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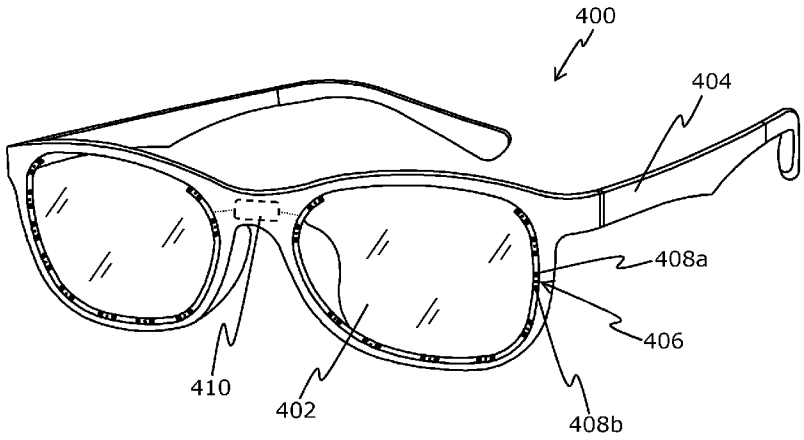


FIG. 4

(57) Abstract: Disclosed is an eye-tracking apparatus (400). At least one light source (406) and a plurality of sensors (408a-b) are arranged at a periphery (104) of a first surface of at least one lens (402). A frame (404) is employed to hold the at least one lens. A processor (410) coupled to the at least one light source and the plurality of sensors is configured to control the at least one light source to emit light towards the user's eye, control the plurality of sensors to sense reflections of the light off a surface of the user's eye, and process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

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EYEGLASS LENS WITH EYE-TRACKING COMPONENTS

TECHNICAL FIELD

The present disclosure relates to eye-tracking apparatuses. Moreover, the present disclosure relates to methods of manufacturing an eye-tracking apparatus. Furthermore, the present disclosure also relates to methods of preparing a lens for use in an eye-tracking apparatus.

BACKGROUND

Eye tracking is increasingly being used in diverse fields, for example, such as academic and research, medical research, military, human-computer interaction, gaming industry, aviation, automation and the like. With such a wide range of application areas, there is a need for eye trackers that are light and compact, and that provide accurate eye-tracking. In this regard, wearable devices have become a popular platform onto which eye trackers can be mounted.

However, there are various design challenges. Incorporating an eye-tracking functionality in wearable devices tends to make the wearable devices bulky with an unwieldy form factor. Incorporating eye-tracking components (including light sources and cameras) into a wearable device may partially obstruct a user's vision, thereby negatively impacting usability and safety. Moreover, multiple components make the setup complex and difficult to manufacture, whilst also negatively impacting the aesthetics of such wearable devices.

Conventionally, eye-tracking components have been integrated into eyeglass frames. Thus, eyeglass frame manufacturers need to take into consideration how to include the eye-tracking components into eyeglass

frames. Such an integration requires a detailed manufacturing know-how and limits the number of choices available to the manufacturers related to materials and manufacturing processes using which such eyeglass frames can be made.

Moreover, the eyeglass frame industry is a fashion and design driven industry that utilises a vast subcontractor network to make a wide variety of shapes and forms from many different kinds of materials using different technologies. Thus, a specific requirement of integrating eye-tracking components into a frame limits the number of choices available to the user.

Furthermore, conventionally, cameras have been used for eye-tracking purposes. However, data processing involved with camera images has a high power consumption. This challenge is possible to be solved to some extent in purpose-built devices like extended-reality (XR) headsets and smart glasses, which include other custom-designed processing elements and displays apart from cameras.

Therefore, in light of the foregoing discussion, there exists a need to overcome the aforementioned challenges associated with incorporating eye tracking in wearable devices.

SUMMARY

The present disclosure seeks to provide an eye-tracking apparatus. Moreover, the present disclosure seeks to provide a method for manufacturing an eye-tracking apparatus. Furthermore, the present disclosure also seeks to provide a method for preparing a lens for use in an eye-tracking apparatus. Furthermore, the present disclosure also seeks to provide a solution to the existing problems of eye-tracking in wearable devices.

In a first aspect, an embodiment of the present disclosure provides an eye-tracking apparatus comprising:

- at least one lens per eye, wherein a first surface of the at least one lens is to face a user's eye when the eye-tracking apparatus is worn by the user;
- a frame employed to hold the at least one lens;
- at least one light source arranged along a periphery of the first surface of the at least one lens;
- a plurality of sensors arranged along the periphery of the first surface of the at least one lens; and
- a processor coupled to the at least one light source and the plurality of sensors, the processor being configured to:
    - control the at least one light source to emit light towards the user's eye;
    - control the plurality of sensors to sense reflections of the light off a surface of the user's eye; and
    - process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

In a second aspect, an embodiment of the present disclosure provides a method for manufacturing an eye-tracking apparatus, the method comprising:

- cutting a lens to fit a shape of a frame;
- arranging at least one light source along a periphery of a first surface of the lens, wherein the first surface of the lens is to face a user's eye when the eye-tracking apparatus is worn by the user;
- arranging a plurality of sensors along the periphery of the first surface of the lens;
- providing connections to the at least one light source and to the plurality of sensors along the periphery of the first surface;

- fitting the lens to the frame;
- coupling the at least one light source and the plurality of sensors to a processor using the connections; and
- configuring the processor to:
  - control the at least one light source to emit light towards the user's eye;
  - control the plurality of sensors to sense reflections of the light off a surface of the user's eye; and
  - process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

In a third aspect, an embodiment of the present disclosure provides a method for preparing a lens for use in an eye-tracking apparatus, the method comprising:

- cutting the lens to fit a shape of a frame of the eye-tracking apparatus;
- arranging at least one light source along a periphery of a first surface of the lens;
- arranging a plurality of sensors along the periphery of the first surface of the lens; and
- providing connections to the at least one light source and to the plurality of sensors along the periphery of the first surface.

Embodiments of the present disclosure substantially eliminate, or at least partially address the aforementioned problems in the prior art, by providing an eye-tracking apparatus that can be easily, reliably and efficiently integrated into an existing wearable device, without having any tangible effect on an overall size and form factor of the wearable device, whilst facilitating an unobtrusive visibility to the user and ensuring that an aesthetic value of the wearable device is maintained.

Additional aspects, advantages, features and objects of the present disclosure would be made apparent from the drawings and the detailed description of the illustrative embodiments construed in conjunction with the appended claims that follow.

It will be appreciated that features of the present disclosure are susceptible to being combined in various combinations without departing from the scope of the present disclosure as defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The summary above, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. However, the present disclosure is not limited to specific methods and instrumentalities disclosed herein. Moreover, those in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers.

Embodiments of the present disclosure will now be described, by way of example only, with reference to the following diagrams wherein:

FIG. 1 depicts a lens prepared for use in an eye-tracking apparatus, in accordance with an embodiment of the present disclosure;

FIG. 2 depicts another lens prepared for use in an eye-tracking apparatus, in accordance with an embodiment of the present disclosure;

FIG. 3 is a schematic view of a portion of an eye-tracking apparatus in operation, in accordance with an embodiment of the present disclosure;

FIG. 4 depicts an eye-tracking apparatus, in accordance with an embodiment of the present disclosure;

FIG. 5 depicts another eye-tracking apparatus, in accordance with an embodiment of the present disclosure;

FIG. 6 depicts yet another eye-tracking apparatus, in accordance with an embodiment of the present disclosure;

FIG. 7 depicts still another eye-tracking apparatus, in accordance with an embodiment of the present disclosure;

FIG. 8 depicts yet another eye-tracking apparatus, in accordance with an embodiment of the present disclosure; and

FIGs. 9A and 9B depict steps of a method for manufacturing an eye-tracking apparatus, in accordance with an embodiment of the present disclosure.

