# A Fisheye Lens 360 Degree Panoramic Monitoring System Based on the FPGA


Da-Peng Lan, Jiang-Hui Deng, Rui-Bin Liu, Feng Li, and Zhi-Yong Pang*

*School of Physics and Engineering, Sun Yet-Sen University*

*No. 135, Xingang Xi Road, Guangzhou, 510275, P. R. China*

* *Instructor*

stspzy@mail.sysu.edu.cn  020-84114462  13480268263



*Abstract*—**This paper designs and implements a panoramic monitoring system based on the FPGA fisheye lens. Fisheye images produced suffer from severe distortion. Therefore, it must be corrected to approximately rectilinear versions. Nowadays, most of the algorithms used to correct the fisheyes distortion are realized by software. In this paper, we compared three algorithms used for panoramic monitoring system. And the obtained result of the spherical perspective projection algorithm is promising. The spherical perspective projection algorithm is implemented on a FPGA and a panoramic monitoring has been achieved in a SOPC system.**



***Keywords*—FPGA; panoramic monitoring; fisheye; spherical perspective projection; SOPC**


## Ⅰ.INTRODUCTION

The fisheye lens are designed to cover the whole hemispherical field in front of the camera, hence, the angle of view is very large, about 180°. So it has more image information and we can use less lens to obtain a wider scene. This will simplify the process of acquiring the image and save hardware resources. Because the fisheye lenses provide very large wide-angle views, the fisheye cameras are finding increasing number of applications in video conference, monitoring and intelligent transportation.

This paper designs a 360° high resolution video monitoring system based on the FPGA. A circular fisheye lens angle with 185°is used and the distortion in the circular view image is corrected. The so-called "360° of view" refers to when the fisheye lens suspended overhead shot down without rotation, it will be able to obtain an image with 180°pitching angle and 360°horizontal angle, as shown in Fig. 1.

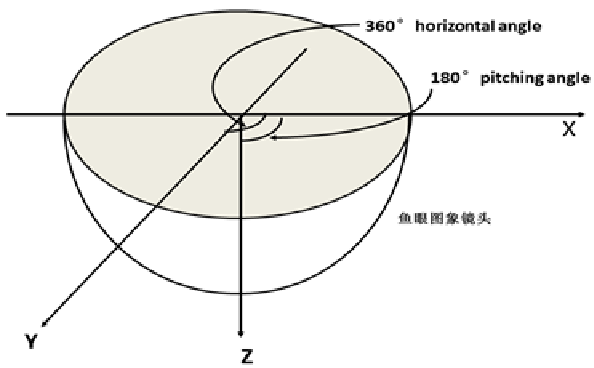


Fig. 1 an image with 180°pitching angle and 360°horizontal angle

But fisheye image with distortion will not only influence the human eye observation but also make the image recognition poor. The closer to the edge of the circular area, the greater the distortion. So the fisheye camera image must be corrected to suit for the human eye observation or using image recognition technology to expand the practicability of fisheye lens.

According to the wide angle of fisheye image, the fish-eye lens can satisfy the demand of real-time monitoring wide range without blind area. Fisheye lens applied in video monitoring has the advantages: fisheye lens has a broad perspective of more than 180 °; the entire room can be monitored with a fish-eye camera, as shown in Fig. 2. The camera angle used by current monitoring system is generally not more than 75 °.

Fig. 2 a fish-eye camera can monitor the whole room

## Ⅱ. ALGORITHM

Fisheye lens is very convenient, but it's images have serious distortion, so it needs to be corrected, which is the key of this system.

