A study and development for STEREO FUNDUS CAMERA SYSTEM using Stereo Matching Technique.

TSURU Kosuke, Inoue T., Ogino N., Matuyama M.,
Aero Asahi Corp.
Saitama Kawagoe Minamidai 3-1-1 Japan

Nanjo T., Yano. N., Hino T.
Nidek Co., LTD.
Aichi Gamagori Hiroishicho 34-14 Japan

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Abstract

Recently, ME equipment are popularized rapidly in field of medical treatment. All eye disease can be treated simply at present. But in case of glaucoma diagnosis, the cases of disease is not clearly known and damages badly. Therefore analyzing system is urgency need. So we developed STEREO FUNDUS CAMERA SYSTEM using stereo matching technique.

This system takes stereo photos with a ocular fundus camera (special stereo camera), create DEM and ortho photo automatically by using stereo matching technique. And the system allow to measure and/or analyze symptoms for glaucoma diagnosis using super imposed DEM to ocular fundus images. Also stored data is worth because of automatically processing has high reproducibility, and the extraction of temporal change of symptoms is easily possible.

KEY WORDS: Medicine, Automation, Matching, DEM/DTM, Close_Range, Optical

1. Introduction

Measurements of the ocular fundus (fig - 1) by photogrammetry using an analytical plotter already is done (Takamoto 1986). And digital system on photogrammetry is developed and tried (Nanba 1989). However both method is doing manual way or require to the assistance by skilled operators. So that the processing time to get the result is big. Or using the systems are required specialists.

On the other hand, analysis of photo images using image correlation technique is being developed as the method to generate contours automatically using aerial photographs from the end of 1950's (Mori 1981, 1982, 1985). As well as there are studies using stereo images by liner array sensor (Murai 1984, 1987). These purpose are automation of stereo matching from stereo images, and area correlation method is used for stereo matching technique.

Using area correlation for map automation, the decision for window size that makes the correlation is difficult. Also there is problems of occlusions like valley and building which hide opposite side of project center. To solve these problems, image filtering and/or step correlation (Course-to-fine) methods are adopted.

Analysis for the fundus of the eye is also taken height information from a pair of stereo photos using area correlation, but there are some remarks and problems.

At first, making maps are require the result to keep high accuracy. However in fundus analysis, first purpose is to monitor the fundus condition. And the system is to be used on site medical examination and treatment, so that speedy processing is require. Also custom friendly operation is require because of oculists whose are nonprofessional for the computer system.

On second, a fundus image is taken photograph through the human crystalline lens and pupil of a patient. This means the crystalline lens assumes one of the camera lenses in the system. Further two bundle of ray for stereo photographing have to through the pupil, this means photo base length is very short.

On third, fundus camera itself is developed for monitoring but not for measuring or analysis, so that the camera lacks high accuracy. Making a dummy model of eye to get camera calibration and orientation factors are very difficult, because of the dummy model of eye itself is very small, and there are some problems like no way to put control points on the fundus of the dummy model of eye. Also adjustment or detection for camera calibration is impossible because of the crystalline lens power is different on each patient, and the focus must be adjusted each time.

On fourth, eye fundus surface is covered by retina and blood veins. And the retina is half transparency and expressionless pattern, therefore possibility for mismatching is high. Even in case the system decided matching success, the system dose not know which stratum of fundus is matched.

This paper mentions solutions for the first and second problems, and introduce the developed system. Also this paper mentions present solutions for the third and forth problems.

2. Glaucoma

The cause of glaucoma disease is not clearly known. The symptoms are progresses slowly, and disease are continue without feeling pain, and finally the glaucoma will lose eyesight from the patient.

The statistic shows that 3 % of 40 years and elder are suffered by glaucoma, and it is highest cause of blind.

