pass through a transparent portion of the spectacles device **2400**, and transparency of a peripheral region **2504** is modified to block such that a corrected peripheral version image may be displayed within peripheral region **2504**, for example using the corrective transformations herein.

In some embodiments, with respect to FIG. **1**A, visioning subsystem **122** may facilitate enhancement of a field of view of a user via projections onto selected portions of an eye of the user (e.g., based on feedback related to a set of stimuli displayed to a user or other feedback). As discussed herein, an enhanced presentation of live image data may be displayed to the user by projecting the enhanced presentation (e.g., modified images derived from the live image data) onto the user's eyes. In addition to or alternatively to the use of dynamic display portions on a screen (e.g., to enable the user to see-through one or more portions of the screen while the user sees modified live image data being displayed on one or more other portions of the screen), the modified image data may be projected onto one or more portions of an eye of the user (e.g., one or more portions of a retina of the user) while simultaneously avoiding projection of the modified image data onto one or more other portions of the user's eye (e.g., one or more other portions of the retina of the user).

In some embodiments, the modified image data may be projected onto one or more intact visual field portions of an eye of the user while simultaneously avoiding projection of the modified image data onto one or more other intact visual field portions of the user's eye. As an example, with respect to the other intact visual field portions where projection of the modified image data is avoided, light from the user's environment can pass through the user's retinas (e.g., without any significant interference from light being emitted by the projector), thereby allowing the user to see the environment via such other intact visual field portions. On the other hand, with respect to the intact visual field portions onto which the modified image data is being projected, the projected light prevents the user from seeing the environment via the projected-onto portions of the user's intact visual field. Nevertheless, by projecting the modified live image data onto those intact visual field portions of the user's eyes, the system allows the modified live image data to be used to augment the user's visual field (e.g., in a manner similar to the use of dynamic display portions to augment the user's visual field).

In some embodiments, visioning subsystem **122** may monitor one or more changes related to one or more eyes of the user and cause, based on the monitoring, an adjustment of one or more projecting portions of a projector (e.g., portions including laser diodes, LED diodes, etc., that are emitting a threshold amount of light visible to the user's eyes). As an example, as with the adjustment of a dynamic display portion on a screen, the monitored changes may include an eye movement, a change in gaze direction, a pupil size change, or other changes. One or more positions, shapes, sizes, brightness levels, contrast levels, sharpness levels, saturation levels, or other aspects of the projecting portions or other portions of the projector may be automatically adjusted based on the monitored changes.

In one use case, a wearable device may include a projector configured to selectively project an enhanced presentation (e.g., modified images derived from live image data) onto one or more portions of the user's eyes (e.g., one or more portions of each retina of the user that correspond to the user's intact visual field) while simultaneously avoiding projection of the modified image data onto one or more other portions of the user's eyes (e.g., one or more other portions of each retina of the user that correspond to the user's intact visual field). In some cases, alignment of such a selective projection plane may be aligned with the other planes (e.g., a visual field plane, a remapped image plane, etc.) via one or more eye tracking techniques (e.g., one or more techniques similar to those described in FIG. **25** with respect to the use of dynamic display portions on a screen).

with respect to FIG. **24**A, a wearable device **2400** may include a transparent display **2402** dynamically configured to have a transparent peripheral portion **2404** and an opaque central portion **2406** such that the light from the user's environment can directly pass through the transparent peripheral portion **2404**, but does not pass through the opaque central portion **2406**. For patients with diagnosed central visual field anomalies **2306**, the foregoing dynamic configuration enables such patients to use their intact peripheral visual field to view the actual un-corrected view of the environment and be presented with a corrected rendition of the central region on the opaque central portion **2406**.

In another use case, with respect to FIG. **24**B, the wearable device **2400** may include the transparent display **2402** dynamically configured to have an opaque peripheral portion **2504** and a transparent central portion **2506** such that the light from the user's environment can directly pass

through the transparent central portion **2506**, but does not pass through the opaque peripheral portion **2504**. For patients with peripheral visual field anomalies, the foregoing dynamic configuration enables such patients to use their intact central visual field to view the actual un-corrected view of the environment and be presented with a corrected rendition of the peripheral region on the opaque peripheral portion **2504**. In each of the foregoing use cases, with respect to FIGS. **24** and **25**, one or more positions, shapes, sizes, transparencies, or other aspects of the transparent display portions **2404**, **2506** or the opaque display portions **2406**, **2504** may be automatically adjusted based on changes related to one or more eyes of the user that are monitored by the wearable device **2400** (or other component of system **100**). Additionally, or alternatively, one or more brightness levels, contrast levels, sharpness levels, saturation levels, or other aspects of the opaque display portions **2406**, **2504** may be automatically adjusted based on changes related to one or more eyes of the user that are monitored by the wearable device **2400**. In some cases, for example, to dynamically accommodate for areas of the user's visual field that have reduced brightness, the user's pupil and line of sight (or other eye characteristics) may be monitored and used to adjust the brightness levels of parts of the opaque display portions **2406**, **2504** (e.g., in addition to or in lieu of increasing the brightness levels of parts of the enhanced image that correspond to the reduced brightness areas of the user's visual field).

In some embodiments, with respect to FIG. **1**A, visioning subsystem **122** may facilitate an increase in a field of view of a user via combination of portions of multiple images of a scene (e.g., based on feedback related to a set of stimuli displayed to the user). As an example, FIG. **26** illustrates a representation of a normal binocular vision for a subject, where a monocular image from the left eye **2602** and from the right eye **2604** are combined into a single perceived image **2606** having a macular central area **2608** and a peripheral visual field area **2610** surrounding the central area **2608**. In some cases, however, a subject may have a tunnel vision condition, wherein the peripheral area **2610** is not visible to the subject, as shown in the representation in FIG. **27**. As shown, for these cases, one or more objects do not appear within a field of view, resulting in a peripheral defect **2612** in the area **2610**, where objects within the area **2610** are not seen by the subject. Thus, for example, visioning subsystem **122** may combine portions of multiple images of a scene (e.g., common and divergent regions of such images) to increase the field of view of the subject.

In some embodiments, visioning subsystem **122** may obtain a plurality of images of a scene (e.g., images obtained via one or more cameras at different positions or orientations). Visioning subsystem **122** may determine a region common to the images, and, for each image of the images, determine a region of the image divergent from a corresponding region of at least another image of the images. In some embodiments, visioning subsystem **122** may generate or display an enhanced image to a user based on the common region and the divergent regions. As an example, the common region and the divergent regions may be combined to generate the enhanced image to include a representation of the common region and representations of the divergent regions. The common region may correspond to respective portions of the images that have the same or similar characteristics as one another, and each divergent region may correspond to a portion of one of the images that is distinct from all the other corresponding portions of the other images. In one scenario, a distinct portion of one image may include a part of the scene that is not represented in the other images. In this way, for example, the combination of the common region and the divergent region into an enhanced image increase the field of view otherwise provided by each of the images, and the enhanced image may be used to augment the user's visual field. In one use case, the common region may be any portion of at least one of the images of the left eye **2602** or the right eye **2604** between any of two of the four vertical dotted lines indicated in FIG. **27** for each such image. In another use case, with respect to FIG. **27**, one of the divergent regions may be any portion of the image of the left eye **2602** to the left of the left-most vertical dotted line for that image. Another one of the divergent regions may be any portion of the image of the right eye **2604** to the right of the right-most vertical dotted line for that image.

