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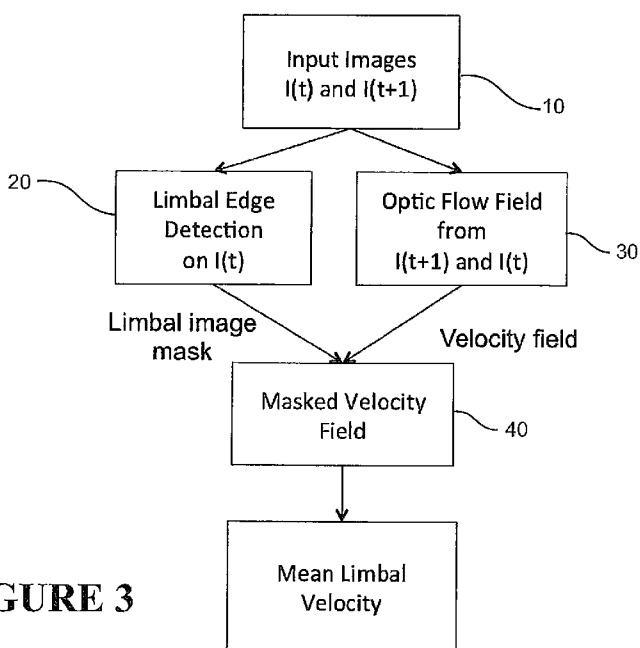


FIGURE 3

(57) Abstract: Embodiments of the invention relate to a method of extracting eye velocity information from a video footage having a plurality of frames, comprising detecting at least part of an eye in at least two frames of the video footage, applying an optical flow algorithm to the at least two frames of the video footage to extract pixel velocity information, and determining a statistical measure from the pixel velocity information within the detected at least part of the eye. Other embodiments of the invention relate to a method of extracting head image trajectory information from a video footage having a plurality of frames, comprising detecting at least part of a facial region of the head image in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement.

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HEAD AND EYE TRACKING

FIELD OF THE INVENTION

- 5 The invention generally relates to systems and methods for processing video information useful for the determination of optokinetic nystagmus and head movement.

BACKGROUND

- 10 Accurate evaluation of visual function in young children in particular is challenging. There are few methods available and none are particularly suitable for use by health care providers who do not have extensive training in paediatric ophthalmology, optometry and/or visual electrophysiology.
- 15 Optokinetic nystagmus (OKN) is the phenomena of involuntary eye movement triggered by a continuously moving pattern or stimulus, and can be used to evaluate visual function. OKN is the repetition of an eye moving to smoothly pursue a target in a visual stimulus followed by a resetting event (saccade) where the eye fixes on a new target of the stimulus. **Figure 1(b)** shows a graph of eye displacement over time showing a saw tooth
- 20 OKN profile that is characteristic of OKN eye movement.

The presence or absence of OKN is an objective indication of visual performance and can also be useful for assessing neurological disorders. Early detection of a vision problem in a person's life is also known to significantly improve the outcome of proceeding treatment.

- 25 An OKN visual stimulus consists of an arrangement of lines or dots having modifiable properties including contrast, frequency or coherence. Manipulating these parameters allows measurement of the threshold at which OKN is no longer present. This threshold is a measure of visual performance.
- 30 One method of eliciting OKN is with use of a spinning hand-held drum that has a visual stimulus. A clinician watches eye movement to make a decision regarding the presence or absence of OKN.
- 35 Another method of detecting OKN is known as electro-oculography. Electrodes placed around the eye measure changes in electrical potential as the eye (a strong dipole) moves in response to a visual stimulus. The signals produced by the electrodes are analysed to determine the presence or absence of OKN.

Another method of detecting OKN is with the use of video-oculography techniques. The position of an eye is tracked by reviewing live or recorded video. Video-oculography is appealing because it is a non-invasive and can be implemented using low cost and basic video hardware. US patent 7,380,938 describes a video-oculography technique where

5 video footage of an eye is recorded, the vertical and horizontal movement of an eye isolated and displacement of the eye in the vertical and horizontal directions is measured. The displacement measurement can be analysed to determine the presence or absence of OKN patterns.

- 10 One disadvantage of video-oculography techniques is that they require a fixed positional relationship between the camera and eyes in order to eliminate performance errors introduced by head movement. To prevent head movement, the subject is often required to place their head in a fixed chin-rest or wear head mounted equipment such as cameras and lighting equipment to improve the video recording. Young children and infants do not
- 15 tolerate head fixing or head-mounted gear which precludes them from an objective assessment of their visual function using video-oculography techniques.

Objects of the present invention relate to ways of assess optokinetic nystagmus which overcomes or at least ameliorates some of the abovementioned disadvantages or which at

20 least provides the public with a useful choice.

In this specification, where reference has been made to external sources of information, including patent specifications and other documents, this is generally for the purpose of providing a context for discussing the features of the present invention. Unless stated

25 otherwise, reference to such sources of information is not to be construed, in any jurisdiction, as an admission that such sources of information are prior art or form part of the common general knowledge in the art.

30 **SUMMARY OF THE INVENTION**

In one broad aspect the invention consists in a method of extracting eye velocity information from a video footage having a plurality of frames, comprising detecting at least part of an eye in at least two frames of the video footage, applying an optical flow algorithm to the at least two frames of the video footage to extract pixel velocity

35 information, and determining a statistical measure from the pixel velocity information within the detected at least part of the eye.

In another broad aspect the invention consists in a eye tracking system comprising a camera arranged to capture footage of an eye, a controller configured to receive the

footage of the eye and perform the steps of detecting at least part of an eye in at least two frames of the footage, applying an optical flow algorithm to the footage to thereby determine pixel velocity information between at least two frames of the footage, and determining a statistical measure from the pixel velocity information within the detected at least part of the eye.

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In another broad aspect the invention consists in a controller device programmed to perform the steps of detecting at least part of an eye in at least two frames of the footage, applying an optical flow algorithm to the footage to thereby determine pixel velocity information between at least two frames of the footage, and determining a statistical measure of the pixel velocity information within the detected at least part of the eye.

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Some embodiments further comprise one or more of the steps of (in any order):

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determining the velocity magnitude and direction of at least part of an eye from the velocity information, determining any velocity maxima and minima from the velocity information, comparing any maxima or minima to a lower velocity threshold and discarding any maxima or minima below the threshold, comparing any maxima or minima to an upper velocity threshold and discarding any maxima or minima above the threshold, comparing the inter-frame distance between adjacent maxima or minima to a frame threshold and discarding any maxima or minima below the frame threshold, determining any sole maxima or sole minima in the velocity information and discarding sole maxima or sole minima, averaging the maxima or minima velocity magnitudes, and/or normalising the maxima or minima velocity magnitudes.

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In some embodiments the statistical measure of the pixel velocity information is an average pixel velocity.

In some embodiments the at least part of the eye is a region of contrast discontinuity of the eye.

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In some embodiments the at least part of the eye is a limbus portion of the eye.

Some embodiments further comprise generating a list of pixel velocity averages for each consecutive frame in the video footage.

▪ 35

Some embodiments further comprise comparing the determined velocity information to healthy velocity information to make a determination of the health of the eye and/or visual pathway.

Some embodiments further comprising comparing the determined velocity information to healthy velocity information to make a determination of the presence and/or strength of OKN.

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In some embodiments the limbus portion of the eye is determined by an edge detection algorithm.

In some embodiments edge detection is performed by application of a Prewitt operator.

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In some embodiments the optical flow algorithm is a Lucas-Kanade optical flow algorithm.

In some embodiments the optical flow algorithm is applied to determine pixel velocity information between consecutive frames of a length of video footage corresponding to several reset events.

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Some embodiments further comprise a visual stimulus arranged in front of the eye, the stimulus operable to elicit optokinetic nystagmus.

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Some embodiments further comprise comparing the average velocity information to known optokinetic nystagmus velocity information to make a determination of the health of an eye in response to the stimulus.

In some embodiments the video footage is obtained from a subject watching a stimulus.

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In some embodiments the stimulus is a screen.

In some embodiments the camera and screen are contained within an enclosure.

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In some embodiments the camera, screen and controller are integrated within an enclosure.

In some embodiments the enclosure is any one or more of a smart phone, tablet or portable computation device.

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In some embodiments detecting at least part of an eye does not include detection of a feature of the eye.

In another broad aspect the invention consists in a method of improving the attention of a subject for eye tracking comprising operating at least one display to show a video of an video functional to gain the attention of a viewer, operating at least one display to show an OKN stimulus video, and recording an eye watching the OKN stimulus video with a camera.

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In some embodiments the video functional to gain the attention of a viewer is an animated video.

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In some embodiments the method further comprises the method of extracting eye velocity information from the recording of the eye according to claim 1.

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In some embodiments the statistical measure is applied to determine information relating to one or more of a person's behaviour, a person's response to advertising, security purposes, or consumer attention.

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Some embodiments further comprise extracting head image trajectory information from the video footage by a method comprising detecting at least part of a facial region of the head in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement.

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Some embodiments further comprise determining the inverse of the transformation map, applying inverse of the transformation to each frame in the video footage such the facial region within the frame is held substantially constant.

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Some embodiments further comprise detecting the facial region from within a frame of the video footage using the Viola-Jones algorithm.

Some embodiments further comprise identifying one or more particular portions of the facial region within the frame using a Harris corner detection algorithm.

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Some embodiments further comprise determining the measure of the movement of the facial region or one or more particular portions of a facial region between consecutive video frames using a Kanade Lucas Tomasi (KLT) point tracker.

In some embodiments the measure of the movement comprises one or more of rotation, scale and/or translation movement.

In some embodiments the transformation map is created from the movement information.

Some embodiments further comprise applying an inverse similarity transformation to offset each frame in the video footage such that the facial region within the frame is held

- 5 substantially constant with respect to each frame.

Some embodiments further comprise applying an inverse similarity transformation to crop each frame in the video footage to generate a new frame such that the facial region within the frame is held substantially constant with respect to each frame.

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In some embodiments the head trajectory information is used to improve the eye velocity information.

- 15 In some embodiments head trajectory information is offset against the eye tracking information to substantially remove eye velocity information caused by head movement.

In another broad aspect the invention consists in a method of processing video footage having a plurality of frames to determine the presence of OKN, the method comprising: extracting head trajectory information by a method comprising detecting at least part of a facial region of the head image in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement, and extracting eye velocity information by a method comprising detecting at least part of an eye in at least two frames of the video footage, applying an optical flow algorithm to the at least two frames of the video footage to extract pixel velocity information, and determining a statistical measure from the pixel velocity information within the detected at least part of the eye.

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- 30 In some embodiments the head trajectory information is offset against the eye tracking information to substantially remove eye velocity information caused by head movement.

In another broad aspect the invention consists in a method of extracting head image trajectory information from a video footage having a plurality of frames, comprising: detecting at least part of a facial region of the head image in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement.

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In another aspect the invention consists in a method of extracting head image trajectory information from a video footage having a plurality of frames, comprising: detecting at least part of a facial region of the head image in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement.

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In another aspect the invention consists in a head tracking system for extracting head image trajectory information comprising: a camera arranged to capture footage of a head and a controller configured to receive the footage of the head and perform the steps of: detecting at least part of a facial region of the head in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement.

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In another aspect the invention consists in a controller device configured to perform the steps of detecting at least part of a facial region of the head in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement.

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In some embodiments the method or steps further comprise: determining the inverse of the transformation map, applying inverse of the transformation to each frame in the video footage such the facial region within the frame is held substantially constant.

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Some embodiments further comprise detecting the facial region from within a frame of the video footage using the Viola-Jones algorithm.

▪ 30

Some embodiments further comprise identifying one or more particular portions of the facial region within the frame using a Harris corner detection algorithm.

Some embodiments further comprise determining the measure of the movement of the facial region or one or more particular portions of a facial region between consecutive video frames using a Kanade Lucas Tomasi (KLT) point tracker.

▪ 35

In some embodiments the measure of the movement comprises one or more of rotation, scale and/or translation movement.

In some embodiments the transformation map is created from the movement information.

Some embodiments further comprise applying an inverse similarity transformation to offset each frame in the video footage such that the facial region within the frame is held substantially constant with respect to each frame.

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Some embodiments further comprise applying an inverse similarity transformation to crop each frame in the video footage to generate a new frame such that the facial region within the frame is held substantially constant with respect to each frame.

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In some embodiments the system or method is to be applied to infants, young children or impaired persons.

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In some embodiments the system or method is to be applied to children under 10 years old.

In some embodiments the system or method is to be applied to children under 8 years old.

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In some embodiments the system or method is to be applied to children under 6 years old.

In some embodiments the system or method is to be applied to children under 4 years old.

In some embodiments the system or method is to be applied to children under 2 years old.

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In some embodiments the system or method is to be applied to children up to 2 years old.

In some embodiments the system or method is to be applied to children up to 3 years old.

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In some embodiments the system or method is to be applied to children up to 4 years old.

The following embodiments may relate to any of the above aspects. Other aspects of the invention may become apparent from the following description which is given by way of example only and with reference to the accompanying drawings.

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As used herein the term "and/or" means "and" or "or", or both.

As used herein "(s)" following a noun means the plural and/or singular forms of the noun.

The term "comprising" as used in this specification means "consisting at least in part of". When interpreting statements in this specification which include that term, the features, prefaced by that term in each statement or claim, all need to be present but other features can also be present. Related terms such as "comprise" and "comprised" are to be interpreted in the same manner.

This invention may also be said broadly to consist in the parts, elements and features referred to or indicated in the specification of the application, individually or collectively, and any or all combinations of any two or more of said parts, elements or features, and where specific integers are mentioned herein which have known equivalents in the art to which this invention relates, such known equivalents are deemed to be incorporated herein as if individually set forth.

