

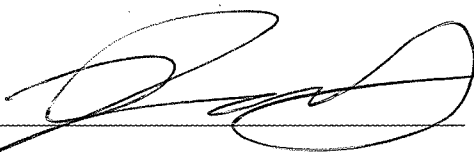
**VERIFICATION OF TRANSLATION**

I, Karen McGillicuddy

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declare that I am well acquainted with both the Japanese and English languages, and that the attached is an accurate translation, to the best of my knowledge and ability, of Japanese Patent Laid-open Publication No. 2000-242773, published September 8, 2000.

Signature

  
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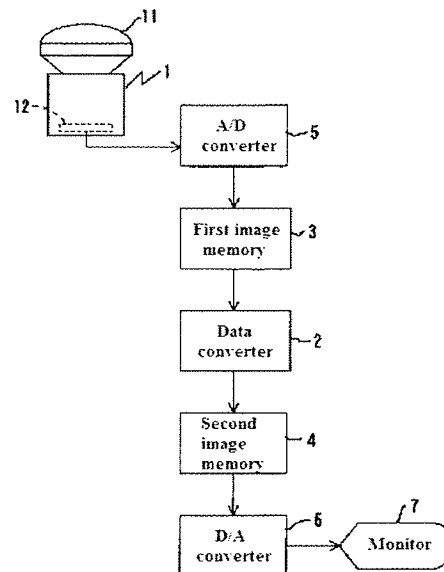
(54) [TITLE OF INVENTION]

**IMAGE DATA CONVERSION DEVICE**

(57) [ABSTRACT]

**[PROBLEM]** To convert image capture data of a full surrounding area obtained by a fish-eye lens such that distortion can be corrected and the image capture data can be displayed as a seamless single image.

**[MEANS FOR SOLVING THE PROBLEM]** With respect to a region for a portion of circular image data obtained by image capture using a fish-eye lens, a point  $(g(\Theta) \cdot \cos\psi, g(\Theta) \cdot \sin\psi)$  in the region on a planar Cartesian coordinate system whose origin point is a center of the circular image (where  $\Theta$  is a parameter fulfilling  $0 < \Theta < \pi/2$ ;  $g(\Theta)$  is a function fulfilling  $g(0) = 0$  and monotonically increasing in the range of  $\Theta$ ; and  $\psi$  is an angle formed by a line segment and a coordinate axis on the planar Cartesian coordinate system, the line segment linking the origin point of the planar Cartesian coordinate system and the point on the circular image) is converted into a point  $(R, \psi, R/\tan\Theta)$  on a cylindrical coordinate system where  $R$  is a constant.



**[SCOPE OF THE CLAIMS]**

**[CLAIM 1]** An image data conversion device wherein, with respect to a region for a portion of circular image data obtained by image capture using a fish-eye lens, a point  $(g(\Theta) \cdot \cos\psi, g(\Theta) \cdot \sin\psi)$  in the region on a planar Cartesian coordinate system whose origin point is a center of the circular image (where  $\Theta$  is a parameter fulfilling  $0 < \Theta < \pi/2$ ;  $g(\Theta)$  is a function fulfilling  $g(0) = 0$  and monotonically increasing in the range of  $\Theta$ ; and  $\psi$  is an angle formed by a line segment and a coordinate axis on the planar Cartesian coordinate system, the line segment linking the origin point of the planar Cartesian coordinate system and the point on the circular image) is converted into a point  $(R, \psi, R/\tan\Theta)$  on a cylindrical coordinate system where  $R$  is a constant.

**[CLAIM 2]** The image data conversion device according to claim 1, wherein the fish-eye lens has a property in which  $h = g(\theta)$  ( $h$  being an image height and  $\theta$  being a field angle).

**[CLAIM 3]** The image data conversion device according to claim 2, wherein the function  $g(\theta)$  is  $g(\theta) = 2f \cdot \tan(\theta/2)$  ( $f$  being a focal distance).

**[CLAIM 4]** The image data conversion device according to claim 2, wherein the function  $g(\theta)$  is  $g(\theta) = f \cdot \theta$  ( $f$  being a focal distance).

**[CLAIM 5]** A computer-readable storage medium storing a program executing operations of the image data conversion device according to any one of claims 1 to 4 on the computer.

**[CLAIM 6]** An image capture system comprising:

the fish-eye lens;

a conversion means converting an image obtained by the fish-eye lens into the image data;

the image data conversion device according to any one of claims 1 to 4; and

a display means displaying the image data on the cylindrical coordinate plane by projecting the image data onto a plane, the image data on the cylindrical coordinate plane having been converted by the image data conversion device.

**[CLAIM 7]** An image data conversion method wherein, with respect to a region for a portion of circular image data obtained by image capture using a fish-eye lens, a point  $(g(\Theta) \cdot \cos\psi, g(\Theta) \cdot \sin\psi)$  in the region on a planar Cartesian coordinate system whose origin point is a center of the circular image (where  $\Theta$  is a parameter fulfilling  $0 < \Theta < \pi/2$ ;  $g(\Theta)$  is a function fulfilling  $g(0) = 0$  and monotonically increasing in the range of  $\Theta$ ; and  $\psi$  is an angle formed by a line segment and a coordinate axis on the planar Cartesian coordinate system, the line segment linking the origin point of the planar Cartesian coordinate system and the point

on the circular image) is converted into a point ( $R, \psi, R/\tan\Theta$ ) on a cylindrical coordinate system where  $R$  is a constant.