In some embodiments, the common region is a region of at least one of the images that corresponds to a macular region of a visual field of an eye (or other central region of the visual field of the eye) or to a region within the macular region. In some embodiments, each of the divergent regions is a region of at least one of the images that corresponds to a peripheral region of a visual field of an eye or to a region within the peripheral region. As an example, with respect to FIG. **27**, the common region may be (i) the portion of the image corresponding to the macular region of the left eye **2602** or (ii) the portion of the image corresponding to the macular region of the right eye **2604** (e.g., given that both such portions are common to both images). As another example, the common region may be the respective portions of the images corresponding to a common region within the macular regions of the left eye **2602** and right eye **2604**. As a further example, based on the common region and the divergent regions, the image **2606** is generated to have the macular central area **2608** and the peripheral visual field area **2610** surrounding the central area **2608**.

In some embodiments, visioning subsystem **122** may determine a region common to a plurality of images of a scene (e.g., captured via a wearable device of the user), and, for each image of the images, determine a region of the image divergent from a corresponding region of at least another image of the images. Visioning subsystem **122** may perform shifting of each image of the images and generate, subsequent to the performance of the shifting, an enhanced image based on the common region and the divergent regions. In some embodiments, the shifting of each of the images may be performed such that (i) a size of the common region is modified (e.g., increased or decreased) or (ii) a size of at least one of the divergent regions is modified (e.g., increased or decreased). In one scenario, the size of the common region may be increased as result of the shifting. In another scenario, the size of at least one of the divergent regions is decreased as a result of the shifting.

As an example, the defect in FIG. **27** may be corrected using a shifting image correction technique. In one use case, with respect to FIG. **28**, each of two visual field cameras (e.g., of a wearable device) may capture a monocular image **2802** and **2804**, respectively (e.g., where each monocular image is different as it's capturing the visual scene from a slightly different (offset) position). The two captured monocular images **2802**, **2804** are then shifted toward each other in the visual correction framework resulting in images **2802'** and **2804'**. As shown in FIG. **28**, the respective areas (e.g., a common region) of the two images **2802** and **2804** between the left-most vertical dotted line and the right-most vertical dotted line for each image **2802** and **2804** (is larger than the respective areas (e.g., a common region) between the two images **2802'** and **2804'** between the left-most vertical dotted

line and the right-most vertical dotted line for each image **2802'** and **2804'**. As such, the common region is decreased in size subsequent the shifting. On the other hand, the divergent regions have increased in size subsequent the shifting (e.g., the area left of the left-most vertical dotted line for image **2802** vs. the area left of the left-most vertical dotted line for image **2802'**, and the area right of the right-most vertical dotted line for image **2804** vs. the area right of the right-most vertical dotted line for image **2804'**).

As a further example, these two shift images are then combined to generate a binocular image **2806** that captures the full periphery of the visual scene. For spectacles device having monitor displays, each display may display the corrected binocular image **2806** to the subject. In some use cases, for example, this shifting transformation can be used to increase the field of view of a subject by 5%, 10%, 15%, 20%, or more, without producing double vision effects for the subject.

In some embodiments, visioning subsystem **122** may determine a region common to a plurality of images of a scene (e.g., captured via a wearable device of the user), and, for each image of the images, determine a region of the image divergent from a corresponding region of at least another image of the images. Visioning subsystem **122** may perform resizing of one or more regions of the images and generate, subsequent to the performance of the resizing, an enhanced image based on the common region and the divergent regions. In some embodiments, visioning subsystem **122** may perform resizing of one or more regions of the images such that an extent of any resizing of the common region is different than an extent of any resizing of at least one of the divergent regions. In some embodiments, the resizing may be performed such that a percentage change in size of the common region represented in a first region of the enhanced image is greater than or less than a percentage change in size of at least one of the divergent regions represented in a second region of the enhanced image. As an example, the percentage change in size of at least one of the divergent regions may be zero, and the percentage change in size of the common region may be greater than zero. As another example, the percentage change in size of at least one of the divergent regions may be greater than zero, and the percentage change in size of the common region may be zero.

In one scenario, with respect to FIG. **29**, captured monocular images **2902** and **2904** are resized only in peripheral areas, while keeping the macular central area (central 20 degrees) unchanged, resulting in corrected images **2902'**, **2904'**. Such resizing transformation will preserve the visual acuity in the center while expanding the visual field. As shown in FIG. **29**, a combined binocular image **2906** captures the objects in the periphery that were missed before, and at the same time, keeps the details of the central macular area. The peripheral objects are clearly noticed by the subject even after resizing them, as the peripheral vision is not as sensitive as the central one. In some use cases, for example, shrinking of up to 20% of the image size can be performed without producing double vision effects for the subject. In various embodiments, resizing of a peripheral region may be performed additionally or alternatively to resizing of a central area. For example, peripheral regions may be resized to the sizes of the peripheral regions while retaining the size of the macular central area (e.g., for glaucoma patients). In another scenario, for patients with macular degeneration, the peripheral vision may be left intact (e.g., with no resizing), and the central area may be resized to reduce the size of the central area. The enhanced image (e.g., the binocular image) may then be generated to include the resized central area.

In some embodiments, visioning subsystem **122** may determine a region common to a plurality of images of a scene (e.g., captured via a wearable device of the user), and, for each image of the images, determine a region of the image divergent from a corresponding region of at least another image of the images. Visioning subsystem **122** may perform a fisheye transformation, a conformal mapping transformation, or other transformation on the common region and generate, subsequent to the performance of the transformation, an enhanced image based on the common region and the divergent regions. In some embodiments, visioning subsystem **122** may perform the fisheye transformation, the conformal mapping transformation, or other transformation on a region of the enhanced image (that includes the common region).

As an example, the fisheye transformation may be performed on a region to modify a radical component of the images in accordance with:

$$r_{new}=r+\alpha r^3, \text{ where } \alpha \text{ is a constant.}$$

As another example, the conformal mapping transformation may be performed on a region to modify a radial component of the images in accordance with:

$$r_{new}=r^{\beta}, \text{ where } \beta \text{ is a constant power of the radial component and } \beta>1$$

In some embodiments, visioning subsystem **122** may modify at least one of a plurality of images of a scene by moving one or more objects in the image (e.g., prior to generating an enhanced image based on common and divergent regions of the images). As an example, with respect to FIG. **30**, for patients with far peripheral defect in one eye, a missing object **3002** in a visual field **3004** of the defective eye can be transferred digitally to a mid-peripheral field region **3006** of the visual field **3004**, while other visual field **3008**, that of the healthy eye, would otherwise cover this area, meaning that the combined binocular image **3010** displays the missing object **3002** within an intact visual field. The subject may notice visual confusion in the area, but the subject can adapt to isolate information in this area of the visual field according to a moving object or the changing environment.

In some embodiments, visioning subsystem **124** may determine one or more defective visual field portions of a visual field of a user (e.g., in accordance with one or more techniques described herein). In some embodiments, visioning subsystem **122** may determine a region common to a plurality of images of a scene (e.g., captured via a wearable device of the user), and, for each image of the images, determine a region of the image divergent from a corresponding region of at least another image of the images. Visioning subsystem may generate an enhanced image based on the common and divergent regions of the images such that at least one of the common or divergent regions in the enhanced image do not overlap with one or more of the defective visual field portions.

