PERFORMANCE EVALUATIONS OF MACRO LENSES FOR DIGITAL DOCUMENTATION OF SMALL OBJECTS

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ABSTRACT:

Recently, documentation and visualization of various cultural heritages have been receiving attention, and small Buddha such as less 10 cm tall which was stored in the womb of Buddha is also included in cultural heritages. In order to document theses small objects in conservation of cultural heritage, zoom lenses are generally used. However, there are still issues for digital documentation of these smaller objects using zoom lenses. These problems include sharp imaging and distortions which occur with changes in focal length setting. On the other hand, macro lenses have ability in sharp imaging of small objects from the view point of working distance.With this motive, zoom and macro lens was mounted on digital single lens reflect camera, and accuracy and performance evaluations of the both lenses were investigated by three imaging modes, P-mode (Aperture value and shutter speed are set automatically), AV-mode (Aperture value are set by manually) and ADE-mode (Aperture value is set automatically by AF frame) respectively.This paper presents that the most remarkable point of the macro lens has ability to neglect lens distortion, macro lens shows stable solution in camera calibration and high quality image be able to taken by the AV mode. Furthermore, 3D modeling of small Buddha is also demonstrated in this paper.

1. INTRODUCTION

Digital documentation of cultural heritages have been receiving attention and terrestrial laser scanners are often used from its ability such as real-time 3D data acquisition (Akca & et al., 2007). On the other hand, the authors also have been concentrating on developing a convenient 3D measurement method using consumer grade digital cameras (Chikatsu & et al., 2006). However, in order to document small Buddha less than 10 cm tall which was stored in the womb of Buddha, acquisition of enlarge and sharp images are indispensable not only accurate measurement. Zoom lenses are convenient lens for these issues.

Zoom lenses are extensively used in computer vision or robot vision for getting depth information in shape from silhouettes (Kubo & et al., 2004). Furthermore, accuracy evaluation of zoom lenses regarding geometric and optical distortions which occur with changes in focal length setting was investigated from the view point of photogrammetry (Wiley & et al., 1990, 1995, Li& & et al., 1996, Al-Ajlouni & et al., 2006). On the contrary, macro lenses are also extensively used in macro photography (Bister & et al., 2006) since macro lenses have high imaging performance.

There are still, however, some issues for zoom and macro lens cameras apply to the documentation of small cultural heritages. These problems include sharp imaging and accurate measurement. In particular, depth of field is issue in documentation of small cultural heritage.

Zoom lenses are now popular as standard lens kit for digital single lens reflect cameras. On the contrary, macro lenses have ability in working distance.

In order to resolve these alternative issues, accuracy and performance evaluations of macro and zoom lens was investigated using three imaging modes (P-mode, AV-mode and ADE-mode) respectively.

2. EXPERIMENT

2.1 Zoom and Macro lenses

Zoom lenses have ability to vary its focal length. Therefore, zoom lenses are commonly used in multipurpose use such as wide angle mode, standard mode, telephoto mode and so on. In particular, standard mode has popularity from multipurpose use, and standard mode is commonly known as standerd lens-kit for digital single lens reflex cameras.

On the other hand, macro lenses are lens of a single focus where the focal length is fixed. The most ability of macro lenses to allow capturing the same size image on the film as the objects, and another important distinction is working distance. The working distance is distance from the front of lens to object. This make it possible to capture sharp images without influence of illumination such as shadow.

2.2 Experiment

Table 1 shows zoom lens and macro lens which were used in this investigation. These lenses were mounted on Canon EOS 20D.

Camera	Canon EOS 20D 8.2 Mega pixels CMOS Sensor size 22.5×15(mm)
Zoom Lens	EF-S24-105mm F4L IS USM focal length: 24～105mm F : 4
Macro Lens	EF100mm F2.8 MACRO USM focal length : 100mm F : 2.8

Table 1. Camera and lenses

Figure 1 shows the test target, and enclosed area with square was used in this investigation. Circle targets were manufactured ±0.05mm accuracy. Diameter of each circle target is 2cm, and the targets are arranged 40mm interval. The height of center targets is 50mm.

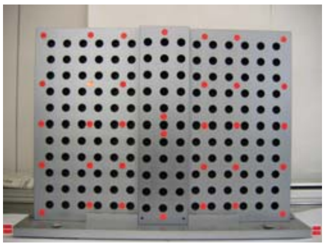


Figure 1. Test target

The center images were taken with the zoom lens (f=100mm) and the macro lens (f=100mm) as the same range on the monitor. The altitude is approximately 1.3m (zoom lens) and approximately 1.5m (macro lens). GCPs (Ground Control Points) and the check points were arranged as shown in Figure 2. The Center coordinates of each circle target was computed as area gravity by image processing procedures.