To those skilled in the art to which the invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the scope of the invention as defined in the appended claims. The disclosures and the descriptions herein are purely illustrative and are not intended to be in any sense limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described by way of example only and with reference to the drawings in which:

Figure 1 shows a picture of an eye. Figure 1(a) illustrates the region of an eye typically monitored for change in displacement. Figure 1(b) shows a graph of eye displacement over time exhibiting a saw tooth profile characteristic of healthy eye movement. Figure 1(c) shows a graph of eye velocity derived from the eye displacement signal.

Figure 2 shows an example where consecutive image frames are transformed into an estimate of pixel velocity. Figure 2(a) is an example image of an eye received from a camera. Figure 2(b) shows an example of pixel velocity vectors provided by an optical flow algorithm. Figure 2(c) is an example of a graph of the regional velocity average of the optical flow velocity vectors.

Figure 3 shows an outline of the preferred process steps of the invention.

Figure 4 shows graphs of simulated limbal edge and detector response. Figure 4(a) shows an example input edge similar in size ($\sigma = 5$) to that observed in. Figure 4(b) shows calculated response curves (for three examples velocities ($v = 1; 3; 5$ pixels/frame

respectively) using saccade velocity values indicative of what would be encountered in practice.

Figure 5 shows an arrangement of one example of components including a camera located proximate a display to present a clear line of sight to view the eyes.

- 5 Figure 5 (inset left) shows an example of a low coherence stimulus. Figure 5 (inset right) shows an example of a full coherence stimulus.

Figure 6 shows a sequence of video frames obtained from the calibration trials that illustrate aspects of the detection process.

Figure 7(a) – (e) show pixel velocity information and OKN consistency values \bar{K} .

- 10 **Figure 8** shows a summary of the distribution of OKN consistency values \bar{K} .

Figure 9 shows a graph of peaks in the velocity information.

Figure 10 shows the process of Figure 3 applied to a single frame, frame 0055, in a piece of video footage.

- 15 **Figure 11** shows an overview of the components of the system including the camera, a screen and a computational device.

Figure 12 shows raw and stabilised head trajectory according to another embodiment of the invention.

Figure 13 shows the head 3D pose estimation and stabilization procedure.

Figure 14 shows the head trajectory estimation for a length of video footage in 3D space.

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DETAILED DESCRIPTION

Eye tracking

- 25 Video-oculography techniques of the prior art require a location in an image for processing by an edge detection algorithm primarily acting on the contrast transitions in the image. The location must therefore be a high contrast feature of the eye such as the pupil, limbus edge or eyelids. Movement of these features can be tracked from frame to frame to determine a displacement signal. The footage recorded by a standard RGB camera will
- 30 typically produce a poor contrast between features of the eye, particularly for dark irises. **Figure 1(a)** illustrates poor contrast in a frame in a video recording. Figure 1(a) also shows how the image can be further contaminated by corneal reactions, eye-lashes and eye-lids. To improve the contrast of these features in a video recording, and therefore the performance of the edge detection algorithm, infra-red light is used to illuminate the eye.
- 35 Head mounts or chin rests may be used to stabilize the eyes relative to the recording equipment. However, young subjects are adverse to head mounted equipment and having their heads fixed in place.

One particular embodiment is a video-oculography system and method that allows detection of OKN from video footage. The video footage is used to make an estimate of the velocity, rather than the displacement, of an eye as a subject watches a visual stimulus. In particular, the invention includes determining a velocity estimate of pixels inside the coarse determination of a limbal region of an eye by application of an image processing algorithm known as optical flow. In preferred embodiments, a Lucas-Kanade optical flow algorithm is used. A significant advantage of this approach is that precise edge detection is not required which improves the robustness of the system and method when working with poor image contrast and other issues that give rise to image distortion. The system and method are also insensitive to stationary obstructions such as eyelids or eyelashes that often confound displacement based approaches of the prior art. Further, detection of particular aspects or features of the eye, for example specks, lines or a clear edge that exist within the eye, is not required. Further, measurement of torsional movement is not required.

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The velocity information obtained from the optical flow algorithm is used to detect whether or not the stimulus has elicited OKN in a subject's eye. The stimulus parameters at the threshold where OKN is no longer detected provides an indication of visual performance. A clinician may review the velocity information determined from the eye movement. Alternatively, a statistical analysis process may be applied to the velocity information to determine the presence or absence of OKN.

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According to some embodiments, the statistical process is calculating a regional average velocity of the optical flow field determined from a region of the eye. In some embodiments, the limbal region of the eye is used where the limbal region is coarsely determined from an edge detection process. In other embodiments, other regions or a combination of regions of the eye are used which provide at least a contrast discontinuity, such as the iris. The contrast discontinuity is used to track a region of the eye from which velocity information is to be analysed.

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- 10 Lucas-Kanade feature tracking may also be used to track head movement. Eye movement may be quantified and also head movement may be quantified. Determination of head movement may negate the requirement for head mounted video equipment.

One example of a visual stimulus used to elicit OKN is a visual display with 250 moving white dots, on a 16" cathode ray tube (CRT) as shown in **Figure 5**. Those skilled in the art will recognise the display may be any screen of adequate size and resolution relative to that of the stimulus video to be displayed. For example, a CRT screen, LCD or handheld display may be used. In some embodiments, the dots are around 0.5° in size and presented in a 8.3° circular window for around 8 seconds. In some embodiments, the dots move at around $8.3^\circ/\text{second}$. In some embodiments, the proportion of dots moving in concert versus the total population of dots is adjustable. Full dot coherence has 100% of the dots moving in the same direction, such as shown in **Figure 5**, inset right, while low dot coherence has between 30-38% of all dots moving in concert, whilst the rest moved randomly such as shown in **figure 5**, inset left. In some embodiments, the coherence of the dots is also adjustable.

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- 30 In one example, a CRT display is placed at a distance of approximately 60 cm from a subject's eyes. Video footage is collected using a SONY digital high definition camera (HDR-CX7EK, Sony Corporation, Tokyo, Japan) delivering video footage of RGB images (1920 by 1080 pixels) at 25 frames per second. A camera is located proximate the display to present a clear line of sight to view the eyes. This arrangement (without the subject) is shown generally in **Figure 5**.

In another example, in particular to improve the attention of young test subjects, the visual stimulus video is interspersed with a video segment that appeals to children, such as a cartoon. A cartoon or other kind of animated video is displayed for a period of time adequate to gain the attention of a young subject before the visual stimulus video is displayed for a period of time adequate to acquire OKN data. The cartoon can be displayed

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when attention wanes or alternatively when the OKN video has finished. The cartoon may be switched to and from the display automatically by a control device or manually by an operator. In another example, the cartoon may be displayed on a first screen and the OKN stimulus video on a second screen. The first screen is switched on to gain the attention of a subject, then the second screen is switched on and the first screen off so that the subject views the OKN stimulus.

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In some embodiments, the video footage is input to system such as a computational device capable of processing video data. One example of such a system is a PC running MATLAB software. The computational device is equipped with hardware and software for receiving video footage and performing manipulation and analysis of that footage. Alternatively the computational device may be a standalone system such as a microprocessor or microcontroller. **Figure 11** shows an overview of the components of the system including the camera 60 for recording the eye footage, a screen 70 for displaying the stimulus and a computational device 80. Each of these components may be contained within an enclosure 90 such as a smart phone or tablet as previously described.

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The method of determining OKN according to various embodiments is conducted according to the following steps. A video sequence containing footage of eye is recorded while the eye watches a stimulus. In some embodiments, the video is colour and high definition, for example, 1920 by 1080 pixels, but may also be black and white and/or a lower definition. In some embodiments, the video footage is reduced to grey scale to reduce computation complexity. An optical flow image processing algorithm is applied to the video footage to determine pixel velocity information from sequential frames. The velocity information is determined from a limited region of the eye and that region is the limbus and/or limbal edge portion of the eye. The region is a coarse estimate of the limbal region of the eye determined by an edge detection algorithm. The image processing algorithm outputs optical flow information represented by pixel velocity information in determined the limbus region of the eye over two consecutive frames in the video footage. The pixel velocity information, including the speed and direction, can be directly assessed to determine the presence and direction of OKN.

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One example of the steps of the process is shown in **Figure 3** where the transformation of two consecutive image frames into an estimate of pixel velocity is shown. In a first step 10, consecutive video frames $I(t)$ and $I(t + 1)$ are taken from high definition colour video footage and reduced to gray scale. In a second step 20, a coarse determination of the limbal region of the eye is determined by an edge detection process applied to the video footage to determine an edge map. The edge map represents a determination of the

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location of the limbus portion of the eye and therefore the area of the video footage from which optical flow information is to be determined. The edge map does not need to be precisely determined for the optical flow information to be useful. The process is robust to variation in the limbal edge maps obtained throughout frames in the video footage. The

- 5 edge detection is ideally performed by application of a Prewitt operator with hysteresis thresholding. However, those skilled in the art will recognise other edge detection strategies or operators could be used to determine the limbal region. Connected regions under a certain weight and regions connected to the image border are removed. In a third
- 10 step 30, which may be processed concurrently or before the second step 20, an optical flow estimation process determines pixel velocity information from spatial and temporal changes in pixel intensity. As shown in Figure 1(c), a limbal region should exhibit a velocity spike during a rapid resetting event of an eye (saccade) and smooth or constant velocity changes during other periods when a stimulus is being observed.

- 15 **Figure 2** shows the optical flow process in greater detail. Figure 2(a) shows an image or single frame of a piece of video footage showing an eye. Figure 2(b) shows a number of vectors indicating the magnitude and direction of pixel travel between consecutive frames. Figure 2(c) is a graph of the average velocity of the pixel vectors of Figure 2(b) for a number of consecutive frames.

- 20 In the fourth step 40 of Figure 3, the limbal region information provided by the edge detection process 20 is combined with the pixel velocity information provided by the optical flow process 30 to produce a masked velocity field. The masked velocity field represents velocity information only within the detected limbal region. In a fifth step 50, the velocity
- 25 information from the masked velocity field is averaged to produce a velocity value for a given pair of consecutive frames in the video footage. The process of figure 3 is performed on as many consecutive frames in the video footage as desired such that a graph of velocity is provided as a function of time. The graph can then be analysed to determine OKN information.

- 30 **Figure 10** shows the process of Figure 3 applied to a single frame, frame 0055, in a piece of video footage. Figure 10(a) shows an image of an eye input to the process. Figure 8(b) shows the limbal region identified by the edge detection process. Figure 10(c) shows the optical flow estimation of pixel velocity. Figure 10(d) shows the detected limbal region
- 35 overlaid with the detected velocity information. Figure 10(e) shows the resultant average velocity information of the optical flow velocity information within the detected limbal region.

The optical flow estimation equation is provided below as equation 1.

$$I_t = -\nabla I(x, y, t) \cdot V \tag{1}$$

And in simple 1D form as equation 2.

$$V = \frac{-I_t}{I_x} \tag{2}$$

- 5 Equation 3 shows a sigmoidal 1D edge (representing the limbus) with a rising intensity edge travelling to the right over time.

$$I = \frac{1}{1 + e^{-(x-vt)/\sigma_I}} \tag{3}$$

Confirmation of $V = v$ is provided by the derivatives of equation 3 being substituted into equation 2. Errors in estimating the pixel velocity will arise from noise, digitization, and the

- 10 assumptions of small temporal or spatial displacements used in deriving equation 1. However, the expected response can be observed from equation 2.

Figure 4(a) shows an example input edge similar in size ($\sigma = 5$) to that observed in practice at three consecutive frames indexed by $t = -1, 0, 1$ (in this case, the edge has a

- 15 velocity of $v = 1$ pixels/frame). Also shown is the scaled spatial derivative of intensity I_x (scaled by 5 for illustrative purposes) taken at $t = 0$.

Figure 4(b) shows calculated response curves (over a $[-20; +20]$ pixel interval) for three examples velocities ($v = 1; 3; 5$ pixels/frame respectively) using saccade velocity values

- 20 indicative of what would be encountered in practice. The response curves show the velocity estimate as a function of position. The mean (\bar{V}) and standard deviation $(\sigma_{\bar{V}})$ of the response curve provides descriptors of the response for a given frame t . The response to the $v = 1$ edge is both unitary and indicates accurate velocity estimation $(\bar{V} = 1.0)$
, $(\sigma_{\bar{V}} = 0.0)$.

- 25 Measurable responses to edges are expected at saccadic velocities. The above analysis also suggests more accurate velocity estimations at lower velocities, with increased deviation from true velocity (toward saturation), as true velocity increases. The velocity information obtained is sufficient to detect a saccadic movement and therefore make a determination
- 30 of the presence or absence of OKN.

A modification to the one dimensional description to facilitate detection of saccadic movements in two dimensional video is possible. In some embodiments, the optical flow algorithm is a Lucas-Kanade method. However, those skilled in the art will recognise that

other optical flow measurement methods may also be used where appropriate. An assumption of the Lucas-Kanade optical flow algorithm is that V is constant over a small region (with pixels indexed $i = 1, \dots, n$) centred on the pixel p . The least squares estimate of velocity at p is shown in equation 4.

$$V(p) = (A^T W A)^{-1} A^T W b \quad (4)$$

Where,

$$A = \begin{bmatrix} I_x(1) & I_y(1) \\ I_x(2) & I_y(2) \\ \vdots & \vdots \\ I_x(n) & I_y(n) \end{bmatrix}, V(p) = \begin{bmatrix} V_x(p) \\ V_y(p) \end{bmatrix}, b = \begin{bmatrix} I_t(1) \\ I_t(2) \\ \vdots \\ I_t(n) \end{bmatrix}$$

and W is the diagonal $n \times n$ matrix shown in equation 5.

$$W = \text{diag}(w(1), w(2), \dots, w(n)) \quad (5)$$

W is the weight contribution of pixels within the local region around p as desired. A Gaussian window may be used. The limbal velocity is the mean of all $V(p)$ over the limbus region and as represented by equation 6,

$$\bar{V} = \begin{cases} \frac{\sum_p q(p)V(p)}{\sum_p q(p)} & \text{if } \sum_p q(p) > 0 \\ \text{undefined} & \text{if } \sum_p q(p) = 0 \end{cases} \quad (6)$$

where p varies over pixels in an image containing the eye. In some embodiments, the following weighting factor $q(p)$ is used as shown in equation 7,

$$q(p) = \begin{cases} 1 & \text{if } p \in \Omega \\ 0 & \text{if } p \notin \Omega \end{cases} \quad (7)$$

where Ω are the set of pixel indices within the image classified as limbus.