### *A. 2D coordinate mapping correction model [1]*

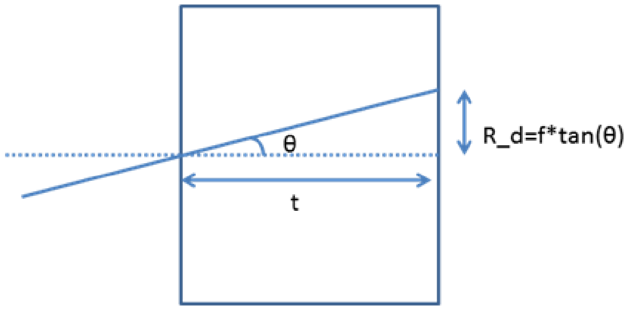


Figure 3 The perspective model

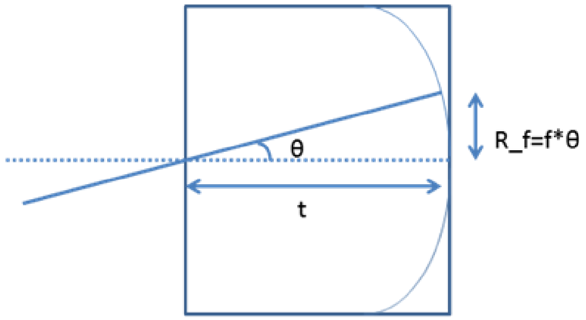


Figure 4 Fisheye model

Figure 2.1 (not fisheye) is perspective projection model, Figure 2.2 is fish eye model. The specific formula is as follows:

$$R_f = 2f\,\sin(\tfrac{\theta}{2}) \qquad (1)$$

$$R_f = 2f\,\tan\theta \qquad (2)$$

$$\frac{x_p}{y_p} = \frac{x_f}{y_f} \qquad (3)$$

So according to the above three equations:

$$x_f = \frac{2x_p \sin\tan^{-1}(\lambda/2)}{\lambda} \qquad (4)$$

$$y_f = \frac{2y_p \sin\tan^{-1}(\lambda/2)}{\lambda} \qquad (5)$$

$$f = \frac{image\_width}{4\sin(FOV_{horz}/2)} \qquad (6)$$

Fisheye-Corrected Images of this algorithm as shown below:

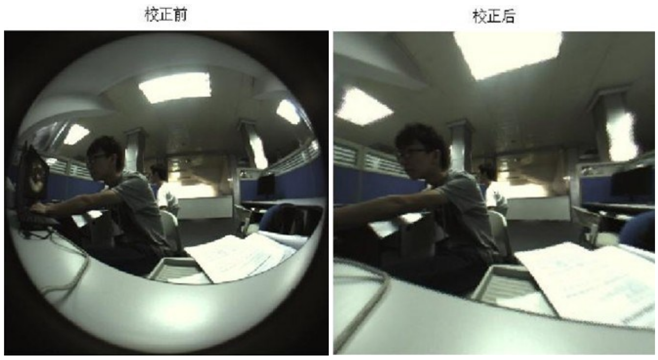


Fig. 5 Fish-eye lens calibration using 2D coordinate mapping correction model

### *B. 2D Spherical Coordinates [2-3]:*

We first calculate the center point of the fisheye image and standard round transformation, and then carry on the spherical coordinates. Fisheye image distortions in the scene can be represented with longitude in figure.6, which means that different pixels of every longitude in corrected images have the same column coordinate values. As shown in figure.6, h and k points in the scene have the same x coordinates without distortion. The greater the longitude of the meridian, the more serious of distortion will be. For any points on the vertical pixel coordinates $Y_j$, the angle from the left border to the right boundary of the sphere are equal, and the matching line segments on the x axis direction evenly split on the longitude. As a result, the distances of different $Y_j$ on longitude on the x direction are equals. Therefore, according to the proportional relationship between images, we can obtain the x coordinates of points h by point k.

$$\frac{x_k}{d_x} = \frac{x_h}{R} \Rightarrow x_k = \frac{x_h}{R} \times \sqrt{R^2 - {y_j}^2} \qquad (7)$$