## **[DETAILED DESCRIPTION OF THE INVENTION]**

**[0001]**

**[Technical Field of the Invention]** The present invention relates to an image data conversion device and, specifically, relates to a device converting image data having a circular shape and obtained by image capture with a fish-eye lens into planar image data in which distortion is corrected and wide area display is possible.

**[0002]**

**[Prior Art]** Conventionally, in an in-store surveillance camera, a traffic regulating camera, and the like, in order to monitor a status of a surrounding area, a camera having a field of view that is limited to a forward view is typically rotated by a drive device such as a motor. However, when such a camera having a limited field of view is rotated, a rotation driver becomes necessary, and thus the device becomes complex. In addition, the camera must be rotated when a specific target is to be captured and so when the target is moving, it may not be possible to capture the target due to limitations of rotation speed. Furthermore, a plurality of directions cannot be imaged simultaneously, constantly resulting in blind spots in a monitored area, and therefore such a camera cannot be said to be sufficient for a monitoring function and the like.

**[0003]** Japanese Patent Publication No. H06-501585 suggests, as a technology resolving such problems, converting image data having a circular shape into a planar image, the image data being obtained by capturing an image of all orientations forward of a fish-eye lens. A simple description of the technology follows. The circular image data obtained by the fish-eye lens can include an image of all orientations, but the image becomes more distorted further toward an outer periphery. This distortion can be largely removed when the circular image data is translated onto a hemisphere surface, but image data translated to the hemisphere surface cannot be displayed on a planar monitor. In the above technology, the portion of the image data translated to the hemisphere surface is further projected onto a planar surface, thereby enabling the image data to be displayed by conversion into a plane. By using such a method, a device can be simplified by making a rotation drive mechanism unnecessary, and switching a display direction simply becomes a matter of control during data processing, and thus can also be sped up remarkably.

**[0004]**

**[Problem to Be Solved by the Invention]** However, even when circular image data obtained in this way by the fish-eye lens is configured to be converted directly into planar image data, an entire hemisphere surface cannot be projected onto a single planar surface with adequate distortion correction, and therefore the image obtained relates only to a specific direction. Accordingly, blind spots occur on a display screen even though the full surrounding area is captured by the fish-eye lens. In addition, as a method to eliminate blind spots, a method performing planar image conversion for a plurality of directions simultaneously and performing simultaneous display can be considered. However, in such a case, seams between images are not continuous and a plurality of different image conversions must be performed.

**[0005]** In order to resolve these problems, the present invention has as an object to convert image capture data of a full surrounding area obtained by a fish-eye lens such that distortion can be corrected and the image capture data can be displayed as a seamless single image.

**[0006]**

**[Means for Solving the Problems]** In order to resolve the above-noted problems, with respect to a region for a portion of circular image data obtained by image capture using a fish-eye lens, an image data conversion device according to the present invention converts a point  $(g(\Theta) \cdot \cos\psi, g(\Theta) \cdot \sin\psi)$  in the region on a planar Cartesian coordinate system whose origin point is a center of the circular image (where  $\Theta$  is a parameter fulfilling  $0 < \Theta < \pi/2$ ;  $g(\Theta)$  is a function fulfilling  $g(0) = 0$  and monotonically increasing in the range of  $\Theta$ ; and  $\psi$  is an angle formed by a line segment and a coordinate axis on the planar Cartesian coordinate system, the line segment linking the origin point of the planar Cartesian coordinate system and the point on the circular image) into a point  $(R, \psi, R/\tan\Theta)$  on a cylindrical coordinate system where  $R$  is a constant. Moreover, what is referred to as a fish-eye lens in the present invention includes not only what is typically called a fish-eye lens, having a viewing angle of substantially  $180^\circ$ , but also includes what is typically called a wide-angle lens, having a narrower viewing angle.

**[0007]** Moreover, the conversion is sufficient when a conversion is performed that, as a result, satisfies the above-noted relationship and the process of the conversion is not discussed. In other words, the above-noted formula need not be applied directly, and cases are also included where conversion is performed using a table showing correspondence between pre-conversion pixels and post-conversion pixels. In addition, the planar Cartesian coordinate system and the cylindrical coordinate system are mutually independent and directions of the coordinates can be defined as desired. In addition, the cylindrical coordinate

system where  $R$  is a constant forms a cylindrical surface. However, herein, cases are also included where the above-described conversion is performed by projecting the image as a plane.

**[0008]** When configured in this way, first, when  $\psi$  is fixed and  $\Theta$  is increased from a small value to a large value within a range where the point  $(g(\Theta) \cdot \cos\psi, g(\Theta) \cdot \sin\psi)$  is in the region for the portion of the circular image data, a line segment oriented in a radial direction from the center of the circular image data is converted into the cylindrical coordinate system where  $R$  is a constant (i.e., as a line segment oriented from up to down on a cylindrical surface of radius  $R$ ). This conversion is further performed for  $\psi$  in a maximum range of  $360^\circ$  such that the above-noted point is in the region for the portion of the circular image data. Therefore, the portion of the circular image data is smoothly converted into a cylindrical surface in a form where distortion is corrected, the portion of the circular image data including image data for a full surrounding area centered on the fish-eye lens and captured by the fish-eye lens. The image converted into a cylindrical surface can be readily made into a planar image by projecting the cylindrical surface. Therefore, distortion of the image capture data of the full surrounding area obtained by the fish-eye lens can be corrected and the image capture data can be displayed as a seamless single image.