In the accompanying drawings, an underlined number is employed to represent an item over which the underlined number is positioned or an item to which the underlined number is adjacent. A non-underlined number relates to an item identified by a line linking the non-underlined number to the item. When a number is non-underlined and accompanied by an associated arrow, the non-underlined number is used to identify an item at which the arrow is pointing.

DETAILED DESCRIPTION OF EMBODIMENTS

The following detailed description illustrates embodiments of the present disclosure and ways in which they can be implemented. Although some modes of carrying out the present disclosure have been disclosed, those skilled in the art would recognize that other embodiments for carrying out or practicing the present disclosure are also possible.

In a first aspect, an embodiment of the present disclosure provides an eye-tracking apparatus comprising:

- at least one lens per eye, wherein a first surface of the at least one lens is to face a user's eye when the eye-tracking apparatus is worn by the user;
- a frame employed to hold the at least one lens;
- at least one light source arranged along a periphery of the first surface of the at least one lens;
- a plurality of sensors arranged along the periphery of the first surface of the at least one lens; and
- a processor coupled to the at least one light source and the plurality of sensors, the processor being configured to:
    - control the at least one light source to emit light towards the user's eye;
    - control the plurality of sensors to sense reflections of the light off a surface of the user's eye; and
    - process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

In a second aspect, an embodiment of the present disclosure provides a method for manufacturing an eye-tracking apparatus, the method comprising:

- cutting a lens to fit a shape of a frame;
- arranging at least one light source along a periphery of a first surface of the lens, wherein the first surface of the lens is to face a user's eye when the eye-tracking apparatus is worn by the user;
- arranging a plurality of sensors along the periphery of the first surface of the lens;
- providing connections to the at least one light source and to the plurality of sensors along the periphery of the first surface;
- fitting the lens to the frame;
- coupling the at least one light source and the plurality of sensors to a processor using the connections; and

- configuring the processor to:
  - control the at least one light source to emit light towards the user's eye;
  - control the plurality of sensors to sense reflections of the light off a surface of the user's eye; and
  - process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

In a third aspect, an embodiment of the present disclosure provides a method for preparing a lens for use in an eye-tracking apparatus, the method comprising:

- cutting the lens to fit a shape of a frame of the eye-tracking apparatus;
- arranging at least one light source along a periphery of a first surface of the lens;
- arranging a plurality of sensors along the periphery of the first surface of the lens; and
- providing connections to the at least one light source and to the plurality of sensors along the periphery of the first surface.

Pursuant to embodiments of the present disclosure, the eye-tracking apparatus can be beneficially implemented on an existing wearable device in a simple, reliable and efficient manner. Such an implementation of the eye-tracking apparatus into an existing wearable device has a negligible additional effect on an overall size and form factor of the wearable device. Moreover, as the at least one light source and the plurality of sensors can be retrofitted onto any wearable device (for example, such as eyeglasses or sunglasses), the eye-tracking apparatus can be worn like a regular eyeglass or sunglass. Arrangement of the at least one light source and the plurality of sensors at the periphery facilitates an unobtrusive visibility to the user, whilst ensuring that an

aesthetic value of the wearable device is maintained. Furthermore, the eye-tracking apparatus is light-weight and has a compact form factor. Moreover, the eye-tracking apparatus is capable of providing an accurate eye-tracking at minimal power consumption.

Throughout the present disclosure, the term "wearable device" refers to an item worn over eyes of a user. Such a wearable device may be worn for various purposes, for example, such as fashion or adornment, protection against the environment, or presentation of an extended-reality scene to the user. Examples of such a wearable device include, but are not limited to, a pair of glasses, a pair of sunglasses, smart glasses, and a head-mounted display.

Optionally, the at least one lens has an optical power prescribed for the user's eye. This enables customisation of the eye-tracking apparatus according to the user's eyesight. It will be appreciated that the optical power may not be as exactly prescribed for the user's eye, but may be selected to conform with the user's need.

Moreover, optionally, the at least one lens is a sunglass lens. Such an implementation enables the user to use the eye-tracking apparatus with ease in an outdoor environment, whilst also being aesthetically pleasing.

The lens can be made of any one of: glass, a polycarbonate, a plastic, a high-index plastic. The lens may have at least one of: an anti-reflective coating, an anti-scratch coating, a photochromic coating, a UV-blocking coating, a polarized coating.

Pursuant to embodiments of the present disclosure, the lens serves as a base onto which the at least one light source and the plurality of sensors (hereinafter collectively referred to as "eye-tracking components", for the sake of convenience only) are arranged directly. As mentioned earlier,

the lens is cut to fit the shape of the frame prior to arranging the eye-tracking components at the periphery of the first surface of the lens.

Throughout the present disclosure, the term "periphery" refers to an area in a proximity of an edge of the first surface. In some implementations, this area could be on the first surface itself. In other implementations, this area could be perpendicular to the first surface. Optionally, a width of this area lies in a range of 0.01 millimetre to 5 millimetres. For example, the width of this area may be from 0.01, 0.05, 0.1, 0.25, 0.5 or 1 millimetre up to 0.1, 0.5, 1, 2.5 or 5 millimetres.

Optionally, in the eye-tracking apparatus, the at least one light source and the plurality of sensors are arranged along the periphery of the first surface using a flexible printed circuit board, wherein the flexible printed circuit board provides connections to the at least one light source and to the plurality of sensors. The flexible printed circuit board can be formed by screen printing of conductive tracks using functional inks on a thin sheet of a flexible material. Examples of such a flexible material include, but are not limited to, a polyimide (for example, such as Kapton® and Cirlex®), a polyester, and a polycarbonate. The flexible printed circuit board is beneficially formed to adapt to a shape of the periphery. The technical benefit of using the flexible printed circuit board is that it eliminates a need for connectors or cables, reduces a cost and time of manufacture, and provides reliable electrical connections and communication, whilst ensuring an optimal use of an available space at the periphery.

Alternatively, optionally, in the eye-tracking apparatus, the at least one light source and the plurality of sensors are arranged along the periphery of the first surface using an electrically-conductive adhesive, wherein the connections to the at least one light source and to the plurality of sensors are provided by wires printed on the periphery of the first surface.

Examples of such an electrically-conductive adhesive include, but are not limited to, silver conductive epoxy adhesive, nickel conductive epoxy adhesive, and electrically-conductive silicone adhesive. The technical benefit of using the electrically-conductive adhesive is that its characteristics (such as a curing temperature) can be matched to a specific material of the lens, and it offers improved fatigue resistance.

It will be appreciated that the connections could be implemented in various different ways. As an example, the connections could be implemented as a bundle of individual wires. As another example, the connections could be implemented as aligned, anisotropic nano wires of a metal or a metal alloy. Some examples of highly conductive metals are silver, gold, copper and aluminium. As yet another example, the connections could be implemented as transparent electrode layers. Such transparent electrode layers may, for example, be made of indium tin oxide (ITO) or doped zinc oxide (ZnO), where ZnO is doped with aluminium or hydrogen.

It will be appreciated that such connections provide electrical power to the eye-tracking components (namely, the at least one light source and the plurality of sensors) for operation as well as facilitate communication between the processor and the eye-tracking components. Such connections are beneficially provided without having to compromise an aesthetic design of the wearable device. For this purpose, a power source that provides the electrical power as well as the processor may be installed at any suitable location on the frame of the eye-tracking apparatus. As an example, the power source can be located at an end of a temple of the frame. As another example, the processor can be located at a bridge of the frame.

Optionally, the eye-tracking apparatus further comprises a wireless communication interface, which enables the processor to send the sensor

data or information pertaining to the gaze direction of the user's eye to an external device.

