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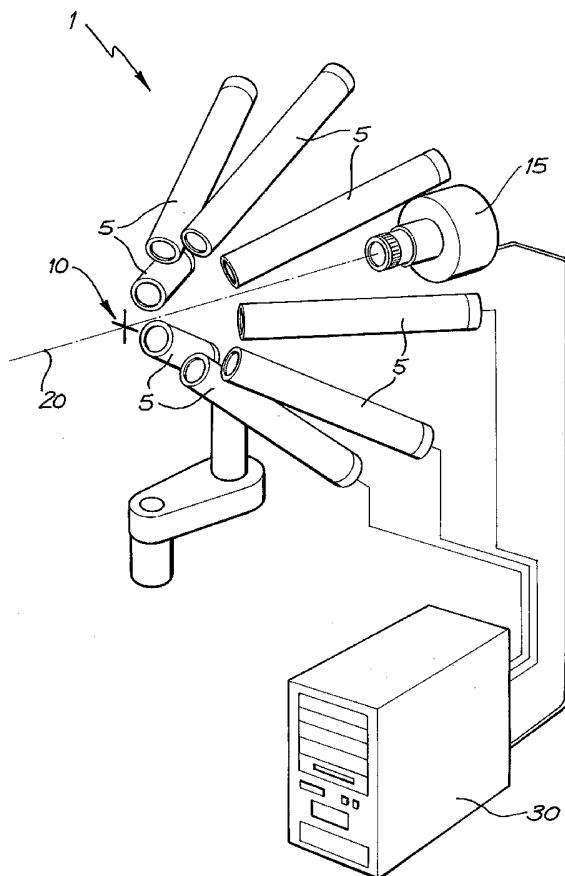
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(54) Title: A CORNEAL TOPOGRAPHER



(57) Abstract: This invention is directed to a corneal topographer (1) and a method for corneal topography. The topographer (1) includes an illumination projection subsystem to project a series of preselected different stationary patterns of one or more slits of light in ordered succession onto the surface of the cornea (100), an image capture subsystem to capture a still image of each projected pattern and an image processing subsystem to convert the still images into topographical information of the cornea. The method involves projecting a series of preselected different stationary patterns of one or more slits of light in ordered succession onto the surface of the cornea, capturing a still image of each projected pattern and converting the still images into topographical information of the cornea.



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Title**A Corneal Topographer****Technical Field**

5 Ophthalmologists and optometrists would like to have an accurate representation of the cornea of the eye, particularly its front surface and its thickness. This information is used to prescribe contact lenses and eye glasses, and to reshape the cornea by surgical procedures, all to improve eyesight. Since it is not possible to measure the cornea with physical objects,
10 remote sensing techniques are used to produce this data. Corneal Topography is the name given to this field of technology, and instruments that measure corneal topography are known as corneal topography machines, or corneal topographers. This invention concerns a corneal topographer, and a method for corneal topography.

15

Background Art

The basic and most common corneal topography systems use a Placido disk to project a series of concentric rings onto the corneal surface. The disturbance to the concentric projections is imaged by a video camera, and
20 then complex algorithms calculate the topography. Unfortunately, this system relies on a number of assumptions and these make most measurements of irregularly shaped eyes very inaccurate. In general people who have irregularly shaped eyes also have the greatest need for accurate surgery.

A much more complex and expensive system scans narrow bands, or
25 slits, of light across the surface of the cornea. The slits are imaged as they scan across the eye, and again complex algorithms calculate the topography. This method does not rely on any assumptions, generating accurate maps of both normal and irregularly shaped corneas. It has the added advantage of simultaneously providing data to measure the thickness of the cornea. This is
30 because the projection of the slit produces a number of reflections as it passes through the cornea and anterior chamber of the eye.

The most common application of corneal topography is for planning refractive surgery. This surgery has been successful in correcting the vision of many millions of people worldwide. However, in almost all cases, these
35 patients have had a simple variation or deviation from the normal corneal shape. There is a larger group of people with irregular variation in corneal

shape (irregular astigmatism). These require custom control of the laser that is reshaping the cornea, which ablates varying amounts of tissue over the cornea. It of course relies on accurate topography data of this Irregular astigmatism. Ideally the topography data is fed directly into the control system for the laser;
5 this is called custom ablation.