**[0009]** In addition, when the fish-eye lens has a property in which  $h = g(\theta)$  ( $h$  being an image height and  $\theta$  being a field angle), an amount that  $g(\Theta)$  increases accompanying an increase of  $\Theta$  is the same as the amount that the image height  $h$  increases. Accordingly, in other words, changing  $\Theta$  is the same as changing the field angle  $\theta$ . In such a case, the circular image is converted into an ideal, undistorted hemisphere surface and, moreover, an image can be obtained in which a converted hemisphere surface image is projected with respect to the cylindrical surface using light projected from a center point of the hemisphere surface and oriented in a radial direction, the cylindrical surface being positioned such that a center axis matches the center axis of the hemisphere surface. Accordingly, an image capture region spanning the entire area on the sides of the fish-eye lens (i.e., an image on an outer peripheral side of the circular image) is converted into an image with almost no distortion.

**[0010]** In addition, when the function  $g(\theta)$  indicating a property of the fish-eye lens is  $g(\theta) = 2f \cdot \tan(\theta/2)$  (where  $f$  is a focal distance), an amount of data for the image on the outer peripheral side of the circular image data is greater. Therefore, reproducibility during conversion into a cylindrical surface of an image capture area spanning the entire area on the sides of the fish-eye lens can be improved.

[0011] Moreover, when the function  $g(\theta)$  indicating a property of the fish-eye lens is  $g(\theta) = f \cdot \theta$  (where  $f$  is a focal distance), the property is that of the most typically used fish-eye lens. Therefore, a low-cost, mass-produced fish-eye lens can be used and cost of the device can be reduced.

[0012] The image data conversion device can also be achieved by installing a program executing the operations of the image data conversion device onto a computer, and the program can be stored on a storage medium readable by the computer.

[0013] Moreover, in order to resolve the above problems, an image capture system according to the present invention includes the fish-eye lens; a conversion means converting an image obtained by the fish-eye lens into the image data; the image data conversion device according to any one of claims 1 to 4; and a display means displaying the image data on the cylindrical coordinate plane as a plane by projecting the cylindrical coordinate plane, the image data on the cylindrical coordinate plane having been converted by the image data conversion device.

[0014] According to such a configuration, the image capture system, as described above, displays the image on the cylindrical surface by projecting the image as a plane, the image data conversion device having corrected distortion of the image and converted the image to remove seams. Therefore, a situation of a surrounding area captured by the fish-eye lens can be entirely shown on one screen. Moreover, the projected plane also includes cases where the projected plane is processed as appropriate, e.g., a case where the projected plane is cut at a predetermined position and each cut section is arrayed as appropriate for display.

[0015] Also, in order to resolve the above-noted problems, with respect to a region for a portion of circular image data obtained by image capture using a fish-eye lens, an image data conversion method according to the present invention converts a point  $(g(\Theta) \cdot \cos \psi, g(\Theta) \cdot \sin \psi)$  in the region on a planar Cartesian coordinate system whose origin point is a center of the circular image (where  $\Theta$  is a parameter fulfilling  $0 < \Theta < \pi/2$ ;  $g(\Theta)$  is a function fulfilling  $g(0) = 0$  and monotonically increasing in the range of  $\Theta$ ; and  $\psi$  is an angle formed by a line segment and a coordinate axis on the planar Cartesian coordinate system, the line segment linking the origin point of the planar Cartesian coordinate system and the point on the circular image) into a point  $(R, \psi, R/\tan \Theta)$  on a cylindrical coordinate system where  $R$  is a constant. The image data conversion method also smoothly converts the portion of the circular image data into a cylindrical surface in a form where distortion is corrected, the portion of the circular image data including image data for a full surrounding area centered on the fish-eye lens and captured by the fish-eye lens. Therefore, distortion can be corrected

and the image capture data for the full surrounding area obtained by the fish-eye lens can be displayed seamlessly.

[0016]

**[Mode for Carrying out the Invention]** Hereafter, a description of an embodiment of the present invention is given with reference to the drawings. Fig. 1 shows a block diagram illustrating a configuration of an image capture system according to the embodiment of the present invention. The image capture system is configured with a camera portion 1, a data converter 2, a first image memory 3, a second image memory 4, an A/D converter 5, a D/A converter 6, and a monitor 7.

[0017] The camera portion 1 uses a fish-eye lens 11 as a lens and is capable of image capture at a field angle of 90° or more at least with respect to an optical axis of the lens. Herein, a fish-eye lens is used having a property wherein

$$h = 2f \cdot \tan(\theta/2) \quad \text{①}$$

When a lens having such a property is used, an amount that an image height  $h$  increases relative to an increase in the field angle  $\theta$  becomes greater in comparison to a typical lens where  $h = f \cdot \theta$ . Therefore, an amount of information can be greater for a range having a large field angle  $\theta$  (i.e., a periphery of a circular image obtained by the fish-eye lens). The circular image obtained by the fish-eye lens 11 having this property is converted into an electronic signal by a CCD 12 for each RGB value of each pixel and is output to the A/D converter 5. Herein, the CCD is, for example, a CCD using 1280x1024 pixels.