Optionally, the sensor data is in a form of an image that is representative of features of the user's eye. Such features may comprise at least one of: a shape of a pupil of the user's eye, a size of the pupil, corneal reflections of the at least one light source from the surface of the user's eye, a relative position of the pupil with respect to the corneal reflections, a relative position of the pupil with respect to corners of the user's eye. Optionally, when processing the sensor data, the processor is configured to:

- process the image to determine the features of the user's eye; and
- determine, based on the features of the user's eye, the gaze direction of the user's eye.

Moreover, optionally, in the eye-tracking apparatus, the light emitted by the at least one light source is infrared light. In other words, the at least one light source and the plurality of sensors optionally operate on infrared light and can be implemented as at least one infrared light source and a plurality of infrared sensors. The infrared light being invisible to the user's eye is not detectable by the user, and thus, is suitable for eye-tracking purposes.

Alternatively, optionally, the light emitted by the at least one light source is ultraviolet light. In such a case, the at least one light source and the plurality of sensors optionally operate on ultraviolet light and can be implemented as at least one ultraviolet light source and a plurality of ultraviolet sensors. In this regard, ultraviolet light in a range of wavelengths that is not harmful to the human eye is selected. For example, a wavelength of the selected ultraviolet light may lie in a range of 315 nm to 400 nm.

It will be appreciated that yet alternatively, the light emitted by the at least one light source can be visible light, which lies in a visible part of the spectrum.

The present disclosure also relates to the method of the second aspect and the method of the third aspect as described above. Various embodiments and variants disclosed above, with respect to the aforementioned first aspect, apply *mutatis mutandis* to both the methods.

Optionally, in the method, the at least one light source and the plurality of sensors are arranged along the periphery of the first surface using a flexible printed circuit board, wherein the flexible printed circuit board provides the connections.

Optionally, in the method, the at least one light source and the plurality of sensors are arranged along the periphery of the first surface using an electrically-conductive adhesive, wherein the connections are provided by printing wires on the periphery of the first surface.

Optionally, in the method, the light emitted by the at least one light source is infrared light. Alternatively, optionally, the light emitted by the at least one light source is ultraviolet light.

Optionally, in the method, the lens has an optical power prescribed for the user's eye. Optionally, in the method, the lens is a sunglass lens.

Moreover, the eye-tracking components are arranged at the periphery of the first surface of the lens by using a multi-step process in which a first step involves holding the lens in a pre-fabricated holder and a second step involves using one or more of the following techniques.

According to an embodiment, the method further comprises:

- machining the first surface of the lens to create a plurality of recesses, wherein the at least one light source and the plurality of sensors are arranged inside the plurality of recesses; and
- filling the plurality of recesses with a material having a same refractive index as the lens, upon arranging the at least one light source and the plurality of sensors.

The first surface of the lens could be machined using Computer Numerical Control (CNC) milling to create the plurality of recesses. In such a case, computerized controls are employed to rotate a multi-point cutting tool to progressively remove material from the lens. This enables in producing a custom-designed recess for arranging the eye-tracking components.

Optionally, prior to filling the plurality of recesses, the connections are drawn from the at least one light source and the plurality of sensors. Optionally, the connections are also embedded along with the eye-tracking components.

The plurality of recesses could be filled using any one of: casting, overmoulding, insert moulding, dispensing, ink jetting. It will be appreciated that overmoulding and insert moulding are typically used in a case where the eye-tracking components are durable and can withstand thermal expansion.

Optionally, the material that can be used to fill the plurality of recesses comprises at least one polymer. Examples of the at least one polymer include, but are not limited to, polymethyl methacrylate, styrene-co-acrylonitrile copolymer, polyamide, thermoplastic polyimide, polyethylene, polypropylene, polyolefin, polycarbonate, polyethylene terephthalate, polybutylene terephthalate, polyether, polyether-ether-ketone, polyether-imide, thermoplastic resin, and epoxy resin.

According to another embodiment, the steps of arranging the at least one light source and the plurality of sensors are performed by casting the at least one light source and the plurality of sensors into the lens along the periphery of the first surface, respectively. In this regard, lens casting technology is employed to embed the at least one light source and the plurality of sensors into the lens. The at least one lens and the plurality of sensors are attached to an inner wall of a mould cavity prior to casting, so as to align them with the periphery of the first surface of the lens upon manufacture. Subsequently, a liquid material is introduced in the mould cavity and allowed to solidify. It will be appreciated that in ophthalmic industry, it is more common to use casting as a manufacturing method. Casting is typically performed using low viscosity monomers, for example, such as a thermosetting plastic. As casting does not involve heating, the thermal stress in the material is low and the residue tension is small. This leads to a higher quality as compared to injection moulding.

According to yet another embodiment, the steps of arranging the at least one light source and the plurality of sensors are performed by using any one of: injection moulding, laminating.

In injection moulding, a molten material is injected under high pressure into a mould and then allowed to cool down. The material can be made of a thermoplastic.

In laminating, the at least one light source and the plurality of sensors are placed along with the connections (at the periphery of the first surface of the lens) between the lens and a perforated lamination film that has openings for the eye-tracking components. Heat is then applied to seal the lamination film to the lens.

According to still another embodiment, the steps of arranging the at least one light source and the plurality of sensors are performed by printing

the at least one light source and the plurality of sensors along the periphery of the first surface of the lens, respectively. Such printing may be performed using three-dimensional (3D) printing of the lens. This enables the eye-tracking components and the connections to be directly embedded in the mechanical structure of the lens.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIG. 1, illustrated is a lens **102** prepared for use in an eye-tracking apparatus, in accordance with an embodiment of the present disclosure. Along a periphery **104** of a first surface of the lens **102**, there are arranged at least one light source, depicted as a light source **106**, and a plurality of sensors, depicted as sensors **108a**, **108b**, **108c** and **108d**. The light source **106** and the sensors **108a-d** are coupled to a processor **110**.

Referring to FIG. 2, illustrated is another lens **202** prepared for use in an eye-tracking apparatus, in accordance with an embodiment of the present disclosure. Along a periphery **204** of a first surface of the lens **202**, there are arranged:

- at least one light source (for the sake of convenience, one out of 10 light sources is referenced as **206**); and
- a plurality of sensors (for the sake of convenience, two out of 20 sensors are referenced as **208a** and **208b**.

The at least one light source and the plurality of sensors are coupled to a processor **210**.

FIGs. 1 and 2 are merely examples, which should not unduly limit the scope of the claims herein. It is to be understood that the specific implementations of the lenses **102** and **202** are provided as examples and are not to be construed as limiting them to specific numbers, types,

or arrangements of light sources and sensors. A person skilled in the art will recognize many variations, alternatives, and modifications of embodiments of the present disclosure.

Referring to FIG. 3, illustrated is a schematic view of a portion of an eye-tracking apparatus in operation, in accordance with an embodiment of the present disclosure. Said portion of the eye-tracking apparatus shows a lens with at least one light source and a plurality of sensors. Dotted lines depict a field of view of individual sensors.

FIG. 3 is merely an example, which should not unduly limit the scope of the claims herein. A person skilled in the art will recognize many variations, alternatives, and modifications of embodiments of the present disclosure.

Referring to FIG. 4, illustrated is an eye-tracking apparatus **400**, in accordance with an embodiment of the present disclosure. The eye-tracking apparatus **400** comprises:

- at least one lens per eye (for the sake of convenience, one out of two lenses is referenced as **402**);
- a frame **404** employed to hold the at least one lens;
- at least one light source arranged along a periphery of the first surface of the at least one lens (for the sake of convenience, one out of 10 light sources is referenced as **406**);
- a plurality of sensors arranged along the periphery of the first surface of the at least one lens (for the sake of convenience, two out of 20 sensors are referenced as **408a** and **408b**); and
- a processor **410** coupled to the at least one light source and the plurality of sensors.

