Analysis of camera image repeatability using manual and automatic lenses

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Abstract
Autofocus lenses are conveniently used for applications such as video metrology. In this study we investigate the stability of capturing images and show that for precision metrology applications the autofocus lenses are not as accurate as manual lenses. The investigation was done by analyzing series of seven repeated images captured from a highly accurate reference artifact using two different lenses; autofocus and manual, mounted on a same camera system.

Keywords: Camera calibration, camera stability, autofocus lens, repeatability, image processing

1. Introduction
Today, camera-based vision systems are used in a wide range of industrial metrology applications [1-3]. Camera calibration is a critical step for increasing the accuracy of these systems. Most of the camera calibration studies are focused on correcting camera lens distortions [4-7]. As far as we looked in literature, not a single study was done in terms of investigating the impact of moving mechanics inside the cameras or inside the autofocus lenses, on the repeatability of the imaging system. In image metrology, repeatability is a critical limiting factor as multiple images will reduce noise as well as improve center of gravity calculations by averaging. Using autofocus lenses in camera-based measurement systems for 3D precision metrology make the measurement process faster, but because of loose moving mechanics inside the lens it might add unpredicted shifts between the images. The aim of this study was to investigate the effect of the moving mirror inside the camera, and the moving mechanics inside an autofocus lens on the repeatability of the image position. The results have been compared to the results of using the same camera system with a manual focus lens and locked mirror condition.

2. Method
A series of images were captured by a Canon 7D camera of a precision reference artifact. The camera, mounted on a stable tripod and provided with RF-remote (Hähnel Combi TF) exposure release, has a quick-return mirror (Figure 1) and the resolution used was 3456 x 5184 pixels. The camera was equipped with either a Samyang ED 35 mm f/1.4 AS UMC manual lens (Figure 2-left) or a Canon EF 100 mm f/2.8L Macro IS USM autofocus lens with image stabilizer (Figure 2-right). The L denotes a professional version of the lens. Two sets of seven images were taken with each lens to investigate the repeatability of the imaging system when the camera’s mirror was locked and when it was moving. The stability of the imaging system was evaluated by analyzing the images of the artifact in these four cases, and the results are presented as the lateral shifts, expressed in micrometers, in the object plane.
2.1. Artifact
The reference artifact used for this study, as shown in Figure 3, was a 18 x 24 inch (457.2 x 609.6 mm), chrome coated glass plate manufactured by Mycronic AB [8]. The plate was written by a system with a maximum absolute position error of <200 nm over the entire area of 457 x 610 mm. As shown in Figure 4, the pattern on the plate is made of repeated cells in X and Y direction. Each cell is a matrix of 3 x 3 circles with 3 different diameters of 3.5, 4 and 5.5 mm in each row. The pitch, i.e. the distance between two neighbour circles is 10 mm.
2.2. Image processing

The absolute positions of the largest circles in the pattern were used as repeated features in the image of the artifact for verification test. As shown in Figure 5, to calculate the center of gravity (COG) of each circle, first the edges were found in pixel resolution using standard edge detection technique. In our case we used Sobel operators to calculate the edge positions. Then the gradient intensity along the edge was used to calculate the local maximum i.e. edge position in subpixel resolution. More explanations about the techniques have been reported in section 3.4. in reference [2].
3. Results
In order to evaluate the repeatability a mid-position X,Y value is calculated for each of the seven images. This mid-position is calculated as the average of all (684) circle center of gravities, following the steps explained above. The average of the seven mid-positions is then calculated and used as the reference mid-X,Y value, when analyzing the lateral shift (offset) of the 7 different mid-positions. The offsets in X and Y direction are plotted in the following graphs, where the scale is in microns at the object, i.e. it reports how much the artifact has been artificially “moved” by the camera and lens mechanics.

3.1. Case 1: Samyang 35 mm lens with the locked camera mirror
The left graph in Figure 6 shows the offsets (camera drift) from the mean reference value in X direction for 7 measurements and the right graph shows the offsets in Y direction. As seen in the graphs the Samyang manual focus 35 mm lens, with the locked mirror, give offsets smaller than 4 μm in both X and Y directions. This is a very good result considering that the whole image covers 35 x 55 cm².

3.2. Case 2: Samyang 35 mm lens with the moving mirror
Figure 7 shows the offsets from the mean reference value in X and Y direction for the second case, where the mirror is flipped back after each exposure using the Samyang lens. Larger shift ranges of ~ 12 μm in X direction and ~ 4.5 μm in Y direction were observed in comparison to the case of using the camera with mirror locked.
3.3. Case 3: Canon macro lens EF 100 mm with the locked mirror

In the case of using the Canon EF 100 mm macro autofocus and image stabilizing lens the result is a lot worse, as can be seen in Figure 8, despite attached on a stable tripod and with the mirror locked. The offsets have diverted to ~ 170 µm in X and Y directions.

3.4. Case 4: Canon macro lens EF 100 mm with the moving mirror

Figure 9 shows the offsets from the mean reference value in X and Y direction for the case of using the Canon macro lens EF 100 mm with the mirror flipping back after each exposure. The offset range in X direction is now increased to ~ 650 µm and in the Y direction to ~ 450 µm. Thus, the vibrations induced by the mirror, has caused the lens to respond by artificially shifting the artifact in the half-mm range. This is not what we want in a precision metrology system.
4. Discussion

This simple investigation has resulted in surprising results. The considerably more expensive and professional Canon lens with image stabilizer and auto focus, shows an uncertainty of the image repeatability of about half a mm in the 55 cm wide object plane. This corresponds to ~900 ppm, while the manual Samyang lens is about 100 times better under the same camera operating conditions. At this point we can only assume that it is the image stabilizer that increases the offset by large amounts, after triggered by the mirror vibrations. The autofocus is more likely to be less dependent on mirror induced vibrations. To illustrate the huge differences Figure 10 shows the offset variations in one and the same scale for all four cases.

Figure 9. Offset values from the mean for Canon macro lens with the moving mirror

Figure 10. Image offsets in the object plane are shown in the same scale. A manual focus lens was used for Case 1 and 2 while an autofocus/image stabilized lens was used for case 3 and 4
5. Conclusion
Precision image metrology demands stable imaging conditions, as lack of repeatability will increase the uncertainty. In this study we investigated the impact of locking or flipping the mirror in a Canon 7D camera on the stability of the image. For a manual Samyang lens the difference was modest when seven repeated images were captured on a precision reference artifact. The relative offset of 3 micrometers corresponds to 5 ppm of the imaged area for the locked mirror while it increases up to 20 ppm when letting the mirror flip back after each exposure. However, for a professional Canon lens provided with autofocus and image stabilizer the flipping mirror caused image repositioning of up to 0.5 mm of a 55 cm object, corresponding to a relative uncertainty of ~900 ppm. Even with the mirror locked, the uncertainty was found to be in the 300 ppm range. This study clearly shows the importance of selecting the right lens if accurate metrology is going to be performed of images captured by standard digital cameras.

6. References