

PUPIL RADIUS DETECTION METHOD AND APPARATUS, COMPUTER DEVICE, AND STORAGE MEDIUM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to Chinese Patent Application No. 2019106767537, filed with the China National Intellectual Property Administration on July 25, 2019 and entitled "PUPIL RADIUS DETECTION METHOD AND APPARATUS, COMPUTER DEVICE, AND STORAGE MEDIUM", which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

This application relates to a pupil radius detection method and apparatus, a computer device, and a storage medium.

BACKGROUND

With development of science and technology, gaze tracking is more widely applied to fields such as health care, human computer interaction, military aviation, and in-person review. In-person loan review is used as an example. At this stage, the response of an interviewee may be automatically obtained through gaze tracking during communication, thereby assisting in determining overall qualifications of the interviewee.

As an important part of the gaze tracking technology, pupil radius detection is crucial to a gaze tracking system. In a conventional pupil radius detection method, geometric characteristics of a pupil are considered, the pupil is considered as a circle or an ellipse, and fitting is performed by using the least square method. However, the inventor recognizes that accuracy of an obtained pupil radius is low.

SUMMARY

According to various embodiments of this application, a pupil radius detection method and apparatus, a computer device, and a storage medium are provided.

A pupil radius detection method is provided and includes:

obtaining a to-be-detected pupil radius image, and extracting a region-of-interest image from the to-be-detected pupil radius image;

performing pixel processing on the region-of-interest image to obtain a pupil region image;

extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

obtaining a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

obtaining a distance between the center and each circle center, selecting a circle center closest to the center, using a minimum enclosing circle corresponding to the closest circle center as a target circle, and using a radius of the target circle as a pupil radius.

A pupil radius detection apparatus is provided and includes:

an image extraction module, configured to: obtain a to-be-detected pupil radius image, and extract a region-of-interest image from the to-be-detected pupil radius image;

a pupil image obtaining module, configured to perform pixel processing on the region-of-interest image to obtain a pupil region image;

a pupil contour obtaining module, configured to extract a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

a center and circle center obtaining module, configured to obtain a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

a pupil radius obtaining module, configured to: obtain a distance between the center and each circle center, select a circle center closest to the center, use a minimum enclosing circle corresponding to the closest circle center as a target circle, and use a radius of the target circle as a pupil radius.

A computer device is provided, where the computer device includes a memory and one or more processors, the memory stores a computer readable instruction, and when executing the computer readable instruction, the one or more processors perform the following steps:

obtaining a to-be-detected pupil radius image, and extracting a region-of-interest image from the to-be-detected pupil radius image;

performing pixel processing on the region-of-interest image to obtain a pupil region image;

extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

obtaining a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

obtaining a distance between the center and each circle center, selecting a circle center closest to the center, using a minimum enclosing circle corresponding to the closest circle center as a target circle, and using a radius of the target circle as a pupil radius.

One or more non-volatile computer readable storage media storing computer readable instructions are provided, where when executing the computer readable instructions, one or more processors perform the following steps:

obtaining a to-be-detected pupil radius image, and extracting a region-of-interest image from the to-be-detected pupil radius image;

performing pixel processing on the region-of-interest image to obtain a pupil region image;

extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

obtaining a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

obtaining a distance between the center and each circle center, selecting a circle center closest to the center, using a minimum enclosing circle corresponding to the closest circle center as a target circle, and using a radius of the target circle as a pupil radius.

The details of one or more embodiments of this application are provided in the accompanying drawings and the description below. Other features and advantages of this application will become obvious from the description, accompanying drawings, and claims.

BRIEF DESCRIPTION OF DRAWINGS

To describe the technical solutions in the embodiments of this application more clearly, the following briefly describes the accompanying drawings required for the embodiments. Clearly, the accompanying drawings in the following description show merely some embodiments of this application, and a person of ordinary skill in the art can still derive other drawings from these accompanying drawings without creative efforts.

FIG. 1 is a diagram of an application scenario of a pupil radius detection method according to one or more embodiments;

FIG. 2 is a schematic flowchart of a pupil radius detection method according to one or more embodiments;

FIG. 3 is a schematic flowchart of a step of obtaining a set of minimum enclosing circles according to one or more embodiments;

FIG. 4 is a schematic flowchart of a step of obtaining a minimum enclosing circle according to one or more embodiments;

FIG. 5 is a block diagram of a pupil radius detection apparatus according to one or more embodiments; and

FIG. 6 is a block diagram of a computer device according to one or more embodiments.

DETAILED DESCRIPTION

To make the technical solutions and advantages of this application clearer and more comprehensible, the following further describes this application in detail with reference to the accompanying drawings and embodiments. It should be understood that the specific embodiments described herein are merely illustrative of this application and are not intended to limit this application.