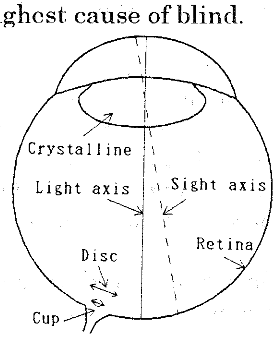


Fig - 1 Fundus

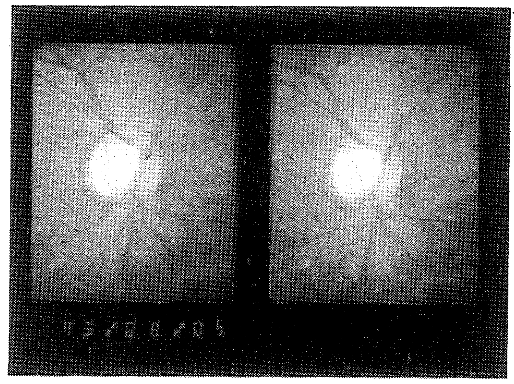


Fig - 2 Stereo photo of fundus

3. Principle

The bundle of ray reflected from ocular fundus by flush light of a fundus camera makes a spatial image by focusing through convex lens of the fundus camera. This spatial image is relayed to a film surface through lenses after the convex lens as stereo viewing (fig - 2). Getting DEM of fundus from the stereo images on the film is divided two systems as below.

1) A ocular fundus to a spatial image
2) A spatial image to a film surface

First, at system of 2) on the basis of photogrammetry principle, height of spatial image is taken by parallax of stereo image. And a fundus height is taken by multiplying magnification of system of 1) to the spatial image height.

The system prepares a CCD camera upon the film surface where fundus images are focusing. Also a normal camera can be set on the same position. In this case, developed films are scanned to digital images by a film scanner which included in the system.