In some embodiments, visioning subsystem **122** may detect an object in a defective visual field portion of a visual field of a user and cause an alert to be displayed. As an example, after correcting for defective visual field portion of a visual field of a user (e.g., via one or more techniques described herein), visioning subsystem **124** may monitor the remaining regions that were not corrected to detect one or more objects (e.g., safety hazards or other objects) and generate alerts (e.g., visual or audible alerts) indicating the

objects, locations of the objects, the size of the objects, or other information related to the objects. In one use case, for a patient with irregular or multi-region defective visual field, the produced modification profile might still not be optimal in fitting the acquired field of view into the intact regions of the patient's visual field. Therefore, to maximize the patient's safety while moving, automatic video tracking algorithms may be implemented to detect objects that are in one of the detective visual field portions. Such objects may include moving objects (e.g., moving car) or other objects in the defective visual field portions of the patient's visual field.

In some embodiments, visioning subsystem **122** may generate a prediction indicating that an object will come in physical contact with a user and cause an alert to be displayed based on the physical contact prediction (e.g., an alert related to the object is displayed on a wearable device of the user). In some embodiments, visioning subsystem **122** may detect an object (e.g., in or predicted to be in a defective visual field portion of a visual field of a user) and cause the alert to be displayed based on (i) the object being in or predicted to be in the defective visual field portion, (ii) the physical contact prediction, or (iii) other information. In some embodiments, visioning subsystem **122** may determine whether the object is outside (or not sufficiently in) any image portion of an enhanced image (displayed to the user) that corresponds to at least one visual field portions satisfying one or more vision criteria. In one use case, no alert may be displayed (or a lesser-priority alert may be displayed) when the object is determined to be within (or sufficiently in) an image portion of the enhanced image that corresponds to the user's intact visual field portion (e.g., even if the object is predicted to come in physical contact with the user). On the other hand, if the object in the defective visual field portion is predicted to come in physical contact with the user, and it is determined that the object is outside (or not sufficiently in) the user's intact visual field portion, an alert may be displayed on the user's wearable device. In this way, for example, the user can rely on the user's own intact visual field to avoid incoming objects within the user's intact visual field, thereby mitigating the risk of dependence on the wearable device (e.g., through habit forming) for avoidance of such incoming objects. It should be noted, however, that, in other use cases, an alert related to the object may be displayed based on the physical contact prediction regardless of whether the object is within the user's intact visual field.

As an example, with respect to FIG. **10**, for the uncompensated blind field **1006**, at blocks **1012** and **1014**, pupil tracking or other vision tracking (e.g., using inward directed image sensors) video tracking of a moving object in the visual field (e.g., through outward directed image sensors such as external cameras) may be used to detect safety hazards in regions of blind spots or that are moving into the regions of blind spots. In one use case, visioning subsystem **124** may compare the position of the safety hazard to a mapped visual field with defects (e.g., as measured in a testing mode) to detect when the safety hazard is in regions of blind spots or when the safety hazard is moving into such regions.

As another example, after correcting for defective visual field portion of a visual field of a user (e.g., via one or more techniques described herein), visioning subsystem **124** may monitor the remaining regions that were not corrected to detect any safety hazard (e.g., in real-time) approaching the user from such regions. If such detected safety hazards are predicted to come in physical contact with the user or come within a threshold distance of the user (e.g., one feet, two feet, or other threshold distance) (as opposed to passing by the user by at least the threshold distance of the user), visioning subsystem **124** may generate an alert related to the detected safety hazard (e.g., a visual alert displayed on a region seeable by the user, an audible alert, etc.).

In one use case, video signals (e.g., a live video stream) acquired from one or more cameras of a wearable device of a user will be preprocessed and filtered to remove residual noise effects. In some cases, the search region may be limited to the blind spots of the user or other defective visual field portions (e.g., that fail to satisfy one or more vision criteria). The limiting of the search region, for example, may reduce the amount of computational resources required to detect objects in the search region or generate related alerts or increase the speed of such detection or alert generation.

In some cases, two successive frames from a live video stream may be subtracted from one another to detect motion of one or more objects. As an example, occurrence of motion may be stored on a first delta frame (e.g., delta frame **1**), and the first delta frame may be used to enable visualization of the moving objects and cancelling the stationary background. Another two successive frames from the live video stream may be subtracted one another to produce a second delta frame (e.g., delta frame **2**). The second delta frame may also be used to enable visualization of the moving objects and cancelling the stationary background. In further cases, comparison between the first and second delta frames may be performed. If a moving object is increasing in size as detected by subtracting the first delta frame and the second delta frame from one another, then the object may be determined to be getting closer. If the increase in size exceeds a predetermined threshold size, then the alert will be issued to the user (e.g., a visual alert displayed on a region seeable by the user, an audible alert, etc.).

In some embodiments, configuration subsystem **112** may store prediction models, modification profiles, visual defect information (e.g., indicating detected visual defects of a user), feedback information (e.g., feedback related to stimuli displayed to users or other feedback), or other information at one or more remote databases (e.g., in the cloud). In some embodiments, the feedback information, the visual defect information, the modification profiles, or other information associated with multiple users (e.g., two or more users, ten or more users, a hundred or more users, a thousand or more users, a million or more users, or other number of users) may be used to train one or more prediction models. In one use case, where a prediction model being trained is a neural network or other machine learning model, model manager subsystem **114** may provide as input to the machine learning model (i) stimuli information (e.g., indicating a set of stimuli and their associated characteristics, such as intensity levels, locations at which a stimuli is to be displayed, etc.) and (ii) feedback information (e.g., indicating feedback related to the set of stimuli) to cause the machine learning model to predict visual defect information, modification profiles, or other outputs. Model manager subsystem **114** may provide reference information (e.g., visual defect information or modification profiles determined to be accurate with respect to the provided stimuli and feedback information) to the machine learning model. The machine learning model may assess its predicted outputs (e.g., predicted visual defect information, predicted modification profiles, etc.) against the reference information and update its configurations (e.g., weights, biases, or other parameters) based on its assessment of its predicted outputs. The foregoing operations may be performed with additional stimuli information (e.g., dis-

played to other users), additional feedback information (e.g., the other users' feedback related to the stimuli displayed to them), and additional reference information to further train the machine learning model (e.g., by providing such information as input and reference feedback to train the machine learning model, thereby enabling the machine learning model to further update its configurations).

In another use case, where the machine learning model is a neural network, connection weights may be adjusted to reconcile differences between the neural network's prediction and the reference information. In a further use case, one or more neurons (or nodes) of the neural network may require that their respective errors are sent backward through the neural network to them to facilitate the update process (e.g., backpropagation of error). Updates to the connection weights may, for example, be reflective of the magnitude of error propagated backward after a forward pass has been completed.

In some embodiments, one or more prediction models may be trained or configured for a user or a type of device (e.g., a device of a particular brand, a device of a particular brand and model, a device having a certain set of features, etc.) and may be stored in association with the user or the device type. As an example, instances of a prediction model associated with the user or the device type may be stored locally (e.g., at a wearable device of the user or other user device) and remotely (e.g., in the cloud), and such instances of the prediction model may be automatically or manually synced across one or more user devices and the cloud such that the user has access to the latest configuration of the prediction model across any of the user devices or the cloud. In one use case, upon detecting that a first user is using a wearable device (e.g., when the first user logs into the user's account or is identified via one or more other techniques), configuration subsystem **112** may communicate with the wearable device to transmit the latest instance of a prediction model associated with the first user to the wearable device such that the wearable device has access to a local copy of the prediction model associated with the first user. In another use case, if a second user is later detected to be using the same wearable device, configuration subsystem **112** may communicate with the wearable device to transmit the latest instance of a prediction model associated with the second user to the wearable device such that the wearable device has access to a local copy of the prediction model associated with the second user.