A pupil radius detection method provided in this application may be applied to an application environment shown in FIG. 1. A target object wears a head-mounted display (HMD) 102 with an eye tracking function, and the eye tracking HMD 102 has a built-in eye tracking camera. A wearing position is adjusted. At the beginning, the eye tracking camera collects a to-be-detected pupil radius image of the target object, and transmits the to-be-detected pupil radius image to a control terminal

104 in real time. The control terminal 104 performs analysis processing on the to-be-detected pupil radius image, extracts a region-of-interest image from the to-be-detected pupil radius image, then performs pixel processing on the region-of-interest image to obtain a pupil region image, extracts a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm, obtains circle centers of minimum enclosing circles of the plurality of pupil contours and a distance between a center of the region-of-interest image and each circle center, and uses a radius of a minimum enclosing circle corresponding to a circle center closest to the center as a pupil radius. The control terminal 104 may be but is not limited to various personal computers, notebook computers, smartphones, and tablet computers.

In an embodiment, as shown in FIG. 2, a pupil radius detection method is provided. An example in which the method is applied to the control terminal in FIG. 1 is used for description. The method includes the following steps.

Step 202: Obtain a to-be-detected pupil radius image, and extract a region-of-interest image from the to-be-detected pupil radius image.

The to-be-detected pupil radius image is collected by an eye tracking camera and sent to the control terminal. The eye tracking camera is an infrared radiation (IR) sensitive camera with an IR band-pass filter function, and the camera allows only infrared light to enter the camera and provides infrared lighting. An infrared lighting apparatus is usually an infrared light emitting diode for lighting a region around an eye. A pupil is usually located in a central region of an eye image, and therefore, a region of interest is specifically an image corresponding to the central region of the eye image output by the eye tracking camera.

Step 204: Perform pixel processing on the region-of-interest image to obtain a pupil region image.

A region of a pupil position is most likely the darkest region in an image captured by an IR band-pass filter through IR lighting, and it is uneasy to perform subsequent processing on an image corresponding to the darkest region. Therefore, the darkest region is converted into the brightest region through bitwise NOT processing. It is easier to perform subsequent processing on the brightest region than the darkest region.

The performing pixel processing on the region-of-interest image to obtain a pupil region image includes: obtaining each pixel value of the region-of-interest image, and performing bitwise NOT processing on each pixel value to obtain each processed pixel value of the region-of-interest image; and setting a pixel value less than a preset threshold in all the processed pixel values of the region-of-interest image to zero, to obtain the pupil region image. A pupil region and a non-pupil region are distinguished by comparing the processed pixel values of the region-of-interest image with the preset threshold. When a pixel value corresponding to an image of a region is less than the preset threshold, it indicates that the region is a non-pupil region. A pixel value corresponding to the non-pupil region in the region of interest is set to zero, so that the non-pupil region can be removed from the region of interest. In this way, only the pupil region remains in the region of interest.

Step 206: Extract a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm.

In digitized binary image processing, boundary tracing is used to extract a series of coordinates or chain codes of a contour of a boundary. The boundary is a boundary between a 1-pixel connected component and a 0-pixel connected component. For example, to convert a binary image into a boundary description, information that needs to be extracted is an enclosing relationship between an outer boundary and a hole boundary. There is a one-to-one correspondence between outer boundaries and connected components 1 and between hole boundaries and connected components 0. Therefore, a topology of a given binary image can be determined.

The boundary tracing algorithm may be used to determine an enclosing relationship between boundaries of a binary image, there is a one-to-one correspondence between outer boundaries and connected components whose pixel values are 1 and between hole boundaries and holes whose pixel values are 0. A binary image representation method is used to extract some features without reconstructing an image. The boundary tracing algorithm may also be used to trace only the outermost contour; in other words, there is no hole boundary enclosing the outer boundary, and may be used for region counting and topology analysis of a binary image.

Step 208: Obtain a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of

minimum enclosing circles.

The region of interest may be specifically the central region of the eye image. When the central region is a geometric region, the center of the region-of-interest image is a geometric center of the geometric region. The obtaining a circle center and a radius of a minimum enclosing circle includes: obtaining four pixels for determining the minimum enclosing circle, randomly selecting two of the four pixels to obtain two different pixel combinations, and obtaining two straight lines by using the two different pixel combinations; separately calculating perpendicular bisectors of the two straight lines, and calculating an intersection point of the two perpendicular bisectors to obtain the circle center of the minimum enclosing circle; and calculating a distance between the circle center and any one of the four pixels to obtain the radius of the minimum enclosing circle.