A video-oculography technique for determining eye velocity information has been described. The technique is substantially robust against the error induced by head movements seen in normal adult fixations, eye blinks, reflections and other error inducing factors. Further, the technique may be combined with head stabilisation for use with young

children or subjects who would not tolerate head mounted equipment. The technique is therefore a video-oculography technique readily applicable to infants or young children who would otherwise be unable to be assessed. The technique may be implemented with standard 'off the shelf' video equipment thereby avoiding the need for expensive

- 5 supporting hardware. The velocity information graph resulting from the above described technique can be analysed directly by a trained clinical professional and/or further processed by an OKN detection process that will now be described.

OKN strength can be determined by the following. Peaks not indicative of OKN are

- 10 rejected, for example, by comparing them to a threshold and discarding those peaks below the threshold. An average of the heights of the surviving peaks is determined and scaled by an appropriate normalization value^{1/σ_v}. A low value will result if peaks are weak or equally distributed between positive and negative. Conversely, if peaks are consistently positive or negative, the measure will scale with the average height, and the sign will
- 15 correlate with the direction of the reset event. **Figure 9** shows a graph of peaks in the velocity information.

A more detailed explanation of the process step for detection of OKN from the obtained velocity information according to various embodiments is provided below:

- 20
 1. Detect all maxima and minima within the given interval of $V_x(t)$ signal and label them $Q(j)$, where $j = 1 \dots M$. A maxima (or minima) is defined as a point with neighbouring points less (or more) than a test point by an absolute threshold of σ_{peak} pixels per frame.
 2. Compare a threshold to these peaks and eliminate all peaks $|Q(j)| < \sigma_{\bar{v}}$ smaller
 - 25 than an empirically determined velocity threshold. Reset M to the number of remaining peaks.
 3. Reject minima (or maxima) that are above (or below) the axis if they do not indicate a reversal in the direction of the eye. A valid velocity peak should in principle, cross the axis defined by zero velocity: the slow-phase and quick-phase
 - 30 occurs in opposite directions (and hence are of opposite sign). This rule also assists with identifying "jagged edges" or noise that may occur on the face of a valid velocity peak. Again, reset M to the number of remaining peaks.
 4. Reject peaks that are less than a given number of frames apart (σ_t). A saccadic movement should follow a period of smooth pursuit. A very short latency period is
 - 35 unusual for OKN. In some embodiments, a threshold of 4 frames corresponding to 133 to 160 ms (for camera frame rates of 30 Hz and 25 Hz) is used. In some embodiments the expected slow phase interval for a stimulus moving at 10 deg/s is

estimated to be greater than 250 ms. Again, reset M to the number of remaining peaks.

- 5. In some embodiments a solitary maxima or minima or minima is rejected (i.e., those with no other peaks of the same sign in the data). An isolated peak is often not enough evidence to support a determination of OKN. Again, reset M to the number of remaining peaks.
- 6. Determine the normalised average peak velocity \bar{K} . If there are remaining peaks then take \bar{K} as the mean of the velocities after normalisation by the velocity threshold σ_V . In some embodiments the threshold is set to 0.5 pixels per frame. If there are no remaining peaks, set the \bar{K} value to zero, as shown by equation 8:

$$\bar{K} = \begin{cases} 1/(M\sigma_V) \sum_{j=1}^M Q(j) & M > 0 \\ 0 & M = 0 \end{cases} \quad (8)$$

The sign of \bar{K} determines the direction of the OKN reset event. For positive \bar{K} the reset event will be rightward, whilst for negative \bar{K} it will be leftward. The magnitude will indicate the consistency of OKN within the data. An absolute value of \bar{K} less than 1 indicates the absence of consistent saccadic movements indicative of OKN. A value of \bar{K} of greater than or equal to 1 indicates the presence of consistent saccadic movements, and hence OKN.

- The following description of experimental work further illustrates the invention.

Experimental data part 1

To test the performance of the detection process, video footage of healthy eyes was recorded for six participants of average age twenty five. Footage obtained was prepared for further processing by manually cropping the video around each eye. The video recording was cut to a temporal length corresponding to the temporal length of the stimulus. In this case, the stimulus was eight seconds. A total of one hundred and fifteen in-focus trials were obtained from participants where seventy there were obtained for a full coherence stimulus and forty two for a low coherence stimulus. The stimulus coherence was expected to alter the OKN response of the eye.

The velocity estimator and OKN detector were applied to each resulting video record. The sign of the resulting OKN strength measure was used as an indicator of OKN direction. The optical flow algorithm used was a version written by Dollar (2012) named the Lucas-Kanade optical flow solver.

▪ 5

The first seventeen trials were recorded using a pure stimulus pattern with 100% coherence. These trials were used to calibrate the parameters for later use. Trial accuracy was 100% for our calibration set of seventeen trials (9 correct left detections, 8 correct right detections) after appropriate adjustment of all algorithm parameters.

▪ 10

Figure 6 shows a sequence of video frames obtained from the calibration trials that illustrate aspects of the detection process. The estimated limbal region is overlaid over greyscale images of the eye. Frame 10 shows a resting eye, whilst frames 54-56 show the occurrence of an OKN reset event. Frame 26 demonstrates the loss of the limbus edge during an eye blink. These observations are further confirmed by inspection of the horizontal and vertical velocity traces for this sequence as shown in **Figures 7(a) and 7(b)**. The frame numbers that appear in the bottom left corner of the stills in **Figure 6**, correspond directly to the horizontal axis of **Figures 7(a) and 7(b)**. The peaks accepted as OKN data are shown boxed.

▪ 20

An empirically set velocity threshold of 0.5 pixels per frame is also shown as a dotted line. The performance of the detector over all 115 trials was 93% with 52 correct left detections, 53 correct right detections and 10 errors. The performance of the detector for the full coherence group was 96% with 38 correct left detections, 32 correct right detections and 3 errors. The performance of the low coherence group was 88% with 14 correct left detections, 21 correct right detections and 7 errors.

▪ 25

The actual distribution of OKN consistency values \bar{K} is summarized by **Figure 8**. The histogram illustrates the distribution of \bar{K} across the two groups which indicate the distributions of correct and incorrect distributions. It is probable that incorrect detections are correlated with low OKN values. There are two likely possibilities for this observation. That the OKN spikes occur infrequently and with low magnitude, and/or the OKN spikes are distributed about zero velocity resulting in a low average.

▪ 30

▪ 35

The three incorrect detections are shown in Figure 7(c), (d) and (e), whilst the final panel, (f), shows a correct detection with a marginal OKN assessment (i.e., close to the mean of the incorrect cases). Bi-directional peaks appear to cancel each other out resulting in a low OKN consistency measure. To confirm this observation, the videos for these cases

- 20 -

were reviewed by an expert observer and it was deemed that the recordings indeed contained sequences of OKN in which direction changed. The peaks were therefore not attributable to spurious errors inherent to the method.

▪ 5 **Experimental data part 2**

The aims this experiment were to assess whether the OKN detection algorithm could correctly classify OKN eye movements as going left or right and to compare the performance of the OKN detector to that of an experienced human observer (TY). For this experiment we used a random dot kinematogram (RDK) with variable motion coherence to elicit OKN. This stimulus was chosen as the perception of global motion within such stimuli is thought to rely on dorsal areas of the extrastriate visual cortex that may be particularly vulnerable to abnormal development. An RDK can elicit reliable slow and fast-phase optokinetic eye movements to measure motion coherence thresholds in young children who cannot yet provide behavioural responses to psychophysical tasks.

▪ 15

The RDK consisted of 250 moving white dots (0.5 deg diameter, 8 deg/sec speed), presented at 100% contrast on a 16" CRT display. The dots were presented in 8.3° circular window for 8 sec and had a limited lifetime whereby each dot had a 25% chance of dying on any given frame and being replotted in a new, random location within the stimulus.

▪ 20

Dots that reached the edge of the stimulus aperture were wrapped around. The coherence level of the stimulus, i.e., the proportion of dots moving in the same direction versus the total population of dots could be adjusted to vary the strength of coherent motion present in the stimulus. We tested full coherence (i.e., 100% of the dots moved in the same direction) and low coherence (between 12-15% of all dots moved in concert, whilst the

▪ 25

rest moved randomly). The direction of coherent motion was randomized across trials. The low coherence level was chosen to be suprathreshold for our observers (i.e. the global motion direction was still clearly visible) while still allowing us to test the algorithm on eye movements elicited by degraded motion signals. The 1600 CRT display was viewed from 50cm. Video footage was collected using a SONY digital high definition camera (HDR-CX7EK, Sony Corporation, Tokyo, Japan), that delivered video consisting of RGB images (1920x1080 pixels) at 25 frames per second. The camera was placed to the side of the CRT, and centred on the closest eye.

▪ 35

Six participants with a mean age of 25 years and normal vision viewed the RDK stimuli binocularly with their head restrained by a chin rest. A fixation point was presented in the centre of the CRT screen before and after each RDK presentation trial. Participants were instructed to fixate on the point in between trials and stare at the centre of the screen during trials. The fixation point was not presented during a trial. Footage obtained from the

trials was prepared for further processing by manually cropping the video around each eye within every trial. The video for each trial was cropped temporally to include only frames recorded when the participant was viewing the motion stimulus. A total of 115 trials (of 8 sec length) were obtained from the participants (73 at full coherence and 42 at low coherence). The participants were able to perceive the direction of the signal dots in each trial as indicated by behavioural responses provided during testing.

5

The velocity estimator and OKN detector were applied offline to each resulting video record. The detector estimated \bar{K} . The absolute value of \bar{K} was thresholded to indicate the presence ($\bar{K} \geq 1$) or absence ($\bar{K} \leq 1$) of OKN. The sign of the measure indicated the direction. The first 17 trials were recorded using the 100% coherence stimuli and were used to calibrate the parameters for the method. Software was written using MATLAB, and we used an implementation of the Lucas-Kanade optical flow solver. The video footage was also viewed by an experienced human observer (TY) who made a 2-alternative forced choice decision as to whether the OKN response was consistent with a left or right moving RDK. The observer was not aware of the results generated by the detection algorithm when viewing the videos. We achieved 100% accuracy for our calibration set of 17 trials (9 correct left detections, 8 correct right detections), after appropriate adjustment of all algorithm parameters.

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The performance of the detector over all 115 trials was 93%, (54 correct left detections, 53 correct right detections, 8 errors) compared to 98% (53 correct left detections, 60 correct right detections, 2 errors) for the human observer. The performance of the detector for the full coherence trials was 96% (38 correct left detections, 32 correct right detections, 3 errors) compared to 100% (38 correct left detections, 35 correct right 14 detections) for the human observer.

25

For the low coherence trials the detector performed at 88% correct (16 correct left detections, 21 correct right detections, 5 errors) compared to 95% correct for the human observer (15 correct left detections, 25 correct right detections, 2 errors), also a non-significant difference (Chi-Square = 1.40, $p = 0.24$). For the full coherence trials 3/3 (100%) incorrectly classified trials had K values less than 1 compared to 18/70 (26%) for the correctly classified trials (Chi-Square = 7.7, $p < 0.005$). Similarly for the low coherence trials 5/5 (100%) incorrectly classified trials had K values less than 1 compared to 17/37 (46%) for the correctly identified trials (Chi-Square = 5.0, $p = 0.02$). An inspection of the velocity traces for the incorrectly classified trials indicated that low values were due to velocity peaks being relatively equally distributed around zero. These bi-directional peaks appeared to cancel each other out resulting in a low OKN consistency measure.

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35

To confirm this observation, the video footage of the 8 trials incorrectly classified by the detector was reviewed for a second time by an experienced human observer (TY). It was confirmed that bi-directional velocity spikes resulted from actual eye movements visible within the video footage and was not caused by spurious errors of the method. It was also found that the recordings indeed contained sequences of OKN in which direction changed.

Experimental data part 3

This experiment had three aims: to assess whether the OKN consistency measure was affected by stimulus velocity, to assess whether the OKN detector would correctly reject trials during which participants passively viewed a stationary stimulus, and to assess whether the detection technique could be applied to footage obtained using a standard webcam. A high contrast square-wave grating stimulus was used for experiment as this type of stimulus is used routinely to induce OKN in clinical studies.

An IBM P275 cathode ray screen (2000 screen, a resolution of 1600x1200 and 60Hz refresh rate) screen was viewed from 1.9 m on which were presented a 100% contrast square wave grating with a fundamental spatial frequency of 3.8 cycles/deg (equivalent to 0.9 LogMAR). Three presentation velocities (0 deg/s, 5 deg/s and 10 deg/s) were used, and the grating always moved right to left. Video footage of the OKN eye responses was obtained using an HD Pro 920 Logitech webcam (set at a 30 Hz frame-rate) positioned 10 cm from the participants eye. The stimuli were presented whilst simultaneously recording the video feed from the webcam.

A group of five observers with mean age = 23 and normal vision viewed the stimuli patterns binocularly and were instructed to stare at the centre of the drifting stimulus pattern during the stimulus presentation period. Observer's heads were restrained using a chin rest. Each observer completed one trial of each stimulus velocity (0, 5 and 10 deg/s). Eye movements were recorded for a minimum of 8 seconds and the recordings were processed using the optic flow methods described above.