In some embodiments, multiple modification profiles may be associated with the user or the device type. In some embodiments, each of the modification profiles may include a set of modification parameters or functions to be applied to live image data for a given context to generate an enhanced presentation of the live image data. As an example, the user may have a modification profile for each set of eye characteristics (e.g., a range of gaze directions, pupil sizes, limbus positions, or other characteristics). As further example, the user may additionally or alternatively have a modification profile for each set of environmental characteristics (e.g., a range of brightness levels of the environment, temperatures of the environment, or other characteristics). Based on the eye characteristics or environmental characteristics currently detected, the corresponding set of modification parameters or functions may be obtained and used to generate the enhanced presentation of the live image data. In one use case, upon detecting that a first user is using a wearable device (e.g., when the first user logs into the user's account or is identified via one or more other techniques), configuration subsystem **112** may communicate with the wearable device to transmit the modification profiles associated with the first user to the wearable device such that the wearable device has access to a local copy of the modification profiles associated with the first user. In another use case, if a second user is later detected to be using the same wearable device, configuration subsystem **112** may communicate with the wearable device to transmit the modification profiles associated with the second user to the wearable device such that the wearable device has access to a local copy the modification profiles associated with the second user.

FIGS. **41-43** are example flowcharts of processing operations of methods that enable the various features and functionality of the system as described in detail above. The processing operations of each method presented below are intended to be illustrative and non-limiting. In some embodiments, for example, the methods may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the processing operations of the methods are illustrated (and described below) is not intended to be limiting.

In some embodiments, the methods may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information). The processing devices may include one or more devices executing some or all of the operations of the methods in response to instructions stored electronically on an electronic storage medium. The processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of the methods.

FIG. **41** shows a flowchart of a method **4100** of facilitating modification related to a vision of a user via a prediction model, in accordance with one or more embodiments.

In an operation **4102**, a visual test presentation may be provided to a user. As an example, the visual test presentation may include a set of stimuli. The set of stimuli may include light stimuli, text, or images displayed to the user. Operation **4102** may be performed by a subsystem that is the same as or similar to testing subsystem **122**, in accordance with one or more embodiments.

In an operation **4104**, one or more characteristics of one or more eyes of the user may be monitored. As an example, the eye characteristics may be monitored during the visual test presentation. The eye characteristics may include gaze direction, pupil size, limbus position, visual axis, optical axis, or other characteristics (e.g., during the visual test presentation). Operation **4104** may be performed by a subsystem that is the same as or similar to testing subsystem **122**, in accordance with one or more embodiments.

In an operation **4106**, feedback related to the set of stimuli may be obtained. As an example, the feedback may be obtained during the visual test presentation, and the feedback may indicate whether or how the user sees one or more stimuli of the set. Additionally, or alternatively, the feedback may include one or more characteristics related to the one or more eyes occurring when the one or more stimuli are displayed. Operation **4106** may be performed by a subsystem that is the same as or similar to testing subsystem **122**, in accordance with one or more embodiments.

In an operation **4108**, the feedback related to the set of stimuli may be provided to a prediction model. As an example, the feedback may be provided to the prediction

model during the visual test presentation, and the prediction model may be configured based on the feedback and the eye characteristic information. As another example, based on the feedback, the prediction model may be configured to provide modification parameters or functions to be applied to image data (e.g., live video stream) to generate an enhanced presentation related to the image data. Operation **4108** may be performed by a subsystem that is the same as or similar to testing subsystem **122**, in accordance with one or more embodiments.

In an operation **4110**, video stream data and the user's current eye characteristics information (e.g., indicating the user's current eye characteristics) may be provided to the prediction model. As an example, the video stream data may be a live video stream obtained via one or more cameras of a wearable device of the user, and the live video stream and the current eye characteristics information may be provided to the prediction model in real-time. Operation **4110** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4112**, a set of modification parameters or functions may be obtained from the prediction model. As an example, the set of modification parameters or functions may be obtained from the prediction model based on the video stream and the current eye characteristics information being provided to the prediction model. As another example, the set of modification parameters or functions may be configured to be applied to the video stream to generate an enhanced image (e.g., that accommodates for dynamic aberrations of the user). Additionally, or alternatively, the set of modification parameters or functions may be configured to be applied to dynamically adjust one or more display portions of a display. Operation **4112** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4114**, an enhanced image may be caused to be displayed to the user based on the video stream data and the set of modification parameters or functions. Operation **4114** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

FIG. **42** shows a flowchart of a method **4200** of facilitating an increase in a field of view of a user via combination of portions of multiple images of a scene, in accordance with one or more embodiments.

In an operation **4202**, a plurality of images of a scene may be obtained. As an example, the images may be obtained via one or more cameras (e.g., of a wearable device) at different positions or orientations. Operation **4202** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4204**, a region common to the images may be determined. As an example, the common region may correspond to respective portions of the images that have the same or similar characteristics as one another. Operation **4204** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4206**, for each image of the images, a region of the image divergent from a corresponding region of at least another image (of the images) may be determined. As an example, each divergent region may correspond to a portion of one of the images that is distinct from all the other corresponding portions of the other images. Operation **4206** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4208**, an enhanced image may be generated based on the common region and the divergent regions. As an example, the enhanced image may be generated such that (i) a first region of the enhanced image includes a representation of the common region and (ii) a second region of the enhanced image comprises representations of the divergent regions. As another example, the enhanced image may be generated such that the second region is around the first region in the enhanced image. Operation **4208** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4210**, the enhanced image may be displayed. As an example, the enhanced image may be displayed via one or more displays of a wearable device of the user. Operation **4210** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

FIG. **43** shows a flowchart of a method **4300** of facilitating enhancement of a field of view of a user via one or more dynamic display portions on one or more transparent displays, in accordance with one or more embodiments.

In an operation **4302**, one or more changes related to one or more eyes of a user may be monitored. As an example, the eye changes may include an eye movement, a change in gaze direction, a pupil size change, or other changes. Operation **4302** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4304**, an adjustment of one or more transparent display portions of a wearable device may be caused based on the monitored changes. As an example, one or more positions, shapes, or sizes of the one or more transparent display portions of the wearable device may be adjusted based on the monitored changes. Operation **4304** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In an operation **4306**, an enhanced image (e.g., derived from live image data) may be displayed on one or more other display portions of the wearable device. As an example, at least one of the other display portions may be around at least one of the transparent display portions of the wearable device such that the enhanced image is displayed around the transparent display portion (e.g., and not within the transparent display portions). Operation **4306** may be performed by a subsystem that is the same as or similar to visioning subsystem **124**, in accordance with one or more embodiments.

In some embodiments, the various computers and subsystems illustrated in FIG. **1**A may include one or more computing devices that are programmed to perform the functions described herein. The computing devices may include one or more electronic storages (e.g., prediction database(s) **132**, which may include training data database (s) **134**, model database(s) **136**, etc., or other electric storages), one or more physical processors programmed with one or more computer program instructions, and/or other components. The computing devices may include communication lines or ports to enable the exchange of information with a network (e.g., network **150**) or other computing platforms via wired or wireless techniques (e.g., Ethernet, fiber optics, coaxial cable, WiFi, Bluetooth, near field communication, or other technologies). The computing devices

may include a plurality of hardware, software, and/or firmware components operating together. For example, the computing devices may be implemented by a cloud of computing platforms operating together as the computing devices.