Disclosure of the Invention

The invention is a corneal topographer, comprising:

An illumination projection subsystem to project a series of preselected
10 different stationary patterns of one or more slits of light onto in ordered succession the surface of the cornea.

An image capture subsystem to capture a still image of each projected pattern.

An image processing subsystem to convert the still images into
15 topographical information of the cornea.

Such a topographer represents a relatively inexpensive device which provides accurate topographical information of the cornea without making assumptions. In particular this is achieved by the use of multiple stationary
20 slits, and elimination of scanning, and therefore moving parts.

The light source may be collimated LEDs, masked and focussed onto the eye.

In total there may be many, such as forty-eight LEDs producing the same number of slits, and these may be projected in, say, fifteen to twenty different
25 patterns to provide sufficient data to map the topography of the cornea. There may be more or less slits; depending on the amount of resolution achieved. The size of the slits may also vary, and the draft angle.

The LEDs may be housed together in sets with a common focussing arrangement.

30 A CCD video camera may be used, under the control of a computer to receive the images. The computer may also control a frame grabber to capture a still image every time a new combination of slits is projected onto the cornea.

Analysis may involve registration of the whole image sequence to compensate for saccadic or other eye movements that occur in the time interval
35 between capture of successive images.

Next, image processing may determine the two edges of the slits as they are shown on the image. The edges of the slits define the anterior and posterior surfaces of the cornea. Other reflections may be off the iris and the two surfaces of the lens of the eye.

5 The edges may then be converted into mathematical curves.

The curves may then be used to determine the external shape of the cornea, the inside surface of the cornea, and all the local shape variations in these surfaces. The thickness of the cornea can also be calculated. The reflections off other surfaces maybe used to calculate the volume of the
10 anterior chamber and distances to the lens.

The topography data may be displayed.

In a further aspect the invention is a method for corneal topography. The method involves:

projecting a series of preselected different stationary patterns of one or
15 more slits of light in ordered succession onto the surface of the cornea;
capturing a still image of each projected pattern; and,
converting the still images into topographical information of the cornea.

Brief Description of the Drawings

20 An example of the invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 is a pictorial diagram of a corneal topographer having eight light emitters and a controlling computer.

Fig. 2 is a sectional view of one of the light emitters of Fig. 1; also
25 showing the relationship between that light emitter, the camera and an eye during use of the topographer.

Fig. 3 is a diagram of an eye showing the arrangement of light slits projected onto it from the topographer of Fig. 1.

Best Modes of the Invention

Referring first to Fig. 1, the corneal topographer 1 comprises eight light emitters 5 mounted to focus slits of light at the same point 10 from different angles. A video camera 15 is arranged with its axis 20 through point 10 to image the slits. A computer 30 controls the emitters 5 and the video camera
35 15.

Referring now to Fig. 2, each emitter 5 comprises a tube 51 having an LED holder 52 and an electrical panel 53 at the remote end, and a lens 54 at the end closest to point 10. Six 5mm LEDs 55 are mounted in separate channels 56 through LED holder 52. A layer of stereo lithography material 58, tinted to be opaque, is mounted to the end of the LED holder 52. A distance, say 100mm, of twice the focal length of lens 54 extends between the layer of stereo lithography material 58 and lens 54.

Each channel 56 in the LED holder 52 collimates the light from the LED mounted in that channel. Slit-like openings in the stereo lithography material at the end of each channel have a draft of 60° to produce a knife edge slit 59 that is 0.2mm wide. Light from LED 55 passes through knife edge slit 59 to produce a light slit 60 that is 24mm wide. Lens 54 reduces the slit of light 60 from 24mm wide to 15mm wide for projection 62 onto the eye 100; as shown in Fig. 3. Light slit 62 is a vertical slit, relative to eye 100, and it is 15mm wide. The image of slit 62 projected on the eye is captured by video camera 15.

In total there are forty-eight LEDs 55 and they are all wired to electrical panels 53 at the remote end of the light tubes 51 so that they can be individually turned on and off under the control of the computer indicated schematically at 30. Should all the LED's be turned on at once they would project over the entire visible surface of the cornea in a pattern of both horizontal and vertical contiguous slits.