[0018] The A/D converter 5 converts an analog signal transmitted from the CCD 12 into a digital signal and outputs the signal to the first image memory 3. The first image memory 3 is configured with a RAM and stores RGB values for each pixel based on the digital signal representing the transmitted circular image. The data converter 2 is equivalent to an image data conversion device according to the present invention and is configured with an arithmetic circuit performing calculations described below. The data converter 2 converts the circular image data stored in the first image memory 3 into cylindrical image data using a conversion described in detail hereafter, then outputs the image data to the second image memory 4.

[0019] The second image memory 4 is again configured with a RAM, and the RGB values for each pixel of the output image data are stored as a plane, described hereafter, onto which the cylindrical surface is projected. In addition, the image onto which the cylindrical surface is projected is long in a width direction. Therefore, in order to obtain the display data



described below, when storing image data, the second image memory 4 stores the projected image such that the image is divided into halves and placed at a predetermined vertical interval. The D/A converter 6 reads the image data having digital values stored in the second image memory 4 and converts the image data into an analog signal, then transmits the analog signal as an image signal in order of scan lines of the monitor 7. The monitor 7 displays the image stored in the second image memory 4 based on the image signal transmitted by the D/A converter 6.

**[0020]** Moreover, portions of the present image capture system except the camera portion 1 can be achieved by installing a program to accomplish the above-noted functions and the below-noted operations on a typical computer. The program can be stored on a storage medium such as a floppy disk that is readable by the computer. In addition, the program can be installed on the computer through a communication means such as the Internet.

**[0021]** At this point, a conversion method of the data converter 2 is described in detail. The data converter 2 converts the image data on the circular surface onto a cylindrical surface. A correspondence relationship between points on the circular surface and points on the cylindrical surface is described with reference to Figs. 2 and 3. Fig. 2 is a view showing a relationship between a desired point P0 on a hemisphere surface O, which supposes an ideal full circumferential surface captured by the fish-eye lens 11, and a point P2 on the cylindrical surface C, which is the converted surface. In Fig. 2, in an xyz coordinate system, the hemisphere surface O has a base circle (a circle configuring an edge of the hemisphere surface) positioned on an xy plane and centered on the origin point. A z axis coincides with the optical axis of the fish-eye lens 11. Furthermore, the cylindrical surface C is a cylinder of radius R axially centered on the z axis. In other words, the cylindrical surface C can be represented as a curved surface in an rψz cylindrical coordinate system where R is constant. In addition, herein, points on the cylindrical surface C are represented by (R, ψ, z) as points on the rψz cylindrical coordinate system. However, ψ is an angle formed by a line segment and an x axis, the line segment being created by the origin point and a point of intersection between a vertical line down to the xy plane and the xy plane. Also, P2 is a point where a straight line extension of a line segment linking the origin point with the desired point P0 on the hemisphere surface O intersects with the cylindrical surface C. Moreover, an angle formed by the z axis and the line segment linking the origin point with the point P0 has a field angle θ with respect to the point P0.

**[0022]** The desired point P0 on the hemisphere surface O, which supposes the above-noted ideally captured full circumferential surface, indicates a position of a point P1 on a captured

image surface F captured by the fish-eye lens 11 in Fig. 3. A circular region on the captured image surface F in Fig. 3 is a region on the CCD 12 bombarded by light through the fish-eye lens 11, and forms a circular surface S displaying converted image data. In Fig. 3, an origin point on an XY coordinate system is occupied by the center of the circular surface S.

Moreover, directions of the X axis and the Y axis are configured to be opposite from the x axis and the y axis of the xyz coordinate system of Fig. 2. This is in order to handle P0 also being shown in a position inverted top to bottom and left to right because the image captured by the camera portion 1 is inverted top to bottom and left to right. However, the cylindrical surface is arbitrary, and so in an actual conversion there is also liberty in how coordinates are handled. In addition, the position of P1 is a position at an image height h distance from the origin point where an angle formed by the X axis and a line segment linking the origin point with P1 is  $\psi$ . h is expressed by the above noted formula 1 and is defined by the field angle  $\theta$ .

**[0023]** The data converter 2 converts P1 shown in Fig. 3 into P2 shown in Fig. 2. Hereafter, a description is given of a concrete calculation. First, a case is considered where parameters are set to  $\theta$  and  $\psi$ . In this case, the coordinates of P1 on the XY plane are  $(h \cdot \cos\psi, h \cdot \sin\psi)$  and, when h is substituted out using the above-noted formula 1, are represented by  $(2f \cdot \tan(\theta/2) \cdot \cos\psi, 2f \cdot \tan(\theta/2) \cdot \sin\psi)$ . Meanwhile, for the coordinates of P2, R is a constant, and z has a relationship according to Fig. 2 in which  $z = R / \tan\theta$ , and thus the coordinates of P2 are represented by  $(R, \psi, R / \tan\theta)$ . Accordingly, the parameters  $\theta$  and  $\psi$  can be moved to specify P1 on the circular image on the XY plane, and a point on the r $\psi$ z cylindrical coordinate system (that is, the point on the cylindrical surface C) can also be specified with respect thereto. Therefore, the image data can be converted according to a formula that indicates P1 and P2. However, in a case where  $\theta = 0$ , the z coordinate of P2 becomes infinitely large, and therefore in reality a value of  $\theta$  is used which is a certain value or more. In the present embodiment, a range of  $\pi/4 \leq \theta < \pi/2$  is used for  $\theta$ .