The electronic storages may include non-transitory storage media that electronically stores information. The electronic storage media of the electronic storages may include one or both of (i) system storage that is provided integrally (e.g., substantially non-removable) with servers or client devices or (ii) removable storage that is removably connectable to the servers or client devices via, for example, a port (e.g., a USB port, a firewire port, etc.) or a drive (e.g., a disk drive, etc.). The electronic storages may include one or more of optically readable storage media (e.g., optical disks, etc.), magnetically readable storage media (e.g., magnetic tape, magnetic hard drive, floppy drive, etc.), electrical charge-based storage media (e.g., EEPROM, RAM, etc.), solid-state storage media (e.g., flash drive, etc.), and/or other electronically readable storage media. The electronic storages may include one or more virtual storage resources (e.g., cloud storage, a virtual private network, and/or other virtual storage resources). The electronic storage may store software algorithms, information determined by the processors, information obtained from servers, information obtained from client devices, or other information that enables the functionality as described herein.

The processors may be programmed to provide information processing capabilities in the computing devices. As such, the processors may include one or more of a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information. In some embodiments, the processors may include a plurality of processing units. These processing units may be physically located within the same device, or the processors may represent processing functionality of a plurality of devices operating in coordination. The processors may be programmed to execute computer program instructions to perform functions described herein of subsystems **112-124** or other subsystems. The processors may be programmed to execute computer program instructions by software; hardware; firmware; some combination of software, hardware, or firmware; and/or other mechanisms for configuring processing capabilities on the processors.

It should be appreciated that the description of the functionality provided by the different subsystems **112-124** described herein is for illustrative purposes, and is not intended to be limiting, as any of subsystems **112-124** may provide more or less functionality than is described. For example, one or more of subsystems **112-124** may be eliminated, and some or all of its functionality may be provided by other ones of subsystems **112-124**. As another example, additional subsystems may be programmed to perform some or all of the functionality attributed herein to one of subsystems **112-124**.

The present techniques may be used in any number of applications, including for example for otherwise healthy subjects frequently affected by quick onset of optical pathologies, subjects such as soldiers and veterans. Loss of visual field compromises the ability of soldiers, veterans, other affected patients to perform their essential tasks as well as daily life activities. This visual disability compromises their independence, safety, productivity and quality of life and leads to low self-esteem and depression. Despite recent scientific advances, treatment options to reverse existing damage of the retina, optic nerve or visual cortex are limited. Thus, treatment relies on offering patients with visual aids to maximize their functionality. Current visual aids fall short in achieving those goals. This underlines the need for having better visual aids to improve visual performance, quality of life and safety. The techniques herein, integrated into spectacles device, are able to diagnose and mitigate common quick onset eye injuries, such as military-related eye injuries and diseases, that cause visual field defects, in austere or remote, as well as general, environments. The techniques herein are able to diagnose and quantify visual field defects. Using this data, the devices process, in real-time, patients' field of view and fits and projects corrected images on their remaining functional visual field. Thus, minimizing the negative effect of the blind (or reduced) part of visual field on patients' visual performance. Moreover, the fact that the spectacles device does not rely on another clinical device to diagnose visual field defects make them specifically useful in austere and remote environments. Similarly, the present techniques may be used to augment the visual field of normal subjects to have a better than normal visual field or vision.

Although the present invention has been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred embodiments, it is to be understood that such detail is solely for that purpose and that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the scope of the appended claims. For example, it is to be understood that the present invention contemplates that, to the extent possible, one or more features of any embodiment can be combined with one or more features of any other embodiment.

The present techniques will be better understood with reference to the following enumerated embodiments:

A1. A method comprising: providing a presentation (e.g., a visual test presentation or other presentation) comprising a set of stimuli to a user; obtaining feedback related to the set of stimuli (e.g., the feedback indicating whether or how the user senses one or more stimuli of the set); providing the feedback related to the set of stimuli to a model (e.g., a machine learning model or other model), the model being configured based on the feedback related to the set of stimuli.

A2. The method of embodiment A1, further comprising: providing live image data, eye characteristic information, or environment characteristic information to the model to obtain an enhanced image derived from the live image data; and causing an enhanced image to be displayed to the user, the eye characteristic information indicating one or more characteristics of one or more eyes of the user that occurred during a live capture of the live image data, the environment characteristic information indicating one or more characteristics of the environment that occurred during the live capture of the live image data.

A3. The method of embodiment A2, further comprising: obtaining the enhanced image from the model based on the live image data, eye characteristic information, or environment characteristic information being provided to the model.

A4. The method of embodiment A2, further comprising: obtaining one or more modification parameters from the model based on the live image data, eye characteristic information, or environment characteristic information being provided to the model; and generating the enhanced image based on the live image data or the one or more modification parameters to obtain the enhanced image.

A5. The method of embodiment A4, wherein the one or more modification parameters comprises one or more transformation parameters, brightness parameters, contrast parameters, saturation parameters, or sharpness parameters.

A6. The method of any of embodiments A1-A5, wherein obtaining the feedback related to the set of stimuli comprises obtaining an eye image captured during the presentation, the eye image being an image of an eye of the user, and wherein providing the feedback related to the set of stimuli comprises providing the eye image to the model.

A7. The method of any of embodiment A5, wherein the eye image is an ocular image, an image of a retina of the eye, or an image of a cornea of the eye.

A8. The method of any of embodiments A1-A7, wherein obtaining the feedback related to the set of stimuli comprises obtaining an indication of a response of the user to one or more stimuli of the set of stimuli or an indication of a lack of response of the user to one or more stimuli of the set of stimuli, and wherein providing the feedback related to the set of stimuli comprises providing the indication of the response or the indication of the lack of response to the model.

A9. The method of embodiment A8, wherein the response comprises an eye movement, a gaze direction, a pupil size change, or a user modification of one or more stimuli via user input of the user.

A10. The method of embodiment A9, wherein the user modification comprises a movement of one or more stimuli via user input of the user or supplemental data provided via user input of the user over one or more stimuli displayed to the user.

A11. The method of any of embodiments A1-A10, further comprising: obtaining a second set of stimuli, the second set of stimuli being generated based on the model's processing of the set of stimuli and the feedback related to the set of stimuli; causing the second set of stimuli to be displayed to the user; obtaining feedback related to the second set of stimuli (e.g., the feedback indicating whether or how the user sees one or more stimuli of the second set); and providing the feedback related to the second set of stimuli to the model, the model being further configured based on the feedback related to the second set of stimuli.

A12. The method of any of embodiments A1-A11, further comprising: determining, via the model, a defective visual field portion of a visual field of the user based on the feedback related to the set of stimuli, the visual field of the user comprising visual field portions, the defective visual field portion being one of the visual field portions that fails to satisfy one or more vision criteria.

A13. The method of embodiment A12, wherein the enhanced image is based on one or more transformations corresponding to the defective visual field portion of the live image data such that an image portion of the live image data is represented in an image portion of the enhanced image outside of the defective visual field portion.

