# Microscopic Stereo Camera with Simultaneous Vergence and Focus Control

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**Abstract:** This paper introduces a stereoscopic stereo camera which equipped with two microscopic video sensors, a micro motor, and a linear stage. Mechanism of simultaneously controlling both vergence and focus of the camera is presented. Parallel-axis design of two video sensors enables the stereo camera to converge and focus on an interesting object simultaneously. Calibration of the camera is done to reconstruct 3D models of real objects using the camera. Experimental results show that the vergence and focus of the camera change with respect to the motion of an object.

## 1. Introduction

Stereoscopic imaging is widely used in the fields of Augmented Reality, Virtual Reality, Remote Operation, Robot Navigation and so on[1,3]. To develop a stereoscopic imaging system, a stereoscopic camera must be prepared as an input device which functions are closely similar to those of human eyes. When we view an object of interest, two visual mechanisms of our eyes, vergence and focus, change to fixate the object[2]. The vergence angle between two optical axes of the left and the right eyes changes to fixate to different object distances. Similarly, focus of the lens of human eyes changes to obtain clear images of the object.

If the vergence angle and focus of a stereoscopic camera can be automatically controlled, a viewer feels less eyestrain or headache. In the research of vergence control, some investigations employ the toed-in stereo configuration. This configuration however causes some geometric distortions when stereo images are reprojected to a planar stereoscopic screen. On the contrary, vergence control using a parallel-axis stereo camera does not distort original stereo videos. In addition to the vergence control, we need to control the focus of the camera to accommodate to different object distances[3,4,5].

Most stereoscopic cameras are designed to be used in general environment. However, recent industrial applications of stereoscopic imaging sometimes require very small-size cameras. For example, stereoscopic imaging can be used in tele-operation, where the size of stereoscopic camera needs to be as small as the size of an endoscope. A good example is the Davinci tele-operation system.

In this paper, we introduce a microscopic stereo camera which employs video sensors available in commercial microscopes. The developed camera accommodates a DC motor, linear guide, micro motion stage, and two limit switches for mechanical implementation of focus control. In addition, the analog video sensors are connected to a video frame grabber to implement electric vergence control. We design the mechanical of both vergence and focus control to activate both of them simultaneously.

A graphic diagram of the developed camera is shown in Fig. 1. Actual implementation and experimental results of vergence and focus control are shown in the following sections. The camera consists of two microscopic video sensors, a micro motor, and a linear stage. An analog CCD is used to capture stereo videos. The micro motor and linear stage are used to control the focus of the camera. Vergence of the camera is implemented by an image processing algorithm. In a host computer, a video frame grabber captures stereo images and to pass to graphic memory of the computer.

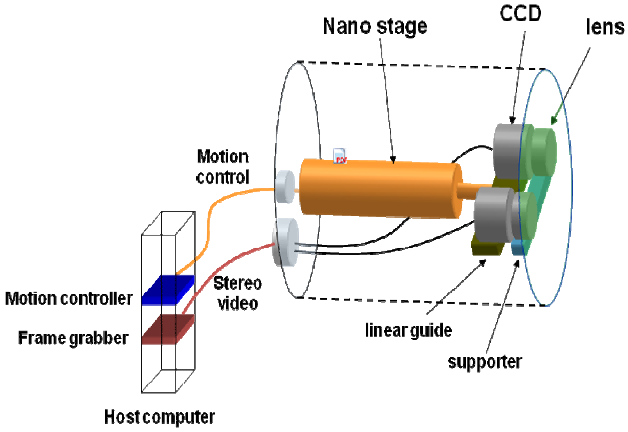


Fig. 1 Graphic diagram of the microscopic stero camera

## 2. Parallel-axis Stereoscopic Camera

### 2.1 Stereo disparity and focus

In the parallel-axis stereo camera, the optical axes of two video sensors are parallel to each other[2,4]. Therefore, the two optical axes converge at infinity. If there is an object very close to the camera, it yields large screen disparity which could result in cybersickness to human viewers. One method of reducing screen disparity is moving either lenses or bodies in parallel to the CCD plane. Suppose a camera lens is separated from the CCD. If the CCD moves in parallel to its image plane, the image of an object on the plane moves in the opposite direction. Therefore, stereo disparity can be controlled by moving both left and right lenses in opposite directions.