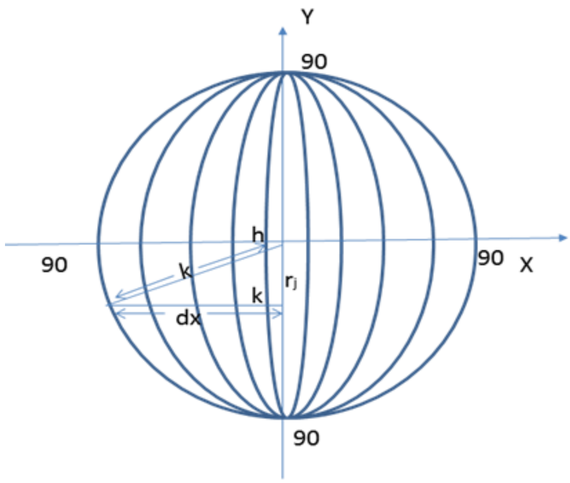


Figure.6 2D spherical coordinates positioning model

R is the radius of the fisheye images. $X_h$ is the distance between h point and the image center point O along x axis. $X_k$ is the distance between k point and the image center point O. Fisheye image whose level horizon is not 180 degrees can also use the same method.

Fisheye-Corrected Images of this algorithm as shown below:

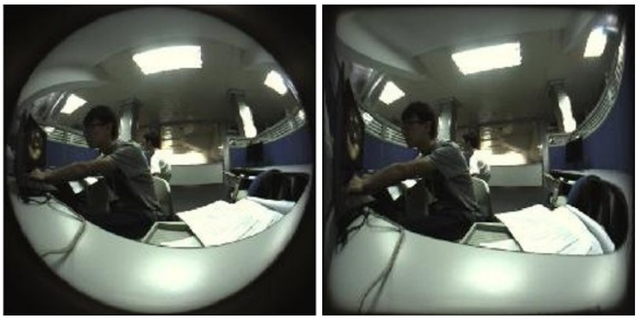

Fig.7 Fish-eye lens calibration using 2D Spherical Coordinates

*C. Spherical perspective projection* [4-5]

As the figure below, fish-eye imaging process can be divided into three steps:

*1)* Each point $P_0$ is mapped to ray $OP_0$ connecting $P_0$ and projection center O;

*2)* Ray $O_{P0}$ maps onto the unit sphere linearly, and obtain spherical perspective projection point $P_1$;

*3)* Nonlinear project spherical point $P_1$ onto plane XOY, and obtain fish-eye photo image points $P_2$. In figure.8, the entire hemisphere on XOY plane projection part is the final fisheye photos.

According to the fish-eye imaging process, in order to extract the whole fisheye three-dimensional information, the hemisphere is added a circumscribed cube. Its front and back, left, right and top surface respectively simulate the realistic circumstance. The cube correction model as shown in the figure below:

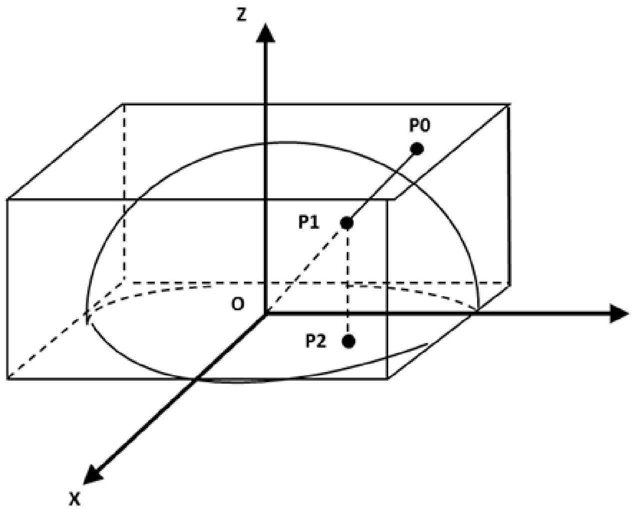


Figure.8 the cube correction model

A hemisphere equation is:

$$\begin{cases} x^2 + y^2 + z^2 = R^2 \\ z \gg 0 \end{cases} \quad (8)$$

Set point $P_0$ (m, n, p), linear $O_{P0}$ equation is:

$$\frac{x}{m} = \frac{y}{n} = \frac{z}{p} \quad (9)$$

By the formula (8) and formula (9) , the coordinates of the point $P_1$ is:

$$\left(\frac{m\times R}{\sqrt{m^2+n^2+p^2}}, \frac{n\times R}{\sqrt{m^2+n^2+p^2}}, \frac{n\times R}{\sqrt{m^2+n^2+p^2}}\right) \quad (10)$$

the coordinates of the $P_2$:

$$\left(\frac{m\times R}{\sqrt{m^2+n^2+p^2}}, \frac{n\times R}{\sqrt{m^2+n^2+p^2}}, 0\right) \quad (11)$$

which is fisheye image pixel coordinates.