Step 210: Obtain a distance between the center and each circle center, select a circle center closest to the center, use a minimum enclosing circle corresponding to the closest circle center as a target circle, and use a radius of the target circle as a pupil radius.

The distance between the center and the circle center may be obtained by using a distance formula between the two points after pixels corresponding to the center and the circle center are obtained.

According to the pupil radius detection method, the region-of-interest image is extracted from the to-be-detected pupil radius image, then pixel processing is performed on the region-of-interest image to obtain the pupil region image, the plurality of pupil contours are extracted from the pupil region image by using the boundary tracing algorithm, circle centers of the minimum enclosing circles of the plurality of pupil contours and the distance between the center of the region-of-interest image and each circle center are obtained, and a radius of the minimum enclosing circle corresponding to the circle center closest to the center is used as the pupil radius. As such, a pupil is positioned by using the minimum enclosing circle whose circle center is closest to the center of the region-of-interest image, so that positioning of the obtained pupil is more accurate, and accuracy of the obtained pupil radius can be improved.

In an embodiment, after the extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm, the method further includes: obtaining a set of pixels

of each of the plurality of pupil contours; sorting pixels in the set of pixels in ascending order of polar angles, where pixels having the same polar angle are sorted in ascending order of distances to the bottom leftmost pixel in the set of pixels; storing sorted pixels by using a structure array, traversing the sorted pixels, and removing a non-vertex pixel to obtain a vertex pixel set; and performing rotation determining on each vertex pixel in the vertex pixel set, and removing a vertex pixel at which rotation is not performed in a preset direction, to obtain pupil contours after convex hull processing; and the obtaining a set of minimum enclosing circles of the plurality of pupil contours includes: obtaining a set of minimum enclosing circles of the pupil contours obtained after convex hull processing. The bottom leftmost pixel in pixels constituting a pupil contour is found, and the pixels constituting the pupil contour are sorted. Sorting is performed in ascending order of polar angles, and pixels having the same polar angle are sorted in ascending order of distances to the bottom leftmost pixel. The outermost pixels of a convex hull are stored by using a structure array, and a while loop is used to remove a pixel other than a vertex of the convex hull from the pixels. Rotation should be performed leftward at each vertex when the convex hull is traversed counterclockwise. Therefore, when it is found that rotation is not performed leftward at a vertex in the while loop, the vertex is removed, where whether a rotation direction is leftwards or rightwards can be determined based on a cross product. The convex hull processing helps eliminate distortion in an image that is caused by reflection of an infrared light emitting diode.

In an embodiment, as shown in FIG. 3, the obtaining a set of minimum enclosing circles of the plurality of pupil contours includes the following steps: Step 302: Obtain minimum enclosing circles respectively corresponding to the plurality of pupil contours and radiuses of the minimum enclosing circles. Step 304: Remove a minimum enclosing circle whose radius is greater than a preset value from the minimum enclosing circles, to obtain the set of minimum enclosing circles of the pupil contours. Removing the minimum enclosing circle whose radius exceeds the preset value can reduce a possibility that a minimum enclosing circle does not belong to a pupil due to a very large pupil. A range of the preset value may be calculated by using image resolution. Several possible circles, for example, an iris or a housing of an eye tracking device leaning against the face, may be detected.

In an embodiment, as shown in FIG. 4, the obtaining minimum enclosing circles respectively corresponding to the plurality of pupil contours includes the following steps: Step 402: Obtain four pixels at the leftmost, rightmost, topmost, and bottommost of each of the plurality of pupil contours, and obtain, based on the four pixels, a minimum circle enclosing the four pixels. Step 404: Traverse all pixels of the pupil contour, and when all the pixels include no pixel located outside a boundary of the minimum circle, determine that the minimum circle is a minimum enclosing circle of the pupil contour.

In an embodiment, the pupil radius detection method further includes: when all the pixels include a pixel located outside the boundary of the minimum circle, determining that the minimum circle is not a minimum enclosing circle of the pupil contour; selecting a pixel farthest from a circle center of the minimum circle from pixels located outside the boundary of the minimum circle, and performing permutation and combination on the selected pixel and any three of the four pixels at the leftmost, rightmost, topmost, and bottommost; obtaining four pixels after permutation and combination, and obtaining, based on the four pixels obtained after permutation and combination, a candidate minimum circle enclosing the four pixels; and when a pixel that is not selected for permutation and combination is not located outside a boundary of the candidate minimum circle, traversing other pixels of the pupil contour, and when the other pixels include no pixel located outside the boundary of the candidate minimum circle, determining that the candidate minimum circle is a minimum enclosing circle of the pupil contour.

