Development of Long Depth of Focus Optical Microscopy using Software-confocal Method and its Application to 3-D Profile Measurement

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Introduction
Optical microscopes are used for observation, profile and dimensional measurement and assembling the superfine parts of miniature machines or micromachines, but the limited depth of focus of the microscopes often obstruct these operations, so the development of a microscope with greater depth of focus is needed to meet the needs of workers and researchers in this field. Other than clear microscopic observation, long depth of focus optical microscopy is useful for 3-D shape measurements such as cutting tool wear [1].

Confocal laser microscopes, which eliminate defocused image of the object by pinhole, are used to obtain clear images for 3-D profiles, but confocal scanning units have very complicated optical systems and are also very expensive.

One of the authors has already reported a research on expanding depth of focus optical microscope [2]. In the research, the multiple focal images of the targets of observation were fed into a computer and only the images in focus synthesized. The computer was first sequentially input with numerous static images sent from a CCD camera while driving the microscope objective lens. Next, Hadamard transform method (frequency distribution comparison method) was introduced to discriminate and synthesize only the images in focus.

But in the algorithm based on Hadamard transform method, optical microscope picture image consists of 640 x 480 pixels must be divided into smaller segments, for example 16 x 16 or 8 x 8 pixels, and focus measure operation is done on each segments. Therefore, the drawback of the algorithm was exact representation for complicated surface structure was not possible. Furthermore, the algorithm has problem that the focused segment also contains diffused light that is introduced from defocused image of the other part of the object.

In this report we propose an algorithm to obtain focused picture image based on the principle of confocal microscopy. A diffused light introduced by defocusing of the image is removed by computer image processing from the microscope images obtained by CCD camera. The method does not need laser and confocal scanners, which are necessary for confocal laser microscope. The system is composed of only a optical microscope, a CCD camera and a personal computer. The long depth of focus picture images and 3-D profile of a measuring objects can be obtained. The new algorithm to remove a diffused light is proposed as the software-confocal method.
The proposed method is applied for actual image composition and 3-D profile measurements. Specimen, an inclined aluminum plate, miniature ball bearing and leg of an insect, were selected as the measuring objects, and the results show validity of the proposed method to the long depth of focus microscope observation and 3-D profile measurement.

**Experimental setup and principle**

Figure 1 shows the experimental setup. The system comprises a optical microscope, a CCD camera, a image frame grabber, a personal computer, a X-Y-Z micro stage. The CCD camera is a black and white type with 640 x 480 pixels.

Figure 2 shows image composition procedure proposed in this research. Incremental microscope displacement that corresponds to the depth of focus is used to obtain the image frame sequence of objects. Camera images are transferred to the computer as bit map files and processed. At each pixels, the image frame among the image sequence, which gives a maximum focus measure, is determined. As the method to calculate maximum focus measure, the Sum-Modified-Laplacian operator [3] can be used. But, in this study, the focus measure of a pixel is calculated simply as the difference of Intensity value of the pixel to the neighboring pixels (differential method).

Figure 3 shows the basic image formation geometry. Each point on the object

![Figure 1: Experimental setup](image1.png)

![Figure 2: Procedure of picture composition](image2.png)

![Figure 3: Focused and defocused image](image3.png)
plane is projected onto a single point on the image plane, thus causing a clear or focused image to be formed on the image plane (Fig. 3 (a)). If, however, the CCD sensor plane does not coincide with the image plane, the light received from the object by the lens is distributed over a circular patch on the sensor plane (Fig. 3 (b)). The distribution of light energy over the circular patch can be modeled as shown in Figure 4.

Intensity value of each pixels must be compensated by removing diffused light that is introduced from defocused image of the other part of the object. Figure 5 shows the feature that the diffused light from the lower part of the surface does not affect the pixels corresponding to higher part of the surface. Therefore, we can remove the defused light from pixels of the CCD camera one by one from upper part to lower part of the surface. After diffused light is removed from all pixels, the focus level that maximizes the focus measure is calculated again at each pixels.

**Experimental results**

A tilted aluminum plate, the angle of obliquity is 39 degrees, is observed by the microscope. The aluminum plate was polished with sandpaper. The height difference of right and left endpoints in the microscope field of view corresponds to 350 µm. The 35 2-D parent images were obtained and 3 of them are shown in Figure 6 (a), (b), and (c). The images were taken with a 10x objective on a tool microscope. The height distance between the images was 10 µm. Figure 6 (d) and (e) show the composite picture images obtained by the differential method and proposed software-confocal method. Figure 6 (e) and (f) show 3-D shapes of the inclined plate obtained by these two methods. It is obvious that software-confocal method can provide far more accurate 3-D shape than conventional method. However, noise components are seen at the left and right side.
right endpoints in Figure 6 (f), further improvement of the image processing algorithm is needed.

**Conclusion**

The purpose of this study was to develop a 3-D shape measuring technique for micro components using a microscope, a CCD camera and a personal computer. Newly proposed software-confocal method can remove a diffused light due to defocusing images from individual pixels of a CCD camera. The proposed method is applied for actual image composition and 3-D profile measurement. Specimen, an inclined aluminum plate, was selected as the measuring object, and the results show validity of the proposed method to the long depth of focus microscope observation and 3-D profile measurement.

**References**