So we can find the coordinate mapping relation, and set the fisheye image coordinates (u, v), then

$$u = \frac{m\times R}{\sqrt{m^2+n^2+p^2}}; \quad (12)$$

$$v = \frac{n\times R}{\sqrt{m^2+n^2+p^2}}. \quad (13)$$

Fisheye-Corrected Images of this algorithm as shown below:

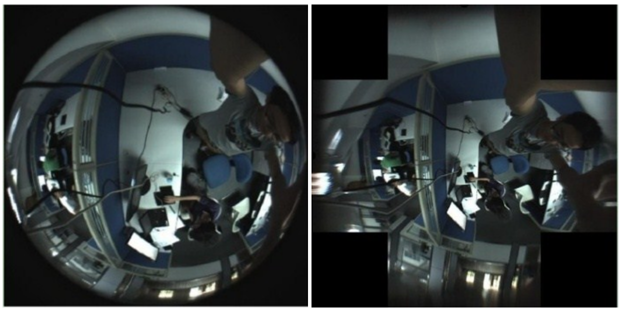

Fig. 9 Fish-eye lens calibration using Spherical perspective projection

After comparing three kinds of algorithm above, we found that 2D correction algorithm is suitable for the angle less than 140 °. For 180°wide angle, spherical perspective projection model is more applicable. The amount of calculation is not complex and easy to implement, so we choose this algorithm for the system.

## III. SYSTEM DESIGN

In the aspect of software implementation, the large fish eye correction computation makes process of the correction slow. And due to the serial nature of the instruction execution, it is difficult to implement real-time correction on PC or DSP platform whose power consumption are large, which made their application suffer lots of limited. Hardware is able to implement correction quickly, but it lacks of flexibility. So considering the problem of software and hardware issue, it is a good solution to combine the FPGA with the Nios ii. We propose using the software resource to improve the flexibility of the system and using the speed of the hardware to improve the speed of fish-eye calibration. It can save the system hardware resources, reducing power consumption.

*A. System hardware structure is shown in the following figure:*

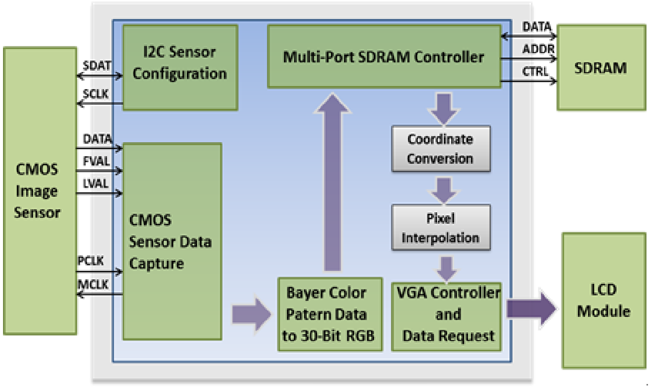


Figure.10 System hardware structure diagram

According to the figure above, the characteristic of fisheye image real-time distortion correction based on FPGA device is that the device includes:

Fisheye image CCD sensor: including fisheye lens, the D5M camera and image collection chip, which is used to collect original fisheye images;

Hardware circuit of image processing: consist of the image acquisition module, SDRAM controller module and image correction module. Image acquisition module is used for the acquisition of the original fish eye image obtained by fisheye image sensor, and they are stored in the storage device through the SDRAM controller modules. By the SDRAM controller module, image correction module has access to SDRAM and implements coordinate transformation and pixel interpolation. After the correction, image is stored in SDRAM.

