

## Portable Optics Adapter to digital camera for fundus imaging

### Field of the invention

The present invention relates to digital cameras for taking at least one image of the fundus region of the rear of an eye of a human or animal subject, that is the interior surface of the eye opposite the lens. In particular, the invention relates to a fundus imaging adapter for interfacing with a separate digital camera.

### Background of the invention

Ophthalmic imaging is commonly used as a diagnostic and screening tool. Some of the diseases which can be diagnosed, from community based screening, are cataracts, glaucoma, diabetic retinopathy, age related macular degeneration, etc., which respectively account for 48 %, 12%, 8.7% and 5% of global blindness respectively according to World Health Organisation (WHO) statistics. However, due to its cost and bulk, the current clinic-based ophthalmic camera has limited reach to the masses and hence many eye disorders, which could have been reversed, cannot be treated due to late diagnosis. Portable camera systems have recently become available in the market, but these are very costly and provide a limited view of the fundus.

At present, to obtain good quality ophthalmic images and to arrive at proper diagnosis, patients are obliged to visit an eye clinic or hospital equipped with an ophthalmic diagnostic tool which is costly and requires extensive setup.

Existing tools which are currently used by the specialists to see inside the fundus of the eye and other structures are the Direct Ophthalmoscope, the Indirect Ophthalmoscope and the Fundus camera. Recently invented systems include an iPhone bracket to a Panoptic portable hand held fundus camera, and the Volk-Pictor digital fundus imaging system. We now describe these tools in more detail in turn.

A Direct Ophthalmoscope is an instrument about the size of a small flashlight (torch) with several lenses that can produce an upright image with approximately 15 times magnification.

An Indirect Ophthalmoscope is made up of a light attached to a headband, and a small handheld lens. It provides a wider view of the inside of the eye. It produces an inverted, or reversed, direct image of 2 to 5 times magnification.

A fundus camera is a specialized low power microscope with an attached camera designed to photograph the interior surface of the eye, including the retina, optic disc, macula, and posterior pole (i.e. the fundus). This fundus camera provides an upright, magnified view of the fundus. A typical camera views 30 to 50 degrees of retinal area, with a magnification of 2.5x, and allows some modification of this relationship through zoom or auxiliary lenses from 15 degrees which provides 5x magnification to 140 degrees with a wide angle lens which reduces the image quality by half. This system is not a portable system and patients need to make appointments with eye clinics for consultation with the specialist before they can have their fundus photo taken. This is the major constraint of this system.

The Volk-Pictor digital imaging system, manufactured by Volk Pictor Imaging Unlimited, is a portable digital imaging device that provides a variety of imaging capabilities with interchangeable modules. Presently four modules are available in the market, including a retinal module. Pictor retinal imaging enables non-mydratic eye fundus examination with a 45 degree field of view. Infrared or white light is used for image targeting and capture, and the image resolution is 1920x1440 pixels.

Another fundus camera system currently in the market is the iExaminer. The iExaminer, from Intuitive Medical Technologies in Shreveport, Louisiana, is a simple iPhone 4 bracket for the popular Welch Allyn PanOptic ophthalmoscope that lets one do fundus examination and share videos and images directly from the iPhone. The iExaminer app also walks users through a full eye exam including visual acuity, pupils, ocular motility, visual fields, intraocular pressure and cobalt blue light for external examination. Because the unit is held with both hands, the patient is at arm's length and the iPhone screen is viewed with both eyes allowing alignment to be more natural and comfortable for both practitioner and patient. The complete unit is portable and can be taken to the patient instead of the patient being taken to the camera. It is also a valuable tool when seeing debilitated patients. Photos of the images can be printed wirelessly from anywhere through a network connection. The iExaminer has been tested in a clinical setting and can be used by clinical

technicians as well as practitioners. The iExaminer takes simultaneous video and high resolution photographs which allows the user to pick the best photos from the imaging session.

Although the bracket is relatively cheap, the Welch AllynPanOptic ophthalmoscope is expensive. In addition, the system also gives a limited field of view of the retina due to the inherently limited field of view of the Pan optic for a non-mydiatic eye.

US2012/0229617 proposes a housing for interfacing with a separate camera, and containing three lenses permitting the camera to take images of the fundus. In the case of a non-mydiatic eye (that is, if the eye to be imaged is not dilated), infrared illumination is provided by infrared LEDs within the housing for the camera to perform auto-focusing, and standard colour flash photography is used to capture the fundus image. However, it is described that if the camera is a "consumer camera" the camera needs to be modified so that the camera is sensitive to infrared light. This is accomplished by removal of an infrared cutoff filter that is present in each consumer camera device. The preferred method of generating the visible light to capture the image is using the flash device of the camera itself, with an optical fibre for piping light from the camera's flash device into the housing. There the visible light is combined with infrared light, and a beam splitter arrangement is provided to introduce the infrared and visible light into the main optical path between the camera and the fundus. On this path three lenses are required.