A significant amount of time may be devoted to the positioning of the light emitters, so that the entire corneal surface will be covered. Optimal resolution will be achieved when each part of the cornea is measured by at least one slit projection.

The topographer 1 is mounted on a conventional ophthalmic assessment stand (not shown), which supports the patient's head on a head and chin rest. The device is mounted so that its position is under the control of a mechanical joystick, allowing back and forth movement for focus, left and right movement to move from one eye to the other, and smaller horizontal and vertical movements to centre the device in front of the eye being assessed.

In use, the topographer is aligned in front of the eye so that the light slits are properly focussed on the cornea, and so that the camera image is in focus. A single or series of LEDs or other lights will be mounted near the camera to which the patient must fixate.

Preselected different patterns of LEDs are then sequentially turned on and off under the control of the computer. The camera 15, a CCD video camera, operates under the control of the computer to receive the light reflected along axis 20 for each pattern. The computer also controls a frame
5 grabber to capture a still image every time a new combination of slits is projected onto the cornea. Each still image is stored as quickly as it is produced, on an image capture card.

The topographer typically produces a series of between 15 and 20 images of each eye, in a total time period less than 2 seconds. The information
10 on the captured images is then converted into topographical information of the cornea.

This involves registration of the whole image sequence to compensate for the (very small) saccadic eye movements or eye drifts that occur in the time interval between capture of successive images. This is done by the use of one
15 or two slits that will always be on, for instance the two slits furthest apart, and using landmarks on the eye to determine if and how far the eye has moved.

Next, image processing determines the two edges of the slits as they are shown on the image. One of the edges determines the outside surface of the cornea, the other determines the inside surface of the cornea.

20 The edges are converted into mathematical curves.

Using trigonometry, the data of all the curves are assembled to determine the shape of the cornea, the inside surface of the cornea, and all the local shape variations in these surfaces. The thickness of the cornea can also be calculated.

25 The software then displays the topography data in various forms. For instance, the corneal data will be displayed as a series of colour coded providing axial, refractive, elevation and irregularity data. Other functions include showing a live view of the cornea before imaging to position the device, and export of data for control of refractive lasers during surgery. Standard data
30 handling functions are also performed, such as storage with patients' data, archiving, comparison between sessions, and printing.

Although the invention has been described with reference to a particular example, it should be appreciated that it includes many variants and
35 alternatives. For instance, 3mm LEDs could be used, and this could lead to the use of fewer light emitters. Fewer or more LEDs may be used with differing

resolution requirements. The slits may be projected at varying angles; not only horizontal and vertical.

It will be appreciated by persons skilled in the art that numerous
5 variations and/or modifications may be made to the invention as shown in the
specific embodiments without departing from the spirit or scope of the invention
as broadly described. The present embodiments are, therefore, to be
considered in all respects as illustrative and not restrictive.

CLAIMS:

1. A corneal topographer, comprising:
an illumination projection subsystem to project a series of preselected
5 different stationary patterns of one or more slits of light in ordered succession
onto the surface of the cornea;
an image capture subsystem to capture a still image of each projected
pattern; and,
an image processing subsystem to convert the still images into
10 topographical information of the cornea.
2. A corneal topographer according to claim 1, wherein the illumination
projection subsystem makes use of collimated LEDs, masked and focussed
onto the eye.
15
3. A corneal topographer according to claim 2, wherein there are up to
forty-eight LEDs producing the same number of slits.
4. A corneal topographer according to claim 1, 2 or 3, wherein the slits are
20 projected in up to twenty different patterns.
5. A corneal topographer according to claim 2 or 3, wherein the LEDs are
housed together in sets with a common focussing arrangement.
- 25 6. A corneal topographer according to any one of claims 1 to 5, wherein a
CCD video camera is used under the control of a computer to capture the still
images.
7. A corneal topographer according to claim 6, wherein the computer also
30 controls a frame grabber to capture a still image every time a new combination
of slits is projected onto the cornea.
8. A corneal topographer according to any preceding claim, wherein
analysis involves registration of the whole image sequence to compensate for
35 saccadic or other eye movements that occur in the time interval between
capture of successive images;

next, image processing determines the two edges of the slits as they are shown on the image;

the edges are then converted into mathematical curves;

the curves are then used to determine the external shape of the cornea,
5 the inside surface of the cornea, and all the local shape variations in these surfaces.