In addition, the amount of image focus in stereo images can be controlled by moving image planes along the optical axes. Both vergence and focus has relationship with the depth to an object. With respect to the object depth, we find that two motions are related in a linear manner[4,5]. This property is very important in designing a stereoscopic camera because the functions can be implemented mechanically or electrically with easy.

## 2.2 Microscopic stereo camera

Let us explain how to develop a microscopic stereo camera and automatic vergence/focus control. Two micro video sensors are used in the camera. The sensor consists of a lens of very short focal length and a sensor body which converts sensor signal to video signal. To implement the mechanism of focus control, the sensor body and the lens are separated. The lens is installed in the front cover of the camera as shown in Fig.2. The body part of the sensor in installed on a micro linear stage to move in the direction of the optical axis. Two sensor's bodies are installed on the same stage. Then a DC micro motor moves the two camera's bodies in the same direction with the optical axis. To keep the motion from being out of the range of the stage, limiter switches are adopted.

Vergence control is to change the disparity of an object in stereo images to facilitate the accommodation to human eyes[6,7]. Without vergence control, human eyes can experience eyestrain and headache while viewing stereo videos for a long time. In our system, vergence control is implemented by using a computer vision technique. To maintain zero disparity to an object of interest, the matching points of the object in stereo images are determined. We use the OpenCV functions for fast computation of pattern matching functions. Fig. 2 shows the front view of the camera. Two micro video lens are installed. Stereo videos captured from the camera are viewed using a stereoscopic display as shown in the figure.

Fig. 2 Developed camera and display system

The microscopic video sensors installed in the stereoscopic camera are employed from industrial videoscopes. The focal length of the lens is 4.8mm, CCD size is 1/4", and image resolution is 640×480 in the NTSC video format. Table 1 shows the specifications of the developed stereo camera.

Table 1 Specification of the developed stereoscopic camera

| | | |
|---|---|---|
| Stereo camera | Sensor size | 1/4 inch |
| | Image resolution | 510 x 492 |
| | Image area | 4x3.08 mm |
| | Baseline | 15 mm |
| | Focal length | 5 mm |
| Focus stage | Travel range | 10 mm |
| | Permission load | 200g |
| | Repeatability | 100nm |
| | Travel speed | 1.5mm/sec |
| | Interface | Quad phase control |

Figure 3 shows real view and interface of the camera. Analog video signals are interfaced to a frame grabber installed in a computer. To control motor, a motion controller is interfaced with camera. The micro motor installed in the camera also has an encoder to record the speed and position of the linear stage. Limit switches are installed as shown in Figure 4. The (-) limit switch stops motor at the farthest focus position. The (+) limit switch stops motor at the closest focus position.

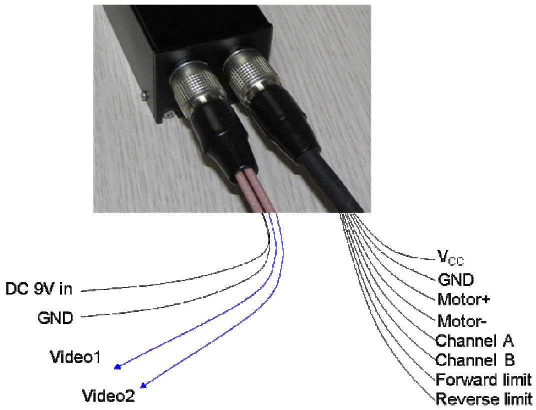


Fig. 3 Rear view and interface of the camera

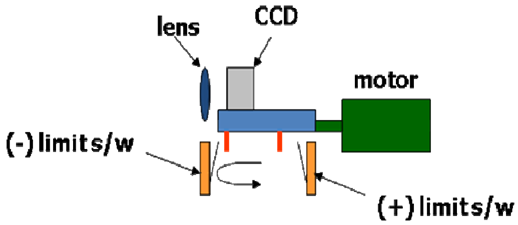


Fig. 4 Operations of limit switches

## 2.3 Operation of the stereo camera

Now let us describe the operation of the stereo camera. To control and vergence and focus of the camera, we need to know the position of the sensor bodies with respect to the lens. However, it is not possible to know the position of the sensor because the encoder we use record only the relative angle or position of the motor. To know the absolute position of the sensor body with respect to the camera lens, we need a calibration step. It is a very important to know the absolute position of the sensor body with respect to the lens because it determines the distance to an object through the lens equation