A14. The method of any of embodiments A12-A13, wherein the enhanced image is based on one or more brightness or contrast modifications of the live image data such that (i) a brightness, contrast, or sharpness level increase is applied to an image portion of the live image data corresponding to the defective visual field portion to generate a corresponding image portion of the enhanced image and (ii) the brightness, contrast, or sharpness level increase is not applied to another image portion of the live stream data to generate a corresponding image portion of the enhanced image.

A15. The method of any of embodiments A12-A14, further comprising: detecting an object (e.g., in the defective visual field portion or predicted to be in the defective visual field portion); determining that the object is not sufficiently in any image portion of the enhanced image that corresponds to at least one of the visual field portions satisfying the one or more vision criteria; generating a prediction indicating that the object will come in physical contact with the user; and causing an alert to be displayed (e.g., over the enhanced image) based on (i) the prediction of physical contact and (ii) the determination that the object is not sufficiently any image portion of the enhanced image that corresponds to at least one of the visual field portions satisfying the one or more vision criteria, wherein the alert indicates an oncoming direction of the object.

A16. The method of any of embodiments A1-15, wherein one or more of the foregoing operations are performed by a wearable device.

A17. The method of embodiment A16, wherein the wearable device comprises one or more cameras configured to capture the live image data and one or more display portions configured to display one or more enhanced images.

A18. The method of any of embodiments A16-A17, wherein the one or more display portions comprise first and second display portions of the wearable device.

A19. The method of embodiment A18, wherein the wearable device comprises a first monitor comprising the first display portion and a second monitor comprising the second display portion.

A20. The method of any of embodiments A16-A19, wherein the one or more display portions comprise one or more dynamic display portions on one or more transparent displays of the wearable device, and wherein one or more enhanced images are displayed on the one or more display portions.

A21. The method of any of embodiments A1-A20, further comprising: monitoring one or more changes related to one or more eyes of the user.

A22. The method of embodiment 21, further comprising: providing the one or more changes as further feedback to the model; and obtaining one or more modification parameters from the model based on the live image data, eye characteristic information, or environment characteristic information being provided to the model; and generating the enhanced image based on the live image data and the one or more modification parameters to obtain the enhanced image.

A23. The method of any of embodiments A21-A22, further comprising: causing, based on the monitoring, an adjustment of one or more positions, shapes, sizes, or transparencies of the first or second display portions on one or more transparent displays of the wearable device, wherein causing the enhanced image to be displayed comprises causing the enhanced image to be displayed on the first or second display portions.

A24. The method of any of embodiments A1-A23, wherein the model comprises a neural network or other machine learning model.

B1. A method comprising: obtaining a plurality of images of a scene; determining a region common to the images; for each image of the images, determining a region of the image divergent from a corresponding region of at least another image of the images; generating an enhanced image based on the common region and the divergent regions; and causing the enhanced image to be displayed.

B2. The method of embodiment B **1**, wherein generating the enhanced image comprises generating the enhanced image based on the common region and the divergent regions such that (i) a first region of the enhanced image comprises a representation of the common region (ii) a second region of

the enhanced image comprises representations of the divergent regions, and (iii) the second region is around the first region in the enhanced image.

B3. The method of embodiment B2, wherein generating the enhanced image comprises generating the enhanced image based on the common region, the divergent regions, and a second region common to the images such that (i) the first region of the enhanced image comprises the representation of the common region and a representation of the second common region and (ii) the second region of the enhanced image comprises representations of the divergent regions.

B4. The method of any of embodiments B1-B3, wherein the common region is a region of at least one of the images that corresponds to a macular region of a visual field of an eye or to a region within the macular region of the visual field.

B5. The method of any of embodiments B1-B4, wherein each of the divergent regions is a region of at least one of the images that corresponds to a peripheral region of a visual field of an eye or to a region within the peripheral region of the visual field.

B6. The method of any of embodiments B1-B5, further comprising: performing shifting of each image of the images, wherein generating the enhanced image comprises generating the enhanced image based on the common region and the divergent regions subsequent to the performance of the shifting.

B7. The method of embodiment B6, wherein performing the shifting comprises performing shifting of each image of the images such that a size of the common region is decreased and a size of at least one of the divergent regions is increased.

B8. The method of any of embodiments B1-B7, further comprising: performing resizing of one or more regions of the images, wherein generating the enhanced image comprises generating the enhanced image based on the common region and the divergent regions subsequent to the performance of the resizing.

B9. The method of embodiment B8, wherein performing the resizing comprises performing resizing of one or more regions of the images such that an extent of any resizing of the common region is different than an extent of any resizing of at least one of the divergent regions.

B10. The method of any of embodiments B8-B9, wherein performing the resizing comprises performing the resizing of one or more regions of the images such that a percentage change in size of the common region represented in the first region of the enhanced image is greater than or less than a percentage change in size of at least one of the divergent regions represented in the second region of the enhanced image.

B11. The method of embodiment B10, wherein the percentage change in size of at least one of the divergent regions is zero, and wherein the percentage change in size of the common region is greater than zero.

B12. The method of embodiment B10, wherein the percentage change in size of at least one of the divergent regions is greater than zero, and wherein the percentage change in size of the common region is zero.

B13. The method of any of embodiments B1-B12, further comprising: performing a fisheye transformation, a conformal mapping transformation, or other transformation on the common region, wherein generating the enhanced image comprises generating the enhanced image based on the common region and the divergent regions subsequent to the performance of the foregoing transformation(s).

B14. The method of any of embodiments B1-B13, further comprising: determining a defective visual field portion of a visual field of the user, wherein the visual field of the user comprises visual field portions, the defective visual field portion being one of the visual field portions that fails to satisfy one or more vision criteria, and wherein generating the enhanced image based on the determined defective visual field portion such that at least one of the common region or the divergent regions in the enhanced image do not overlap with the defective visual field portion of the visual field of the user.

B15. The method of any of embodiments B1-B14, further comprising: determining a visual field portion of the user's visual field that satisfies (i) one or more vision criteria, (ii) one or more position criteria, and (iii) one or more size criteria, and wherein generating the enhanced image based on the visual field portion such that at least one of the common region or the divergent regions in the enhanced image is within the visual field portion.

B16. The method of embodiment B15, wherein the one or more size criteria comprises a requirement that the visual field portion be a largest visual field portion of the user's visual field that satisfies the one or more vision criteria and the one or more position criteria.

B17. The method of any of embodiments B15-B16, wherein the one or more position criteria comprises a requirement that a center of the visual field portion correspond to a point within a macular region of an eye of the user.

B18. The method of any of embodiments B1-B17, wherein one or more of the foregoing operations are performed by a wearable device.

B19. The method of embodiment B18, further comprising: causing one or more display portions of the wearable device to be transparent, wherein causing the enhanced image to be displayed comprises causing an enhanced image to be displayed on one or more other display portions of the wearable device other than the one or more transparent display portions.

B20. The method of embodiment B19, further comprising: causing an adjustment of the one or more transparent display portions and the one or more other display portions of the wearable device.

B21. The method of embodiment B20, further comprising: monitoring one or more changes related to one or more eyes of the user, wherein causing the adjustment comprises causing, based on the monitoring, the adjustment of the one or more transparent display portions and the one or more other display portions of the wearable device.

B21. The method of embodiment B20, further comprising: monitoring one or more changes related to one or more eyes of the user, wherein causing the adjustment comprises causing, based on the monitoring, the adjustment of the one or more transparent display portions and the one or more other display portions of the wearable device.