**[0024]** In an actual conversion, calculation is facilitated by using data directly representing a position of each pixel in the captured CCD 12 or a post-conversion position of each pixel on the converted cylindrical surface C as the parameters. Use of x and  $\psi$  as parameters directly representing the post-conversion position of each pixel on the cylindrical surface C is considered. In such a case, when the point P2 on the cylindrical surface C is represented with the parameters z and  $\psi$ , the coordinates are  $(R, \psi, z)$ . The converted cylindrical surface C is projected and displayed on the monitor 7, and each pixel is aligned at equal intervals of a pixel pitch d in a longitudinal direction and a lateral direction. Fig. 4 illustrates a view representing a relationship between the projected cylindrical surface C and the circular

surface S. The longitudinal direction of the cylindrical surface C coincides with the parameter z. Therefore, when a change is made to the parameter z in units of the pixel pitch d, the changes coincide with the longitudinal direction pixel positions of the cylindrical surface C. An amount of change accompanying an amount of change in  $\psi$  in the lateral direction of the projected cylindrical surface can be represented by  $R \cdot \psi$ . Therefore, when the amount of change of the parameter  $\psi$  corresponding to the pixel pitch d of the cylindrical surface C is  $\Delta\psi$ , the amount of change can be represented as  $\Delta\psi = d / R$ . Accordingly, when a change is made to the parameter  $\psi$  in units of  $d / R$ , the change coincides with the lateral direction pixel positions of the cylindrical surface C. Moreover, a range where the circular surface S has hatching in the drawings is a range of the circular surface S corresponding to  $\pi/4 \leq \theta < \pi/2$  and indicates the range converted into the cylindrical surface C.

**[0025]** Meanwhile, representing the point P1 on the circular image using the parameters z and  $\psi$  is considered. First, when transforming the above-noted formula ① using a double-angle formula for a trigonometric function,

$$h = 2f \cdot \tan(\theta/2) = 2f \cdot \{\sin\theta / (1 + \cos\theta)\} \quad \text{①'}$$

results. Fig. 2 shows that  $\sin\theta = R / (R^2 + z^2)^{1/2}$ ,  $\cos\theta = z / (R^2 + z^2)^{1/2}$ , and therefore when these are substituted into the formula 1 and simplified,  $h = 2f \cdot R / \{(R^2 + z^2)^{1/2} + z\}$  results. Therefore, as a result, P1 is  $(2f \cdot R \cdot \cos\psi / \{(R^2 + z^2)^{1/2} + z\}, 2f \cdot R \cdot \sin\psi / \{(R^2 + z^2)^{1/2} + z\})$ .

Accordingly, as noted above, changes are made to z in units of d, and changes are made to  $\psi$  in units of  $d / R$ , then the pixel positions on the circular surface S, in which each pixel position on the cylindrical surface C is converted by the formula, can be found. In such a case, the pixel positions obtained by calculation and the pixel positions actually captured by the CCD 12 fail to coincide completely, and therefore the nearest pixel is extracted.

Specifically, obtained X coordinate values and Y coordinate values are, for example, divided by a pixel pitch ds of the CCD 12 and those values at or below a decimal point, for example, are discarded. Thereby, the obtained integer value can be extracted as a number for the pixel. Moreover, in such a case, where the origin point of the XY coordinates is (0, 0), each pixel of the CCD 12 is respectively defined with a positive or negative in accordance with each quadrant of the XY coordinates.

**[0026]** Using the above method, the data converter 2 calculates the circular surface S pixel position corresponding to each pixel on the post-conversion cylindrical surface C, then converts the pixel data of the pixel positions as respective pixel data on the cylindrical surface C. As a result, as shown in Fig. 4, the pixel data on the circular surface S is converted

as respective pixel data on the cylindrical surface C. Moreover, an unambiguous determination is made as to which pixel position of the cylindrical surface each pixel of the circular image is transformed into. Therefore, the data converter 2 can be provided with a table showing a correspondence between the pixels of the circular image and the pixel positions on the cylindrical surface without performing calculations, and the data conversion can be performed based on this.

**[0027]** Next, a description is given of operations of the image capture system having the above-noted configuration. Moreover, the camera portion 1 is mounted inside a room, oriented downward from a center of a ceiling. Further, a range of  $z$  of the converted cylindrical surface is  $0 < z \leq R$ . In other words, the range of  $\theta$  is defined as  $\pi/2 > \theta \geq \pi/4$ . Fig. 5 is a flowchart illustrating operations of the image capture system. First, a panoramic view of the room is captured by the camera portion 1 as a circular image through the fish-eye lens 11. The circular image is converted to an electrical signal by the CCD 12, then is further converted to digital values for each pixel by the A/D converter 5. Then, this data is stored in the first image memory 3 (s101). Furthermore, 0 is input for each of the parameters  $\psi$  and  $z$  as an initial value (s102).

**[0028]** Next, using the data converter 2, a parameter  $\psi_i$  is increased in units of  $d / R$  until  $i = 1 \sim n$  ( $n = 2\pi R / d$ ), and a parameter  $z_j$  is increased in units of  $d$  until  $j = 1 \sim m$  ( $m = R / d$ ).