$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}. \tag{1}$$

First, we calibrate the focal length of the camera. Using a simple calibration step, we decide the focal length *f* to 5.795mm. It can be different than the specification of the lens because it follows a simple thin lens model as shown in Figure 5. As the second step, we move the body so that it focuses on the object at u=100mm, which is equivalent with $v_0$=6.151mm. With respect to the focus position at infinity, the encoder value yields 2950 steps. That means the encoder resolution is 8275mm per encoder pulse.

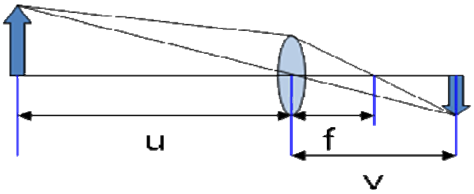


Fig. 5 Thin lens model

Let us set the encoder value to 0 and move the body to another position so that the camera focuses on the object at 450mm. In this position, $v_1$=5.870mm and encoder value is -2324. Because the object distance *u* inversely proportional to stereo disparity *d* such that

$$u=\frac{2fB}{d}, \tag{2}$$

we set an equation

$$u=\frac{\kappa}{(|disparity|+\alpha)} \tag{3}$$

to determine disparity with respect to object distance. In Equation (2), *B* means the baseline.

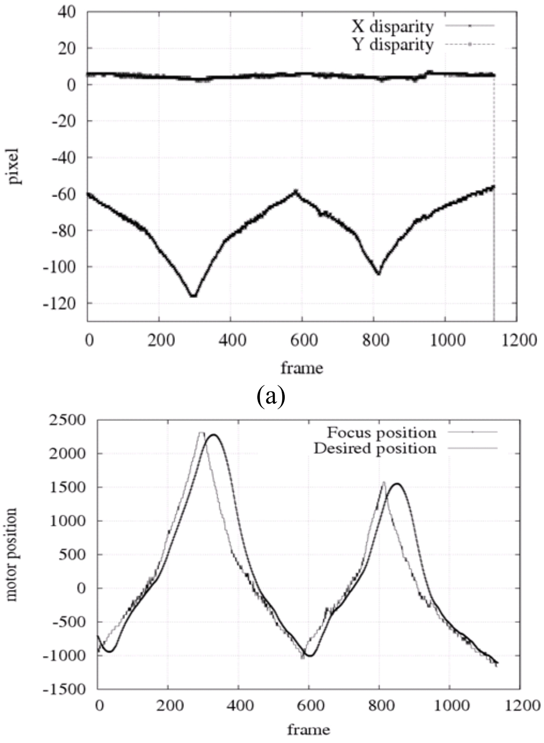
We calibrate κ and α using the two object distances which are described previously. At u=450, image disparity is 450 in pixel, and at u=100 disparity is 117 in pixel. Therefore, using Equation (3), we determine the object distance by knowing the stereo disparity. Simple description of the focus and vergence control algorithm is as follows:

- Disparity of stereo images is computed
- Image distance v = fu/(u-f), where f is the focal length and u is object distance
- Compute difference of image distance with respect to the initial position
- Compute motor encoder value
- Move the motor to the desired position

# 3. Experimental Results

## 3.1 Vergence and focus control

The developed stereo camera has automatic vergence control. The vergence control is implemented by measuring stereo disparity between left and right images. Vergence and focus control is implemented in real-time using a Pentium-based computer. Fig. 6 shows graphs of vergence and focus control. In the top graph, disparity in the x direction changes with respect to the motion of an object. In this experiment, a user moves an object in his hand freely in the front of the camera. In the bottom, focus is controlled by the micro motor, where desired motion is computed in advance after calibrating the DC motor with respect to the object distance.