B22. The method of any of embodiments B20-B21, wherein causing the adjustment comprises causing an adjustment of one or more positions, shapes, sizes, or transparencies of the one or more transparent display portions of the wearable device based on the monitoring.

B23. The method of any of embodiments B20-B22, wherein the enhanced image or the adjustment is based on the one or more changes.

B24. The method of any of embodiments B18-B23, wherein causing the enhanced image to be displayed comprises causing one or more of the common region or the divergent regions to be displayed on the one or more other display portions of the wearable device such that at least one of the

common region or the divergent regions are not displayed on the one or more transparent display portions of the wearable device.

B25. The method of any of embodiments B18-B24, wherein the wearable device comprises first and second cameras, and wherein obtaining the images comprises obtaining at least one of the images via the first camera of the wearable device and obtaining at least another one of the images via the second camera of the wearable device.

B26. The method of any of embodiments B18-B25, wherein the one or more monitors of the wearable device comprises first and second monitors, and wherein causing the enhanced image to be displayed comprises causing the enhanced image to be displayed via the first and second monitors.

B27. The method of any of embodiments B18-B26, wherein the wearable device comprises a wearable spectacles device.

B28. The method of any of embodiments B1-B27, wherein the enhanced image or the adjustment is based on feedback related to a set of stimuli (e.g., the feedback indicating whether or how the user senses one or more stimuli).

C1. A method comprising: monitoring one or more changes related to one or more eyes of a user; causing, based on the monitoring, an adjustment of one or more transparent display portions or one or more other display portions of a wearable device; and causing an enhanced image to be displayed on the one or more other display portions of the wearable device, wherein the enhanced image is based on live image data obtained via the wearable device.

C2. The method of embodiment C1, wherein causing the adjustment comprises causing, based on the monitoring, an adjustment of one or more positions, shapes, sizes, brightness levels, contrast levels, sharpness levels, or saturation levels of the one or more transparent display portions of the wearable device or the one or more other display portions of the wearable device.

C3. The method of any of embodiments C1-C2, further comprising: determining a defective visual field portion of a visual field of the user, wherein the visual field of the user comprises visual field portions, the defective visual field portion being one of the visual field portions that fails to satisfy one or more vision criteria, and wherein causing the adjustment comprises causing an adjustment of one or more positions, shapes, or sizes of the one or more transparent display portions of the wearable device such that the one or more transparent display portions do not overlap with the defective visual field portion.

C4. The method of embodiment C3, further comprising: detecting an object (e.g., in the defective visual field portion or predicted to be in the defective visual field portion); determining that the object is not sufficiently in any image portion of the enhanced image that corresponds to at least one of the visual field portions satisfying one or more vision criteria; generating a prediction indicating that the object will come in physical contact with the user; and causing an alert to be displayed (e.g., over the enhanced image) based on (i) the prediction of physical contact and (ii) the determination that the object is not sufficiently any image portion of the enhanced image that corresponds to at least one of the visual field portions satisfying the one or more vision criteria, wherein the alert indicates an oncoming direction of the object.

C5. The method of any of embodiments C1-C4, further comprising: providing information related to the one or more eyes to a model, the model being configured based on the information related to the one or more eyes; subsequent to the configuring of the model, providing the monitored one or more changes related to the one or more eyes to the model to obtain a set of modification parameters, wherein causing the adjustment of the one or more transparent display portions comprises causing the adjustment of the one or more transparent display portions based on one or more modification parameters of the set of modification parameters.

C6. The method of embodiment C5, wherein the information related to the one or more eyes comprises one or more images of the one or more eyes.

C7. The method of any of embodiments C5-C6, wherein the information related to the one or more eyes comprises feedback related to a set of stimuli (e.g., the feedback indicating whether or how the user senses one or more stimuli).

C8. The method of any of embodiments C1-C7, wherein the one or more changes comprises an eye movement, a change in gaze direction, or a pupil size change.

C9. The method of any of embodiments C1-C8, wherein the enhanced image or the adjustment is based on feedback related to a set of stimuli (e.g., the feedback indicating whether or how the user senses one or more stimuli).

C10. The method of any of embodiments C1-C9, wherein the enhanced image or the adjustment is based on the one or more changes.

C11. The method of any of embodiments C1-C10, wherein the adjustment is performed simultaneously with the display of the enhanced image.

C12. The method of any of embodiments C1-C11, wherein one or more of the foregoing operations are performed by the wearable device.

C13. The method of any of embodiments C1-C12, wherein the wearable device comprises a wearable spectacles device.

D1. A method comprising: monitoring one or more eyes of a user (e.g., during a first monitoring period in which a set of stimuli are displayed to the user); obtaining feedback related to the set of stimuli (e.g., during the first monitoring period); and generating a set of modification profiles associated with the user based on the feedback related to the set of stimuli, each modification profile of the set of modification profiles (i) being associated with a set of eye-related characteristics and (ii) comprising one or more modification parameters to be applied to an image to modify the image for the user when eye-related characteristics of the user match the associated set of eye-related characteristics.

D2. The method of embodiment D1, wherein the feedback related to the set of stimuli indicates whether or how the user sees one or more stimuli of the set of stimuli.

D3. The method of any of embodiments D1-D2, wherein the feedback related to the set of stimuli comprises one or more characteristics related to the one or more eyes occurring when the one or more stimuli are displayed (e.g., during the first monitoring period).

D4. The method of any of embodiments D1-D3, further comprising: monitoring the one or more eyes of the user (e.g., during a second monitoring period); obtaining image data representing an environment of the user (e.g., during the second monitoring period); obtaining one or more modification profiles associated with the user based on (i) the image data or (ii) characteristics related to the one or more eyes (e.g., from the second monitoring period); and causing modified image data to be displayed to the user (e.g., during the second monitoring period) based on (i) the image data and (ii) the one or more modification profiles.

D5. The method of embodiment D4, wherein the characteristics related to the one or more eyes comprises gaze direction, pupil size, limbus position, visual axis, optical axis, or eyelid position.

D6. The method of any of embodiments D1-D5, wherein obtaining the feedback related to the set of stimuli comprises obtaining an eye image captured during the first monitoring period, the eye image being an image of an eye of the user, and wherein generating the set of modification profiles comprises generating the set of modification profiles based on the eye image.

D7. The method of embodiment D6, wherein the eye image is an image of a retina of the eye or an image of a cornea of the eye.

D8. The method of any of embodiments D1-D7, wherein obtaining the feedback related to the set of stimuli comprises obtaining an indication of a response of the user to the one or more stimuli or an indication of a lack of response of the user to the one or more stimuli, and wherein generating the set of modification profiles comprises generating the set of modification profiles based on the indication of the response or the indication of the lack of response.

D9. The method of embodiment D8, wherein the response comprises an eye movement, a gaze direction, or a pupil size change.

D10. The method of any of embodiments D1-D9, wherein one or more of the foregoing operations are performed by a wearable device.

D11. The method of embodiment D10, wherein the wearable device comprises a wearable spectacles device.

E1. A tangible, non-transitory, machine-readable medium storing instructions that, when executed by a data processing apparatus, cause the data processing apparatus to perform operations comprising those of any of embodiments A1-A24, B1-B28, C1-C13, or D1-D11.

E2. A system comprising: one or more processors; and memory storing instructions that, when executed by the processors, cause the processors to effectuate operations comprising those of any of embodiments A1-A24, B1-B28, C1-C13, or D1-D11.