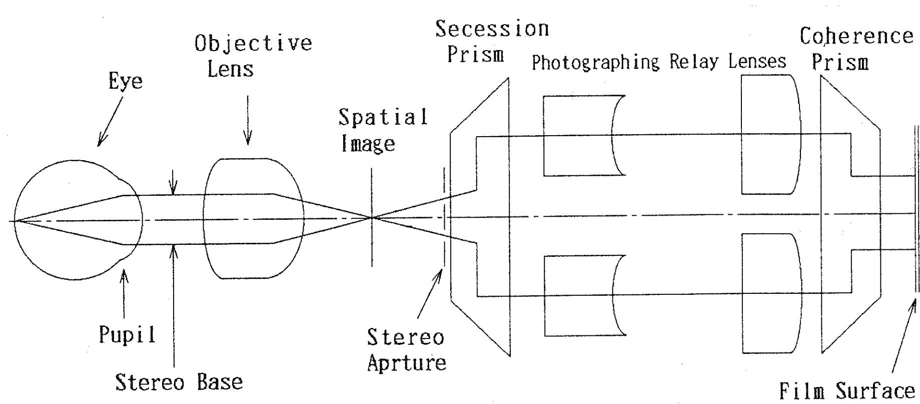


Fig - 3 Photographing optical system of the fundus camera

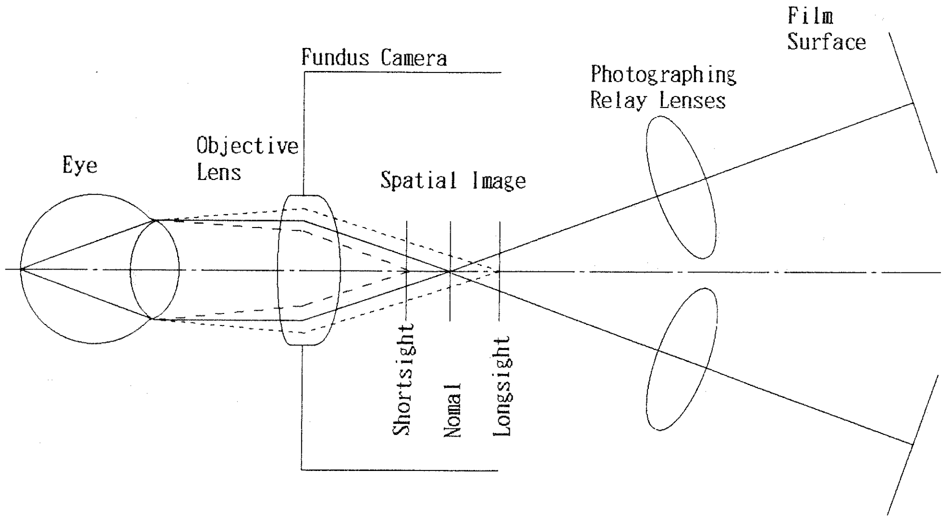


Fig - 4 Optical concept on photogrammetry

4. Processing flow

Processing flow of the system for the ocular fundus DEM and diagnostic analysis is as fig - 5.

1) Extraction

Stereo ocular fundus images are taken in one file according to the fundus camera structure. Therefore, those images have to extract in each file to be obeyed photogrammetric order.

One bit image is made from the original image, and noises in the image is removed. Next, according to method of least squares, the solution of a linear equation of four side lines of fundus image is calculated. From those result of correlation coefficients, one of four side lines that have most high straightness is used as basis of extraction. Then, according to the scale of image frame in the fundus camera, stereo images are extracted to each files (fig - 6).

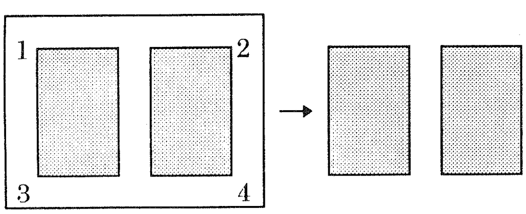


Fig - 6 Extraction

2) Interpolation

Image data getting form CCD camera is not fine enough pixel size for measuring accurately. So that cubic convolution is incorporated, and the resolution of height is enlarged (fig - 14).

3) Orientation

It is impossible to make control points on ocular fundus surfaces. Also it is very hard to makes fundus model with control points. So that we used nominal values of the fundus camera as the orientation factors (fig - 7).

4) Datum plane

A spatial image moves to front or back depend on shortsightedness or longsightedness. According to this phenomenon, a stereo fundus image move to inside or outside on the film. On this length of shift value, basis of height become a unique on each ocular fundus. So that to make standard level of height, the slide difference is modified according to extracted distinctive features.

Relation of spatial image movement by shortsightedness and longsightedness are as fig - 8 and fig - 9.

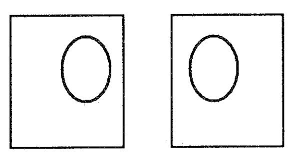


Fig - 8 Shortsightedness

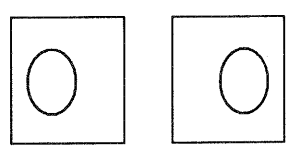


Fig - 9 Longsightedness

The shift value of entire up/down for vertical parallax and left/right for eyesight on both images is calculated also using stereo matching method. Then image which has less entire shift value.

This process also decides zero position. In short, the distinctive points on around fundus except disc cupping are extracted. The standard deviation of pixel differences (parallax) between stereo image are calculated. Further, average of pixel differences which removed points more than 2 σ of dispersion is calculated. And the half of average is given both image, then entire pixels are moved. So those pixel position become close. The position where distinctive points are coincided (parallax is nearly zero), is become datum plane (height is zero).