The limbus detection parameters were modified to account for the larger image of the eye that resulted from positioning the camera closer to the eye. In experiment 1, groupings of pixels with a weight below 20 were discarded. In this experiment, the threshold was increased to 300 pixels to account for the increased size of the recorded limbus. It is also noted that an additional heuristic rule was introduced in this experiment. If two subsequent peaks were detected (in the same direction), but the time interval between subsequent saccadic peaks was greater than a 4 second threshold, then it was assumed that the interval between the peaks was not consistent with being due to the slow phase of

OKN. In the absence of additional neighbouring peaks (of the same sign) these two peaks would be discarded.

For the stationary stimuli, velocity traces either did not pass through the algorithm to allow

- 5 estimation of \bar{K} (3/5 traces) or \bar{K} did not exceed threshold (2/5 traces, $|\bar{K}| \leq 0.6$ pixels/frame). The direction of all moving stimuli was classified correctly by the detector and the $|\bar{K}|$ values for the 5 deg/s trials did not differ significantly from those for the 10 deg/s trials (5 deg/s mean $|\bar{K}| = 2.38$, SD = 0.15; 10 deg/s mean $|\bar{K}| = 2.85$, SD = 0.62; $t = 1.45$, $p = 0.22$).

- 10 The OKN detector was sensitive to the presence or absence of OKN when provided with web-cam footage of participants viewing square wave grating stimuli. In the case where valid OKN was detected, the $|\bar{K}|$ values produced by the OKN detector did not change when the stimulus velocity was doubled suggesting that this measure for detecting OKN is
- 15 relatively robust to stimulus velocity.

Testing therefore indicates that the embodiments herein described can detect OKN elicited by RDKs and square wave gratings and has an accuracy that is comparable to that of an experienced human observer. Objectively evaluation of visual function in young children is

- 20 therefore possible by using involuntary, reflexive eye movement of OKN. In particular, children of 2 or approximately 2 years old have been found to especially benefit from the information the invention can provide.

The above described embodiments have use in the fields of advertising and security. For example, the direction of a person's gaze may be tracked to determine information

- 25 relevant to consumer interest or behaviours.

Head tracking

- 30 As previously discussed, children do not tolerate chinrests or head mounted eye-tracking equipment. Further, head movements within video footage with the above described OKN detection process can inadvertently be interpreted as eye movement and detrimentally affect the accuracy of eye movement measurements. However, such equipment has previously been thought to be the only method of retrieving stable video footage of eye
- 35 movement from persons unable to remain still.

Further embodiments of the invention relate to the determination of head movement within video footage, and optionally compensating for that determined head movement. Accurate determination of head movement allows chinrests or head mounted equipment to be disregarded and the above described OKN detection process to be optimised.

▪ 5

In some applications, head movement information is quantified and used in conjunction with the above-described OKN analysis system to mitigate errors introduced by excessive head movement that are inadvertently determined to be eye movement. In other applications, head movement information is used independently from the above described OKN analysis system.

▪ 10

According to a particular embodiment, head movement information is obtained from video footage by a process, ideally undertaken by a computational system that comprises:

▪ 15

- detecting at least part of the same facial region in at least two frames of the video footage,
- determining a measure of the movement of the at least part of the same facial region between the at least two frames, and
- determining transformation information corresponding to the determined measure of the movement.

▪ 20

Robust facial features comprise areas of distinctive colour or shading contrast that are easily identified by a camera. Lighting adjustments are optionally applied to the subject and/or the video footage is processed to improve distinction of facial features. In some embodiments one or more robust facial features within a facial region are determined so that their movement can be tracked.

▪ 25

The facial features are identified in at least two frames of video footage and tracked by determining movement information relating to those facial features between the at least two frames. The movement information is quantified by a metric such as the number of pixels in the frame. The movement information relates to planar movement and may optionally further relate to rotation or scale movement.

▪ 30

The transformation information relates to movement of the head within the video frame. The transformation information is used to stabilise the head movement within the frame by moving or cropping the frame to compensate for the movement of the head.

▪ 35

In some embodiments, the movement information is used to produce a transformation map that contains data relating to one or more of rotation, scale and translation movement

of the facial features, and therefore the head, within the video footage. A similarity transformation map determined for each frame of the video footage, with respect to a first or prior frame, provides rotation, scale and translation movement information for the head image within that frame.

▪ 5

In some embodiments, video footage is processed by a computer or control device (controller) capable of undertaking computational instructions. The controller calculates and applies an inverse of the transformation map to offset each frame in the video footage to generate a new frame position. The outcome is that the head portion of the footage

▪ 10

within the frame remains relatively still and is therefore stabilised to one location whilst the frame moves by the transformed amount. In some embodiments, the controller calculates and applies an inverse of the transformation map to is actively crop and centre each frame about the region of interest, such as the facial region or eye region, to produce new video footage with that portion centred and stabilised within each frame.

▪ 15

The stabilised head position is useful for improving the performance of, for example, the above mentioned OKN detection process as head movement no longer substantially affects eye movement data obtained from the processed footage. In some embodiments the portion of the frame containing the eyes is cropped such that stabilised footage of the eyes

▪ 20

is obtained for further OKN analysis, such as use with the above described automated OKN detection method. The information gathered by this process is similar to or the same as the information gathered when a person has had their head fixed in place by a chin rest or if head mounted equipment was to be used. Yet this process does not require the burden of such equipment.

▪ 25

In some embodiments a non-reflective similarity transformation map is created using the POSIT algorithm which estimates translation and rotation information of a 3D object from a 2D video frame. At least four 3D model points (world-space coordinates) and corresponding 2D image points, focal length and principal point of camera are needed for

▪ 30

accurate estimation. The 3D model point coordinates, for example, the marker corners, are fixed and the corresponding 2D image points identified. The camera properties are estimated using equations (9) - (11) as shown below.

$$f_x = f_y = \frac{\frac{w}{2}}{\tan\left(\frac{120}{2} \times \frac{\pi}{180}\right)} \tag{9}$$

▪ 35

$$c_x = \frac{w}{2} \tag{10}$$

- 26 -

$$c_y = \frac{h}{2} \quad (11)$$

In these equations the terms f_x and f_y are the focal lengths in x and y directions respectively (assumed to be equal) and are expressed in pixel units. The image dimensions are given by (w, h) , the principal point of the camera by (c_x, c_y) . Rodrigues' rotation formula is used to retrieve rotations for X, Y, Z directions respectively. A POSIT error assessment is performed by reprojecting 3D model points to the 2D image plane by the transformation presented in equation (12).

$$s \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & T_x \\ r_{21} & r_{22} & r_{23} & T_y \\ r_{31} & r_{32} & r_{33} & T_z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad (12)$$

In equation (12), s is the pixel size, x and y are 2D image points, X , Y and Z are 3D model coordinates, r_{ij} are rotation parameters and T_x , T_y and T_z are translations.

In one exemplary embodiment, a face region is detected from within a video frame of video footage using the Viola-Jones algorithm provided by the Computer Vision ToolBox MATLAB (MathWorks, Natick, VA), as well as the PittPatt SDK version 5.2.2 (acquired by Google). Robust facial features within the frame are identified using the Harris corner detection algorithm. The robust facial features are tracked between consecutive frames using the Kanade Lucas Tomasi (KLT) point tracker also available in MATLAB. In some embodiments a non reflective similarity transformation is generated from the variation in the tracked points between subsequent frames using a POSIT algorithm. The inverse similarity transformation is then applied as an offset to each frame to compensate for changes in the position of facial features between subsequent frames. The facial features are thereby computationally held in the initial position. The region around each eye is able to be cropped in each frame to isolate the eye movement from head movement.

Figure 13 outlines a manual process to compare the accuracy of the automated exemplary process. Figure 13(d) shows visual markers manually placed on a subjects' face prior to the video footage being recorded. The visual markers provide a clear point from which movement can be measured in the recorded footage. For each frame in the recorded footage, five corner points of each marker were selected manually using the MATLAB ginput command. The order in which the features were selected was consistent across frames to maintain correspondence of features from frame to frame. A Kalman filter was used to smooth the feature tracking because manual point selection introduces noise. Four

references points were inserted into each recording and tracked across each video frames. Superimposing these points allowed differences between manual and automated stabilisation to be calculated. Coordinates of these points were compared between frames manually stabilised and frames automatically stabilised.

▪ 5

Figure 13(a) shows Harris corners located in the automatically detected face region. Figure 13(b) shows a stabilised video with the eye region "locked" to the centre of each frame. Figure 13(c) shows the region around the eyes was cropped. Figure 13(d) shows markers with manually selected centre points. Figure 13(e) shows 3D pose estimation was

▪ 10

determined by a POSIT algorithm where units are in centimetres. Figure 13(f) shows re-projection of the manually selected marker points showing estimated head pose. **Figure 14** illustrates the head trajectory estimation for a length of video footage in 3D space.

▪ 15 **Figure 12** has '+' symbols showing the trajectory of determined facial features within an example length of video footage. The '*' symbols show the effectively stabilised result after the inverse transformation map has been applied to each frame.

▪ 20 In Figure 12, the faces are localised to a coordinate of $(523.8037, 253.3558) \pm (18.6676, 8.9088)$ pixels prior to stabilisation, and $(500.4114, 260.0309) \pm (1.8828, 1.4282)$ after stabilisation. The resulting stabilised footage exhibits a tight grouping of the facial feature locations which in turn illustrates substantial stabilisation of head portion compared to the original footage. The stabilised footage is then able to be consistently cropped to a desired region.

▪ 25 The average mean squared error between automatic and manual stabilization was 7.7494 pixels. Percentage error of 3D pose estimation was 0.2428 %. This data indicates that a more labour intensive manual tracking approach involving markers, although robust, is no longer necessary to achieve stabilised video footage that is useful for many purposes, and in particular is useful for use with the above described OKN detection process.

▪ 30

In some embodiments the head trajectory information is used to improve the eye velocity information. In some embodiments the head trajectory information is offset against the eye tracking information to substantially remove eye velocity information caused by head movement. For example, data relating to the velocity of head movement can be offset

▪ 35 against data relating to eye movement so error caused by non zero head velocity is substantially reduced or removed from the eye velocity information.

- 28 -

Where in the foregoing description reference has been made to elements or integers having known equivalents, then such equivalents are included as if they were individually set forth. Although the invention has been described by way of example and with reference to particular embodiments, it is to be understood that modifications and/or improvements

- 5 may be made without departing from the scope of the invention as set out in the claims.

CLAIMS

1. A method of extracting eye velocity information from a video footage having a plurality of frames, comprising:
 - 5 detecting at least part of an eye in at least two frames of the video footage, applying an optical flow algorithm to the at least two frames of the video footage to extract pixel velocity information, and determining a statistical measure from the pixel velocity information within the detected at least part of the eye.
 - 10
2. An eye tracking system comprising:
 - a camera arranged to capture footage of an eye, a controller configured to receive the footage of the eye and perform the steps of:
 - 15 detecting at least part of an eye in at least two frames of the footage, applying an optical flow algorithm to the footage to thereby determine pixel velocity information between at least two frames of the footage, and determining a statistical measure from the pixel velocity information within the detected at least part of the eye.
- 20 3. A controller device programmed to perform the steps of:
 - detecting at least part of an eye in at least two frames of the footage, applying an optical flow algorithm to the footage to thereby determine pixel velocity information between at least two frames of the footage, and determining a statistical measure of the pixel velocity information within the
 - 25 detected at least part of the eye.
4. The method, system or device as claimed in any one of claims 1 to 3, further comprising one or more of the steps of (in any order):
 - 30 determining the velocity magnitude and direction of at least part of an eye from the velocity information, determining any velocity maxima and minima from the velocity information, comparing any maxima or minima to a lower velocity threshold and discarding any maxima or minima below the threshold, comparing any maxima or minima to an upper velocity threshold and
 - 35 discarding any maxima or minima above the threshold, comparing the inter-frame distance between adjacent maxima or minima to a frame threshold and discarding any maxima or minima below the frame threshold, determining any sole maxima or sole minima in the velocity information and discarding sole maxima or sole minima,

- 30 -

averaging the maxima or minima velocity magnitudes, and/or
normalising the maxima or minima velocity magnitudes.

- 5. The method, system or device as claimed in any one of claims 1 to 4, wherein the statistical measure of the pixel velocity information is an average pixel velocity.
- 6. The method, system or device as claimed in any one of claims 1 to 5, wherein the at least part of the eye is a region of contrast discontinuity of the eye.
- 7. The method, system or device as claimed in any one of claims 1 to 6, wherein the at least part of the eye is a limbus portion of the eye.
- 8. The method, system or device as claimed in any one of claims 1 to 7, further comprising generating a list of pixel velocity averages for each consecutive frame in the video footage.
- 9. The method, system or device as claimed in any one of claims 1 to 8, further comprising comparing the determined velocity information to healthy velocity information to make a determination of the health of the eye and/or visual pathway.
- 10. The method, system or device as claimed in any one of claims 1 to 9, further comprising comparing the determined velocity information to healthy velocity information to make a determination of the presence and/or strength of OKN.
- 11. The method, system or device as claimed in any one of claims 1 to 10, wherein the limbus portion of the eye is determined by an edge detection algorithm.
- 12. The method, system or device as claimed in claim 11, wherein edge detection is performed by application of a Prewitt operator.
- 13. The method, system or device as claimed in any one of claims 1 to 12, wherein the optical flow algorithm is a Lucas-Kanade optical flow algorithm.
- 14. The method, system or device as claimed in any one of claims 1 to 13, wherein the optical flow algorithm is applied to determine pixel velocity information between consecutive frames of a length of video footage corresponding to several reset events.