9. A corneal topographer according to claim 8, wherein the thickness of the cornea is also calculated.

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10. A corneal topographer according to claim 8, wherein reflections off other surfaces are used to calculate the volume of the anterior chamber and distances to the lens.

15 11. A corneal topographer according to any one of claims 1 to 10, further including means to display the topography data.

12. A method for corneal topography, comprising the following steps:
projecting a series of preselected different stationary patterns of one or
20 more slits of light in ordered succession onto the surface of the cornea;
capturing a still image of each projected pattern; and,
converting the still images into topographical information of the cornea.

13. A method according to claim 12, wherein analysis involves registration of
25 the whole image sequence to compensate for saccadic or other eye movements that occur in the time interval between capture of successive images.

14. A method according to claim 12 or 13, wherein image processing
30 determines the two edges of the slits as they are shown on the image.

15. A method according to claim 14, wherein the edges are converted into mathematical curves.

16. A method according to claim 15, wherein the curves are used to determine the external shape of the cornea, the inside surface of the cornea, and all the local shape variations in these surfaces.

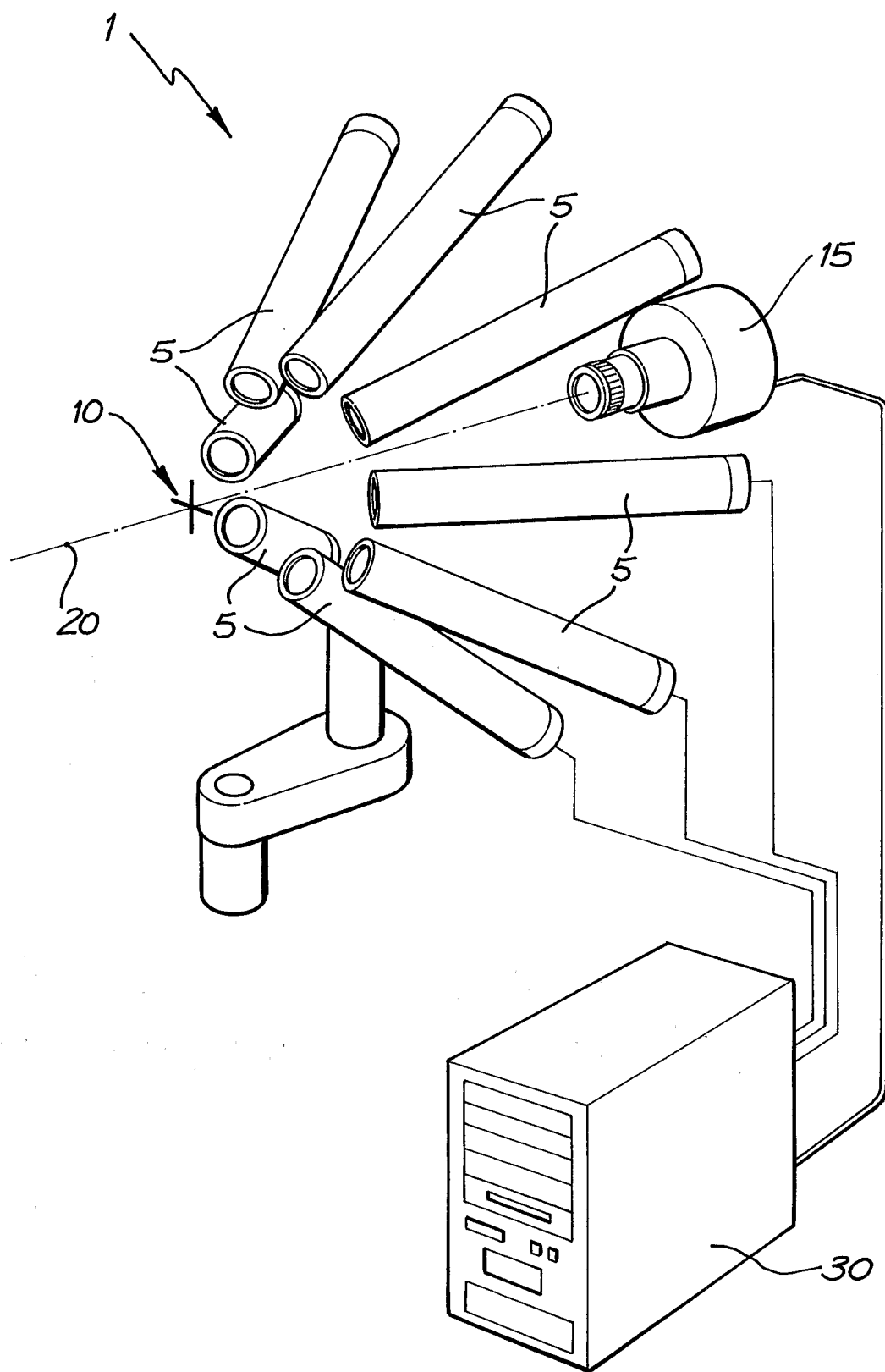
5 17. A method according to claim 16, wherein the thickness of the cornea is also calculated.