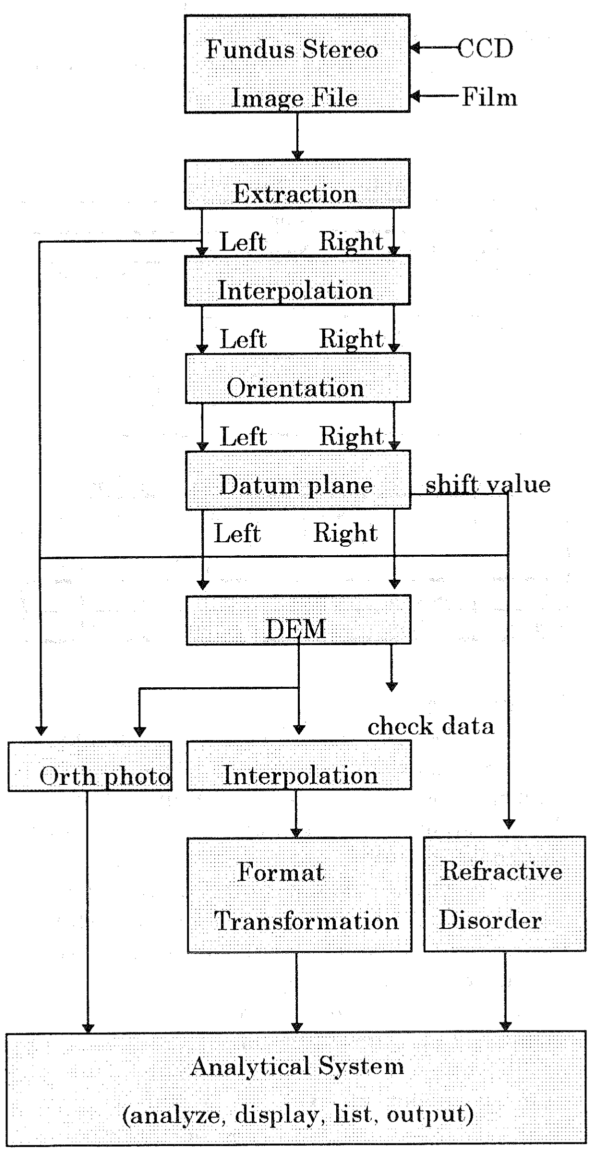


Fig - 5 Processing flow

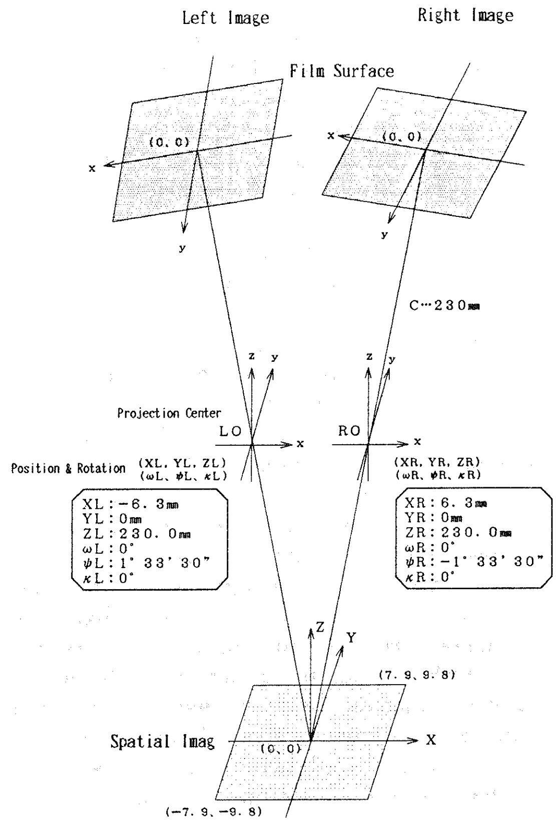


Fig - 7 Orientation factors (Nidek 3-DX/NM)

5) DEM

By the requested steps on ordered area, using template matching method of correlation, height is decided by parallax of stereo images, then DEM is generated.

On this processing, both side reference is adopted of the purpose to make matching accuracy higher. Reciprocal reference is to reference right side based on left image, and to reference left side based on right image. From the result of reciprocal reference filter of miss-matching, the matching result is decided how to adopt. In case the both references are succeeded, average of the results is adopted. In case the result is only one side, this result is adopted. And the both references are failed, this result of the position are interpolated from surrounding.

From these result, DEM numerical value and DEM check image data are generated.