What is claimed is:

1. A system for facilitating live video stream modifications for dynamic vision defects, the system comprising:

a computer system that comprises one or more processors executing computer program instructions that, when executed, cause the computer system to:

monitor, via a wearable device, one or more eyes of a user during a first monitoring period in which a set of stimuli are displayed to the user;

obtain, via the wearable device during the first monitoring period, feedback related to the set of stimuli, the feedback related to the set of stimuli indicating (i) whether or how the user sees one or more stimuli of the set of stimuli and (ii) one or more characteristics related to the one or more eyes occurring when the one or more stimuli are displayed during the first monitoring period;

generate, via a prediction model, a set of modification profiles associated with the user based on the feedback related to the set of stimuli, each modification profile of the set of modification profiles (i) being associated with a set of eye-related characteristics and (ii) comprising one or more modification parameters to be applied to an image to modify the image for the user when eye-related characteristics of the user match the associated set of eye-related characteristics;

subsequent to the generation of the set of modification profiles, monitor, via the wearable device, the one or more eyes of the user during a second monitoring period;

provide, to the prediction model, via the wearable device during the second monitoring period, (i) live video stream data representing an environment of the user and (ii) characteristics related to the one or more eyes from the second monitoring period to obtain one or more modification profiles from the prediction model; and

causing, via the wearable device during the second monitoring period, modified video stream data to be displayed to the user based on (i) the live video stream data and (ii) the one or more modification profiles.

2. The system of claim **1**, wherein the characteristics related to the one or more eyes comprises gaze direction, pupil size, limbus position, visual axis, optical axis, or eyelid position.

3. The system of claim **1**, wherein obtaining the feedback related to the set of stimuli comprises obtaining, via the wearable device during the first monitoring period, an eye image captured during the first monitoring period, the eye image being an image of an eye of the user, and

wherein generating the set of modification profiles comprises generating, via the prediction model, the set of modification profiles based on the eye image.

4. The system of claim **3**, wherein the eye image is an image of a retina of the eye or an image of a cornea of the eye.

5. The system of claim **1**, wherein obtaining the feedback related to the set of stimuli comprises obtaining, via the wearable device during the first monitoring period, an indication of a response of the user to the one or more stimuli or an indication of a lack of response of the user to the one or more stimuli, and

wherein generating the set of modification profiles comprises generating, via the prediction model, the set of modification profiles based on the indication of the response or the indication of the lack of response.

6. The system of claim **5**, wherein the response comprises an eye movement, a gaze direction, or a pupil size change.

7. The system of claim **5**, wherein the response comprises a user modification of the one or more stimuli via user input of the user.

8. The system of claim **1**, wherein obtaining the feedback related to the set of stimuli comprises obtaining, via the wearable device, an indication of a response of the user to the one or more stimuli, and

wherein generating the set of modification profiles comprises generating, via the prediction model, the set of modification profiles based on the indication of the response.

9. The system of claim **1**, wherein obtaining the feedback related to the set of stimuli comprises obtaining, via the wearable device, an indication of a lack of response of the user to one or more stimuli of the set of stimuli, and

wherein generating the set of modification profiles comprises generating, via the prediction model, the set of modification profiles based on the indication of the lack of response.

10. A method being implemented by one or more processors executing computer program instructions that, when executed, perform the method, the method comprising:

monitoring one or more eyes of a user during a first monitoring period in which a set of stimuli are displayed to the user;

obtaining, during the first monitoring period, feedback related to the set of stimuli, the feedback related to the set of stimuli indicating (i) whether or how the user sees

one or more stimuli of the set of stimuli and (ii) one or more characteristics related to the one or more eyes occurring when the one or more stimuli are displayed during the first monitoring period;

generating a set of modification profiles associated with the user based on the feedback related to the set of stimuli, each modification profile of the set of modification profiles (i) being associated with a set of eye-related characteristics and (ii) comprising one or more modification parameters to be applied to an image to modify the image for the user when eye-related characteristics of the user matches the associated set of eye-related characteristics;

subsequent to the generation of the set of modification profiles, monitoring, via a wearable device, the one or more eyes of the user during a second monitoring period;

providing, to a prediction model, via the wearable device during the second monitoring period, (i) video stream data representing an environment of the user and (ii) characteristics related to the one or more eyes from the second monitoring period to obtain one or more modification profiles from the prediction model; and

causing, via the wearable device during the second monitoring period, modified video stream data to be displayed to the user based on (i) the video stream data and (ii) the one or more modification profiles.

11. The method of claim **10**, wherein the prediction model comprises a neural network.

12. The method of claim **10**, wherein the characteristics related to the one or more eyes comprises gaze direction, pupil size, limbus position, visual axis, optical axis, or eyelid position.

13. The method of claim **10**, wherein the one or more processors are part of the wearable device, and wherein the monitoring of the one or more eyes during the second monitoring period, the obtainment of the one or more modification profiles, and the display of the modified video stream data are performed by the one or more processors of the wearable device.

14. The method of claim **10**, wherein obtaining the feedback related to the set of stimuli comprises obtaining, during the first monitoring period, an eye image captured during the first monitoring period, the eye image being an image of an eye of the user, and

wherein generating the set of modification profiles comprises generating the set of modification profiles based on the eye image.

15. The method of claim **14**, wherein the eye image is an image of a retina of the eye or an image of a cornea of the eye.

16. The method of claim **10**, wherein obtaining the feedback related to the set of stimuli comprises obtaining, during the first monitoring period, an indication of a response of the user to the one or more stimuli or an indication of a lack of response of the user to the one or more stimuli, and

wherein generating the set of modification profiles comprises generating the set of modification profiles based on the indication of the response or the indication of the lack of response.

17. The method of claim **16**, wherein the response comprises an eye movement, a gaze direction, or a pupil size change.

18. One or more non-transitory computer-readable media comprising instructions that, when executed by one or more processors, cause operations comprising:

monitoring one or more eyes of a user while a set of stimuli are displayed to the user;

obtaining feedback related to the set of stimuli, the feedback related to the set of stimuli indicating (i) whether or how the user sees one or more stimuli of the set of stimuli and (ii) one or more characteristics related to the one or more eyes occurring when the one or more stimuli are displayed;

generating a set of modification profiles associated with the user based on the feedback related to the set of stimuli, each modification profile of the set of modification profiles (i) being associated with a set of eye-related characteristics and (ii) comprising one or more modification parameters to be applied to an image to modify the image for the user when eye-related characteristics of the user matches the associated set of eye-related characteristics;

subsequent to the generation of the set of modification profiles, monitoring, via a wearable device, the one or more eyes of the user during a monitoring period;

providing, to a prediction model, via the wearable device during the monitoring period, (i) video stream data representing an environment of the user and (ii) characteristics related to the one or more eyes from the monitoring period to obtain one or more modification profiles from the prediction model; and

causing, via the wearable device during the monitoring period, modified video stream data to be displayed to the user based on (i) the video stream data and (ii) the one or more modification profiles.

19. The one or more non-transitory computer-readable media of claim **18**, wherein monitoring the one or more eyes of the user during the monitoring period comprises monitoring, via the wearable device, the one or more eyes of the user while the wearable device is obtaining the video stream data representing the environment of the user.

20. The one or more non-transitory computer-readable media of claim **18**, wherein the one or more processors are part of the wearable device, and wherein the operations are performed by the one or more processors of the wearable device.

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