Referring to FIG. 5, illustrated is another eye-tracking apparatus **500**, in accordance with an embodiment of the present disclosure. The eye-tracking apparatus **500** comprises:

- at least one lens per eye (for the sake of convenience, one out of two lenses is referenced as **502**);
- a frame **504** employed to hold the at least one lens;
- at least one light source arranged along a periphery of the first surface of the at least one lens (for the sake of convenience, one out of 10 light sources is referenced as **506**);
- a plurality of sensors arranged along the periphery of the first surface of the at least one lens (for the sake of convenience, two out of 20 sensors are referenced as **508a** and **508b**); and
- a processor (not shown in the figure) coupled to the at least one light source and the plurality of sensors.

Referring to FIG. 6, illustrated is yet another eye-tracking apparatus **600**, in accordance with an embodiment of the present disclosure. The eye-tracking apparatus **600** comprises:

- at least one lens per eye (for the sake of convenience, one out of two lenses is referenced as **602**);
- a frame **604** employed to hold the at least one lens;
- at least one light source arranged along a periphery of the first surface of the at least one lens (for the sake of convenience, one out of nine light sources is referenced as **606**);
- a plurality of sensors arranged along the periphery of the first surface of the at least one lens (for the sake of convenience, two out of 18 sensors are referenced as **608a** and **608b**); and
- a processor (not shown in the figure) coupled to the at least one light source and the plurality of sensors.

Referring to FIG. 7, illustrated is still another eye-tracking apparatus **700**, in accordance with an embodiment of the present disclosure. The eye-tracking apparatus **700** comprises:

- at least one lens per eye (for the sake of convenience, only one lens is referenced as **702**);
- a frame **704** employed to hold the at least one lens;
- at least one light source arranged along a periphery of the first surface of the at least one lens (for the sake of convenience, only one light source is referenced as **706**);
- a plurality of sensors arranged along the periphery of the first surface of the at least one lens (for the sake of convenience, only two sensors are referenced as **708a** and **708b**); and
- a processor (not shown in the figure) coupled to the at least one light source and the plurality of sensors.

Referring to FIG. 8, illustrated is yet another eye-tracking apparatus **800**, in accordance with an embodiment of the present disclosure. The eye-tracking apparatus **800** comprises:

- at least one lens per eye (for the sake of convenience, only one lens is referenced as **802**);
- a frame **804** employed to hold the at least one lens;
- at least one light source arranged along a periphery of the first surface of the at least one lens (for the sake of convenience, only one light source is referenced as **806**);
- a plurality of sensors arranged along the periphery of the first surface of the at least one lens (for the sake of convenience, only two sensors are referenced as **808a** and **808b**); and
- a processor (not shown in the figure) coupled to the at least one light source and the plurality of sensors.

FIGs. 4-8 are merely examples, which should not unduly limit the scope of the claims herein. As mentioned earlier, the periphery of the first surface is an area that is in a proximity of an edge of the first surface. In FIGs. 4, 5 and 6, this area is on the first surface itself, whereas in FIGs. 7 and 8, this area is perpendicular to the first surface. Moreover, in FIGs. 4-8, the frame **404**, the frame **504**, the frame **604**, the frame **704** and the frame **804** have been shown as a full-rim frame, a half-rim frame, a rimless frame, another full-rim frame and another rimless frame, respectively. It is to be understood that the specific implementations of the eye-tracking apparatuses **400**, **500**, **600**, **700** and **800** are provided as examples and are not to be construed as limiting them to specific numbers, types, or arrangements of light sources and sensors. A person skilled in the art will recognize many variations, alternatives, and modifications of embodiments of the present disclosure.

Referring to FIGs. 9A and 9B, illustrated are steps of a method for manufacturing an eye-tracking apparatus, in accordance with an embodiment of the present disclosure. At a step **902**, a lens is cut to fit a shape of a frame. At a step **904**, at least one light source is arranged along a periphery of a first surface of the lens, wherein the first surface of the lens is to face a user's eye when the eye-tracking apparatus is worn by the user. At a step **906**, a plurality of sensors are arranged along the periphery of the first surface of the lens. At a step **908**, connections to the at least one light source and to the plurality of sensors are provided along the periphery of the first surface. At a step **910**, the lens is fitted to the frame. At a step **912**, the at least one light source and the plurality of sensors are coupled to a processor using the connections. At a step **914**, the processor is configured to:

- control the at least one light source to emit light towards the user's eye;

- control the plurality of sensors to sense reflections of the light off a surface of the user's eye; and
- process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

The aforementioned steps are only illustrative and other alternatives can also be provided where one or more steps are added, one or more steps are removed, or one or more steps are provided in a different sequence without departing from the scope of the claims herein. For example, the steps **904** and **906** may be performed simultaneously.

Moreover, the steps **902**, **904**, **906** and **908** can also be considered to represent steps of a method for preparing a lens for use in an eye-tracking apparatus, in accordance with an embodiment of the present disclosure.

Modifications to embodiments of the present disclosure described in the foregoing are possible without departing from the scope of the present disclosure as defined by the accompanying claims. Expressions such as "including", "comprising", "incorporating", "have", "is" used to describe and claim the present disclosure are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural. It will be appreciated that the terms "first", "second", "third" and the like used herein do not denote any order, quantity or importance, but rather are used to distinguish one element from another.

CLAIMS

1. An eye-tracking apparatus (400, 500, 600, 700, 800) comprising:

- at least one lens (102, 202, 402, 502, 602, 702, 802) per eye, wherein a first surface of the at least one lens is to face a user's eye when the eye-tracking apparatus is worn by the user;
- a frame (404, 504, 604, 704, 804) employed to hold the at least one lens;
- at least one light source (106, 206, 406, 506, 606, 706, 806) arranged along a periphery (104, 204) of the first surface of the at least one lens;
- a plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) arranged along the periphery of the first surface of the at least one lens; and
- a processor (110, 210, 410) coupled to the at least one light source and the plurality of sensors, the processor being configured to:
    - control the at least one light source to emit light towards the user's eye;
    - control the plurality of sensors to sense reflections of the light off a surface of the user's eye; and
    - process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

2. The eye-tracking apparatus (400, 500, 600, 700, 800) of claim 1, wherein the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged along the periphery (104, 204) of the first surface using a flexible printed circuit board, wherein the flexible printed circuit board provides connections to the at least one light source and to the plurality of sensors.

3. The eye-tracking apparatus (400, 500, 600, 700, 800) of claim 1, wherein the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged along the periphery (104, 204) of the first surface using an electrically-conductive adhesive, wherein connections to the at least one light source and to the plurality of sensors are provided by wires printed on the periphery of the first surface.

4. The eye-tracking apparatus (400, 500, 600, 700, 800) of any of the preceding claims, wherein the light emitted by the at least one light source (106, 206, 406, 506, 606, 706, 806) is infrared light.

5. The eye-tracking apparatus (400, 500, 600, 700, 800) of any of the preceding claims, wherein the at least one lens (102, 202, 402, 502, 602, 702, 802) has an optical power prescribed for the user's eye.

6. The eye-tracking apparatus (400, 500, 600, 700, 800) of any of the preceding claims, wherein the at least one lens (102, 202, 402, 502, 602, 702, 802) is a sunglass lens.

7. A method for manufacturing an eye-tracking apparatus (400, 500, 600, 700, 800), the method comprising:

- cutting a lens (102, 202, 402, 502, 602, 702, 802) to fit a shape of a frame (404, 504, 604, 704, 804);
- arranging at least one light source (106, 206, 406, 506, 606, 706, 806) along a periphery (104, 204) of a first surface of the lens, wherein the first surface of the lens is to face a user's eye when the eye-tracking apparatus is worn by the user;
- arranging a plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) along the periphery of the first surface of the lens;

- providing connections to the at least one light source and to the plurality of sensors along the periphery of the first surface;
- fitting the lens to the frame;
- coupling the at least one light source and the plurality of sensors to a processor (110, 210, 410) using the connections; and
- configuring the processor to:
  - control the at least one light source to emit light towards the user's eye;
  - control the plurality of sensors to sense reflections of the light off a surface of the user's eye; and
  - process sensor data pertaining to the sensed reflections to determine a gaze direction of the user's eye.