These result are on the spatial image. So that transformation from the spatial image to fundus is necessary. This transformation is done by using shift value of refractive disorder calculated on the process. The relation between shift value and transformation factor (β) is measured in advance. The relation between spatial and fundus on position and height are as below.

(position on fundus) = (position on spatial) $\times \beta$
(height on fundus) = (height on spatial) $\times \beta^2$

6) Analytical processing for diagnosis

The results of stereo matching can be presented on the monitor as a natural colored 3D image. Thus, it offers oculists realizable condition image of the cup and disc in the area. In addition, it is also possible to display the wire frame, the contour lines, cross-sectional drawings, and so on.

One side, arranged data obtained from the stereo matching can be utilized for diagnosis in routine work or as diagnosis soft ware. Other side, by using the interactive analysis function, many measured data can be utilized for various clinical applications.

For the glaucoma diagnosis, after the drawing a disc outline by manual on the displayed ortho photo in the system, analytical values and lines as below are automatically calculate.

Cup outline
Horizontal cross section
Vertical cross section
Nerve fiber analysis
Max. disc diameter (vertical)
Max. disc diameter (horizontal)
Cup / Disc ratio (vertical)
Cup / Disc ratio (horizontal)
Disc area
Cup area
Rim area
Cup / Disc area ratio
Rim / Disc area ratio
Max. cup depth
Cup volume

Also these analytical processing as below are incorporated in the system.

Contour lines
Multi cross sections
GUI functions
List up of diagnosis history for a fundus

5. Examination

Examination for the system is done using each images by film scanner and CCD camera.

Table - 1 Examination image

	Pixel × line	resolution
film scanner	3883 × 2592	9.4 μ m
CCD camera	768 × 480	47.5 μ m

From the result for matching used these image, remarkable feature points are plotted on the image as figure - 13. These images show matching is done exactly.

Also bird eye view images are made from DEM and image taken CCD camera and two enlarged images by interpolation from same images are shown as figure - 14. This proves the interpolation is effective.

The system configuration using these examination is table - 2 and figure - 12. And process time for one image is as table - 3.

Table - 2 Hard ware

Item	Name
fundus camera	Nidek 3-Dx
CCD	1/2 inch 3CCD (SONY DXC-930)
Still Video Recorder	FUJIX DF-10M
Computer	PC
CPU	i486 DX2 66MHz
Memory	24MB

Table - 3 Result for the processing time

	pixels	resolution [μ m]	DEM time [second]	analysis time [second]
CCD	768 X 480	47.5	90	120
scanner	1024X612	35.6	180	340

5. Accuracy

Dummy model of eyes are made to confirm matching accuracy. One of the dummy model of eye is two laminated small discs shaped doughnut figure which thickness is 0.5mm each (fig - 11). The inner diameter of each doughnut is different 1 mm and 2 mm. And random burns on doughnut laminates are made by laser beam. Using this dummy model of eye, matching without interpolation is done. And profiles are measured on four directions. The average of profile value is refer to nominal value of dummy model of eye. So that horizontal direction is not good because of occlusion by cliffs of doughnut, however vertical direction in around 50 μ m .