A minimum enclosing circle of a pupil contour may be obtained through the following steps:

- (1) Traverse all pixels of the pupil contour, find four pixels at the leftmost, rightmost, topmost, and bottommost, and calculate a minimum circle enclosing the four pixels at the leftmost, rightmost, topmost, and bottommost, specifically including a circle center and a radius of the minimum circle.
- (2) Traverse all the pixels of the pupil contour to determine whether there is a pixel located outside a boundary of the minimum circle, where if there is no pixel located outside the boundary of the minimum circle, the minimum circle is the minimum enclosing circle of the pupil contour; or if there is a pixel located outside the boundary of the minimum circle, the minimum circle is not the minimum enclosing circle of the pupil contour.
- (3) When the calculated minimum circle is not the

minimum enclosing circle of the pupil contour, select a pixel farthest from the circle center of the minimum circle from pixels outside the boundary of the minimum circle, perform permutation and combination on the pixel farthest from the circle center of the minimum circle and any three of the four previously found pixels at the leftmost, rightmost, topmost, and bottommost of the pupil contour, and determine, based on four pixels obtained after re-permutation and re-combination, a minimum circle enclosing the four pixels, to obtain a minimum circle 1 enclosing the farthest pixel, the leftmost pixel, the rightmost pixel, and the topmost pixel, a minimum circle 2 enclosing the farthest pixel, the leftmost pixel, the rightmost pixel, and the bottommost pixel, a minimum circle 3 enclosing the farthest pixel, the leftmost pixel, the topmost pixel, and the topmost pixel, and a minimum circle 4 enclosing the farthest pixel, the rightmost pixel, the topmost pixel, and the bottommost pixel. (4) When the bottommost pixel is not located outside a boundary of the minimum circle 1, traverse all the pixels of the pupil contour to determine whether there is a pixel located outside the boundary of the minimum circle 1, where if there is no pixel located outside the boundary of the minimum circle 1, the minimum circle 1 is the minimum enclosing circle of the pupil contour; or if there is a pixel located outside the boundary of the minimum circle, the minimum circle 1 is not the minimum enclosing circle of the pupil contour. (5) When the minimum circle 1 is not the minimum enclosing circle of the pupil contour, select a pixel farthest from a circle center of the minimum circle 1 from pixels outside the boundary of the minimum circle 1, perform permutation and combination on the pixel farthest from the circle center of the minimum circle 1 and any three of the four pixels for determining the minimum circle 1, and repeat steps (3) and (4) until all the pixels of the pupil contour are traversed, where when there is no pixel located outside a boundary of a calculated minimum circle, the calculated minimum circle is the minimum enclosing circle of the pupil contour.

In an embodiment, in-person loan review is used as an example. The control terminal may prestore historical pupil radius data of an interviewee that is obtained when a specific question is answered. For example, an average value of historical pupil radius data is used as a pupil radius reference value of the interviewee. In an actual in-person loan review process, the interviewee wears an HMD with an eye tracking function, the eye tracking HMD has a built-in eye tracking

camera, and at the beginning of the interview, the eye tracking camera collects a real-time to-be-detected pupil radius image of the interviewee, and transmits the real-time to-be-detected pupil radius image to the control terminal in real time. The control terminal performs analysis processing on the real-time to-be-detected pupil radius image, extracts a region-of-interest image from the real-time to-be-detected pupil radius image, then performs pixel processing on the region-of-interest image to obtain a pupil region image, extracts a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm, obtains circle centers of minimum enclosing circles of the plurality of pupil contours and a distance between a center of the region-of-interest image and each circle center, and uses a radius of a minimum enclosing circle corresponding to a circle center closest to the center as a real-time pupil radius. Then the control terminal compares the real-time pupil radius with the pupil radius reference value of the interviewee to obtain a lie detection result of answering the question by the interviewee. For example, during answering of a specific question, if a real-time pupil radius is greater than a corresponding pupil radius reference value, it is determined that the interviewee lies when answering the question.

It should be understood that although the steps in the flowcharts of FIG. 2 to FIG. 4 are shown in sequence indicated by arrows, these steps are not necessarily performed in such sequences. Unless expressly stated herein, these steps are not limited to a strict execution sequence, and may be performed in another sequence. In addition, at least some of the steps in FIG. 2 to FIG. 4 may include a plurality of substeps or stages. These substeps or stages are not necessarily performed and completed at the same moment, but may be performed at different moments. These substeps or stages are not necessarily performed in sequence, either, but may be performed in turn or alternately with other steps or at least some substeps or stages of the other steps.