8. The method of claim 7, wherein the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged along the periphery (104, 204) of the first surface using a flexible printed circuit board, wherein the flexible printed circuit board provides the connections.

9. The method of claim 7, wherein the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged along the periphery (104, 204) of the first surface using an electrically-conductive adhesive, wherein the connections are provided by printing wires on the periphery of the first surface.

10. The method of any of claims 7-9, further comprising:

- machining the first surface of the lens (102, 202, 402, 502, 602, 702, 802) to create a plurality of recesses along the periphery (104, 204), wherein the at least one light source (106, 206, 406, 506, 606, 706, 806)

and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged inside the plurality of recesses; and

- filling the plurality of recesses with a material having a same refractive index as the lens, upon arranging the at least one light source and the plurality of sensors.

11. The method of any of claims 7-9, wherein the steps of arranging the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are performed by casting the at least one light source and the plurality of sensors into the lens (102, 202, 402, 502, 602, 702, 802) along the periphery (104, 204) of the first surface, respectively.

12. The method of any of claims 7-9, wherein the steps of arranging the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are performed by printing the at least one light source and the plurality of sensors along the periphery (104, 204) of the first surface of the lens (102, 202, 402, 502, 602, 702, 802), respectively.

13. The method of any of claims 7-9, wherein the steps of arranging the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are performed by using any one of: injection moulding, laminating.

14. The method of any of claims 7-13, wherein the light emitted by the at least one light source (106, 206, 406, 506, 606, 706, 806) is infrared light.

15. The method of any of claims 7-14, wherein the lens (102, 202, 402, 502, 602, 702, 802) has an optical power prescribed for the user's eye.

16. The method of any of claims 7-15, wherein the lens (102, 202, 402, 502, 602, 702, 802) is a sunglass lens.

17. A method for preparing a lens (102, 202, 402, 502, 602, 702, 802) for use in an eye-tracking apparatus (400, 500, 600, 700, 800), the method comprising:

- cutting the lens to fit a shape of a frame (404, 504, 604, 704, 804) of the eye-tracking apparatus;
- arranging at least one light source (106, 206, 406, 506, 606, 706, 806) along a periphery (104, 204) of a first surface of the lens;
- arranging a plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) along the periphery of the first surface of the lens; and
- providing connections to the at least one light source and to the plurality of sensors along the periphery of the first surface.

18. The method of claim 17, wherein the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged along the periphery (104, 204) of the first surface using a flexible printed circuit board, wherein the flexible printed circuit board provides the connections.

19. The method of claim 17, wherein the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged along the periphery (104, 204) of the first surface using an electrically-conductive adhesive, wherein the connections are provided by printing wires on the periphery of the first surface.

20. The method of any of claims 17-19, further comprising:

- machining the first surface of the lens (102, 202, 402, 502, 602, 702, 802) to create a plurality of recesses along the periphery (104, 204),

wherein the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are arranged inside the plurality of recesses; and

- filling the plurality of recesses with a material having a same refractive index as the lens, upon arranging the at least one light source and the plurality of sensors.

21. The method of any of claims 17-19, wherein the steps of arranging the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are performed by casting the at least one light source and the plurality of sensors into the lens (102, 202, 402, 502, 602, 702, 802) along the periphery (104, 204) of the first surface, respectively.

22. The method of any of claims 17-19, wherein the steps of arranging the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are performed by printing the at least one light source and the plurality of sensors along the periphery (104, 204) of the first surface of the lens (102, 202, 402, 502, 602, 702, 802), respectively.

23. The method of any of claims 17-19, wherein the steps of arranging the at least one light source (106, 206, 406, 506, 606, 706, 806) and the plurality of sensors (108a-d, 208a-b, 408a-b, 508a-b, 608a-b, 708a-b, 808a-b) are performed by using any one of: injection moulding, laminating.

24. The method of any of claims 17-23, wherein the light emitted by the at least one light source (106, 206, 406, 506, 606, 706, 806) is infrared light.

25. The method of any of claims 17-24, wherein the lens (102, 202, 402, 502, 602, 702, 802) has an optical power prescribed for the user's eye.