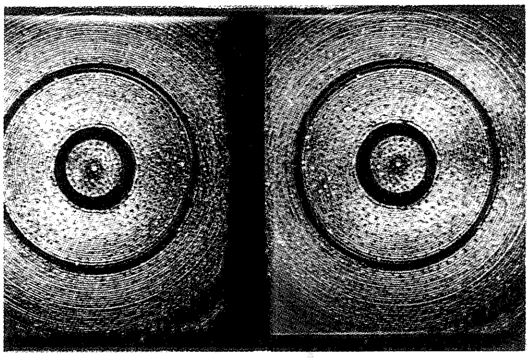


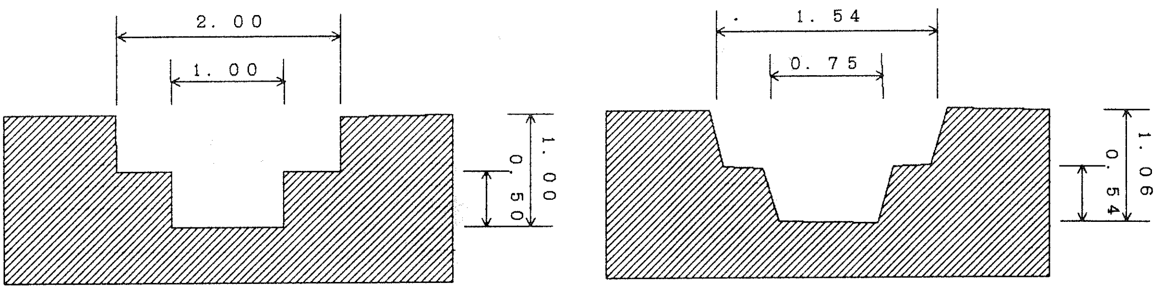
Fig - 10　Fundus dummy model of eye

4. Conclusion

Our stereo fundus camera system is fully automatic after taking ocular fundus images, and processing time for DEM is about 90 seconds, processing time for same analysis from DEM takes less than 120 seconds.

This system made on the purpose that oculists use on daily work. So that processing time is very important, but accuracy is lose. For example it is no lens distortion to calibrate. Orientation result which came from fundus camera design is not tied. Further more, on the surface of the ocular fundus semitransparent membrane is exist, and matching position is disquiet upside or downside of the membrane.

We continue to solve those problems, and to confirm accuracy, and to get more high accuracy.



Dummy model of eye　　　　Stereo matching result

Fig - 11　Matching accuracy on model [mm]

