A NEW SMART VISION SYSTEM USING A QUICK-RESPONSE DYNAMIC FOCUSING LENS

Takashi Kaneko, Naoki Mitsumoto and Nobuaki Kawahara
Research Laboratories, DENSO CORPORATION
500-1 Minamiyama, Komenoki-cho, Nisshin-shi, Aichi 470-0111, JAPAN
e-mail: {tkaneko, nmitumo, nkawaha}@rlab.denso.co.jp

ABSTRACT

We propose a new smart vision system using a quick-response dynamic focusing lens suitable for micro parts assembling. This system realizes real-time observation for micro parts with a deep depth of field, as well as three-dimensional shape measurement using only one image sensor. In this paper, we report a newly developed real-time algorithm called one pixel method for generating clear image having a deep depth of field. This method is able to process one original picture (640 x 480 pixels per frame) in approximately 1.0 ms. We also report the results three-dimensional shape measurement in high accuracy using the contrast of brightness method.

1. INTRODUCTION

A number of research activities concerning the micro manipulator for micro parts assembling have been studied [1, 2]. When we operate the manipulator, observation equipment such as an optical microscope is needed to recognize positions of objects and manipulation tools. For three-dimensional observation by optical microscope, we can observe only one focalized image because the depth of field of the microscope is restricted. At Transducers '97, we proposed the dynamic focusing lens (DFL) as an application of the micro actuator and showed the previous type of vision system using quick shift of focal length [3]. With this vision system, when DFL was operated at over 60 Hz to change the focal length of the object, we could observe deep depth of field images in real-time due to the afterimage effect of the human eye. However, the resolution of the image was reduced because the defocused images were superimposed on the properly focused images.

To overcome this problem, a computer image processing technique was applied to the system. Image processing extracts in-focus pixels or areas from original pictures at different focal lengths, and generates all-focused pictures. Several image processing methods that distinguish between the in-focus area and the out-of-focus area by their contrast have been suggested [4]. However, these methods cannot calculate all-focus pictures in real-time (video rate, 16.6 ms per field). A fast algorithm to generate all-focus pictures in real-time is strongly demanded.

In order to realize real-time observation with clear all-focused images, we newly developed a real-time algorithm called one pixel method (OPM). To reduce the processing time, OPM distinguishes between in-focus pixels and out-of-focus pixels by brightness change in response to focal length instead of contrast change.

The distance between DFL and the object can be easily estimated by the applied voltage of the micro actuator. Therefore, another strong point of the new system is that it can measure the 3-D shape of the object using only one image sensor.

It should be noted that our new smart vision system is applicable to real-time observation and recognition for micro manipulators or micro factories.

2. STRUCTURE AND PRINCIPLE

2.1 PRINCIPLE OF THE SMART VISION SYSTEM

Figure 1 shows the principle of the new smart vision system using quick response of DFL for generating all-focus images and 3-D shape data. The system consists of DFL attached to an objective, an image sensor, and a computer image processing unit.

DFL can quickly change the focal length using the micro actuator. The detail of DFL is described in our previous paper [3]. Figure 2 are photos showing the appearance of DFL. Figure 3 shows a schematic cross-sectional view of the DFL. DFL is comprised of two glass diaphragms having a thickness of 50 micron (each having a different diameter, 10 mm and 14 mm, respectively), silicone oil exhibiting a refractive index of 1.50 sealed between them as the transparent working fluid, and a multi-layered piezoelectric bimorph actuator mounted thereon [5]. The optical characteristics of the lens can be changed to a greater extent by adjusting the pressure of the transparent working fluid through push/pull operation of the actuator to the glass diaphragms as shown in Figure 3.

A close-up lens with a focal length (f) set to 25 mm, F number set to 5, and object space focal length set to 64.5 mm was used as the objective. The depth of field of the objective was approximately 2 mm. Lateral magnification of the vision system was approximately 50 on a 15-inch monitor. The range of movement of the focal plane was calculated through geometrical optics with respect to the characteristics of DFL. According to the calculated result, movement of the focal plane is in the range from -4 mm to +4 mm.

The computer image processing unit extracts in-focus pixels or areas from original pictures at different focal lengths, and generates all-focused pictures. To generate all-focused pictures in real-time, we newly developed OPM. Detailed account of the theory is given in the following chapter.