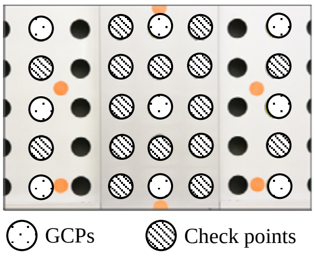


Figure 2. GCPs and Check Points

3. CALIBRATION

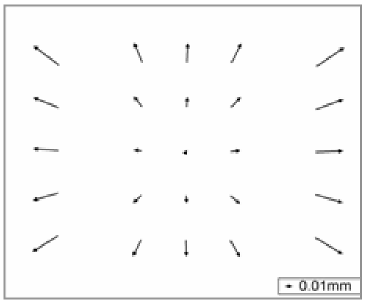
3.1 Lens distortion

At first, in order to evaluate lens distortion of the zoom and the macro lens, 3rd polynomial function, 3rd polynomial with tangential functions, 5th polynomial function, 5th polynomial with tangential functions were investigated. However, only 3rd polynomial function provide stable results. Therefore, following 3rd polynomial function was used in this investigation.

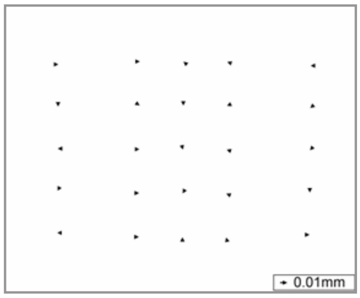
$$dx = k_1 r^2 x$$
$$dy = k_1 r^2 y \qquad (1)$$

where $r^2 = x^2 + y^2$, k_1 : coefficient of radial distortion

Figure 3 shows residual distribution on the CCD sensor before correction and after correction. It can be seen that there are significant lens distortion in case of the zoom lens, and the distortion was efficiently corrected by 3rd polynomial radial distortion model.



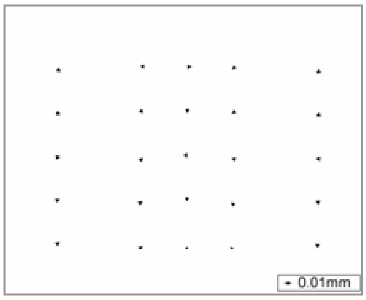
Before correction



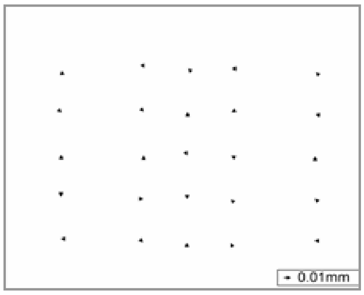
After correction

Figure 3. Residual distribution of zoom lens

Similarly, Figure 4 shows residual distribution of the macro lens before correction and after correction, and it can be seen that the macro lens didn't show any significant lens distortion. Therefore, it can be said that lens distortion for the macro lens can be neglect. This gives quite important information that it becomes possible to reduce unknown parameters regarding lens distortion in calibration procedures.



Before correction



After correction

Figure 4. Residual distribution of macro lens

3.2 Imaging modes

The imaging mode is one of the important functions for taking the best images, the most camera have the function. In order to 3D modeling of small cultural heritages, out of focus which is caused by depth of field is an important issue.
With this motive, following three imaging modes were considered.

P-mode (Program Auto Exposure): Aperture value and shutter speed are set automatically by brightness.

AV-mode (Aperture Value): Aperture value is able to change by manually. Maximal value was used in this study.

ADE-mode (Auto-Depth of Field): Aperture value is set automatically by AF frame.

3.2.1 Verification of image quality

In order to confirm out of focus, the scales were set top and bottom of the target. The images for three modes were taken using each lens with 1.3m altitude (zoom lens) and 1.5m altitude (macro lens) respectively. It can't find significant out of focus on the top scale for each lens. However, it can be found clear out of focus on the bottom scale in both lens. Figure 5 shows enlarge images of the bottom scales which were taken by the macro lens. From this figure, it was verified that the most sharpest image is able to take by the AV mode.