15. The method, system or device as claimed in any one of claims 1 to 14, further comprising a visual stimulus arranged in front of the eye, the stimulus operable to elicit optokinetic nystagmus.
- 5 16. The method, system or device as claimed in claim 15, further comprising comparing the average velocity information to known optokinetic nystagmus velocity information to make a determination of the health of an eye in response to the stimulus.
 - 10 17. The method, system or device as claimed in one of claims 1 to 16, wherein the video footage is obtained from a subject watching a stimulus.
 - 18. The method, system or device as claimed in claim 17, wherein the stimulus is a screen.
 - 15 19. The method, system or device as claimed in claim 18, wherein the camera and screen are contained within an enclosure.
 - 20. The method, system or device as claimed in claim 18, wherein the camera, screen and controller are integrated within an enclosure.
 - 20 21. The method, system or device as claimed in claim 19 or 20, wherein the enclosure is any one or more of a smart phone, tablet or portable computation device.
 - 22. The method, system or device as claimed in any one of claims 1 to 21, wherein detecting at least part of an eye does not include detection of a feature of the eye.
 - 25 23. A method of improving the attention of a subject for eye tracking comprising:
 - operating at least one display to show a video of an video functional to gain the attention of a viewer,
 - operating at least one display to show an OKN stimulus video, and
 - 30 recording an eye watching the OKN stimulus video with a camera.
 - 24. The method of claim 23, wherein the video functional to gain the attention of a viewer is an animated video.
 - 35 25. The method of claim 23 or claim 24, wherein the method further comprises the method of extracting eye velocity information from the recording of the eye according to claim 1.
 - 40 26. The method, system or device as claimed in any one of claims 1 to 25, wherein the statistical measure is applied to determine information relating to one or more of a

person's behaviour, a person's response to advertising, security purposes, or consumer attention.

- 27. The method, system or device as claimed in any one of claims 1 to 26, further comprising extracting head image trajectory information from the video footage by a method comprising:
 - 5 detecting at least part of a facial region of the head in at least two frames of the video footage,
 - 10 determining a measure of the movement of the at least part of a facial region between the at least two frames, and
 - determining a transformation map from the measure of the movement.
- 28. The method, system or device as claimed in claim 27, further comprising:
 - 15 determining the inverse of the transformation map,
 - applying inverse of the transformation to each frame in the video footage such the facial region within the frame is held substantially constant.
- 29. The method, system or device as claimed in any one of claims 27 or 28, further comprising detecting the facial region from within a frame of the video footage using the Viola-Jones algorithm.
 - 20
- 30. The method, system or device as claimed in any one of claims 27 to 29, further comprising identifying one or more particular portions of the facial region within the frame using a Harris corner detection algorithm.
 - 25
- 31. The method, system or device as claimed in any one of claims 27 to 30, further comprising determining the measure of the movement of the facial region or one or more particular portions of a facial region between consecutive video frames using a Kanade Lucas Tomasi (KLT) point tracker.
 - 30
- 32. The method, system or device as claimed in any one of claims 27 to 31, wherein the measure of the movement comprises one or more of rotation, scale and/or translation movement.
- 33. The method, system or device as claimed in any one of claims 27 to 32, wherein a similarity transformation map is created from the movement information.
 - 35

34. The method, system or device as claimed in claim 33, further comprising applying the similarity transformation map to offset each frame in the video footage such that the facial region within the frame is held substantially constant with respect to each frame.

- 5 35. The method, system or device as claimed in any one of claims 27 to 34, further comprising applying an inverse similarity transformation to crop each frame in the video footage to generate a new frame such that the facial region within the frame is held substantially constant with respect to each frame.

- 10 36. The method, system or device as claimed in any one of claims 27 to 35, wherein the head trajectory information is used to improve the eye velocity information.

37. The method, system or device as claimed in any one of claims 27 to 35, wherein head trajectory information is offset against the eye tracking information to substantially

- 15 remove eye velocity information caused by head movement.

38. A method of processing video footage having a plurality of frames to determine the presence of OKN, the method comprising:

extracting head trajectory information by a method comprising:

- 20 detecting at least part of a facial region of the head image in at least two frames of the video footage,
determining a measure of the movement of the at least part of a facial region between the at least two frames, and
determining a transformation map from the measure of the movement, and
- 25 extracting eye velocity information by a method comprising:
detecting at least part of an eye in at least two frames of the video footage,
applying an optical flow algorithm to the at least two frames of the video footage to extract pixel velocity information, and
determining a statistical measure from the pixel velocity information within
- 30 the detected at least part of the eye.

39. A method as claimed in claim 38 wherein the head trajectory information is offset against the eye tracking information to substantially remove eye velocity information caused by head movement.

- 35

40. A method of extracting head image trajectory information from a video footage having a plurality of frames, comprising:

detecting at least part of a facial region of the head image in at least two frames of the video footage,

- 34 -

determining a measure of the movement of the at least part of a facial region between the at least two frames, and
determining a transformation map from the measure of the movement.

- 5 41. A head tracking system for extracting head image trajectory information comprising:
 - a camera arranged to capture footage of a head and a controller configured to receive the footage of the head and perform the steps of:
 - detecting at least part of a facial region of the head in at least two frames of the video footage,
 - 10 determining a measure of the movement of the at least part of a facial region between the at least two frames, and
 - 15 determining a transformation map from the measure of the movement.
- 20 42. A controller device configured to perform the steps of:
 - 15 detecting at least part of a facial region of the head in at least two frames of the video footage,
 - determining a measure of the movement of the at least part of a facial region between the at least two frames, and
 - 20 determining a transformation map from the measure of the movement.
- 25 43. The method, system or device as claimed in any one of claims 40 to 42, wherein the method or steps further comprise:
 - determining the inverse of the transformation map,
 - applying inverse of the transformation to each frame in the video footage such the
 - 25 facial region within the frame is held substantially constant.
- 30 44. The method, system or device as claimed in any one of claims 40 to 43, further comprising detecting the facial region from within a frame of the video footage using the Viola-Jones algorithm.
- 35 45. The method, system or device as claimed in any one of claims 40 to 44, further comprising identifying one or more particular portions of the facial region within the frame using a Harris corner detection algorithm.
- 40 46. The method, system or device as claimed in any one of claims 40 to 45, further comprising determining the measure of the movement of the facial region or one or more particular portions of a facial region between consecutive video frames using a Kanade Lucas Tomasi (KLT) point tracker.

47. The method, system or device as claimed in any one of claims 40 to 46, wherein the measure of the movement comprises one or more of rotation, scale and/or translation movement.

▪ 5

48. The method, system or device as claimed in any one of claims 40 to 47, wherein a similarity transformation map is created from the movement information.

▪ 10

49. The method, system or device as claimed in claim 49, further comprising applying the similarity transformation map to offset each frame in the video footage such that the facial region within the frame is held substantially constant with respect to each frame.

▪ 15

50. The method, system or device as claimed in any one of claims 40 to 49, further comprising applying an inverse similarity transformation to crop each frame in the video footage to generate a new frame such that the facial region within the frame is held substantially constant with respect to each frame.

51. The method, system or device as claimed in any one of claims 1 to 35 in combination with the method, system or device of any one of claims 40 to 50.