18. A method according to claim 16 or 17, wherein reflections off other surfaces are used to calculate the volume of the anterior chamber and
10 distances to the lens.

19. A method according to any one of claims 12 to 18, further including the step of displaying the topography data.

15 20. A corneal topographer substantially as hereinbefore described with reference to the accompanying drawings.

21. A method for corneal topography substantially as hereinbefore described with reference to the accompanying drawings.

**FIG. 1**

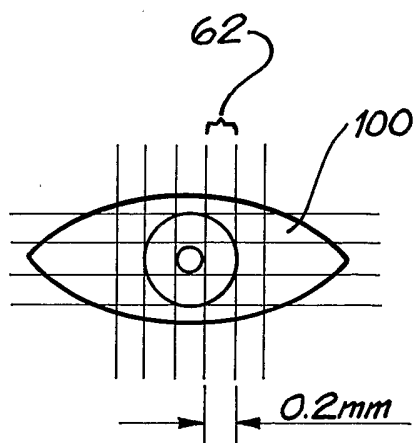
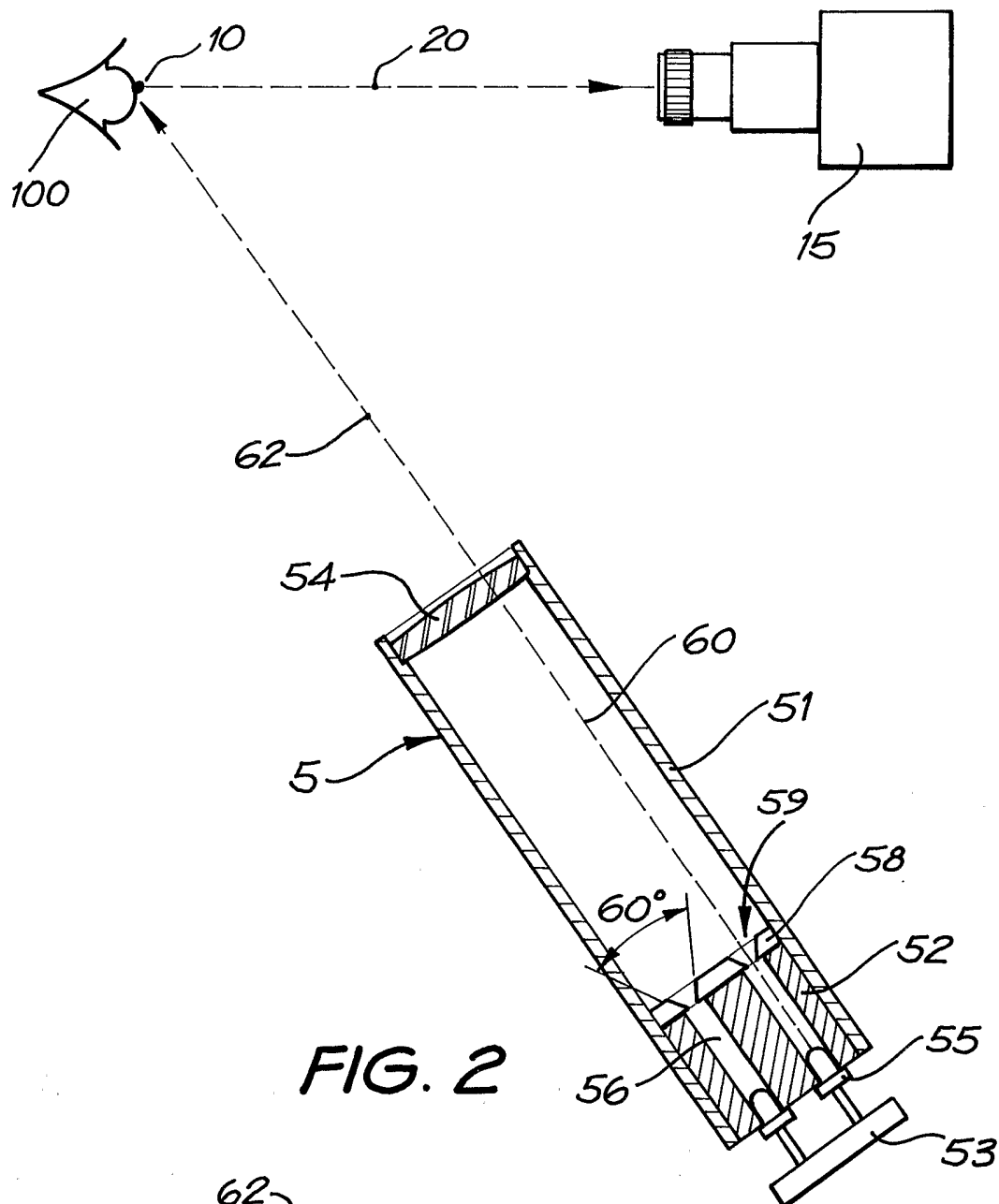