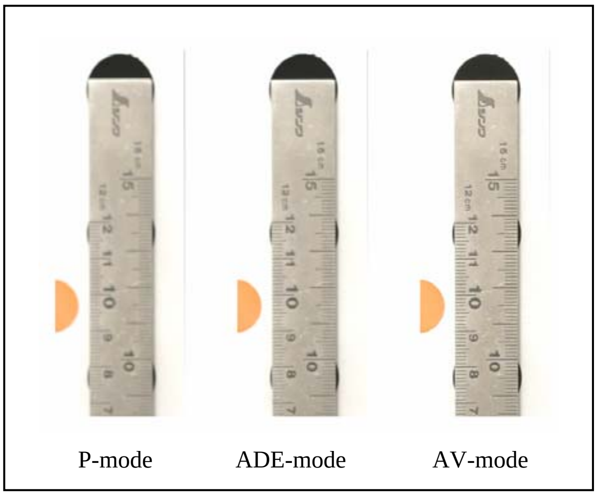
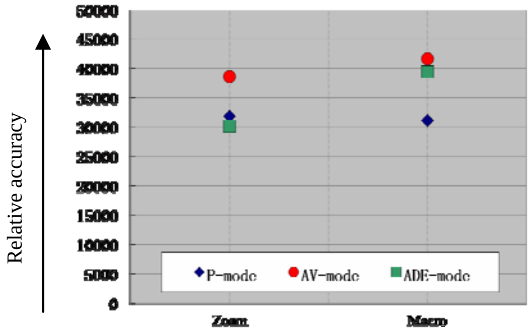


Figure 5. Verification of the Images

3.2.2 Verification of accuracy.

In order to evaluate relationship between accuracy and imaging mode, stereo images were taken using the zoom and the macro lens respectively with baseline ratio is 0.34, altitude is 1.3m (zoom lens) and 1.5m (macro lens). Focal length of the zoom lens and the macro lens was set to 100mm as well as distortion investigation.

Figure 6 shows the relative accuracy for the three imaging mode. It seems that AV-mode shows high accuracy in each lens. Furthermore, accuracy for the both lens show almost same value. However, in the calibration procedures, iteration number for zoom lens had greater than macro lens. Detail describe about iteration numbers will be given in section 3.2.4.



$$\text{Relative accuracy} = \frac{1}{\dfrac{H}{\sqrt{(\sigma_x^2 + \sigma_y^2 + \sigma_z^2)}}}$$

where H : Altitude

$\sigma_x, \sigma_y, \sigma_z$: root mean square error

Figure 6. Relative accuracy in each imaging mode

3.2.3 Accuracy in changing focal length

In order to evaluate accuracy in changing focal length, the triplet images were taken so that imaging size at different exposure stations become the same size on the monitor (Figure 7). Table 2 shows the focal length values and altitude for each exposure stations.

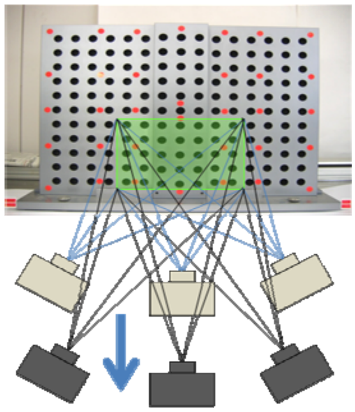


Figure 7. Changing focal length

focal length f(mm)	Altitude H(mm)
28	508
40	620
50	703
60	831
70	995
80	1090
90	1187
100	1312

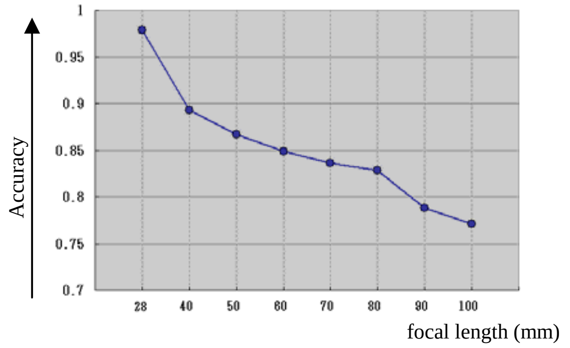
Table 2. Focal length and altitude

Figure 8 shows relationship between accuracy and focal length which were obtained using stereo images (left and right image).

Accuracy in Figure 8 means ratio of relative accuracy for measurement accuracy and standard accuracy, and standard accuracy were computed by equation (2) using the value of altitude, focal length, baseline ratio and reading accuracy (σ_P = 0.0005).