26. The method of any of claims 17-25, wherein the lens (102, 202, 402, 502, 602, 702, 802) is a sunglass lens.

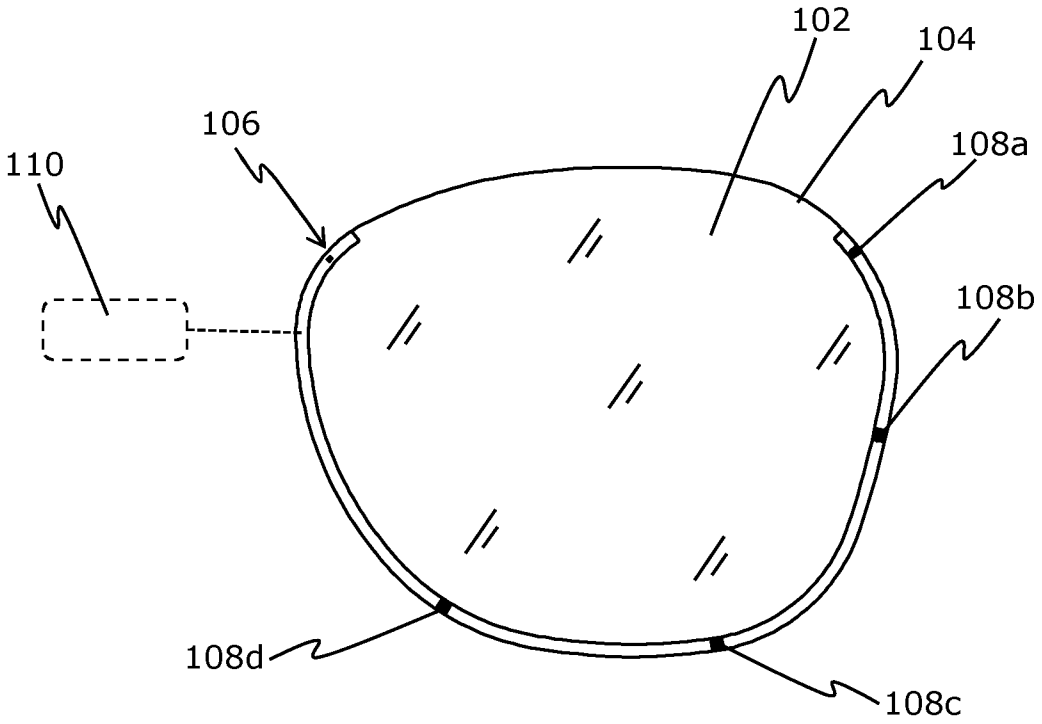


FIG. 1

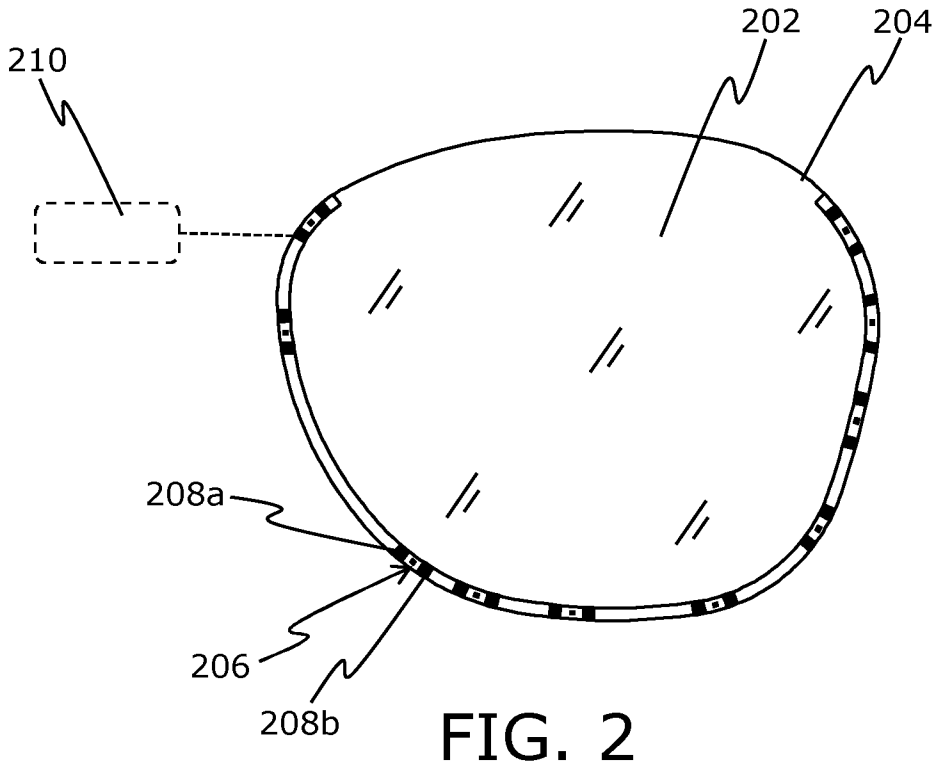


FIG. 2

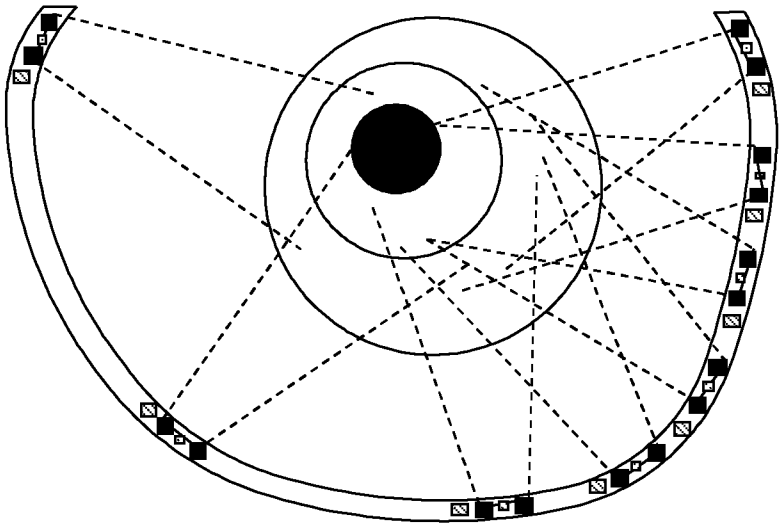


FIG. 3

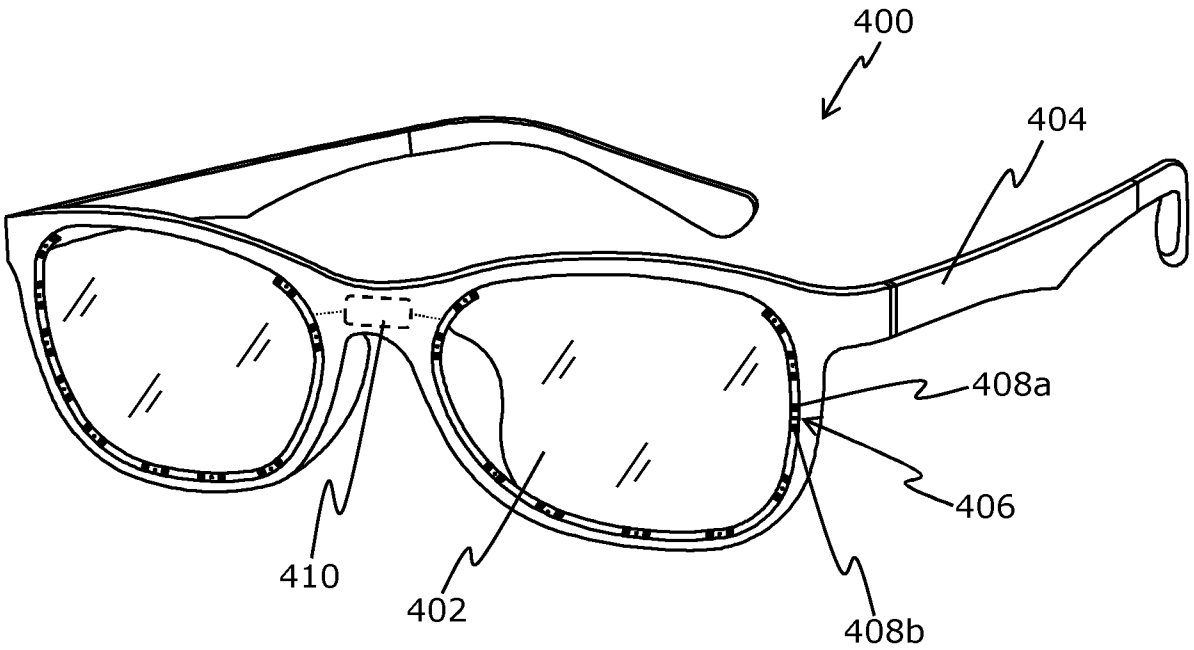


FIG. 4

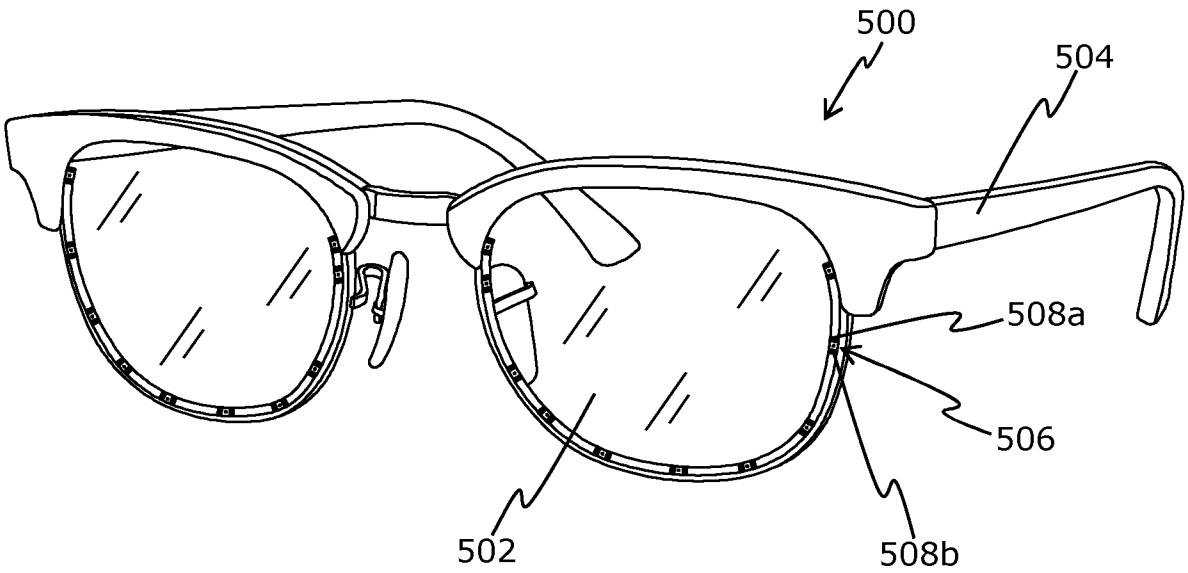


FIG. 5

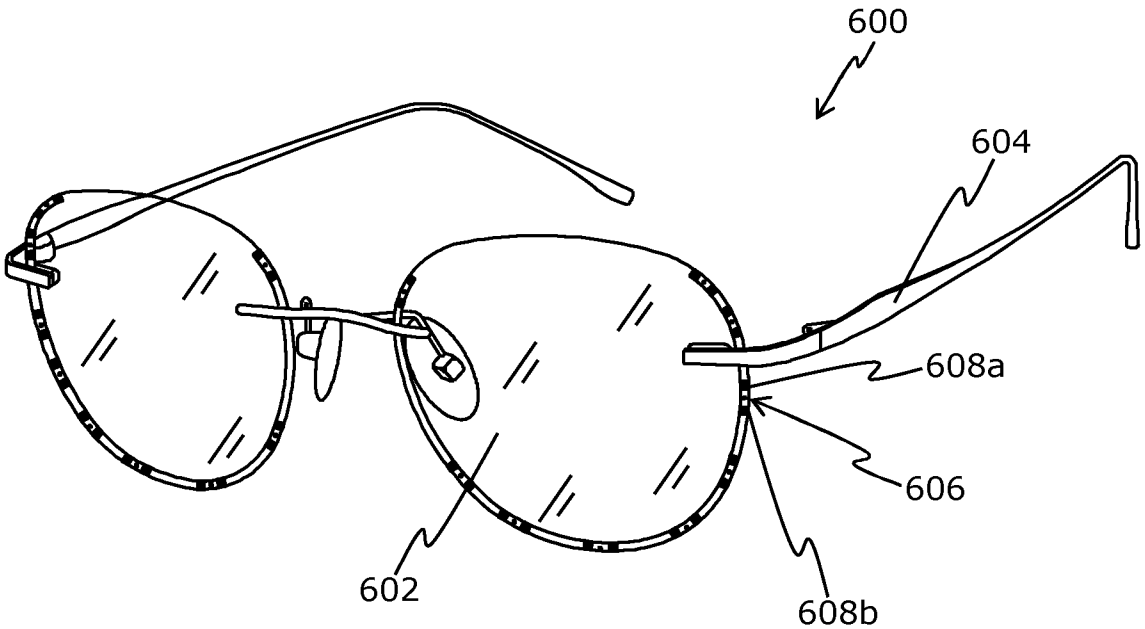


FIG. 6

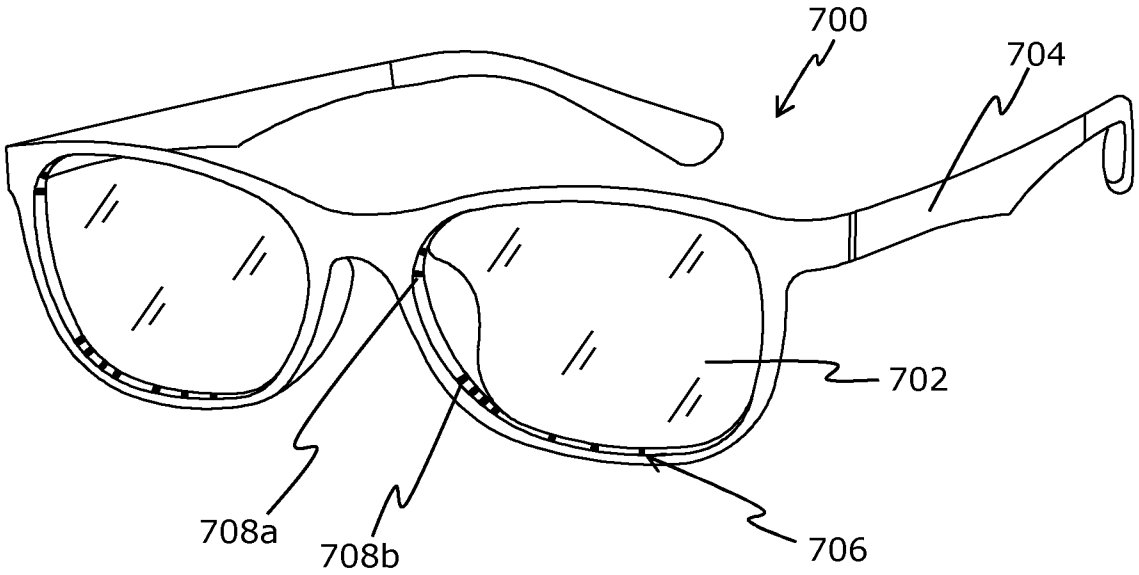


FIG. 7

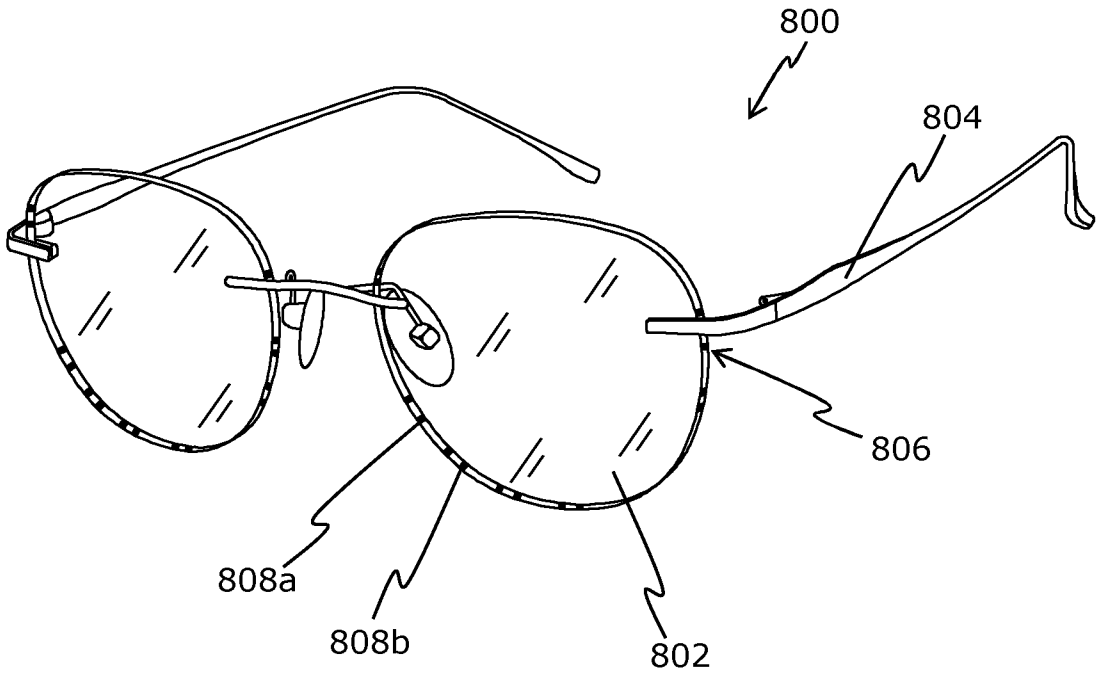


FIG. 8

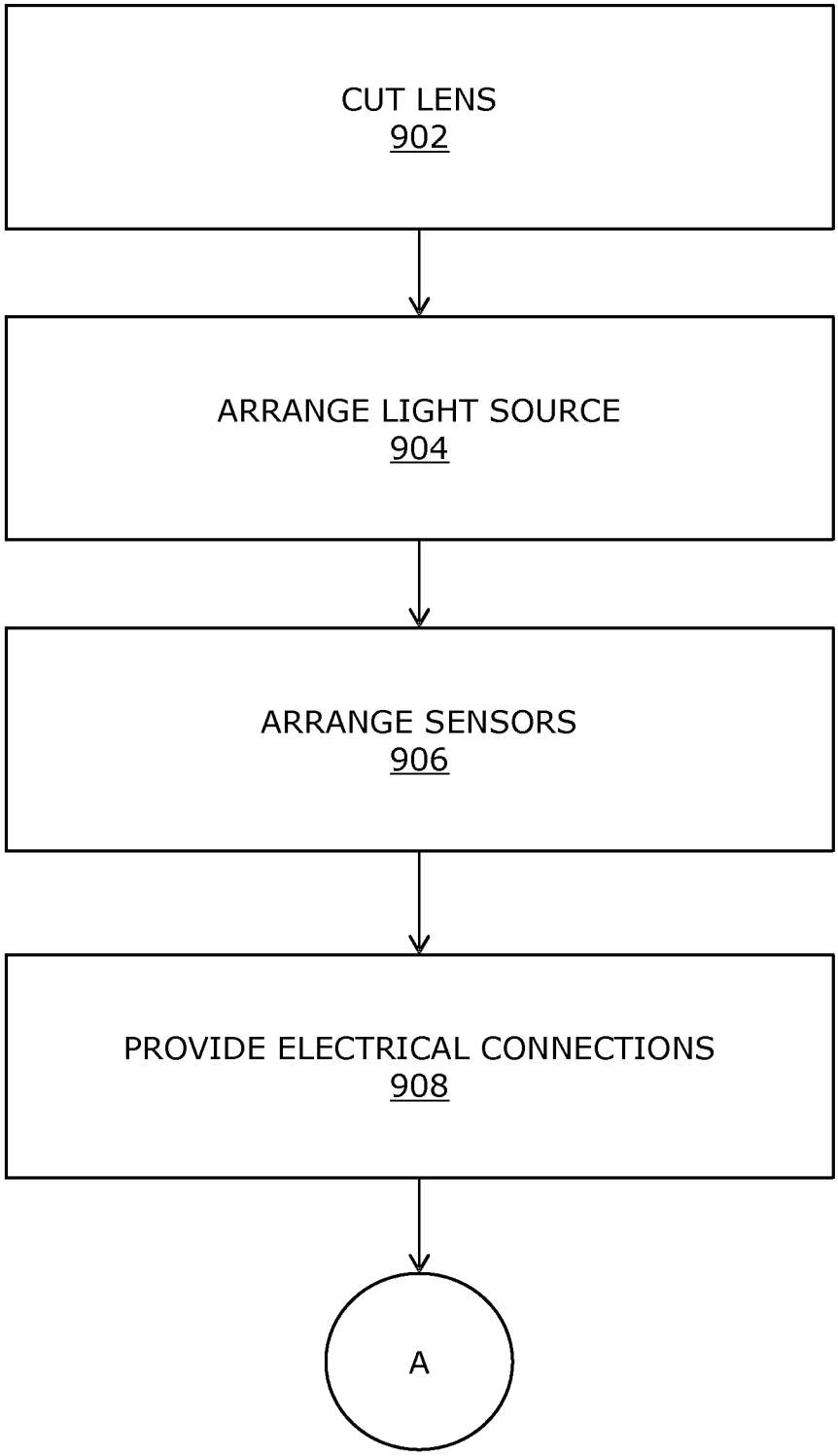

CUT LENS
902
ARRANGE LIGHT SOURCE
904
ARRANGE SENSORS
906
PROVIDE ELECTRICAL CONNECTIONS
908
A

FIG. 9A

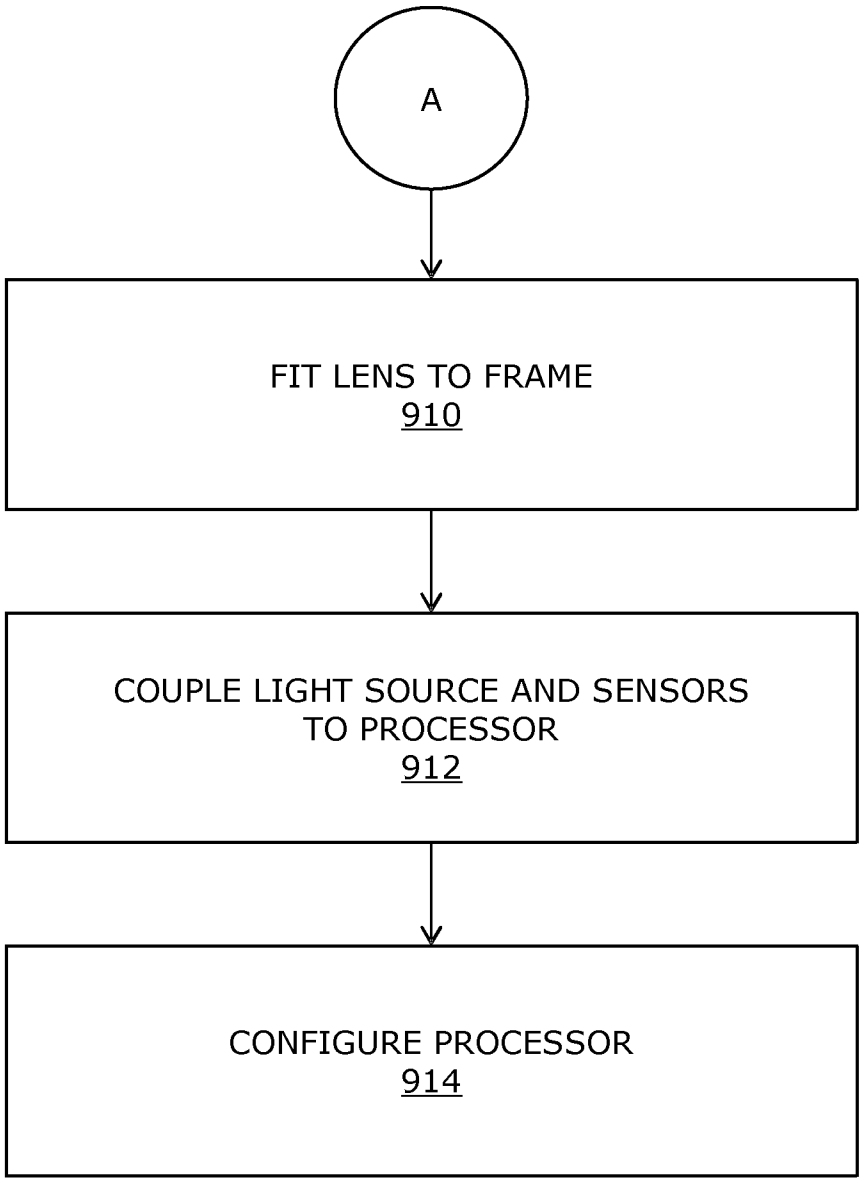

A
FIT LENS TO FRAME
910