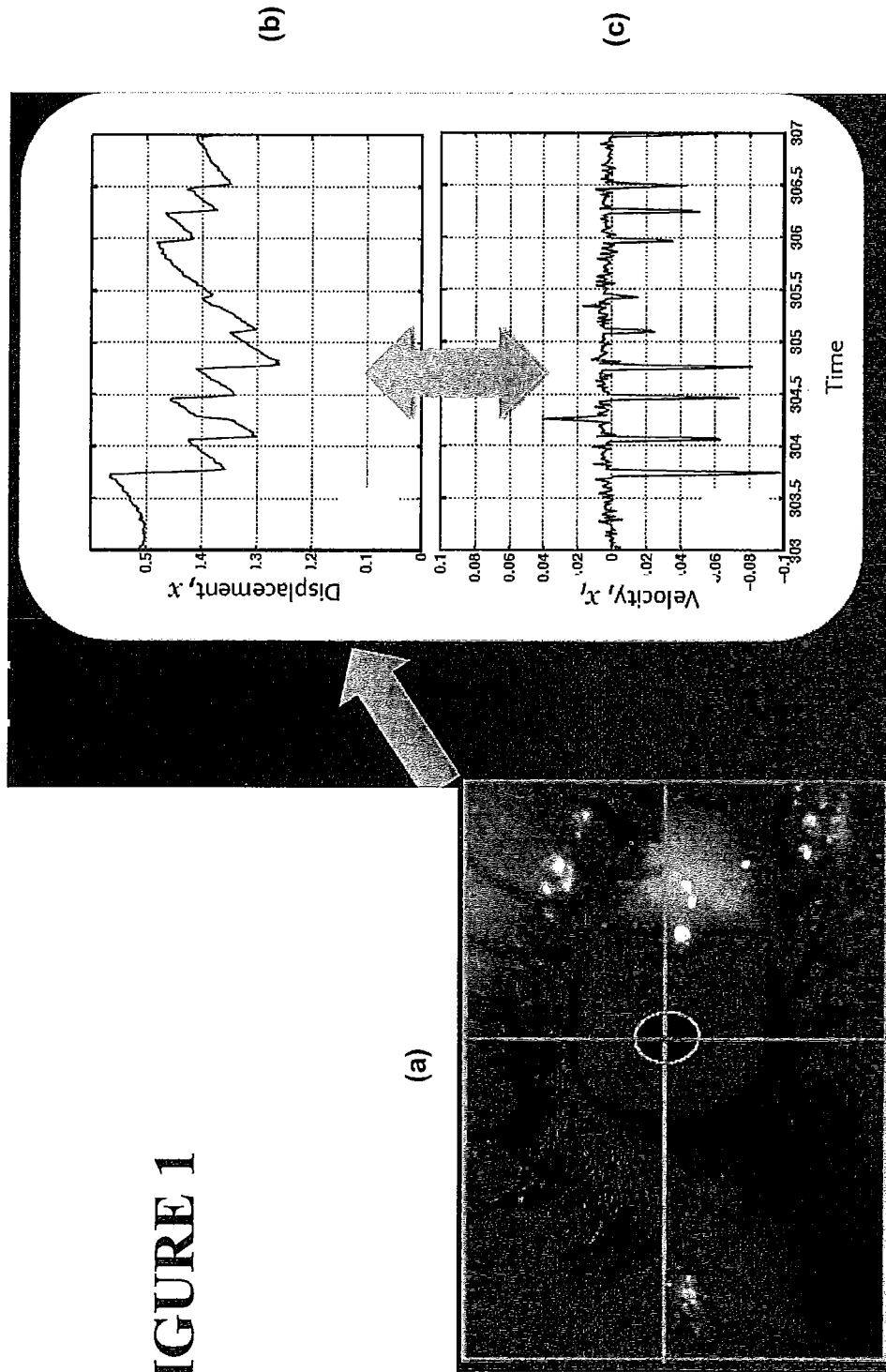


FIGURE 1

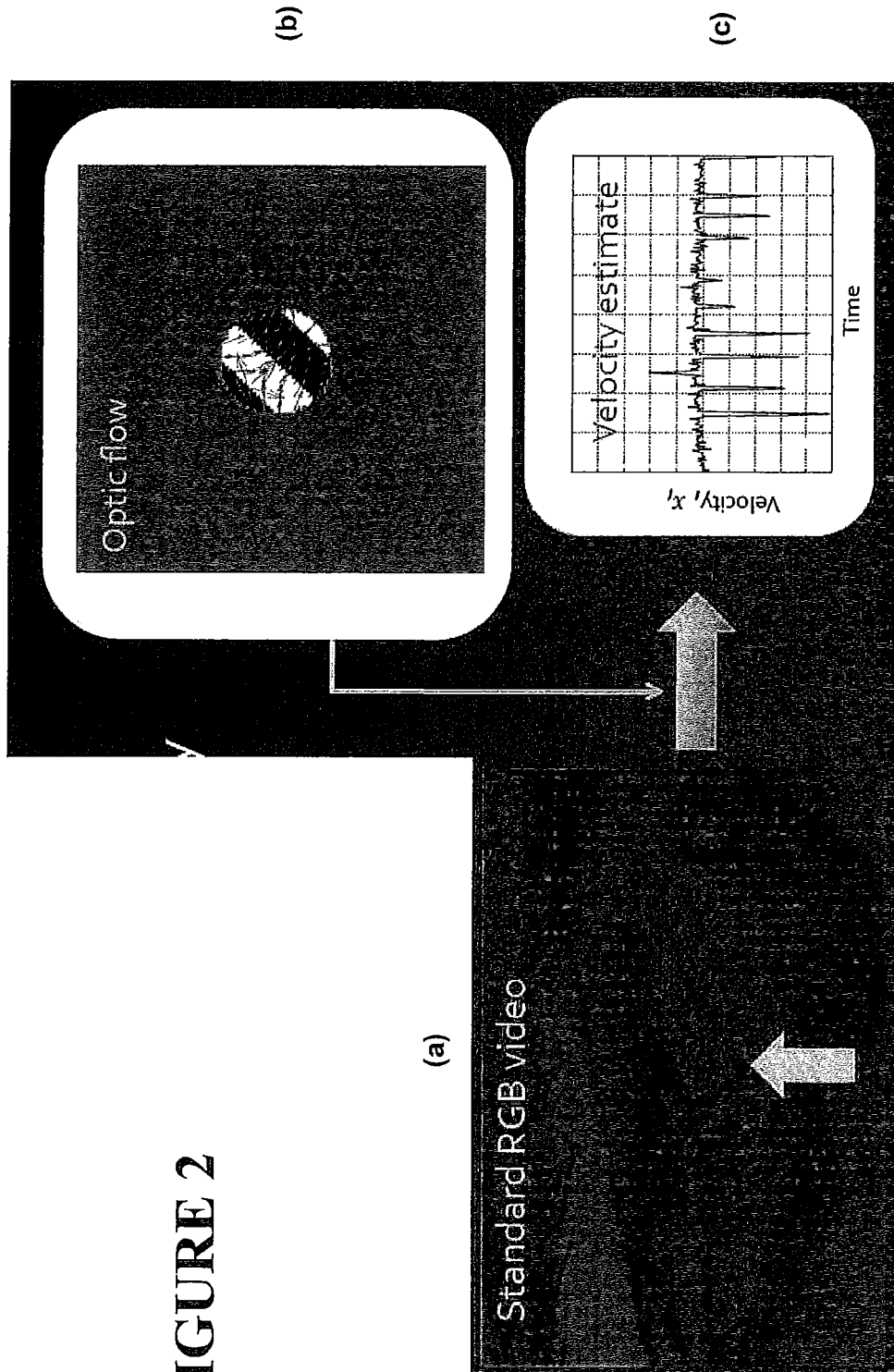


FIGURE 2

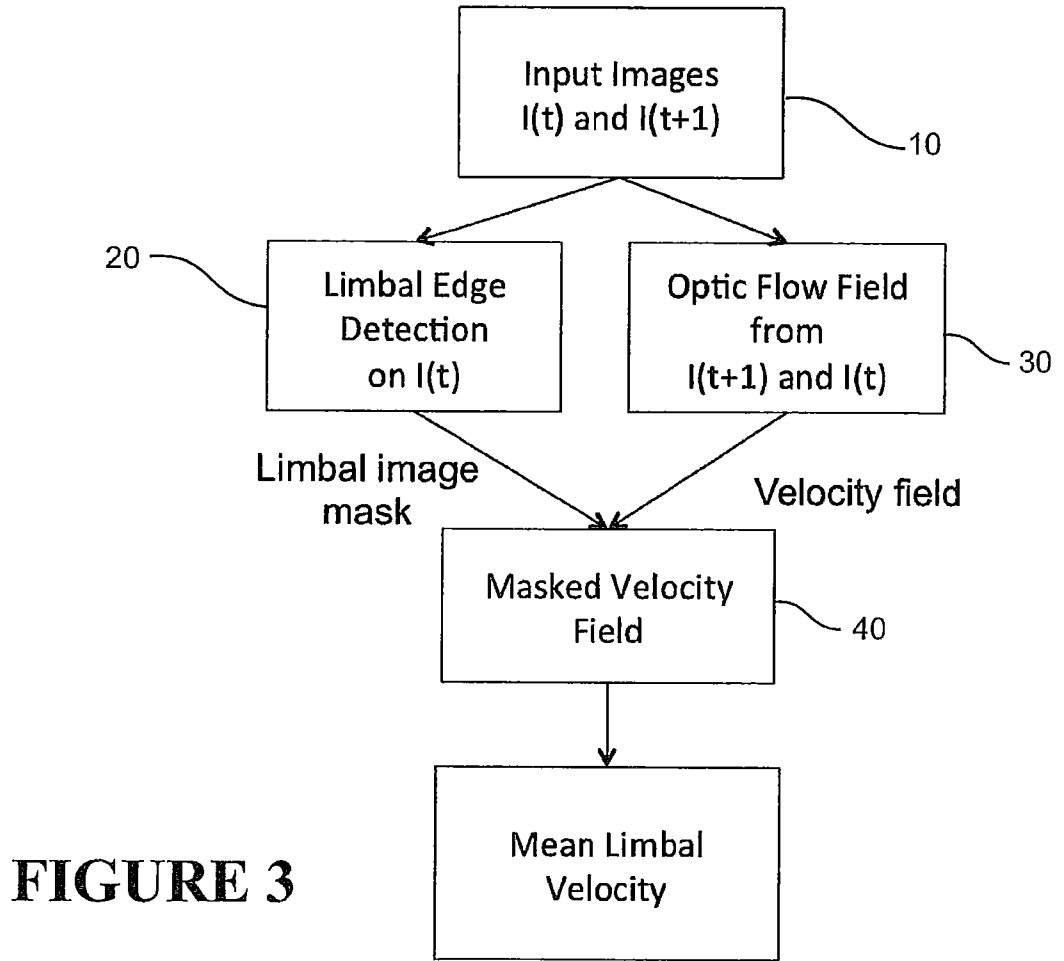


FIGURE 3

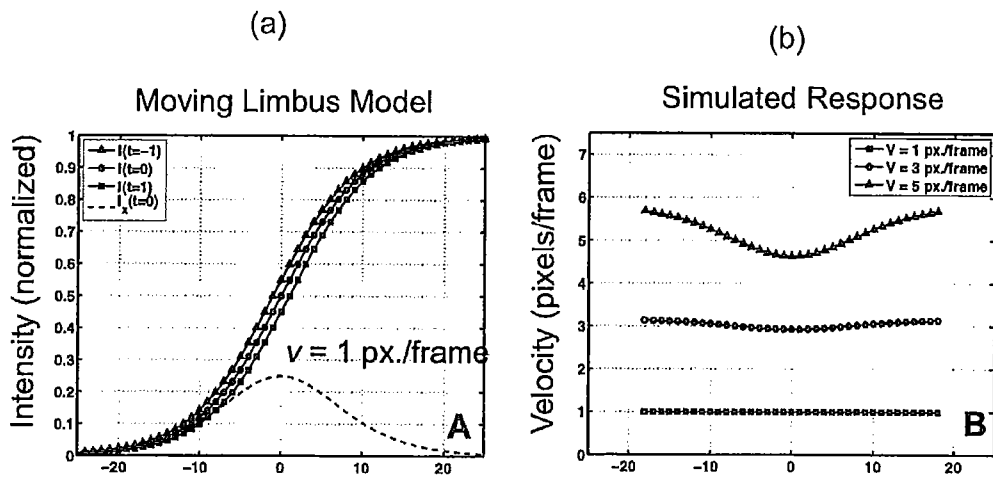


FIGURE 4

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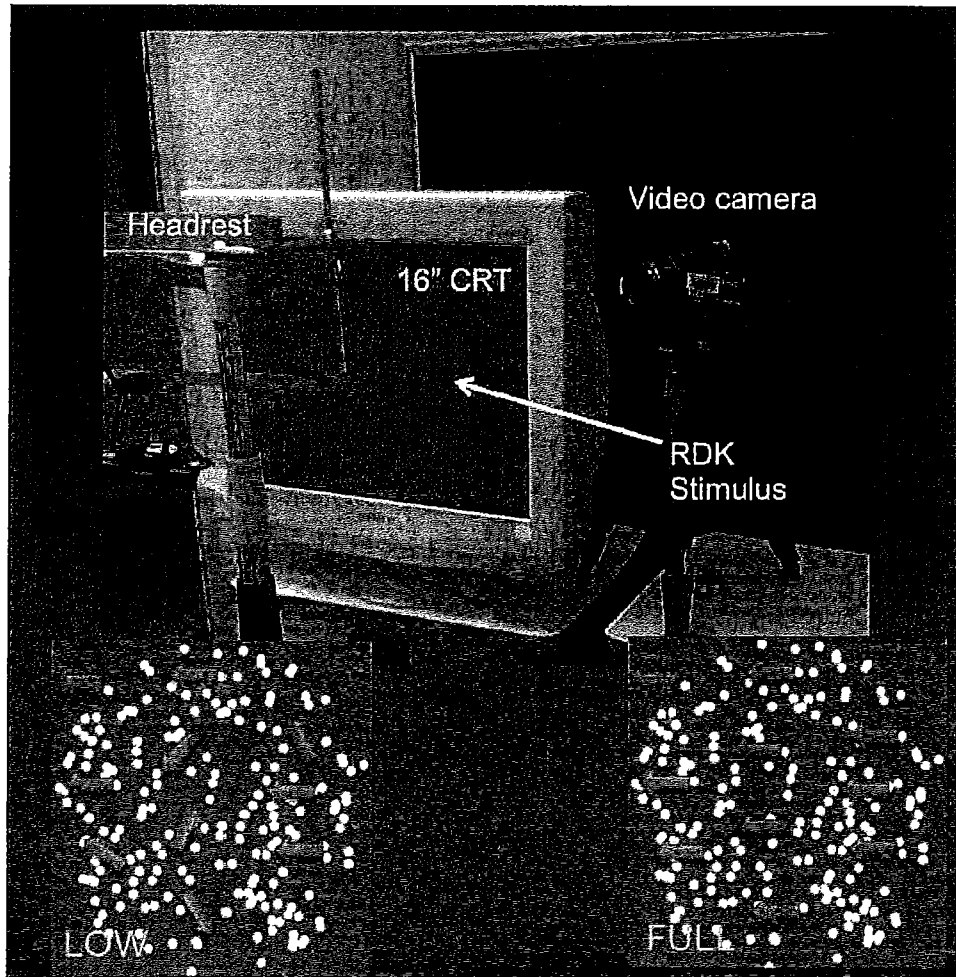


FIGURE 5



FIGURE 6

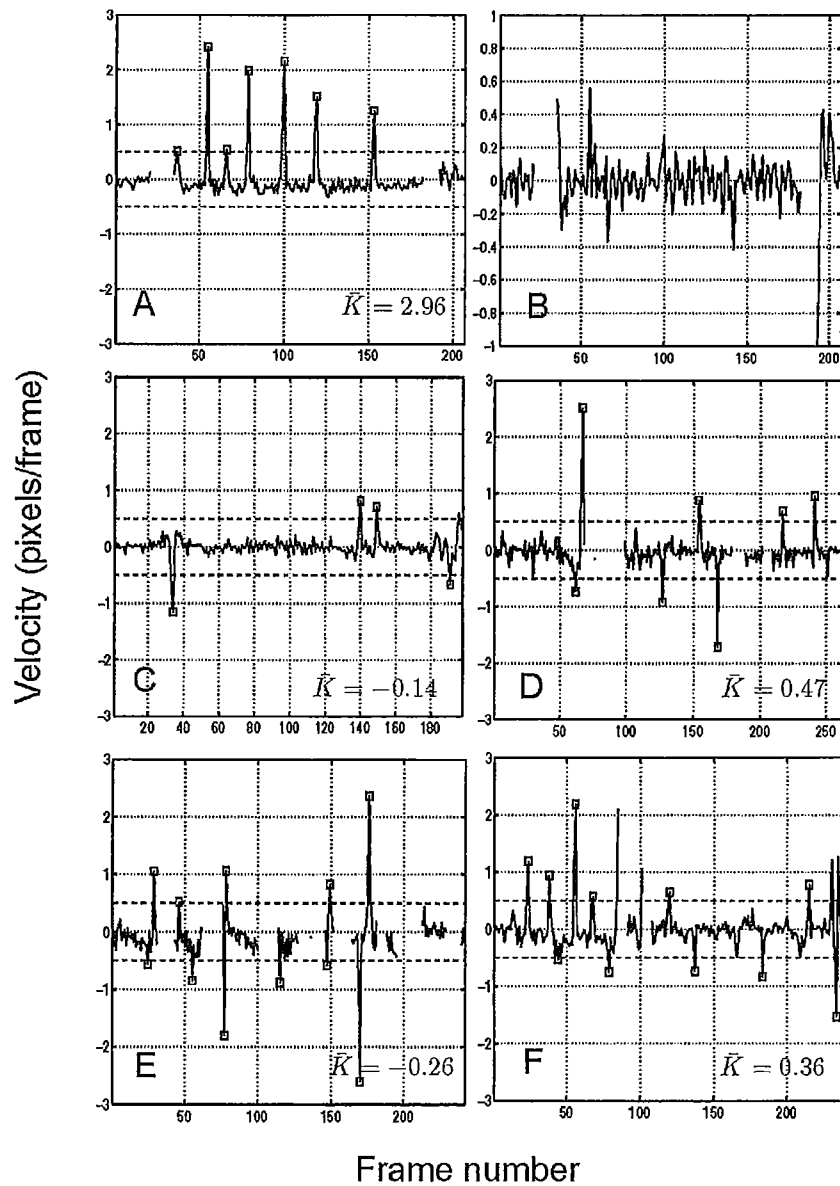


FIGURE 7

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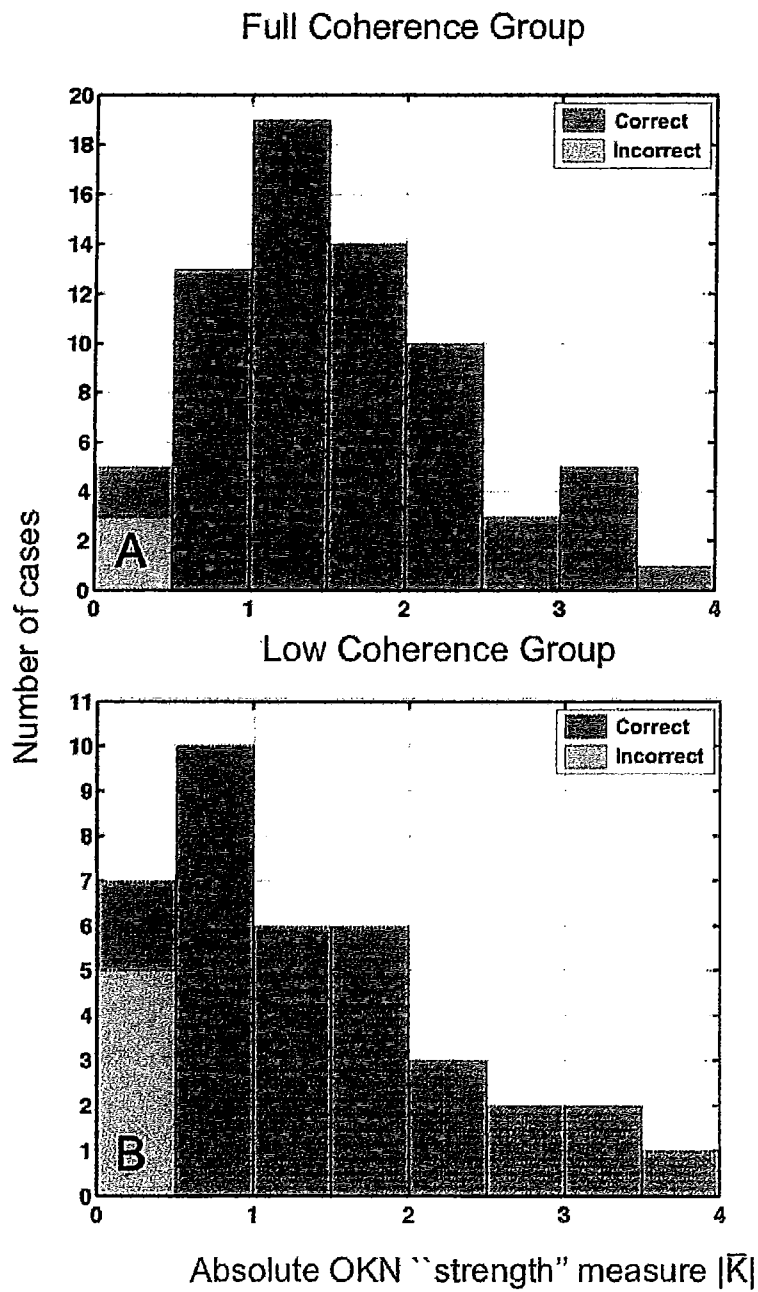