It seems that the accuracy shows lower when the focal length becomes long.

$$\sigma_{xy} = \frac{H}{f}\cdot \sigma_P \quad , \quad \sigma_z = \sqrt{2}\frac{H}{f}\cdot\frac{H}{B}\cdot \sigma_P \qquad (2)$$



$$\bullet = \frac{H}{\sqrt{(\sigma_x^2+\sigma_y^2+\sigma_z^2)}} \Bigg/ \frac{H}{\sqrt{(\sigma_{0x}^2+\sigma_{0y}^2+\sigma_{0z}^2)}}$$

where $\sigma_x, \sigma_y, \sigma_z$: root mean square error(mesurement accuracy)

$\sigma_{0x}, \sigma_{0y}, \sigma_{0z}$: root mean square error(standard error)

Figure 8. Relationship between accuracy and focal length

Furthermore, Figure 9 shows the standard deviations of orientation parameters for each focal length, and calibration was performed using center image in this case. Lower position in this figure means higher accuracy, and it can be said that the accuracy becomes lower according to longer focal length.

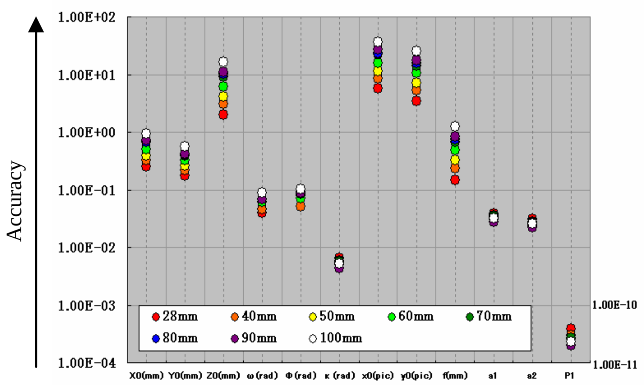


Figure 9. Standard deviations of orientation parameters for each focal length

On the other hand, in order to evaluate geometric distortion, position of principal point for the center images were considered. Figure 10 shows the position of principal points which were obtained by camera calibration for the center images.

It can be said from this figure that the principal point of zoom lens linearly move away from nominal principal point, and shifting values amounted about 80 pixels in x, y direction respectively instead of about 20-30 pixels in the macro lens (f=100mm).

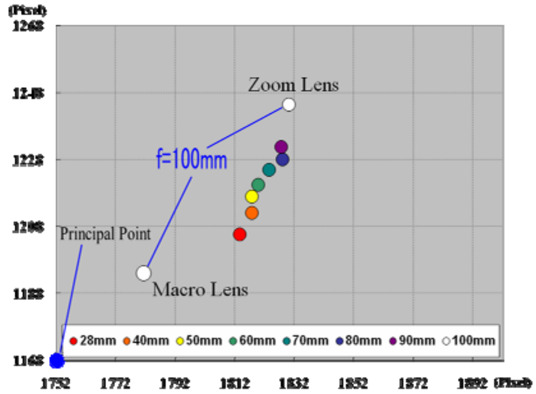


Figure 10. Geometric distortion

3.2.4 Alternative of zoom lens and macro lens

In order to reach alternative problem such as zoom lens or macro lens, both aspects of accuracy and performance should be considered, and followings are interest results from this paper.

(1) lens distortion for macro lens is able to neglect.

(2) zoom and macro lens shows almost the same accuracy in AV mode.

(3) shifting values of principal point for zoom lens shows larger than macro lens.

From these interest results, it may be said that macro lenses are efficient for documentation of small cultural heritages, and this assumption is decided by following calibration results using center images of zoom lens.

Figure 11 shows the iteration number in camera calibration for each focal length, iteration number for longer 80mm focal length shows larger numbers and iteration number for 100mm focal length shows 31 instead of 8 for macro lens.

Generally, iteration number in camera calibration is less than ten from our experiences. Therefore, it should be said that camera calibration for zoom lens with longer focal length is quite unstable, and it is concluded that the macro lens is adequate lens to documentation of small cultural heritages.

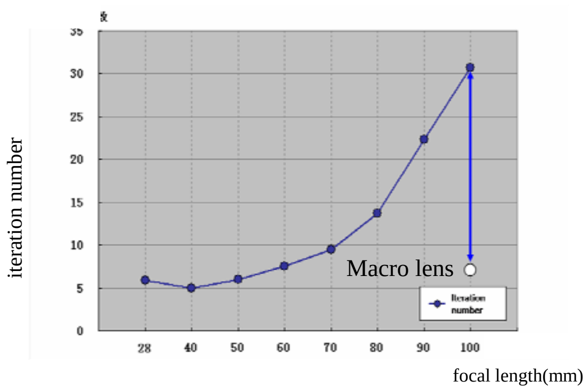


Figure 11. Iteration number

4. ARCHAEOLOGICAL 3D MODELING

In order to investigate an adaptability of the macro lens for documentation of small cultural heritages, triplet images for small Buddha which was stored in the womb of Buddha were taken by EOS 20D with the macro lens about 0.5m altitude.