SDRAM memory device: used for storage of original fisheye images and images after correction.

Display unit: including VGA controller and LCD display which is used to display the image after correction sented from the storage device.

*B. System software structure as shown in the figure below:*

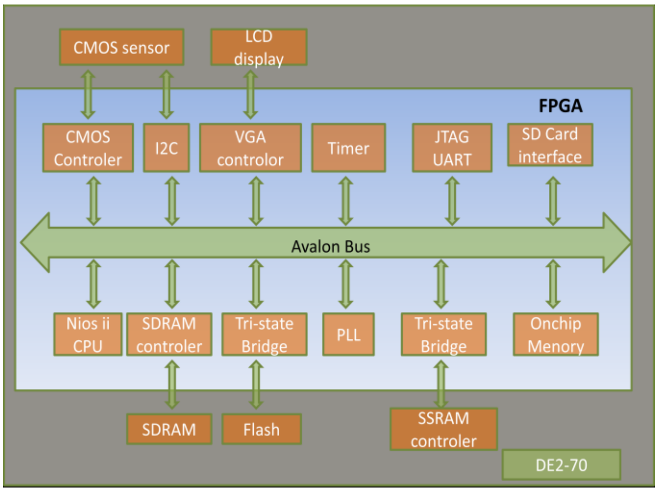


Figure.11 system software structure

## IV. Module Design

*A.CMOS sensor module*

We use the Terasic company D5M camera for this fisheye sensor. To achieve the fish-eye effect, we use a NL1796DTF fisheye lens, which is about 180 °angle. As is shown in the figure below:

Figure.12 Fisheye lens

*B. CCD Controller and peripherals IP module*

We referred to Terasic "TRDB D5M - the Hardware specification Verilog" manual and designed the CCD Controller IP with Avalon bus, controlling and initializing the camera through the software program. At the same time, the CCD Controller IP could read cache of two continuous images in the SDRAM and the image coordinate signal send from VGA Controller, which enables the Nios II to collect image data in real-time and process for moving target detection.

CCD is controlled by the I2C mode, and the pulse for CCD module is produced by the I2C .The D5M is configured through the I2C bus interface, its serial bus timing parameters is shown in the figure below;

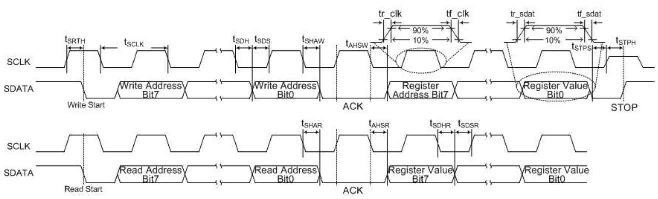


Figure.13 the I2C serial bus timing parameters

*C. RAW to RGB modules:*

Raw data means the CCD sensor raw data. A single pixel can only be induced a kind of color. T5M cameras are using Bayer pattern to output pixel data. As is shown in figure.14, black pixel values to 0. Odd lines contain green and red color of the pixel and even lines contain blue and green color pixels. Odd columns contain green and blue colors of pixels, and an even columns contain red and green color pixels.

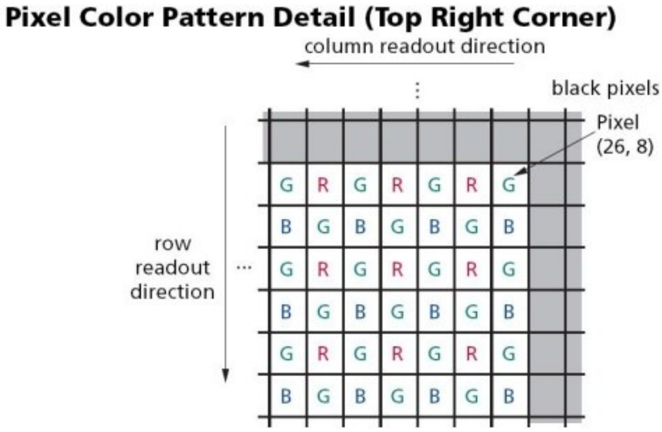


Figure.14 Bayer pattern output pixel data model

Overview: the line buffer and line processing mode.