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2003/001547

A. CLASSIFICATION OF SUBJECT MATTER		
Int. Cl. ⁷ : A61B 3/107		
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)		
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) DWPI and keywords: cornea, eye, shape, light, image, capture, irregularity and similar terms.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2002082980 A2 (LASERSIGHT TECHNOLOGIES INC) 24 October 2002 Whole document, particularly page 5 paragraph 4 lines 5-12, page 6 paragraph 2, and page 8 paragraphs 4-5.	1- 21
Y	Whole document	1- 21
Y	WO 2001077739 A2 (JEAN et al) 18 October 2001 Whole document, particularly page 12 lines 8- 21.	1- 21
Y	WO 1998006320 A (XEYEX CORPORATION) 19 February 1998 Whole document, particularly page 4 lines 1- 4.	1- 21
☒ Further documents are listed in the continuation of Box C ☒ See patent family annex		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "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 20 February 2004		Date of mailing of the international search report 1 MAR 2004
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. (02) 6285 3929		Authorized officer SOOSA GNANASINGHAM Telephone No : (02) 6283 2172

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International application No.

PCT/AU2003/001547

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 1989001756 A (EL HAGE) 9 March 1989 Whole document, particularly page 8 paragraph 2 lines 7- 17.	1- 21
A	WO 2002049506 A1(SMART EYE AB) 27 June 2002 Whole document	1- 21
A	WO2002028272 A1 (JOHNSON & JOHNSON VISION CARE) 11 April 2002 Whole document	1- 21
	NOTE: For the Y indication, WO 2001082980 can be combined with any one of WO 2001077739, WO 1998006320 or WO 1989001756.	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU2003/001547

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report			Patent Family Member		
WO	02082980	US	2002044258	US	2002154269
WO	0177739	AU	60197/01	EP	1274341
WO	9806320	AU	38264/97	CA	2263249
		US	5873832	US	6059773
		US	6447119	EP	0955861
WO	8901756	EP	0329757	US	5227818
WO	0249506	AU	16567/02	US	6206522
WO	0228272	AU	94623/01	CA	2424169
		US	6616279	US	2004004696
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