#### Summary of the invention

In general terms, the present invention proposes an adapter for interfacing with an independent image recording device (camera), and allowing the camera to take a retina image of a fundus image of an eye. The adapter defines an optical path between the camera and an aperture to be directed at the fundus.

The adapter contains both at least one infrared light source and at least one visible light source. The human eye can generally perceive visible wavelengths ranging from approximately 400 to 700 nm, while infrared light (which is defined as light with wavelengths in the range 700 nm to 1 mm). The infrared light source used enables the camera to auto-focus without affecting the eye, and the visible light source provides illumination during the capturing of an image.

In a first aspect, the invention proposes that at least one visible light source (emitter) and at least one infrared light source (emitter) are arranged proximate the end of the adapter having the aperture, and off the optical path but emitting light towards the aperture along a line which converges towards the optical path.

5 This provides a way of generating the visible and infrared light which does not require complex components, such as a beam splitter, to introduce visible and infrared light onto the optical path. It further means that the light is generated in close proximity to a subject's eye. Both these features tend to reduce the size of the adapter.

10 In a second aspect, the invention proposes that the optical path includes an aspheric and achromatic lens. The lens reduces the two major aberrations of the lens which are spherical and chromatic aberrations. By using this system a sharp image can be obtained, preferably without the use of a third lens.

In a third aspect of the invention, the infrared light source(s) generate at least a  
15 portion of the infrared light (for example, at least 50% of the total energy) with a wavelength in a range below 950nm, and preferably within a range from about 700nm to about 910nm.

This is advantageous because a conventional off-the-shelf commercial camera has a cutoff wavelength which, while varying from one camera to another, typically has an  
20 absolute cut-off wavelength at around 950nm, due to the 3dB roll-off. Hence infrared light in the range 700nm to 910nm is detectable by the CMOS detector of the conventional camera. This makes the operation suggested by US2012/0229617 of removing the infrared filter of the camera unnecessary, and means that, unlike US2012/0229617, the present adapter is suitable for use with conventional off-the-  
25 shelf cameras without modification of the camera.

The present invention thus makes possible a new portable optics adapter which can be fitted onto any off the shelf digital camera and making it both low cost and portable and hence facilitates mass screening. Besides its use in mass screening, such portable adapter with the digital camera can also be utilized for patients who  
30 are bed ridden, patients who are admitted into intensive care unit, patients in

Tuberculosis Care Unit, HIV-AIDS patients in communicable disease clinic, in homes for aged and for the school health screening.

#### Brief description of the drawings

Embodiments of the invention will now be described, for the sake of example only, with reference to the following figures, in which:

Fig. 1 is composed of Figs. 1(a), 1(b) and 1(c), which are respectively a front view, a side view and a perspective view of an optics adapter which is an embodiment of the invention;

Fig. 2 is composed of Fig. 2(a) which is a cross-sectional diagram of the embodiment, and Fig. 2(b) which is an "exploded" view of the embodiment;

Fig. 3 illustrates a lighting system of the embodiment;

Fig. 4 is a circuit diagram of a circuit to activate white light LEDs in the lighting system of the embodiment;

Fig. 5, which is composed of Figs. 5A to 5D, shows different views of a switch for controlling the embodiment and an associated camera;

Fig. 6 is a circuit diagram of the circuit for controlling infrared LEDs in the embodiment; and

Fig. 7 shows a scheme for collecting a plurality of fundus images showing different respective portions of the retina.

#### Detailed description of the embodiments

Referring to Fig. 1(a)-(c), an embodiment of the invention is illustrated in front, side and perspective views. The embodiment is an add-on adaptor 1 to an off-the-shelf commercial digital camera 7. The adapter 1 has an exterior cover 3 which as explained in below provides a housing for lenses and LEDs. At a first end of the cover 3 is a mounting unit 2 for releasably attaching the adapter 1 to the camera 7. In the embodiment of Fig. 1, the mounting unit 2 is shown as defining a chamber for receiving the camera 7. At the opposite end of the cover 3 is an eye-piece 4 including a cushion for placement against the face of a subject. It may be made of

soft rubber for comfort. The eye-piece 4 has a central aperture 5 for alignment with the subject's eye. The adapter 1 further includes a power unit 6. A control knob 8 is provided as discussed below.

The camera 7 is selected to have auto-focusing capacity. The adapter 1 can be used with a wide range of camera models. With a slight variation in the shape of mounting unit, it can be used with digital SRLs. It is designed to produce the same image quality as the clinic-based fundus camera. As digital camera technology improves, the camera 7 can be updated so as to obtain higher quality images.