Then, for each of the values,

$$X_i = [2f \cdot R \cdot \cos \psi_i / \{(R^2 + z_j^2)^{1/2} + z_j\} \cdot ds]$$

$$Y_j = [2f \cdot R \cdot \sin \psi_i / \{(R^2 + z_j^2)^{1/2} + z_j\} \cdot ds]$$

is calculated and, based on the results,  $(X_i, Y_j)$  order pixel data stored in the first image memory 3 is extracted and stored in the second image memory 4 as pixel data of the  $(i, j)$  order pixel in the cylindrical surface (s103 - s108). Moreover, in the second image memory 4, in order to display the image as shown in Fig. 6 on the monitor 7, the pixels  $(i, j)$  on the cylindrical surface are divided into two parts, one part in which  $i = 1 \sim n/2$  and  $j = 1 \sim m$  and one part in which  $i = (n/2) + 1 \sim n$  and  $j = 1 \sim m$ , and are stored so as to obtain an image in which the latter part is positioned so as to be a predetermined interval below the former part. Moreover, text data indicating the angle, shown in Fig. 6, is pre-stored in the second image memory 4.

**[0029]** The image data stored in the second image memory 4 is output to the monitor 7 as an image signal by the D/A converter 6 (s109) and is displayed by the monitor 7 (s110). The image data is divided into two parts and formed so as to be positioned vertically, as noted above, and thus a screen shown in Fig. 6 is displayed. In this way, in the image capture

system according to the present embodiment, footage of an environment in 360° captured by the fish-eye lens can be fully and seamlessly displayed, and a status of the environment of the lens can be fully monitored without blind spots.

**[0030]** In the above-described embodiment, a fish-eye lens was used having a property represented by the above formula 1. However, the fish-eye lens may also have a property not represented in formula 1. Specifically, when the property of the fish-eye lens is generalized to  $h = g(\theta)$ , P2 remains as described above and P1 can be represented with  $(g(\theta) \cdot \cos\psi, g(\theta) \cdot \sin\psi)$ . Therefore, in a case where the parameters are  $\theta$  and  $\psi$ , it is sufficient to use the same. Moreover, in a case where the parameters are  $z$  and  $\psi$ , as described above, it is possible to use the expression  $\theta = \tan^{-1}(R/z)$ , per Fig. 2. Therefore, P2 remains as described above and P1 can be represented with  $(G(\tan^{-1}(R/z)) \cdot \cos\psi, G(\tan^{-1}(R/z)) \cdot \sin\psi)$ . Therefore, similar to the above, corresponding P2 and P1 pixel positions can be found while changing the values of  $z$  and  $\psi$ .

**[0031]** For example, in a case where a commonly used fish-eye lens having a property in which  $h = f \cdot \theta$  is used as the fish-eye lens, it is sufficient to make similar conversions as above in which, when the parameters are  $\theta$  and  $\psi$ , P1 is  $(f \cdot \theta \cdot \cos\psi, f \cdot \theta \cdot \sin\psi)$ , and when the parameters are  $z$  and  $\psi$ , P1 is  $(f \cdot G(\tan^{-1}(R/z)) \cdot \cos\psi, f \cdot G(\tan^{-1}(R/z)) \cdot \sin\psi)$ . Moreover,  $\tan^{-1}(R/z)$  can be found using a known regression calculation.

**[0032]** Moreover, a fish-eye lens having a property in which  $h = f \cdot \theta$  can be swapped for the fish-eye lens 11 in the above-described embodiment, while other components remain the same. This is because, although a rate of expansion and contraction of an image in a radial direction differs between the circular image obtained by the fish-eye lens having the property according to the above-noted formula 1 and the fish-eye lens circular image having the property  $h = f \cdot \theta$ , an adjacency relationship between the images does not change, and therefore the obtained image can fulfill a role as a surveillance image with only minor differences of expansion and contraction appearing in the  $z$  direction.

**[0033]** Even more generally, using a monotonically increasing function  $g(\Theta)$  in a range where  $0 < \Theta < \pi/2$ , when P1 is  $(g(\Theta) \cdot \cos\psi, g(\Theta) \cdot \sin\psi)$ , images are displayed for various kinds of fish-eye lenses, the images differing only in the rate of expansion and contraction in the  $z$  direction. In addition, by using, as the function  $g(\Theta)$ , a function having a least amount of  $z$ -direction distortion in response to the property of the fish-eye lens being used, a surveillance image that is easier to see can be obtained.

**[0034]** Further, the image capture system in the above-described embodiment is configured to convert and display an image for all of a 360° environment captured by the fish-eye lens

11. However, in a case where the camera portion 1 is installed where a wall meets the ceiling, for example, converting and displaying a 180° portion excluding the wall direction is sufficient, and in a case where the camera portion 1 is installed in a corner, converting and displaying a 90° portion excluding the wall directions that enclose the corner is sufficient. In this way, depending on a situation, a range for conversion can be determined as desired.

[0035] In addition, in the image capture system of the above-noted embodiment, the range of  $0 \leq \theta < \pi/4$  is not displayed. However, because this range has a small amount of distortion in the original circular image, the range may also be configured to be matched with the image of the cylindrical surface C and displayed on the monitor 7 as the circular image, without performing conversion.