(a)

(b)

Fig. 6 Vergence and focus control results

Figure 7 shows a result of vergence control. In Fig7(a), stereoscopic display shows an object without vergence control. Here, the camera focuses at infinity. In Fig7(b), the object disparity in the image center becomes close to zero after vergence control.

(a) (b)

Fig. 7. (a) Before and (b) after vergence control

### 3.2 3D reconstruction

A general application of the stereo camera is 3D reconstruction from stereo images. To get 3D information of an object using the camera, it must be calibrated with respect to the world coordinate system. The calibration is done by using a well-known calibration toolkit. A pyramid-based stereo matching is applied to a pair of images to obtain depth image of the object. Figure 8 shows steps of 3D reconstruction. Stereo images are first rectified and the result images are matched to find correspondences. A pyramid-based stereo matching algorithm then generates 3D point clouds models of real object.

Figure 9 and 10 shows results of 3D reconstruction using two real objects, ball and toy. Here, the 3D shapes of ball and toy including background are reconstructed as point clouds models.

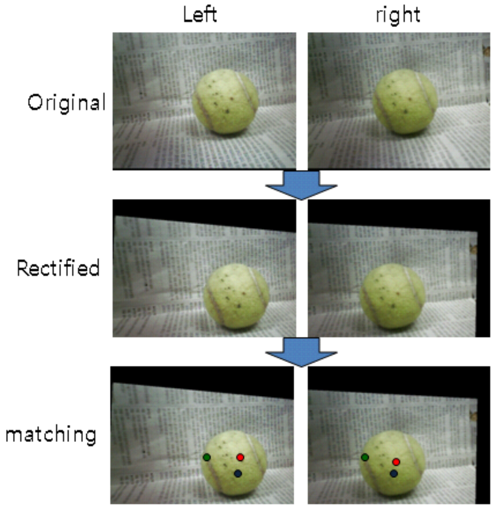


Fig. 8 Steps of 3D reconstruction

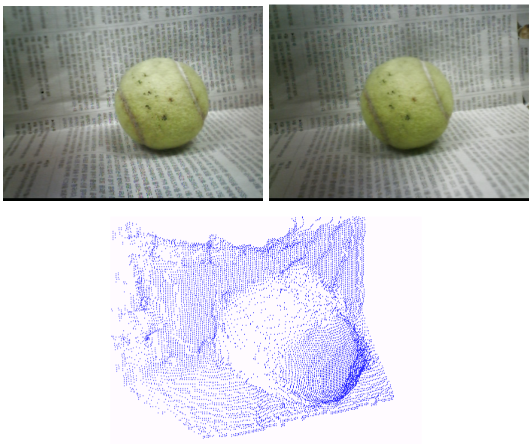


Fig. 9. Top: Left and right images of a ball. Bottom: 3D reconstruction result

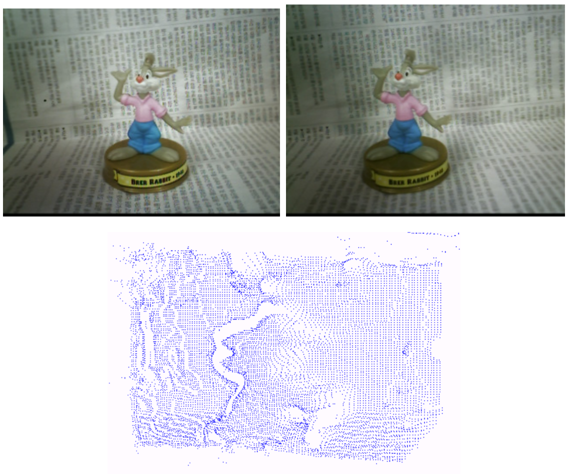


Fig. 10. Top: Left and right images of a toy. Bottom: 3D reconstruction result

## 4. Conclusions

In this paper, we introduce a microscopic stereo camera whose vergence and focus are automatically controlled. Stereo vergence is implemented by computer vision algorithms and the focus mechanism is achieved by a micro motor and a motion stage. The developed stereoscopic system including display and application software can provide realistic view of the scene of interest to human operators.

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