Figure 12 shows Buddha with 11 faces so called eleven-headed gods. Tall is 11 cm and constructed around 18 century. Figure 13 shows small Buddha with 4 cm tall which was stored in the womb of Buddha (Figure 13). The bigger Buddha was constructed around 18 century, and the small Buddha was constructed around 16 century. Therefore, it is supposed that the bigger Buddha was constructed for the small Buddha.

After camera calibration for triple images using the 3DiVision, 3D modeling was performed. Figure 14 shows 3D modeling of the small Buddha. (a) shows overall of 3D modeling. (c) shows the enlarge image of the small Buddha's left hand. (b) and (d) show contour image with 0.1mm interval.

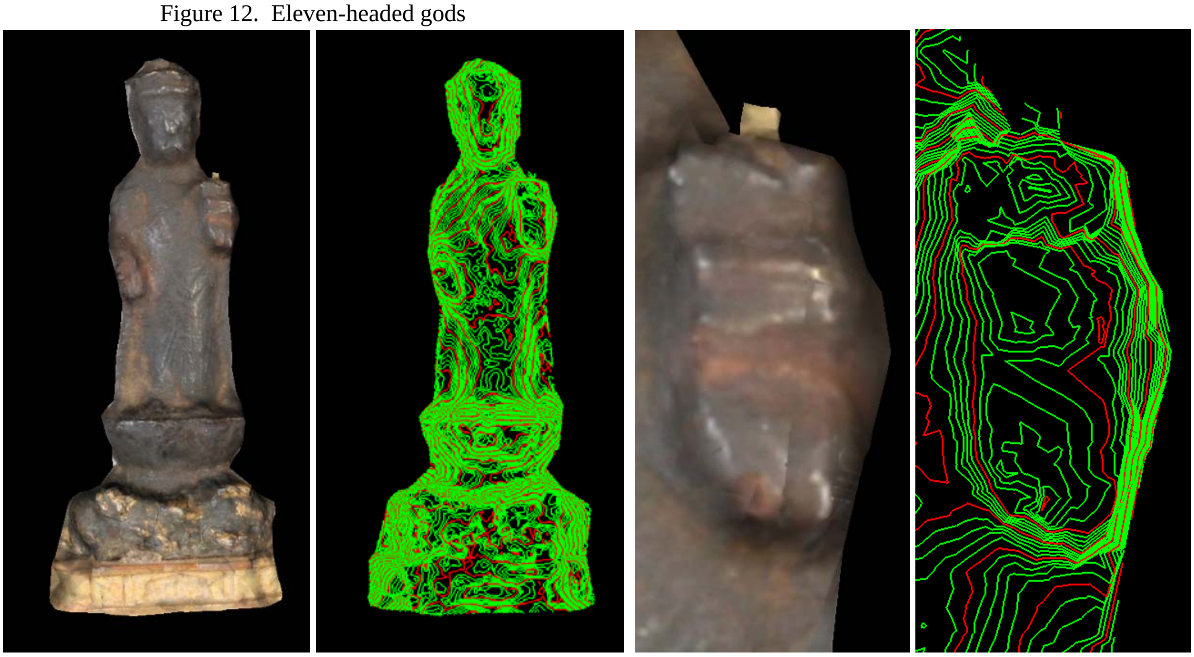
Figure 12. Eleven-headed gods

5. COCLUSION

From application standpoint such as documentation of small cultural heritages, accuracy and performance evaluations of the zoom and macro lens were investigated in this paper.

It was verified that (1) lens distortion for the macro lens was neglected. (2) high quality image was taken by the AV mode. (3) zoom and macro lens shows almost the same accuracy in AV mode. (4) shifting values of principal point for zoom lens shows larger than macro lens. (5) macro lens show quite stable solution in camera calibration. Furthermore, 3D modeling for extremely small cultural heritage was achieved using macro lens.
Consequently, it is concluded that the macro lens is adequate lens to documentation of small cultural heritages.

Figure 13. Small Buddha



(a) (b) (c) (d)
Figure 14. 3D Modeling of Small Buddha

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