In an embodiment, as shown in FIG. 5, a pupil radius detection apparatus is provided. The apparatus includes an image extraction module 502, a pupil image obtaining module 504, a pupil contour obtaining module 506, a center and circle center obtaining module 508, and a pupil radius obtaining module 510. The image extraction module is configured to: obtain a to-be-detected pupil radius image, and extract a region-of-interest image from the to-be-detected pupil radius image. The pupil image obtaining module is configured to perform pixel processing on the region-of-interest

image to obtain a pupil region image. The pupil contour obtaining module is configured to extract a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm. The center and circle center obtaining module is configured to obtain a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles. The pupil radius obtaining module is configured to: obtain a distance between the center and each circle center, select a circle center closest to the center, use a minimum enclosing circle corresponding to the closest circle center as a target circle, and use a radius of the target circle as a pupil radius.

In an embodiment, the pupil image obtaining module is further configured to: obtain each pixel value of the region-of-interest image, and perform bitwise NOT processing on each pixel value to obtain each processed pixel value of the region-of-interest image; and set a pixel value less than a preset threshold in all the processed pixel values of the region-of-interest image to zero, to obtain the pupil region image.

In an embodiment, after the pupil image obtaining module, the apparatus further includes a convex hull processing module, configured to: obtain a set of pixels of each of the plurality of pupil contours; sort pixels in the set of pixels in ascending order of polar angles, where pixels having the same polar angle are sorted in ascending order of distances to the bottom leftmost pixel in the set of pixels; store sorted pixels by using a structure array, traverse the sorted pixels, and remove a non-vertex pixel to obtain a vertex pixel set; and perform rotation determining on each vertex pixel in the vertex pixel set, and remove a vertex pixel at which rotation is not performed in a preset direction, to obtain pupil contours after convex hull processing. The center and circle center obtaining module is configured to obtain a set of minimum enclosing circles of the pupil contours obtained after convex hull processing.

In an embodiment, the center and circle center obtaining module is further configured to: obtain minimum enclosing circles respectively corresponding to the plurality of pupil contours and radiuses of the minimum enclosing circles; and remove a minimum enclosing circle whose radius is greater than a preset value from the minimum enclosing circles, to obtain the set of minimum enclosing circles of the pupil contours.

In an embodiment, the center and circle center obtaining module is further configured to: obtain four pixels at the leftmost, rightmost, topmost, and bottommost of each of the plurality of pupil contours, and obtain, based on the four pixels, a minimum circle enclosing the four pixels; and traverse all pixels of the pupil contour, and when all the pixels include no pixel located outside a boundary of the minimum circle, determine that the minimum circle is a minimum enclosing circle of the pupil contour.

In an embodiment, the center and circle center obtaining module is further configured to: when all the pixels include a pixel located outside the boundary of the minimum circle, determine that the minimum circle is not a minimum enclosing circle of the pupil contour; select a pixel farthest from a circle center of the minimum circle from pixels located outside the boundary of the minimum circle, and perform permutation and combination on the selected pixel and any three of the four pixels at the leftmost, rightmost, topmost, and bottommost; obtain four pixels after permutation and combination, and obtain, based on the four pixels obtained after permutation and combination, a candidate minimum circle enclosing the four pixels; and when a pixel that is not selected for permutation and combination is not located outside a boundary of the candidate minimum circle, traverse other pixels of the pupil contour, and when the other pixels include no pixel located outside the boundary of the candidate minimum circle, determine that the candidate minimum circle is a minimum enclosing circle of the pupil contour.

In an embodiment, the pupil radius detection apparatus further includes a circle center and radius module, configured to: obtain four pixels for determining a minimum enclosing circle, randomly select two of the four pixels to obtain two different pixel combinations, and obtain two straight lines by using the two different pixel combinations; separately calculate perpendicular bisectors of the two straight lines, and calculate an intersection point of the two perpendicular bisectors to obtain a circle center of the minimum enclosing circle; and calculate a distance between the circle center and any one of the four pixels to obtain a radius of the minimum enclosing circle.

For a specific limitation on the pupil radius detection apparatus, refer to the limitation on the pupil radius detection method above. Details are omitted here for simplicity. All or some of the modules in the foregoing pupil radius detection apparatus may be implemented by using software,

hardware, or a combination thereof. The foregoing modules may be built in a processor of a computer device in a hardware form or independent of a processor of a computer device, or may be stored in a memory of a computer device in a software form, so that the processor invokes the modules and performs operations corresponding to the foregoing modules.