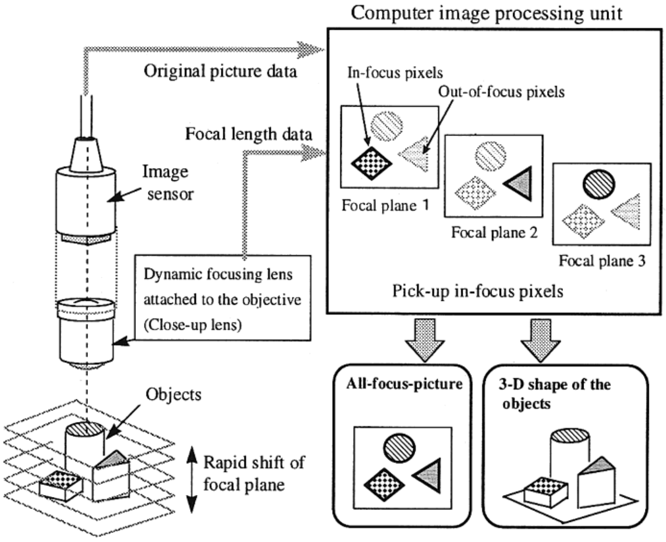


Figure 1. Structure of the smart vision system

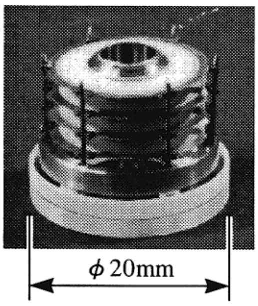


Figure 2. Photo of DFL

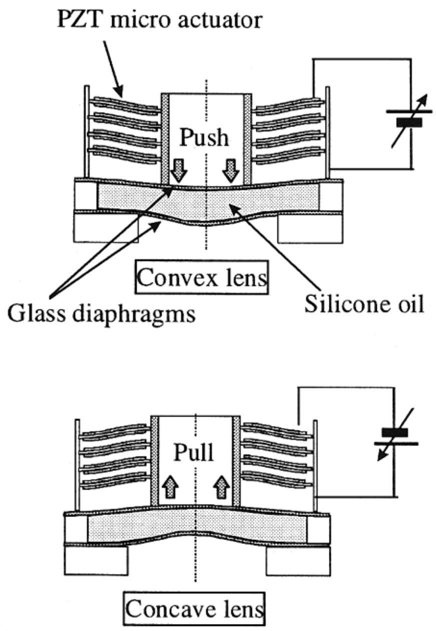


Figure 3. Focal plane shift mechanism

2.2 PRINCIPLE OF THE ONE PIXEL METHOD

To reduce the processing time, OPM distinguishes between in-focus pixels and out-of-focus pixels by brightness change in response to focal length instead of contrast change. Figure 4 shows the brightness change in different focal length when the object has white and black pattern. As Figure 4(a) shows, the brightness has one peak when DFL focuses on the white area on the object. As Figure 4(c) shows, the brightness has one valley when the object is black. On the other hand, the brightness has peak and valley as shown in Figure 4(b), when DFL focuses on the border between black and white area.