Fig. 2(a) is a cross-sectional view of the embodiment, showing the internal structure of the optics adaptor 1. The housing 3 contains an imaging optic unit which comprises two lenses: a hybrid aspheric achromatic lens 11 in the front having a focal length of for example 40mm; and a biconvex lens 12, with a focal length of for example 75mm, mounted on an adjustable slide mechanism 13. Thus, an optical path extends in the left-right direction of the figure between the camera 7 and the aperture 5 in the eyepiece 4. The aspheric achromatic lens 11 combines the colour correction performance of a hybrid lens with the ability to eliminate spherical aberration. This is ideal for imaging and ophthalmic applications. The position of the biconvex lens is designed to be adjustable using the sliding mechanism 13 under the control of control knob 8 to achieve a focused image to accommodate for the different focal lengths of various off-the-shelf digital camera models.

Fig. 2(b) is an "exploded" view of the embodiment showing that the cover 3 is made of two shell portions 3a, 3b, and the mounting unit 2 is similarly formed from two portions 2a, 2b. The embodiment further includes twelve LEDs 15, 16 as described below.

The adapter is designed to collect light reflected from the subject's retina and provide the system with magnification of 2-3 times. As the retina has limited reflectivity in this visible wavelength range, only a portion of light entering the eye and incident on the retina is actually reflected for ophthalmic imaging. Hence, even for the clinical ophthalmic camera system, a very bright flash is needed to ensure sufficient light is reflected from the retina for imaging purposes.

The lighting system is located as a ring encircling the achromatic lens 11. The axis of the ring is parallel to the left-right direction in Fig. 2 and passes through the centres of the lenses 11, 12. The only parts of the lighting system which are visible in Fig. 1 are LEDs 15 at the top and bottom of the ring. The lighting system is further

5 illustrated by Fig. 3, which shows a cross-sectional view in the direction which is left-right in Fig. 2. There are typically a plurality (normally at least three) visible light LEDs angularly spaced apart about the optical axis, and a plurality (normally at least three) infrared LEDs in the lighting system, also angularly spaced apart about the optical axis. In this embodiment, the lighting system comprises four ultra-bright  
10 white-light LEDs 15 with 3W power are used as the flash source for capturing the retina image. The four white-light LEDs 15 are respectively shown above, below, to the left and to the right of the optical path (which is at the centre of Fig. 3 and extending in the direction into the page). The lighting system further comprises eight infrared LEDs 16, with pairs of the LEDs 16 between each neighbouring pair of LEDs  
15 15.

Note that not all the light generated by the LEDs 15, 16 will pass through the aperture 5 and the pupil. In fact, probably a small portion will pass through the pupil. Optionally, a ring-shaped aspheric lens may be placed in front of the LEDs 15, 16 that will focus most of the light through the pupil. The central hole of the ring-shaped  
20 aspheric lens will lie on the optical path, and the ring-shaped aspheric lens will not affect the two lenses 11, 12 for image capture.

As shown in Fig. 3, these LEDs 15, 16 are placed in a circular array in the front portion of the optics adaptor 1, encircling the optical path between the camera 7 and the aperture 5. More LEDs can be added to increase the brightness of the image if  
25 required.

To generate the flash from the white light LEDs 15, the circuit shown in Fig. 4, comprising a 555 timer is used. The user has the flexibility to adjust the duration of the LEDs 15 from 0.4 seconds to 3 seconds by adjusting the variable resistor. To activate this timer, an external switch has been incorporated beside the trigger  
30 button of the camera to synchronize with the camera flash as shown in Fig. 5. Fig. 5A is an enlarged view of the mounting unit 2 holding a camera 7. The mounting unit contains an aperture 21 through which a portion of the camera 7 including the

camera trigger button 71 is visible. Fig. 5B is a further enlarged view of the aperture 21 (at a time when no camera 7 is within the mounting unit 2), showing that it contains a mechanical switch 22. Fig. 5D is equivalent to Fig. 5B except that a camera 7 is located within the mounting unit 2. Fig. 5C shows the mounting unit (again at a time when no camera 7 is within it) looking in the direction shown as "C" in Fig. 1(c). The mechanical switch 22 is configured such that it is depressed simultaneously with the camera trigger button 71. Depression of the mechanical switch 22 is detected by circuitry 23. A small amount of depression of the mechanical switch 22 causes the infrared LEDs 16 to be triggered, and a simultaneous small amount of depression of the trigger button 71 causes the camera to begin the auto-focus operation. A larger amount of depression of the mechanical switch 22 causes the white LEDs 15 to be triggered, and a simultaneous larger amount of depression of the trigger button 71 causes the camera to capture an image.

In variations of the above scheme, a mechanical switch of the adapter 1 can be used to control selectively the LEDs 15 and 16, and to control electronic circuitry of the adapter 1 which interfaces electronically with the camera 7 to cause the camera to respectively perform the auto-focus operation and image capture operation.