FIGURE 8

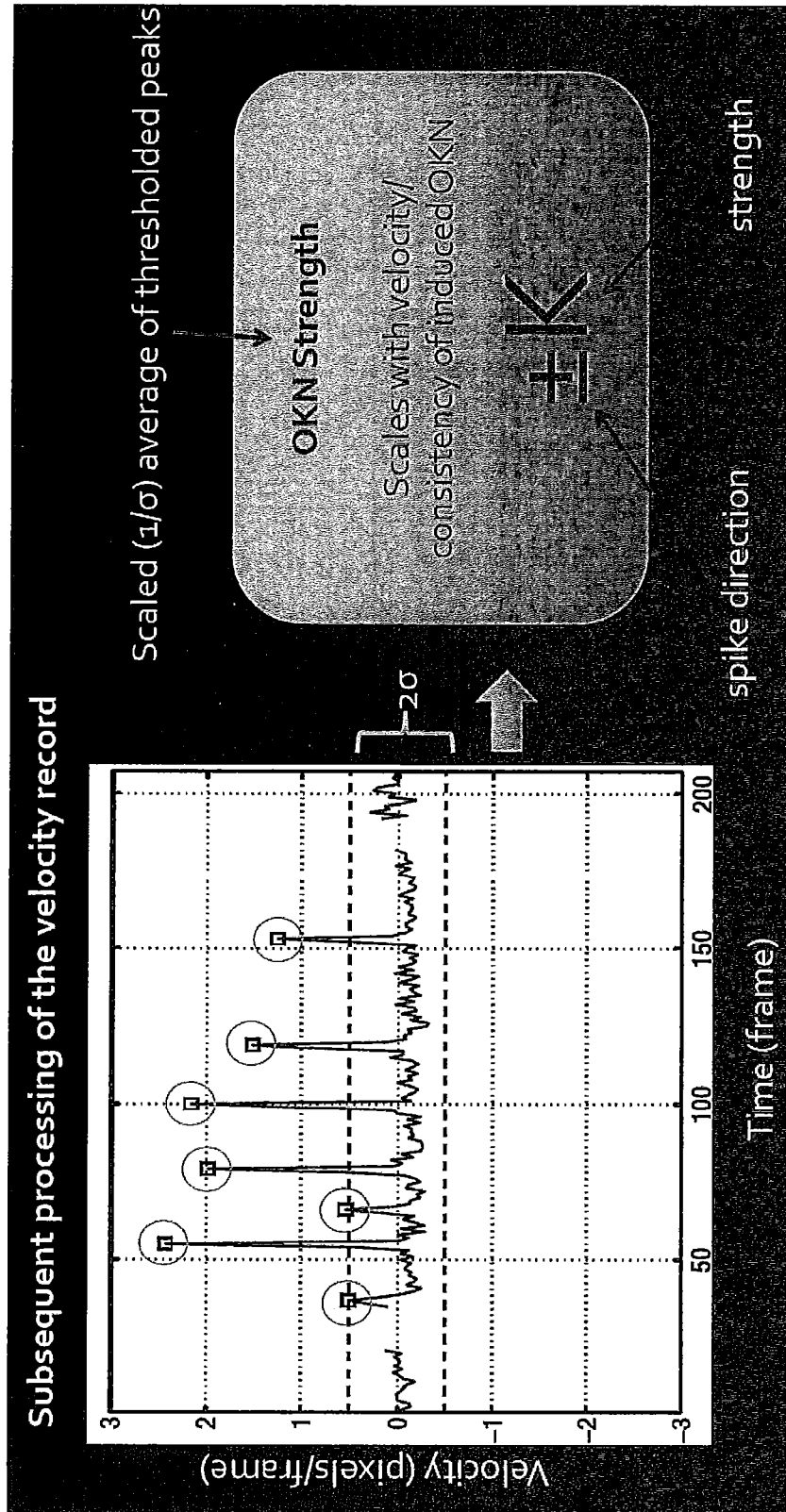


FIGURE 9

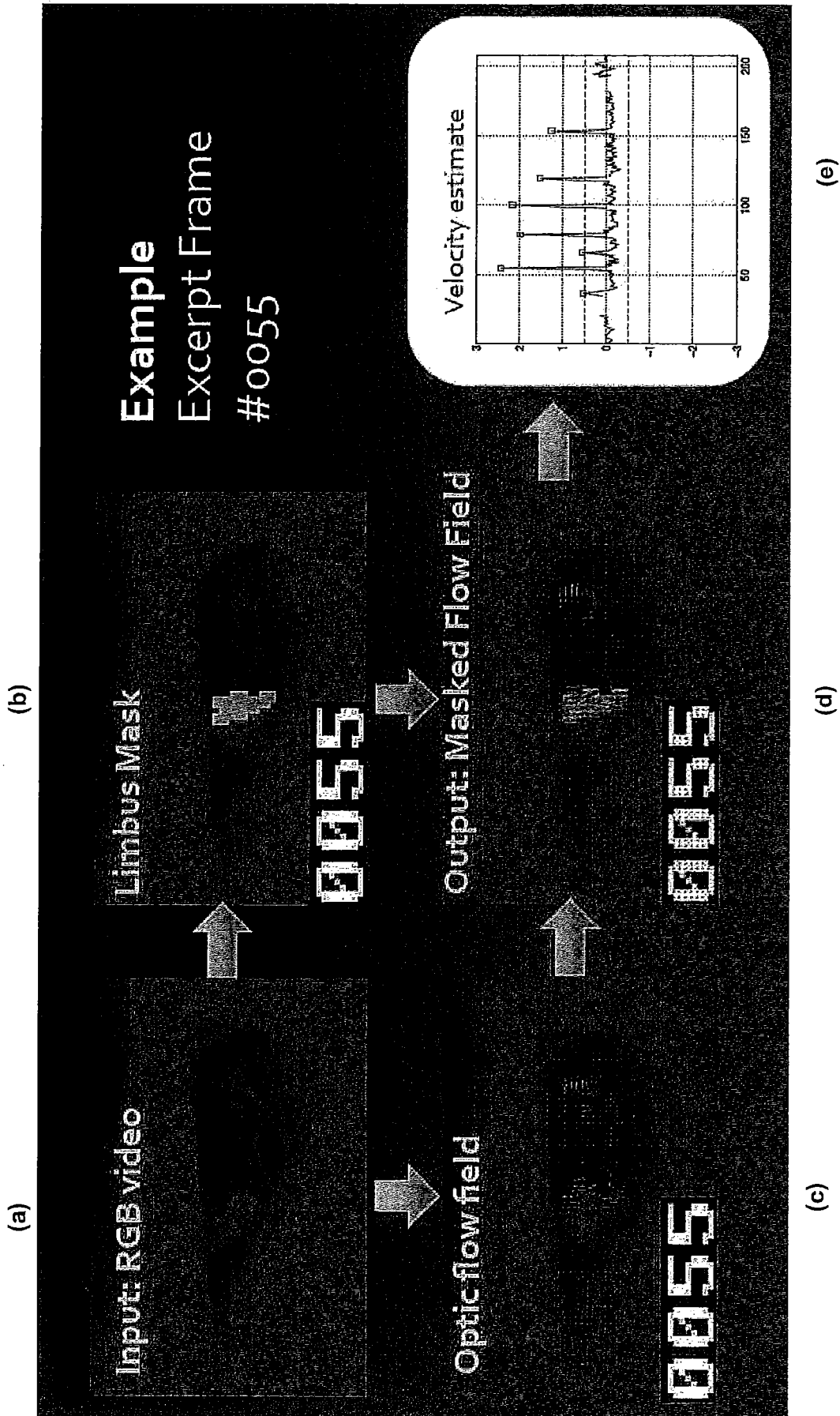


FIGURE 10

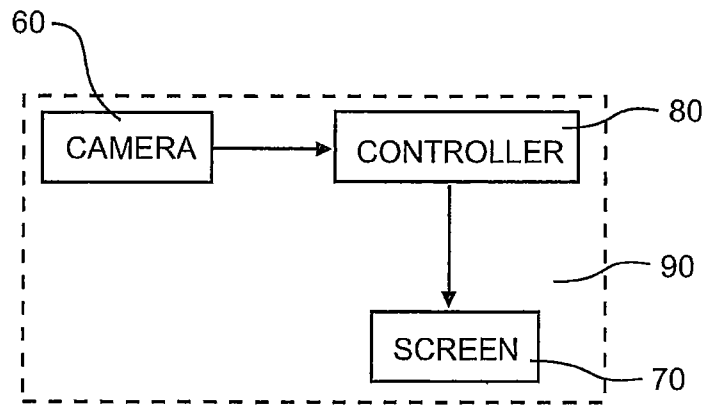


FIGURE 11

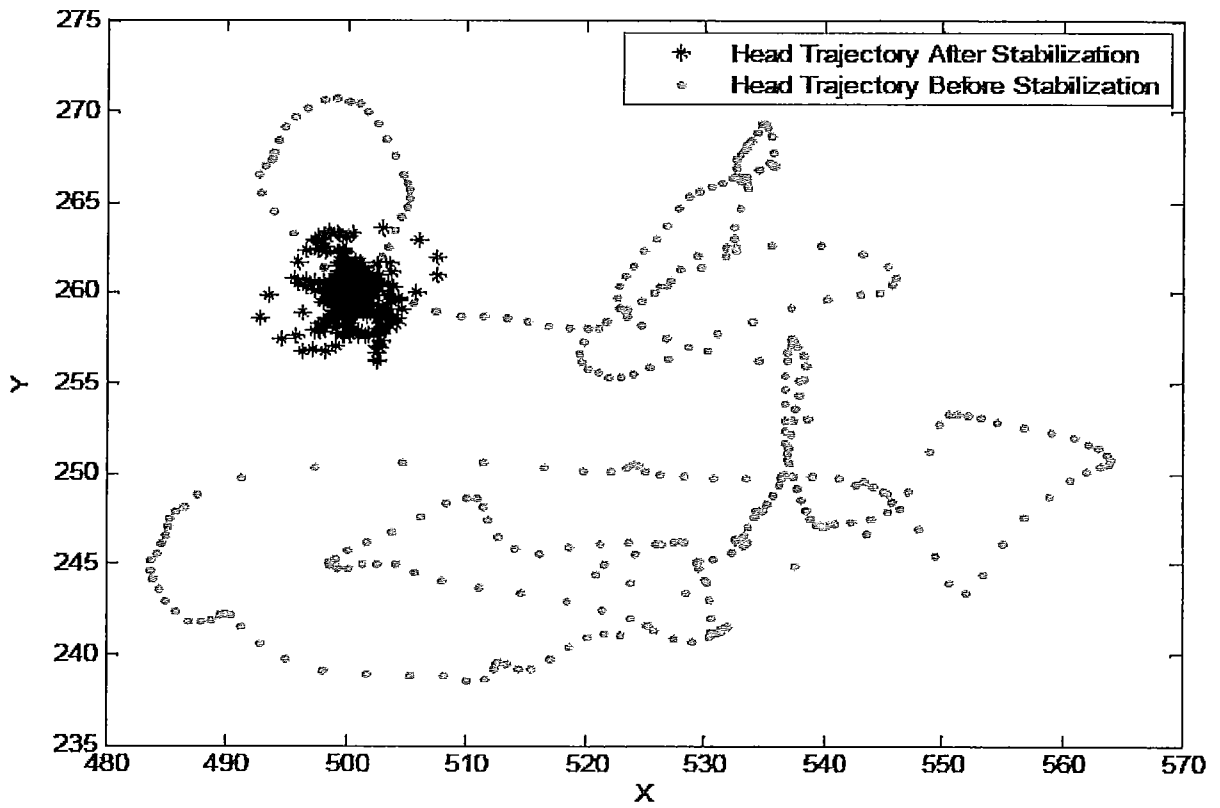


FIGURE 12

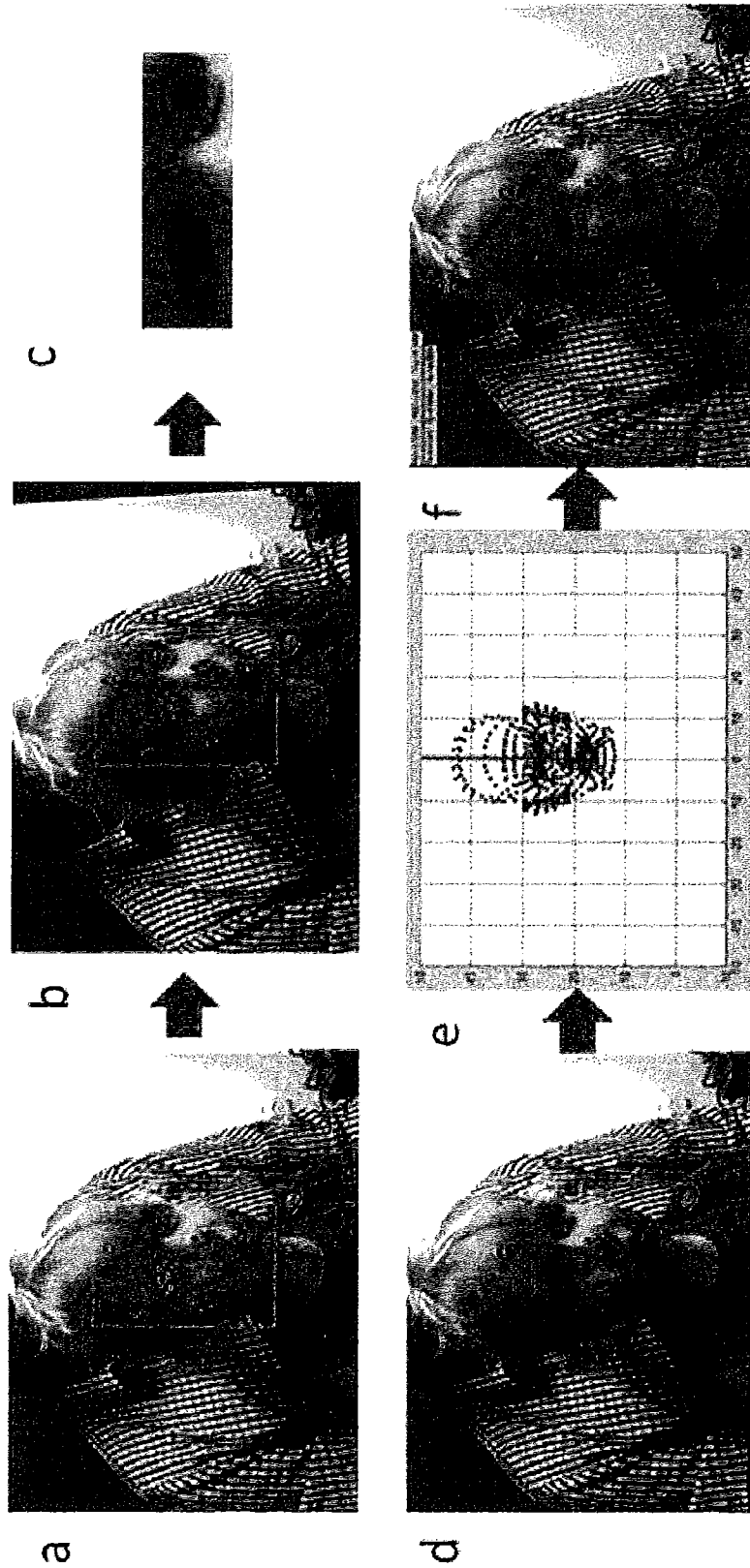


FIGURE 13

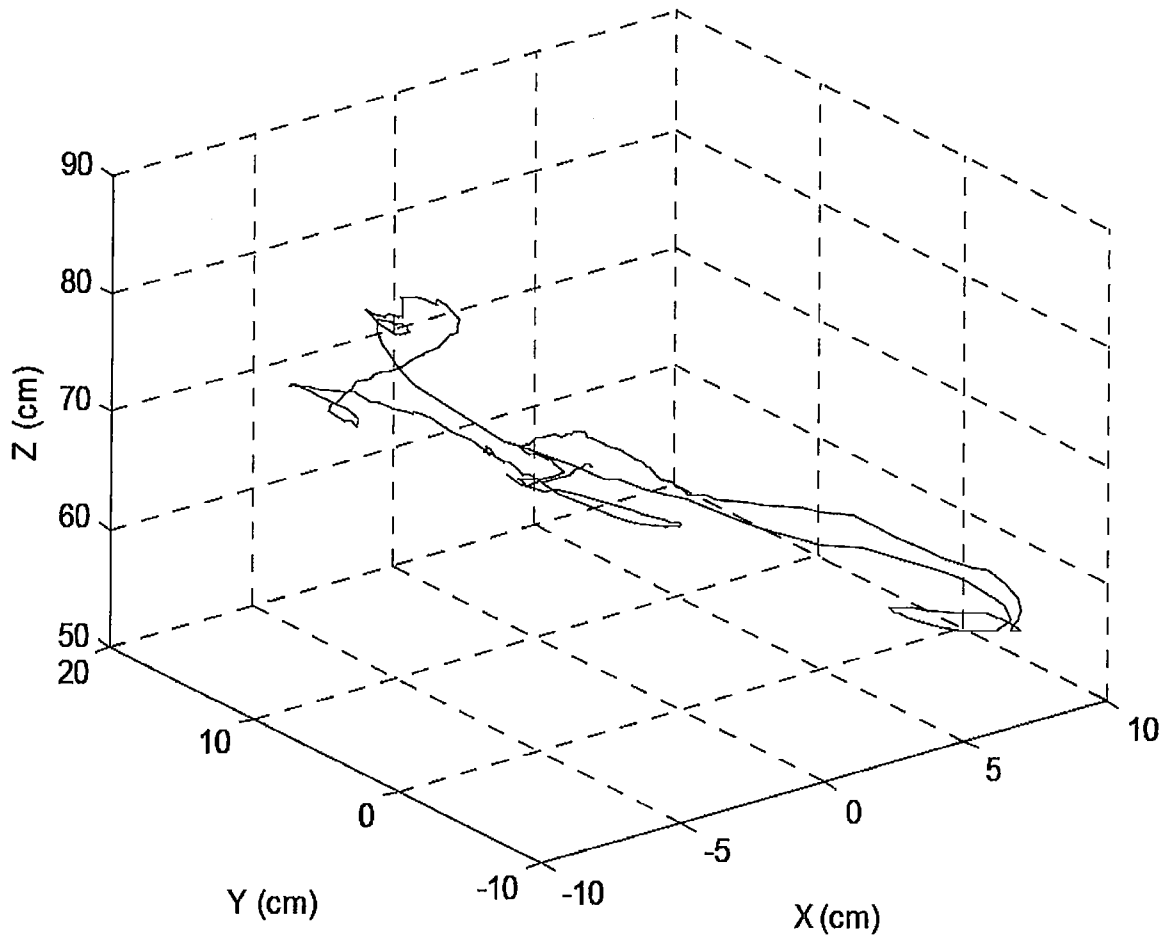


FIGURE 14

A. CLASSIFICATION OF SUBJECT MATTER

G06T 7/20 (2006.01) A61B 3/14 (2006.01) A61B 5/11 (2006.01)

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)

WPI, EPODOC: IPC A61B G06F G02B G06T H04N G06K & Keywords (eye oculo pupil gaze limbus head optokinetic reflex nystagmus face movement track compensate account for subtract video frame optical flow visual stimulus unrestrained child infant velocity movement speed eht facial region detection) & like terms; Google scholar: Keywords (pixel camera video image eye velocity prewitt lucas-kanade optokinetic nystagmus stimulus response patient healthy face "Viola-Jones" "Harris corner detection" "Kanade Lucas Tomasi" Turuwhehua) & like terms; Espacenet Worldwide: Inventor & Keywords (eye velocity head),

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Documents are listed in the continuation of Box C		



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	"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	
"E" earlier application or patent but published on or after the international filing date	"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	
"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)	"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	
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	
"P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
9 July 2014Date of mailing of the international search report
09 July 2014

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INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation).		PCT/NZ2014/000063
DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/0073136 A1 (LARSSON et al.) 07 April 2005 The whole document, especially abstract, figs 1, 2, 19, 20, paragraphs 0016, 0018-0021, 0041, 0043, 0053, 0105, 0109, 0126, 0159, 0189-0191, 0200	1-5, 8, 14, 26-28, 32, 33, 36, 37, 40-43, 47, 48, 51
Y	The whole document, especially abstract, figs 1, 2, 19, 20, paragraphs 0016, 0018-0021, 0041, 0043, 0053, 0105, 0109, 0126, 0159, 0189-0191, 0200	9, 10, 13, 15-22, 25, 29-31, 34, 35, 38, 39, 44-46, 49, 50
X	YU, T.-Y.: 'Assessing visual function and motion processing in 2 -year -old children', Presentation at the Southern Regional Congress of Optometry Victoria, 2012 The whole document, especially pages 2-3	23, 24
Y	The whole document, especially pages 2-3	25
X	SANDERS, B. C. S.: 'Opportunistically Learning Relevant Objects in Real Environments', Thesis Proposal for the Degree Doctor of Philosophy, Department of Computer Science, University of Rochester, Rochester, New York, 2002 The whole document, especially pages 21 and 27-28	1-3, 6, 7, 11, 12
Y	PIETERS, R.S., 'Active Vision: Directing Visual Attention', DCT 2008.145, Master's thesis, Technische Universiteit Eindhoven, Department Mechanical Engineering, Eindhoven, November, 2008 The whole document, especially page 32	13, 22
Y	GARBUTT, S. et al., 'Abnormalities of optokinetic nystagmus in progressive supranuclear palsy', J Neurol Neurosurg Psychiatry 2004;75:1386-1394. The whole document, especially fig 5, pages 1-2, 5-7	9, 10, 15-21, 38, 39
Y	VIOLA, P. et al., 'Robust real-time face detection', International Journal of Computer Vision 57, no. 2 (2004): 137-154. The whole document	29, 44
Y	WENDONG, Z. et al., 'An Eye Feature Extraction Based on Harris Algorithm', GCSE 2011: 28-30 December 2011, Dubai, UAE, Published by Elsevier Ltd. The whole document	30, 34, 35, 45, 49, 50