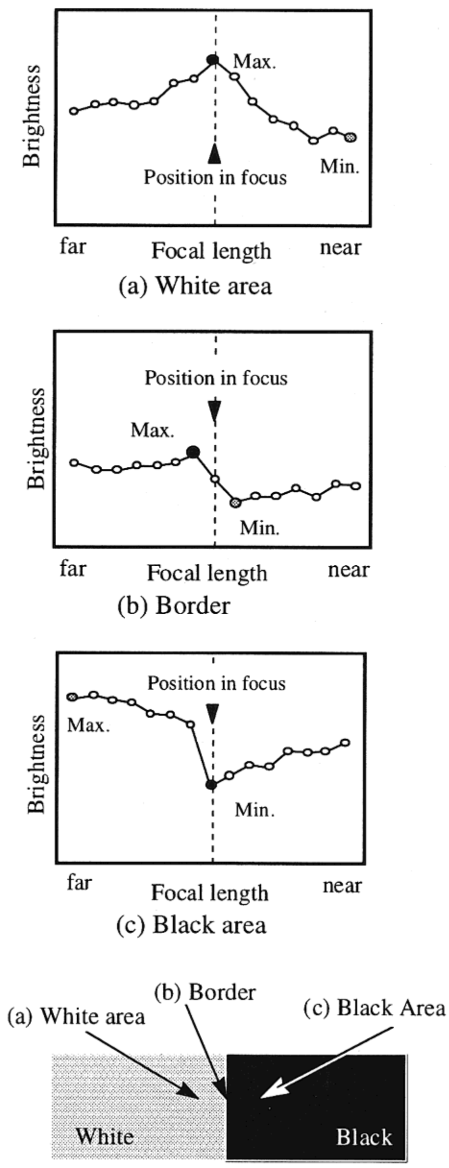


Figure 4. Brightness change in response to focal length

According to the above mentioned phenomena, in-focus pixels are extracted by OPM as shown in Figure 5. At first, several original pictures of different focal length are recorded. Pixels at the same coordinates and of different focal length are compared. Then, two pixels of maximum brightness (*Pmax*) and minimum brightness (*Pmin*) are extracted and used for in-focus decision. Next, the differentials of brightness at the two pixels are calculated. When the brightness curve has only one peak or valley as shown in Figure 4(a), 4(c), the pixel with a null differential is extracted as the in-focus pixel on condition 1. On the other hand, when the brightness curve has peak and valley as shown in Figure 4(b), *Pmax* is extracted as the in-focus pixel on condition 2. When *Pmax* is not in-focus pixel as shown in Figure 4(b), OPM can not find the in-focus pixels correctly. However, we consider that several errors are allowable for observation because the *Pmax* is near to the in-focus position.

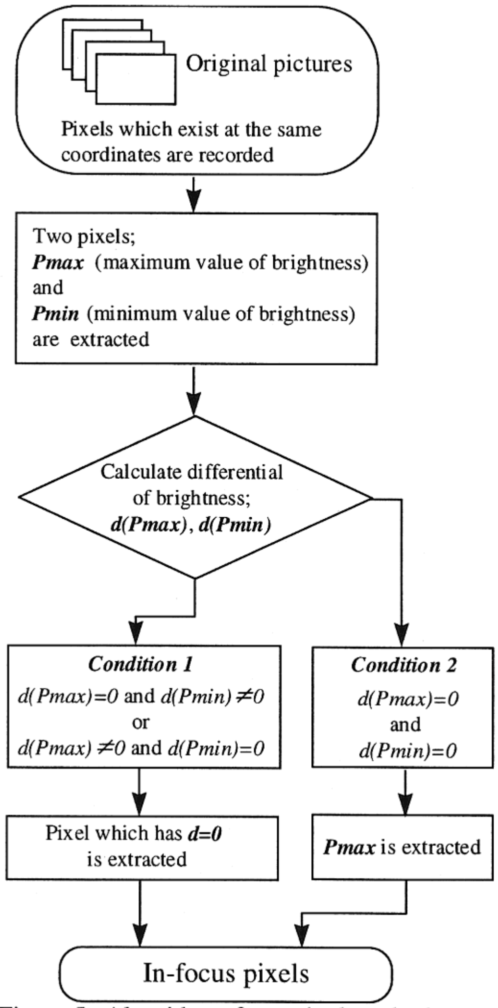


Figure 5. Algorithm of one pixel method

2.3 THREE-DIMENSIONAL SHAPE MEASUREMENT METHOD

The original picture and the applied voltage of the micro actuator are simultaneously recorded at different focal lengths. The distance between DFL and the object can be estimated by the applied voltage of the actuator. Therefore the system can measure the 3-D shape of the object.

We defined a parameter to evaluate the accuracy of in-focus for 3-D shape measurement. The accuracy is given by the equation shown in Figure 6. When DFL shifts the focal length, the vision system extracts the in-focus areas from in-focus and out-of-focus pictures. The accuracy indicates the percentage of the in-focus areas in one all-focused picture.

We applied contrast of brightness method instead of OPM for 3-D shape measurement. Contrast of brightness method calculates the difference between the maximum and the minimum in brightness of an area (5 x 5 pixels). Furthermore, to reduce the noise and obtain more than 95% in the accuracy, we tried to generate the contrast values with two step calculation: (1) difference values of nine areas (one center area and eight surrounding areas) are averaged, (2) the mean is given as the contrast value to the center area. We call this method averaged contrast of brightness method. The averaged contrast of brightness method extracts the in-focus areas which have the largest contrast value.