In an embodiment, a computer device is provided. The computer device may be a server. FIG. 6 may be a diagram of an internal structural of the computer device. The computer device includes a processor, a memory, a network interface, and a database that are connected through a system bus. The processor of the computer device is configured to provide computing and control capabilities. The memory of the computer device includes a non-volatile storage medium and an internal memory. The non-volatile storage medium stores an operating system, a computer readable instruction, and a database. The internal memory provides an environment for running the operating system and the computer readable instruction in the non-volatile storage medium. The database of the computer device is configured to store data such as a circle center of a minimum enclosing circle and a radius of the minimum enclosing circle. The network interface of the computer device is configured to be connected to and communicate with an external terminal through a network. A pupil radius detection method is implemented when the processor executes the computer readable instruction.

A person skilled in the art can understand that the structure shown in FIG. 6 is merely a block diagram of a partial structure related to the solution of this application, and does not constitute a limitation on the computer device to which the solution of this application is applied. Specifically, the computer device may include more or fewer components than those shown in the figure, or combine some components, or have different component arrangements.

A computer device is provided, where the computer device includes a memory and one or more processors, the memory stores a computer readable instruction, and when the computer readable instruction is executed by the processor, the steps of the pupil radius detection method provided in any embodiment of this application are implemented.

One or more non-volatile computer readable storage media storing computer readable

instructions are provided, where when executing the computer readable instructions, one or more processors implement the steps of the pupil radius detection method provided in any embodiment of this application.

A person of ordinary skill in the art can understand that all or some of processes for implementing the methods in the foregoing embodiments may be implemented by instructing related hardware by using a computer readable instruction. The computer readable instruction may be stored in a non-volatile computer readable storage medium. The processes of the methods in the embodiments described above may be performed when the computer readable instruction is executed. Any reference to a memory, storage, a database, or other media used in the embodiments provided in this application may include a non-volatile memory and/or a volatile memory. The non-volatile memory may include a read-only memory (ROM), a programmable ROM (PROM), an electrically programmable ROM (EPROM), an electrically erasable programmable ROM (EEPROM), or a flash memory. The volatile memory may include a random access memory (RAM) or an external cache memory. By way of illustration instead of limitation, a plurality of forms of RAMs may be obtained, for example, a static RAM (SRAM), a dynamic RAM (DRAM), a synchronous DRAM (SDRAM), a double data rate SDRAM (DDRSDRAM), an enhanced SDRAM (ESDRAM), a synchlink DRAM (SLDRAM), a Rambus direct RAM (RDRAM), a direct Rambus dynamic RAM (DRDRAM), and a Rambus dynamic RAM (RDRAM).

The technical features of the foregoing embodiments may be combined arbitrarily. For brevity of description, not all possible combinations of the technical features of the foregoing embodiments are described. However, it should be considered that combinations of these technical features all fall within the scope of the present specification provided that the combinations are not contradictory.

The foregoing embodiments describe merely several implementations of this application, and description of the implementations is relatively specific and detailed, but shall not be understood as a limitation on the scope of the present invention. It should be noted that a person of ordinary skill in the art may make several variations and improvements without departing from the idea of this application, and the variations and improvements shall fall within the protection scope of this

application. Therefore, the protection scope of this application shall be subject to the protection scope of the claims.

CLAIMS

1. A pupil radius detection method, comprising:

obtaining a to-be-detected pupil radius image, and extracting a region-of-interest image from the to-be-detected pupil radius image;

performing pixel processing on the region-of-interest image to obtain a pupil region image;

extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

obtaining a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

obtaining a distance between the center and each circle center, selecting a circle center closest to the center, using a minimum enclosing circle corresponding to the closest circle center as a target circle, and using a radius of the target circle as a pupil radius.

2. The method according to claims 1, wherein the performing pixel processing on the region-of-interest image to obtain a pupil region image comprises:

obtaining each pixel value of the region-of-interest image, and performing bitwise NOT processing on each pixel value to obtain each processed pixel value of the region-of-interest image; and

setting a pixel value less than a preset threshold in all the processed pixel values of the region-of-interest image to zero, to obtain the pupil region image.

3. The method according to claims 1, wherein after the extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm, the method further comprises:

obtaining a set of pixels of each of the plurality of pupil contours;

sorting pixels in the set of pixels in ascending order of polar angles, wherein pixels having the same polar angle are sorted in ascending order of distances to the bottom leftmost pixel in the set of pixels;

storing sorted pixels by using a structure array, traversing the sorted pixels, and removing a non-vertex pixel to obtain a vertex pixel set; and

performing rotation determining on each vertex pixel in the vertex pixel set, and removing a vertex pixel at which rotation is not performed in a preset direction, to obtain pupil contours after convex hull processing; and

the obtaining a set of minimum enclosing circles of the plurality of pupil contours comprises:

obtaining a set of minimum enclosing circles of the pupil contours obtained after convex hull processing.