The wavelength of the infrared LEDs 16 can range from 700nm to 1000nm, but preferably the majority of the emitted energy in the range 700 nm to 910 nm. For example, LEDs 16 which generate substantially all their energy with a wavelength of 850nm may be used. The purpose of these LEDs 16 is to illuminate the retina sufficiently to facilitate the auto-focus of the camera 7. Since human eyes are not sensitive to infrared wavelength, the use of these LEDs 16 will not cause the subject's pupil to contract, hence allowing more light to pass through the pupil for imaging purposes. The circuit diagram is shown in Fig. 6.

An additional feature of the adapter is a scheme to direct the subject's focus successively in different directions. Each of these directions corresponds to a respective angular position of the eye (relative, for example, to the optical path) and a fundus image is obtained at each position. This scheme will allow the camera to capture images of different parts of the retina systematically. These images can then be digitally stitched together to form a wide and focused view of the retina, i.e. a composite image.

The scheme may be implemented independently of the adapter, for example, by asking the patient to look successively at tracking images successively generated in different matrix positions in sequence (eg, Positions 1, 2, 3, ...) as illustrated in Fig. 7. For example, the tracking images may be single image successively moved from one position to another.

Alternatively, the scheme may also be adapted internally to the adapter. In this case, the adapter contains a mechanism for generating a digital image which is perceived by the subject to move to successive positions, so that the mechanism will successively direct the focus of the eye causing the eye to move and hence for the camera to capture different parts of the retina.

Comparing the embodiment with the Volk Pictor system, although both systems are portable and easy to use, the embodiment has the advantage of being able to adapt to any digital camera system available in the market. When compared to the direct ophthalmoscope, it allows images to be captured and stored for future processing or sent for diagnosis by an ophthalmologist.

Commercially the portable optics adapter system of the embodiment can be used on any off the shelf digital camera. Based on low cost and portability, embodiments of the invention can be readily used for mass screening in remote areas. They can also be used by general practitioners to acquire the retinal images at their clinic and subsequently get those images reviewed by ophthalmologist for further opinion and advice. The proposed device is also very useful for bed ridden patients and severely sick patients at a nursing home who are unable to come for eye check-up or follow up and hence decision regarding their eye status and follow up can be made based on retinal and optic disc image. This product can be made available possibly in retailer shops that can offer preliminary screening services to the public. Besides commercial use in old aged patients, patients with diabetes and other systemic disease, the invention can be readily used in infectious disease unit (TB unit, HIV unit) where there is always a high risk of eye involvement as a monitoring and screening tool.

### Claims

1. An adapter for interfacing with a camera to allow the camera to take a fundus image of an eye of a subject, the adapter comprising:

a mounting unit for attachment to the camera,

5 an eye piece defining an aperture to be directed at a fundus of the eye;

a lens system defining an optical path between the mounting unit and the aperture, the lens system including a plurality of lenses arranged to receive light reflected from the eye of the subject; and

10 a lighting system comprising at least one infrared light source and at least one visible light source, whereby the infrared light source enables the camera to auto-focus without affecting the eye, and the visible light source provides illumination during the capturing of a fundus image;

15 the at least one visible light source and at least one infrared light source being arranged off the optical path and proximate the eye piece, and each being located to emit light which propagates towards the aperture in a direction which converges towards the optical path, and passes through the aperture without having passed through the lens system.

2. An adapter according to claim 1 in which there are a plurality of visible light sources and infrared light sources arranged in an array surrounding the optical path.

20 3. An adapter according to claim 2 in which the array is circular and encircles the optical path.

4. An adapter according to any preceding claim in which there are at least three visible light sources and at least three infrared light sources.

25 5. An adapter according to any preceding claim in which the lens system includes an aspheric and achromatic lens.

6. An adapter according to claim 5 when dependent upon claim 3, in which the array of visible light sources and infra-red light sources encircles the achromatic lens.

7. An adapter according to any preceding claim in which there are exactly two lenses in the lens system.
8. An adapter according to any preceding claim in which at least 50% of the energy of the infrared light emitted by the at least one infrared light source has a wavelength below 950nm.  
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9. An adapter according to claim 8 in which at least 50% of energy of the infrared light emitted by the at least one infrared light source has a wavelength below 910nm.
10. An adapter according to any preceding claim further including a mechanism for generating images at successive respective angular positions relative to the eye of the subject.  
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11. A method of generating an fundus image of the eye, the method comprising capturing a plurality of fundus images using an adapter according to any preceding claim, the eye being in a different angular position relative to the optical path in each said image, and combining the images to form a composite fundus images.  
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12. A method according to claim 11 further comprising generating an image successively at a plurality of successive angular positions relative to the eye, and capturing said plurality of fundus images when the subject's eye is directed towards a respective one of the plurality of angular positions.