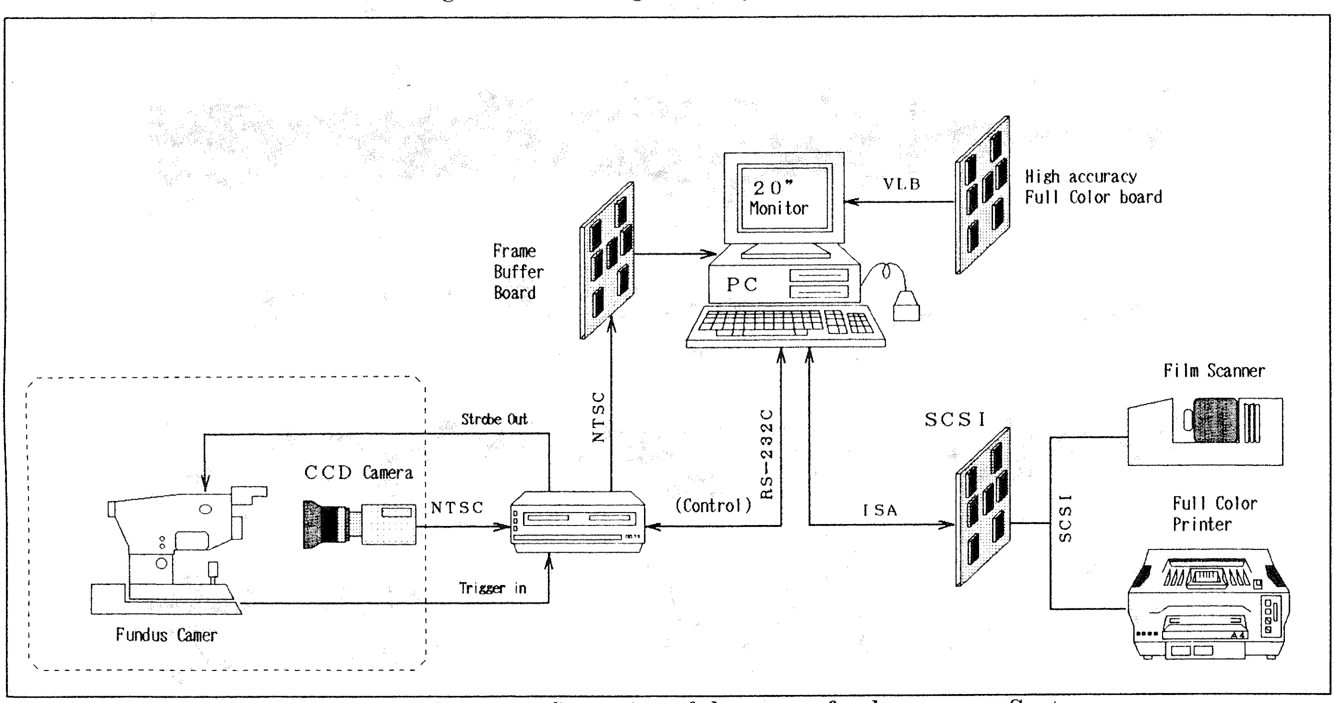


Fig - 12　Hardware configuration of the stereo fundus camera System

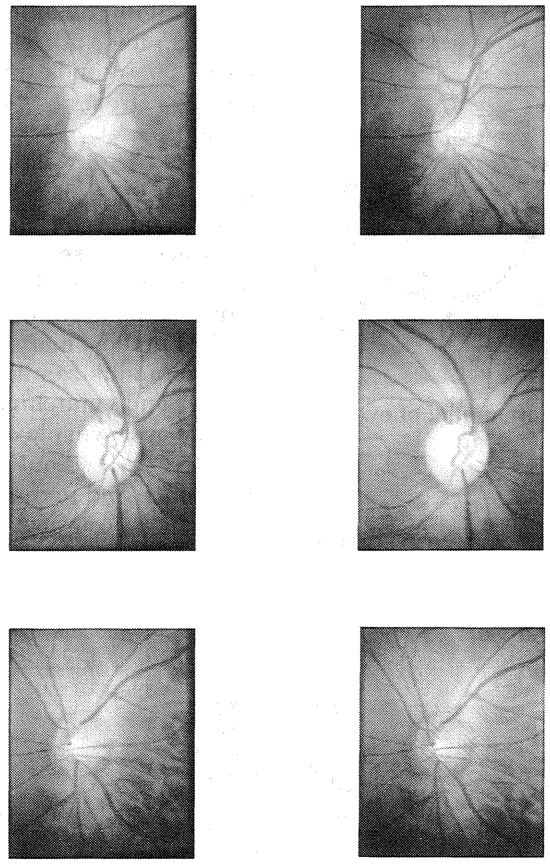


Fig - 13 matching verification on fundus (g0, g1, g2)

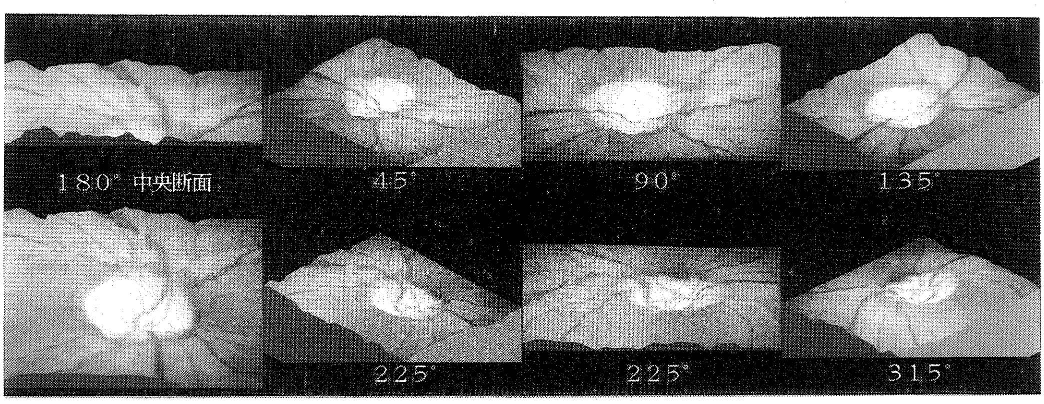


Fig - 14 bird eye views on original image (g1)