The row data (Bayer color pattern) fetched in the former stage can be real-time covered to standard 30bit RGB data and sampled properly, in order to facilitate the subsequent image processing and display.

*D. Fisheye calibration module:*

Fisheye calibration module is the key to this system. This module consists of two parts: coordinate calculation and pixel interpolation correction.

*1) Coordinate calculation*

Coordinates calculation has a key skill: the repeatability of coordinate calculation. Repeatability refers that for each frame, coordinate calculation results are the same, which means that the calculating result has nothing to do with the image content. Repeatability of coordinate calculation can be achieved by two ways. One is to store the result in the flash ROM in advance. After the system start up, it will copy the coordinates from the flash ROM onto SRAM block to achieve the desired computational speed. But it will increase the reliance on outside (flash ROM). The second method is calculating the coordinate by hardware and storing the results in the SRAM. This method will consume part of hardware resources, but it can reduce the dependence of the outside world.

Considering the repetitive characteristic, calculating by hardware is definitely a better choice. So the system chooses the second scheme. So our system chooses the second scheme.

Calibration module mainly is to realize the distortion correction algorithm. The specific formulas are shown in *(12), (13)*. These formulas require multiply, Mac, Square root and division operation.

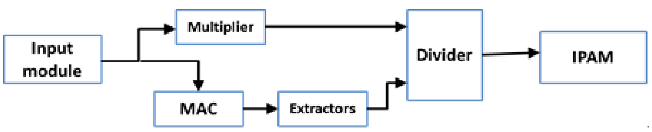


Fig.15 calculate operation

Because the FPGA contains hardware multiplier internally, multiplication can be realized by using hardware multiplier in just one clock cycle. Additionally, Altera provides the basic algorithm IP core which can easily finish the function above. We simply use the IP core in the development software with correct timing sequence. The Schematic diagram after synthesis is shown below:

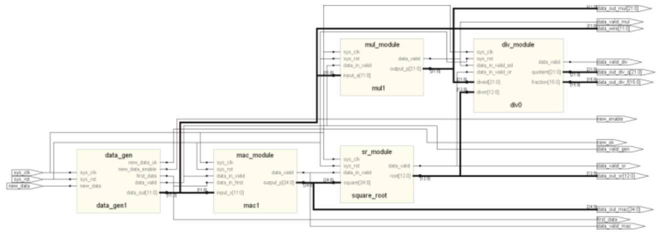

Fig.17 the schematic diagram after synthesis

*2) Optimization: The compression of storage*

Because the demanding speed of calibration is higher in this paper, so the coordinates should be stored in the storage device, such as the SRAM. In order to reduce the storage size of SRAM as far as possible, this system uses a compression method to store the coordinate data: the compression based on the symmetry [6], shown as figure. 18:

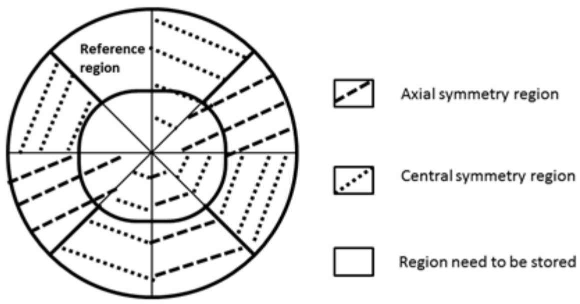


Fig.18 the symmetry of the fisheye image

Fisheye images are symmetrical about calibration center. Each pixel on the periphery of the center line and edge line is axisymmetric. Therefore, the division of the fisheye image has four axis of symmetry. Also the fisheye image itself has a center of symmetry. In combination with two symmetrical, fisheye image can be obtained by copying a part of the image. So we call the copy of the source image “the reference region”. Then the reference region has axially symmetric or central symmetry relations with the rest of the region. For axisymmetric area, we can use mirror copy method, and for symmetrical to center area, we can rotate it with the center point. But if we only store the reference area ,it will make the correction of reference image irregular scanning sequence. So we need to store the 1/4 image, namely two of the eight pieces of the center fisheye image. After removing the redundant coordinates, the data compression ratio is 16%.