3. EXPERIMENTAL RESULTS

3.1 ALL-FOCUSED PICTURE GENERATION

The characteristics of the new vision system were evaluated by generating all-focused pictures. In the experiments, five recorded original pictures (640 x 480 pixels per frame) shown in Figure 7 were used instead of the live pictures from the image sensor. Figure 8 shows the all-focused pictures generated by the two vision system: (1) the newly developed type using DFL and image processing (OPM), and (2) the previous type using DFL (quickly shift the focal plane). These results indicate that the new vision system not only enlarges the depth of field, but also clarifies the image with sufficient resolution.

We estimated the calculation speed when the image processing algorithm was processed by the FPGA (Field Programmable Gate Array, Xilinx XC4025E). OPM is able to process one original picture in approximately 1.0 ms. It shows that 16 original pictures at different focal lengths can be calculated at maximum in the video rate.

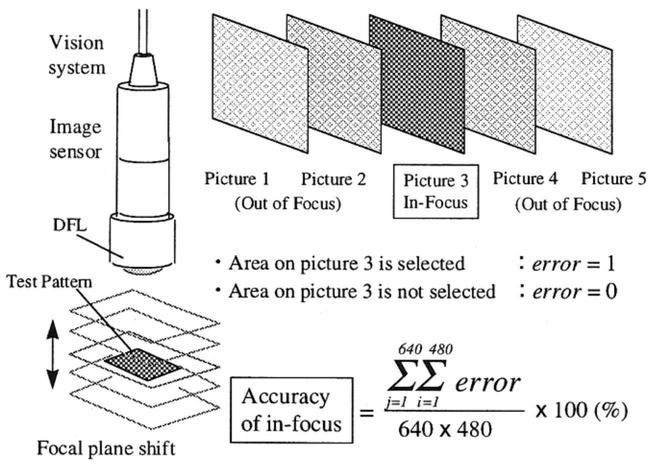


Figure 6. Definition of the accuracy

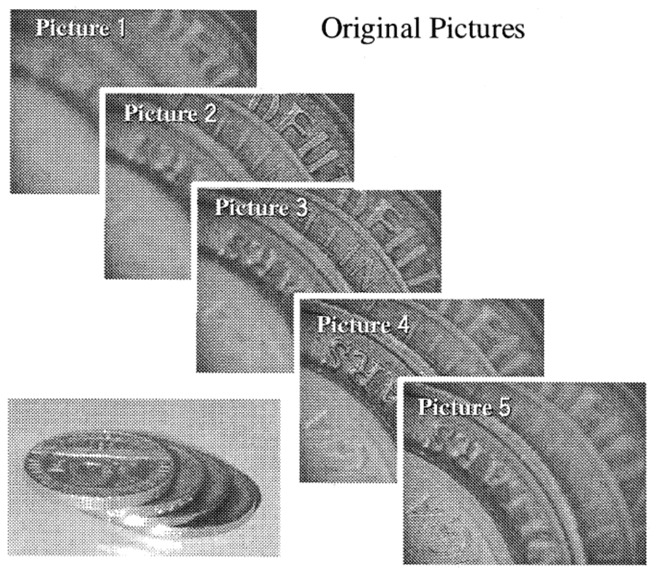
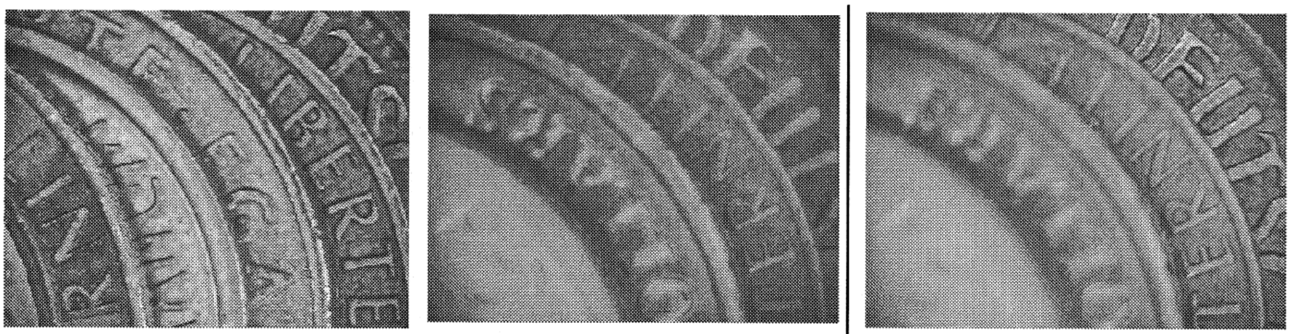