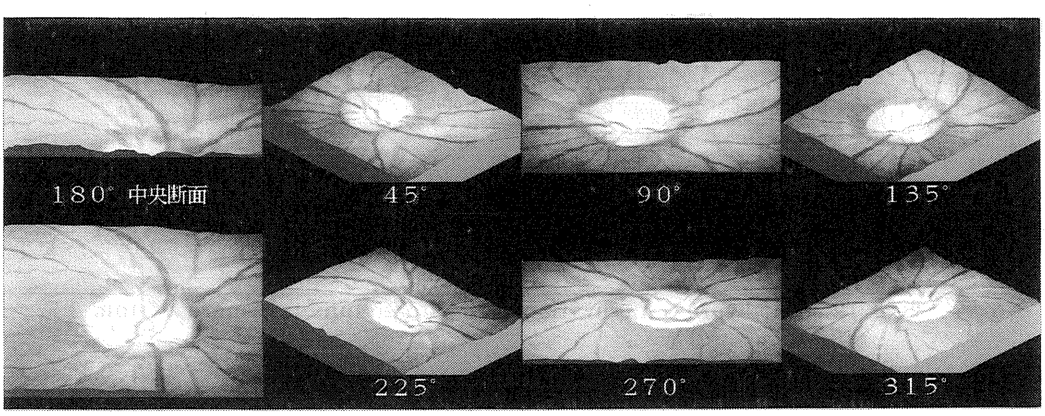


Fig - 15 bird eye views on interpolated image (g1)

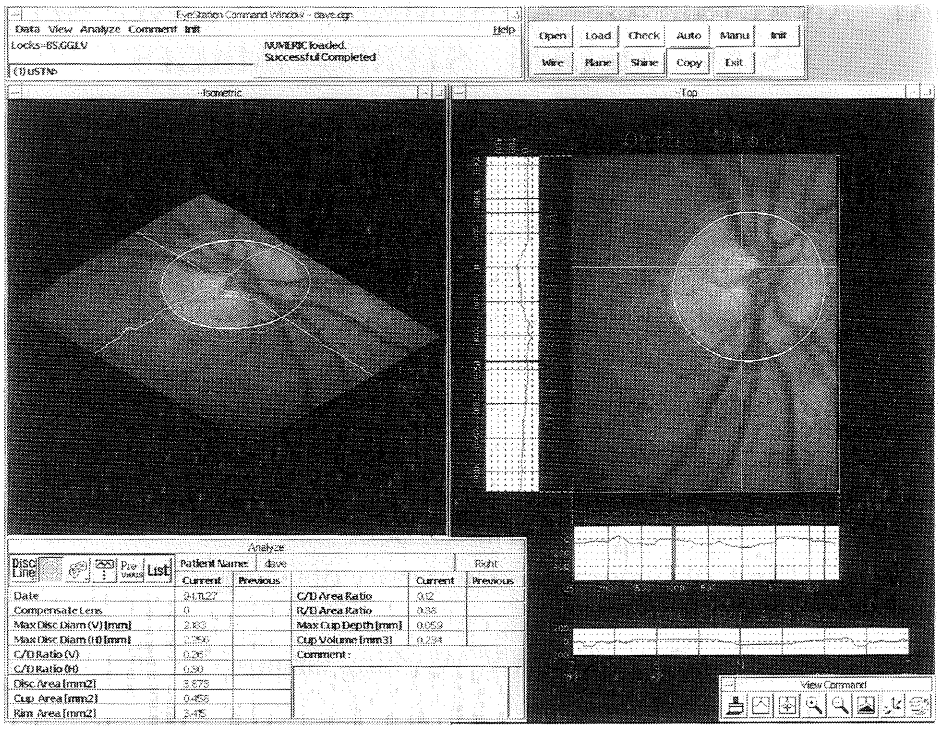


Fig - 16 Display of the stereo fundus camera system

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