*E. Pixel Interpolation*

Nearest Neighbor Interpolation is relatively simple in operation. But its treatment effect will cause obvious image defects. For bicubic interpolation, it is a high order interpolation method which is more complex. It is not suitable for this system because it takes all the pixels in the correlation of all the pixels in the 4×4 image block into account. Less complex and high speed in operation make bilinear interpolation being a good choice in our system.

The interpolation module will get a set of interpolated information per period, including interpolation coordinates and four image points around it.

And pipeline is used in the interpolation process of this system.

*1) Transverse linear interpolation*

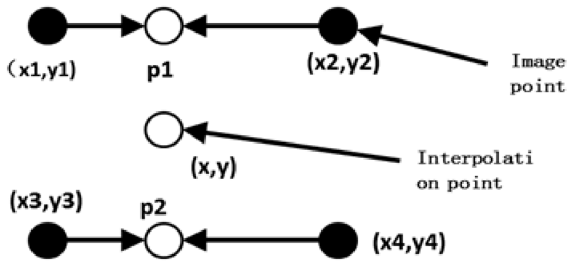


Fig. 19 Transverse linear interpolation

As showed in the figure above, two middle points have to be calculated firstly in the transverse linear interpolation.

$$p1 = \lambda p(x1, y1) + (1 - \lambda)p(x2, y2), \lambda = x2 - x \qquad (14)$$

$$p2 = \lambda p(x3, y3) + (1 - \lambda)p(x4, y4), \lambda = x4 - x \qquad (15)$$

Operations of multiplication and addition between two points are included in this section. In the formula, operations of two points have to be made simultaneously, which can be done by four multiplying units and two summing units.

*2) The longitudinal linear interpolation*

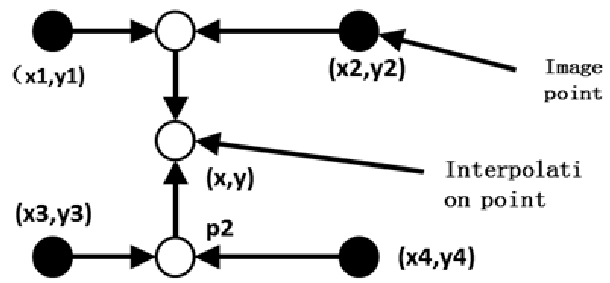


Fig.20 the longitudinal linear interpolation

In this section, it has to figure out the value of the insertion point which can be realized by multiplication and addition of a point. That means it should include two multiplying units and one summing unit.

*3) Fixed amplification factor*

In order to keep the accuracy, amplification has to be made before fixed-point calculation. On the contrary, the amplified data should be restored and dealt with saturated operation before getting the end result.

*F. VGA display module*

By using the D5M camera and thronging the RAW to RGB module, the output data contain a total of 1024 rows, and each line has 1280 points. The resolution of VGA output is 1280*1024.The specific timing sequence is as follows:

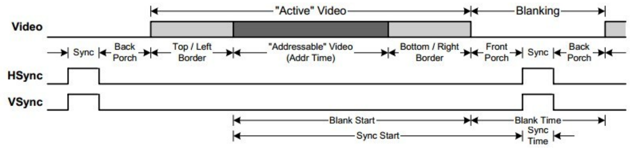


Fig. 21 VGA timing sequence

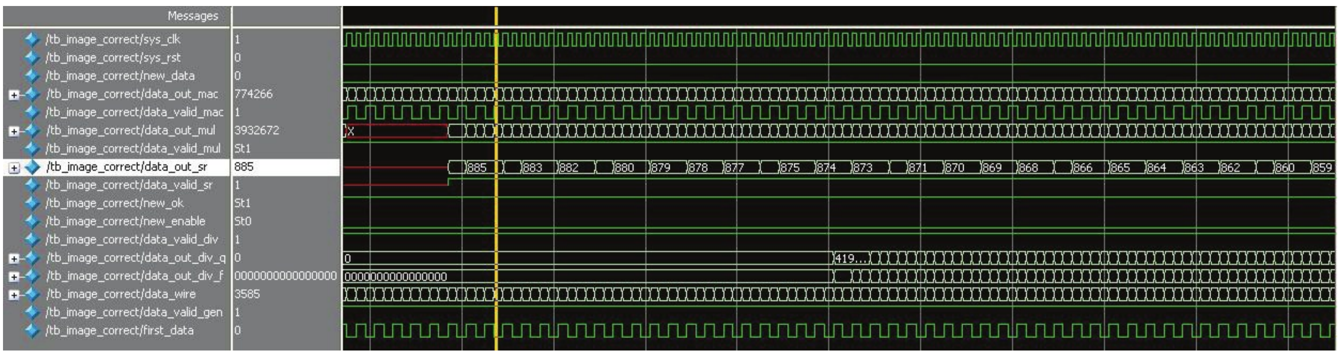


Fig. 22 the simulation result

## V. Simulation & Results

*A. simulation*

The simulation result of top module can be shown above, and especially data_out_div_q is the end-result. From the result, we know that after address being generated into address module, the data separately enter the multiply module and multiply-accumulate module. Time delay in multiply module makes it synchronous with the CORDIC algorithm module, and the two modules put out their corresponding data into the divider module at the same time. After 37 clock cycles, the divider module put out the processing result. As we can see, every being module is working properly, results being correct, deviation being small, which can meet the requirements.

### *B. System calibration result*

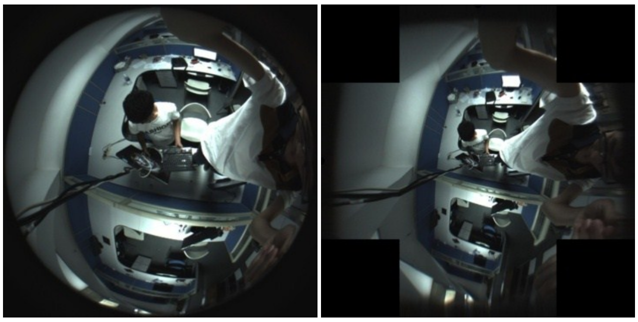

Fig. 23 Fish-eye lens calibration using Spherical perspective projection

Fig. 24 Fish-eye lens calibration using Spherical perspective projection

## VI. CONCLUSION

We propose using the software resource to improve the flexibility of the system and using the speed of the hardware to improve the speed of fish-eye calibration. The spherical perspective projection algorithm is implemented on a FPGA and a panoramic monitoring has been achieved in a SOPC system. The obtain result obtained by the panoramic monitoring system is promising, as is shown above.

## ACKNOWLEDGMENT

This work was supported in part by the Strategic emerging industry key technology special project of Guangdong Province (2011168014 and 2011912004).

## REFERENCES

[1] ALTERA Corporation, "A Flexible Architecture for Fisheye Correction in Automotive Rear-View Cameras", ALTERA White Paper,2008.

[2] T・N・Mundhenk，M・J・Rivett，Techniques for Fisheye Lens Calibration using a Minimal Number of Measurements，Procof the SPIE Intelligent Robotics and Computer Vision Conference, Boston, Massachusetts，2000，v01・11，pp：8—9・

[3] 陈明伟,徐丹东·球面坐标定位校正鱼眼图片合成全景图的方法·云南大学学报，2004，V01・13，No・3，PP：214-217・

[4] 英向华，胡占义.一种基于球面透视投影约束的鱼眼镜头校正方法・计算机学报，2003，V01・26，No 12：1702・1708・

[5] 薛军涛,贺怀清.一种采用纹理映射技术实现鱼眼镜头快速校正的方法 .电子技术应用，2006，6

[6] 赵红旭.鱼眼图像校正的研究与实现.上海交通大学硕士论文,2011，12.