Y	Bourel, F. et al., 'Robust Facial Feature Tracking' Proceedings of the British Machine Vision Conference, pages 24.1-24.10. BMVA Press, September 2000. The whole document	31, 46
A	WO 2003/017203 A1 (QINETIQ LIMITED) 27 February 2003	
A	WO 2008/129356 A2 (IMOTIONS EMOTION TECHNOLOGY AS) 30 October 2008	

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including
2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

Supplemental Box**Continuation of: Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1-22 (and also claims 25-39 and 51) are directed to the determination of eye velocity information. The feature of detecting at least part of an eye in at least two frames of the video footage, applying an optical flow algorithm to the at least two frames of the video footage to extract pixel velocity information, and determining a statistical measure from the pixel velocity information within the detected at least part of the eye is specific to this group of claims.
- Claims 23 and 24 (and also claim 25 and claims 26-37, when appended to claim 23 or its dependencies) are directed to improving the attention of a subject for eye tracking. The feature of operating at least one display to show a video of an video functional to gain the attention of a viewer, operating at least one display to show an OKN stimulus video, and recording an eye watching the OKN stimulus video with a camera is specific to this group of claims.
- Claims 40-50 (and also claims 38, 39 and 51) are directed to extracting head image trajectory information from a video footage having a plurality of frames. The feature of detecting at least part of a facial region of the head image in at least two frames of the video footage, determining a measure of the movement of the at least part of a facial region between the at least two frames, and determining a transformation map from the measure of the movement is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a priori*.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/NZ2014/000063

This Annex lists known 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/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
US 2005/0073136 A1	07 April 2005	US 7460940 B2	02 Dec 2008
		AU 2003211065 A1	09 Sep 2003
		AU 2003269772 A1	04 May 2004
		BR 0307760 A	04 Apr 2006
		BR 0315384 A	06 Sep 2005
		CN 1627915 A	15 Jun 2005
		CN 1705454 A	07 Dec 2005
		CN 101317763 A	10 Dec 2008
		CN 101317763 B	03 Apr 2013
		EP 1478268 A1	24 Nov 2004
		EP 1478268 B1	20 Jun 2012
		EP 1553872 A1	20 Jul 2005
		EP 1553872 B1	13 Jan 2010
		EP 2204118 A2	07 Jul 2010
		EP 2296008 A1	16 Mar 2011
		EP 2298155 A2	23 Mar 2011
		EP 2305106 A1	06 Apr 2011
		EP 2314207 A1	27 Apr 2011
		JP 2006502796 A	26 Jan 2006
		JP 4551766 B2	29 Sep 2010
		JP 2005517484 A	16 Jun 2005
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		JP 2011019921 A	03 Feb 2011
		JP 5248558 B2	31 Jul 2013
		JP 2010131401 A	17 Jun 2010
		JP 2013056180 A	28 Mar 2013
		US 2003181822 A1	25 Sep 2003
		US 6974414 B2	13 Dec 2005
		WO 03070093 A1	28 Aug 2003
		WO 2004034905 A1	29 Apr 2004

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

Form PCT/ISA/210 (Family Annex)(July 2009)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/NZ2014/000063

This Annex lists known 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/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
WO 2003/017203 A1	27 February 2003	CA 2457090 A1	27 Feb 2003
		EP 1417645 A1	12 May 2004
		JP 2005500630 A	06 Jan 2005
		JP 4181037 B2	12 Nov 2008
		US 2004196433 A1	07 Oct 2004
		US 7391887 B2	24 Jun 2008
WO 2008/129356 A2	30 October 2008	CA 2639125 A1	13 Sep 2007
		EP 2007271 A2	31 Dec 2008
		JP 2009530071 A	27 Aug 2009
		US 2007265507 A1	15 Nov 2007

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

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