4. The method according to claim 1, wherein the obtaining a set of minimum enclosing circles of the plurality of pupil contours comprises:

obtaining minimum enclosing circles respectively corresponding to the plurality of pupil contours and radiuses of the minimum enclosing circles; and

removing a minimum enclosing circle whose radius is greater than a preset value from the minimum enclosing circles, to obtain the set of minimum enclosing circles of the pupil contours.

5. The method according to claim 4, wherein the obtaining minimum enclosing circles respectively corresponding to the plurality of pupil contours comprises:

obtaining four pixels at the leftmost, rightmost, topmost, and bottommost of each of the plurality of pupil contours, and obtaining, based on the four pixels, a minimum circle enclosing the four pixels; and

traversing all pixels of the pupil contour, and when all the pixels comprise no pixel located outside a boundary of the minimum circle, determining that the minimum circle is a minimum enclosing circle of the pupil contour.

6. The method according to claim 5, further comprising:

when all the pixels comprise a pixel located outside the boundary of the minimum circle, determining that the minimum circle is not a minimum enclosing circle of the pupil contour;

selecting a pixel farthest from a circle center of the minimum circle from pixels located outside the boundary of the minimum circle, and performing permutation and combination on the selected pixel and any three of the four pixels at the leftmost, rightmost, topmost, and bottommost;

obtaining four pixels after permutation and combination, and obtaining, based on the four pixels obtained after permutation and combination, a candidate minimum circle enclosing the four pixels; and

when a pixel that is not selected for permutation and combination is not located outside a boundary of the candidate minimum circle, traversing other pixels of the pupil contour, and when the other pixels comprise no pixel located outside the boundary of the candidate minimum circle, determining that the candidate minimum circle is a minimum enclosing circle of the pupil contour.

7. The method according to claim 1, further comprising:

obtaining four pixels for determining a minimum enclosing circle, randomly selecting two of the four pixels to obtain two different pixel combinations, and obtaining two straight lines by using the two different pixel combinations;

separately calculating perpendicular bisectors of the two straight lines, and calculating an intersection point of the two perpendicular bisectors to obtain a circle center of the minimum enclosing circle; and

calculating a distance between the circle center and any one of the four pixels to obtain a radius of the minimum enclosing circle.

8. A pupil radius detection apparatus, comprising:

an image extraction module, configured to: obtain a to-be-detected pupil radius image, and extract a region-of-interest image from the to-be-detected pupil radius image;

a pupil image obtaining module, configured to perform pixel processing on the region-of-interest image to obtain a pupil region image;

a pupil contour obtaining module, configured to extract a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

a center and circle center obtaining module, configured to obtain a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

a pupil radius obtaining module, configured to: obtain a distance between the center and each circle center, select a circle center closest to the center, use a minimum enclosing circle

corresponding to the closest circle center as a target circle, and use a radius of the target circle as a pupil radius.

9. The apparatus according to claim 8, wherein the pupil image obtaining module is further configured to obtain each pixel value of the region-of-interest image, and perform bitwise NOT processing on each pixel value to obtain each processed pixel value of the region-of-interest image; and

set a pixel value less than a preset threshold in all the processed pixel values of the region-of-interest image to zero, to obtain the pupil region image.

10. A computer device, comprising a memory and one or more processors, wherein the memory stores a computer readable instruction, and when executing the computer readable instruction, the one or more processors perform the following steps:

obtaining a to-be-detected pupil radius image, and extracting a region-of-interest image from the to-be-detected pupil radius image;

performing pixel processing on the region-of-interest image to obtain a pupil region image;

extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

obtaining a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

obtaining a distance between the center and each circle center, selecting a circle center closest to the center, using a minimum enclosing circle corresponding to the closest circle center as a target circle, and using a radius of the target circle as a pupil radius.

11. The computer device according to claim 10, wherein when executing the computer readable instruction, the processors further perform the following steps:

obtaining each pixel value of the region-of-interest image, and performing bitwise NOT processing on each pixel value to obtain each processed pixel value of the region-of-interest image; and

setting a pixel value less than a preset threshold in all the processed pixel values of the region-of-interest image to zero, to obtain the pupil region image.

12. The computer device according to claim 10, wherein when executing the computer readable instruction, the processors further perform the following steps:

obtaining a set of pixels of each of the plurality of pupil contours;

sorting pixels in the set of pixels in ascending order of polar angles, wherein pixels having the same polar angle are sorted in ascending order of distances to the bottom leftmost pixel in the set of pixels;

storing sorted pixels by using a structure array, traversing the sorted pixels, and removing a non-vertex pixel to obtain a vertex pixel set;

performing rotation determining on each vertex pixel in the vertex pixel set, and removing a vertex pixel at which rotation is not performed in a preset direction, to obtain pupil contours after convex hull processing; and

obtaining a set of minimum enclosing circles of the pupil contours obtained after convex hull processing.