COUPLE LIGHT SOURCE AND SENSORS TO PROCESSOR
912
CONFIGURE PROCESSOR
914

FIG. 9B

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2022/050574

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B27/01
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 299 308 B1 (VORONKA NESTOR [US] ET AL) 9 October 2001 (2001-10-09)	1-9, 11-19, 21-26
Y	figure 2 column 2, lines 47-64 column 2, line 22	10,20
X	JP 2019 139743 A (RICOH CO LTD) 22 August 2019 (2019-08-22)	1,3,5-7, 9,11-13, 15-17, 19,21-26
	figure 1 paragraph [0035]	

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[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 January 2023	03/02/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Orignac, Xavier

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2022/050574

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US RE 39 539 E (TORCH) 3 April 2007 (2007-04-03) figure 10 column 6, line 11 - line 29	1,3,5-7, 9,11-13, 15-17, 19,21-26
Y	FR 3 079 936 A1 (INST MINES TELECOM [FR]) 11 October 2019 (2019-10-11) figure 1	10,20

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/FI2022/050574

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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JP 2019139743 A	22-08-2019	NONE	
US RE 39539 E	03-04-2007	US RE39539 E	03-04-2007
		US RE41376 E	15-06-2010
		US RE42471 E	21-06-2011
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		FR 3079936 A1	11-10-2019
		US 2021157133 A1	27-05-2021
		WO 2019193028 A1	10-10-2019