Figure 7. Original pictures



(1) New vision system (DFL + image processing (OPM))

(2) Previous vision system (DFL)

(3) Original picture (focus on one position)

Figure 8. All-focused pictures

3.2 THREE-DIMENSIONAL SHAPE MEASUREMENT

Table 1 shows the accuracy of the vision system using the following three methods: (1) OPM, (2) contrast of brightness method, and (3) averaged contrast of brightness method. When method (3) was used, 99% accuracy was obtained. Figure 9 shows an example of 3-D shape measurement when piled coins were measured from the upper side. A round and stepped shape of the piled coins was obtained. These results indicate that the new smart vision system can obtain not only the all-focused picture but also 3-D shape of the object using only one image sensor.

Table 1. Accuracy of 3 methods

Processing Method	Accuracy of in-focus (%)
OPM	70
Contrast of brightness method	75
Averaged contrast of brightness method	99

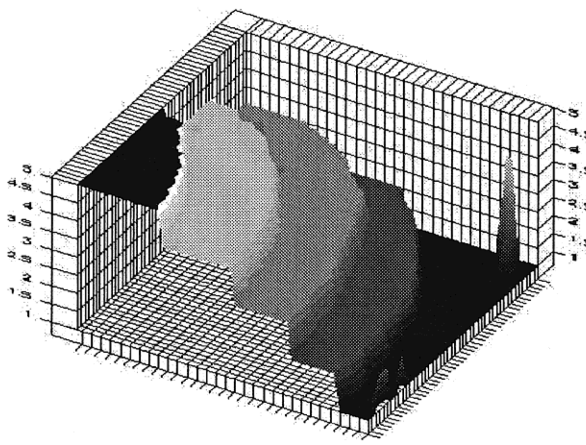


Figure 9. 3-D shape (piled coins)

4. CONCLUSIONS

A new smart vision system using a quick-response dynamic focusing lens was developed. This system realizes real-time observation for micro parts with a deep depth of field, as well as three-dimensional shape measurement using only one image sensor.

To generate all-focused pictures in real-time, a high speed image processing algorithm called one pixel method was developed. This method is able to process one original picture in approximately 1.0 ms. Furthermore, the vision system can measure the 3-D shape of an object with approximately 99% accuracy using the contrast of brightness method. Our new smart vision system is applicable to real-time observation and recognition for micro manipulators or micro factories.

ACKNOWLEDGEMENTS

A part of this work was performed under the management of the Micromachine Center as the Industrial Science and Technology Frontier Program 'Research and Development of Micromachine Technology' of MITI, supported by the New Energy and Industrial Technology Development Organization.

REFERENCES

[1] T. Sato, K. Koyano, M. Nakao, and Y. Hatamura, "Novel Manipulator for Micro Object Handling as Interface between Micro and Human Worlds," Proc. Int. Conf. on Intelligent Robots and Systems, Vol. 3, pp. 1674-1681, 1993.

[2] T. Tanikawa, T. Arai, and P. Ojala, "Two-Finger Micro Hand," Proc. Int. Conf. on Robotics and Automation, Vol. 3, pp. 1674-1679, 1995.

[3] T. Kaneko, T. Ohmi, N. Ohya, N. Kawahara and T. Hattori : "A New, Compact and Quick-Response Dynamic Focusing Lens", Proc. 9th Int. Conf. Solid-State Sensors and Actuators (Transducers '97, Chicago, 1997) pp. 63-66

[4] T. Shiraishi, and K. Mitsui, Image Processing System for Expanding Depth of Focus of Optical Microscope-Composition of Expanded Depth of Focus Image and Three Dimensional Expression of Shape, JSPE, 60, 8 (1994) pp. 1112 1116.

[5] S. Kawakita, T. Isogai, N. Ohya and N. Kawahara, Multi-Layered Piezoelectric Bimorph Actuator, Proc. of 1997 Int. Symposium on Micromechatronics and Human Science, Nagoya, Japan, Oct. 5 8, 1997, pp. 73 78.