13. The computer device according to claim 10, wherein when executing the computer readable instruction, the processors further perform the following steps:

obtaining minimum enclosing circles respectively corresponding to the plurality of pupil contours and radiuses of the minimum enclosing circles; and

removing a minimum enclosing circle whose radius is greater than a preset value from the minimum enclosing circles, to obtain the set of minimum enclosing circles of the pupil contours.

14. The computer device according to claim 13, wherein when executing the computer readable instruction, the processors further perform the following steps:

obtaining four pixels at the leftmost, rightmost, topmost, and bottommost of each of the plurality of pupil contours, and obtaining, based on the four pixels, a minimum circle enclosing the four pixels; and

traversing all pixels of the pupil contour, and when all the pixels comprise no pixel located outside a boundary of the minimum circle, determining that the minimum circle is a minimum enclosing circle of the pupil contour.

15. The computer device according to claim 14, wherein when executing the computer readable instruction, the processors further perform the following steps:

when all the pixels comprise a pixel located outside the boundary of the minimum circle, determining that the minimum circle is not a minimum enclosing circle of the pupil contour;

selecting a pixel farthest from a circle center of the minimum circle from pixels located outside the boundary of the minimum circle, and performing permutation and combination on the selected pixel and any three of the four pixels at the leftmost, rightmost, topmost, and bottommost;

obtaining four pixels after permutation and combination, and obtaining, based on the four pixels obtained after permutation and combination, a candidate minimum circle enclosing the four pixels; and

when a pixel that is not selected for permutation and combination is not located outside a boundary of the candidate minimum circle, traversing other pixels of the pupil contour, and when the other pixels comprise no pixel located outside the boundary of the candidate minimum circle, determining that the candidate minimum circle is a minimum enclosing circle of the pupil contour.

16. One or more non-volatile computer readable storage media storing computer readable instructions, wherein when executing the computer readable instructions, one or more processors perform the following steps:

obtaining a to-be-detected pupil radius image, and extracting a region-of-interest image from the to-be-detected pupil radius image;

performing pixel processing on the region-of-interest image to obtain a pupil region image;

extracting a plurality of pupil contours from the pupil region image by using a boundary tracing algorithm;

obtaining a center of the region-of-interest image, a set of minimum enclosing circles of the plurality of pupil contours, and a circle center of each minimum enclosing circle in the set of minimum enclosing circles; and

obtaining a distance between the center and each circle center, selecting a circle center closest to the center, using a minimum enclosing circle corresponding to the closest circle center as a target circle, and using a radius of the target circle as a pupil radius.

17. The storage media according to claim 16, wherein when executing the computer readable instructions, the processors further perform the following steps:

obtaining each pixel value of the region-of-interest image, and performing bitwise NOT processing on each pixel value to obtain each processed pixel value of the region-of-interest image; and

setting a pixel value less than a preset threshold in all the processed pixel values of the region-of-interest image to zero, to obtain the pupil region image.

18. The storage media according to claim 16, wherein when executing the computer readable instructions, the processors further perform the following steps:

obtaining a set of pixels of each of the plurality of pupil contours;

sorting pixels in the set of pixels in ascending order of polar angles, wherein pixels having the same polar angle are sorted in ascending order of distances to the bottom leftmost pixel in the set of pixels;

storing sorted pixels by using a structure array, traversing the sorted pixels, and removing a non-vertex pixel to obtain a vertex pixel set;

performing rotation determining on each vertex pixel in the vertex pixel set, and removing a vertex pixel at which rotation is not performed in a preset direction, to obtain pupil contours after convex hull processing; and

obtaining a set of minimum enclosing circles of the pupil contours obtained after convex hull processing.

19. The storage media according to claim 16, wherein when executing the computer readable instructions, the processors further perform the following steps:

obtaining minimum enclosing circles respectively corresponding to the plurality of pupil contours and radiuses of the minimum enclosing circles; and

removing a minimum enclosing circle whose radius is greater than a preset value from the minimum enclosing circles, to obtain the set of minimum enclosing circles of the pupil contours.

20. The storage media according to claim 19, wherein when executing the computer readable instructions, the processors further perform the following steps:

obtaining four pixels at the leftmost, rightmost, topmost, and bottommost of each of the plurality of pupil contours, and obtaining, based on the four pixels, a minimum circle enclosing the four pixels; and

traversing all pixels of the pupil contour, and when all the pixels comprise no pixel located outside a boundary of the minimum circle, determining that the minimum circle is a minimum enclosing circle of the pupil contour.