#### [BRIEF DESCRIPTION OF THE DRAWINGS]

[FIG. 1] is a block diagram illustrating a configuration of an image capture system according to an embodiment.

[FIG. 2] is a view showing a relationship between a point on a hemisphere surface, which supposes an ideal full circumferential surface captured by a fish-eye lens, and a point on a converted cylindrical surface.

[FIG. 3] is a view showing a point on a captured image surface corresponding to a point on a hemisphere surface, which supposes an ideal full circumferential surface captured by the fish-eye lens.

[FIG. 4] is a view illustrating a projected cylindrical surface.

[FIG. 5] is a flowchart illustrating operations of the image capture system.

[FIG. 6] is a view illustrating a display screen using a monitor.

#### [DESCRIPTION OF REFERENCE NUMERALS]

- 1 Camera portion
- 2 Data converter
- 3 First image memory
- 4 Second image memory
- 5 A/D converter
- 6 D/A converter
- 7 Monitor
- 11 Fish-eye lens
- 12 CCD

Fig. 1

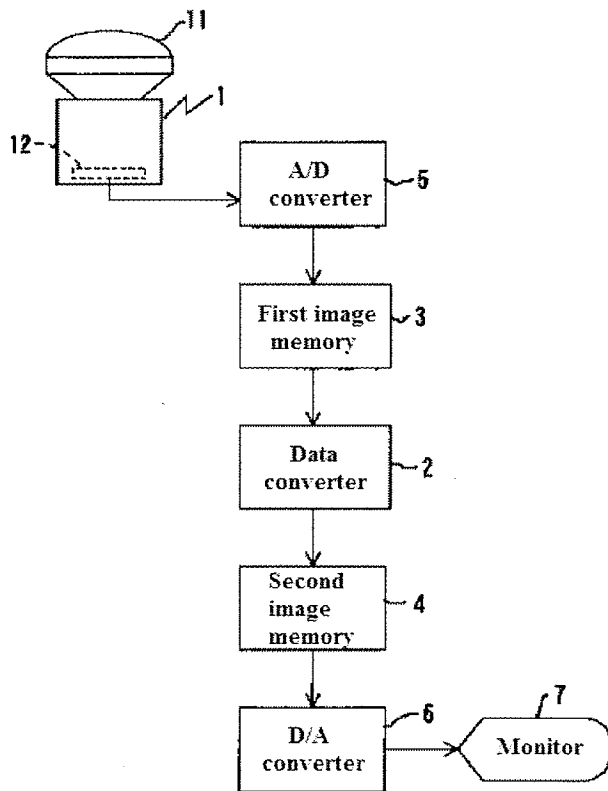


Fig. 2

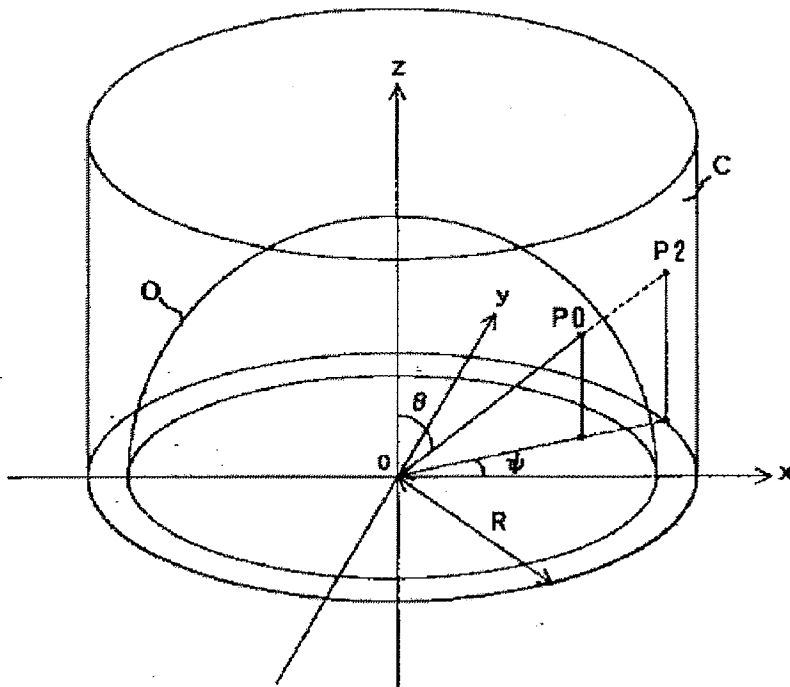


Fig. 3

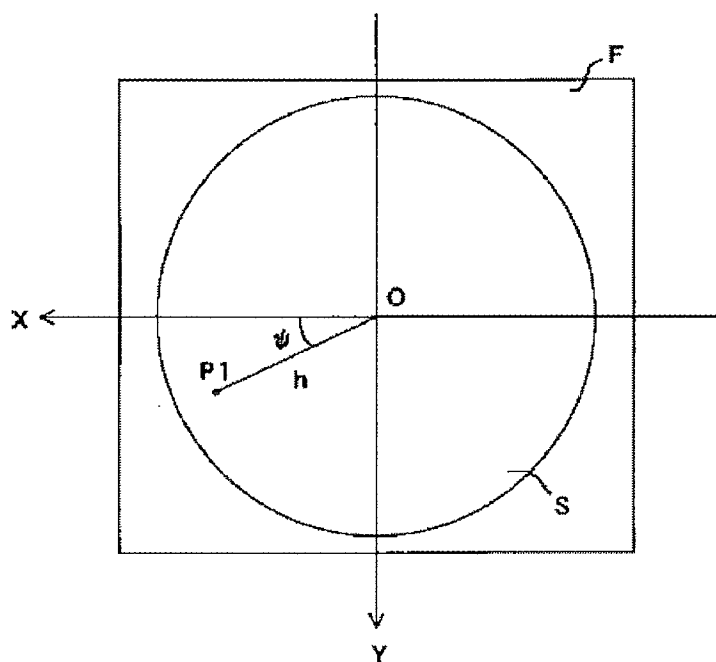


Fig. 4

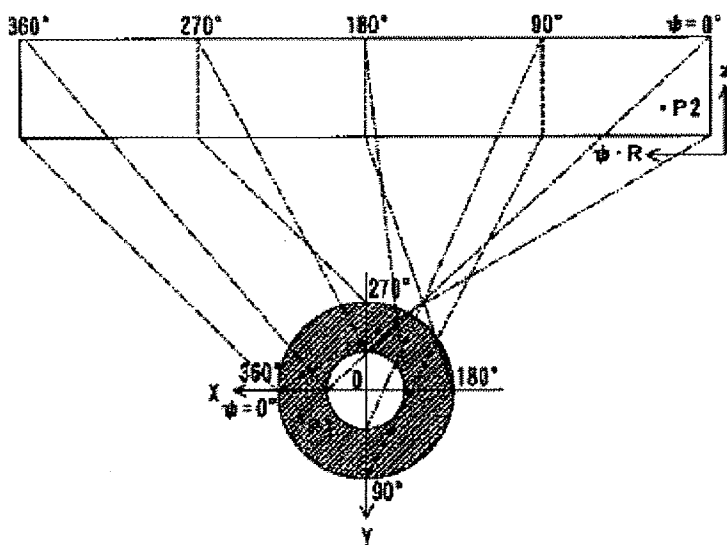




Fig. 5

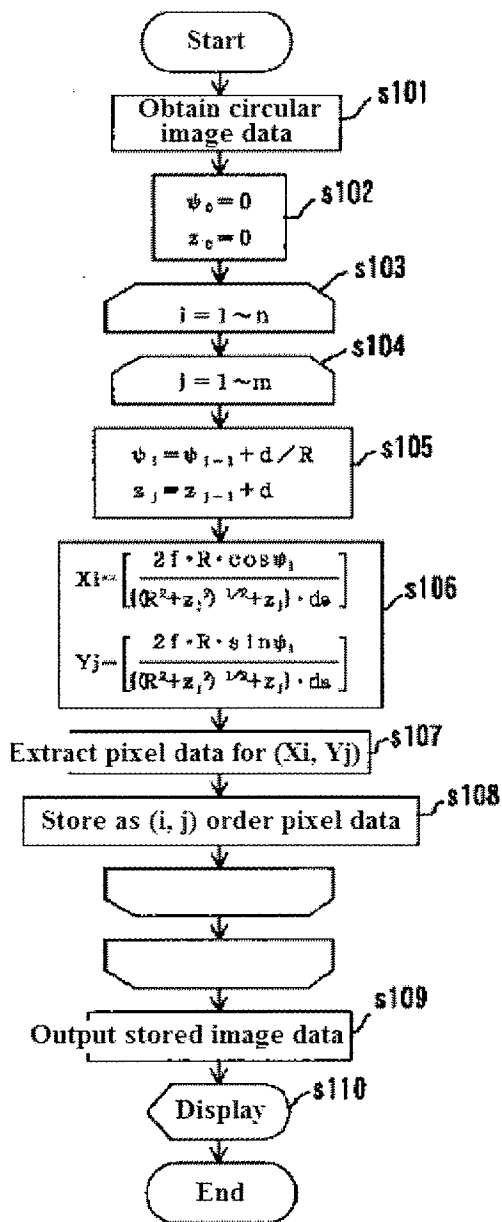
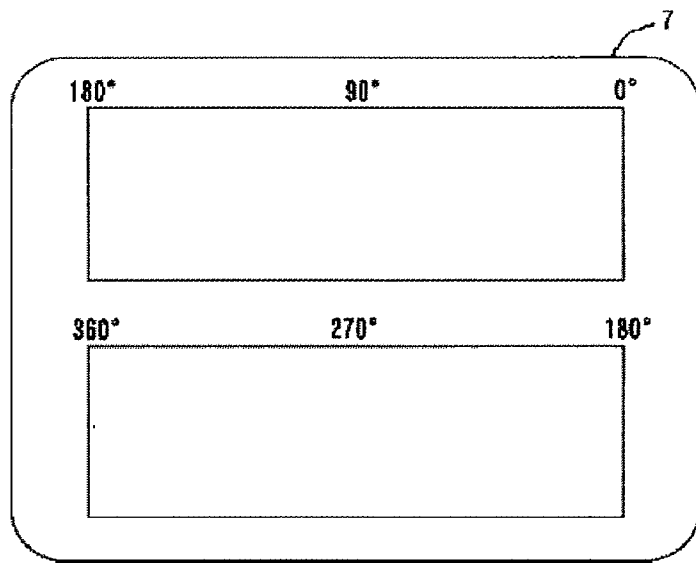


Fig. 6



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