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A Method for Evaluating Camera Auto-Focusing Performance using a Transparent Display Device

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Abstract

With the development of various autofocusing (AF) technologies, sensor manufacturers are demanded to evaluate their performance accurately. The basic method of evaluating AF performance is to measure the time to get the refocused image and the sharpness of the image while repeatedly inducing the refocusing process. Traditionally, this process was conducted manually by covering and uncovering an object or sensor repeatedly, which can lead to unreliable results due to the human error and light blocking method. To deal with this problem, we propose a new device and solutions using a transparent display. Our method can provide more reliable results than the existing method by modulating the opacity, pattern, and repetition cycle of the target on the transparent display.

Introduction

In modern camera techniques, autofocus (AF) technique is an essential function to find the optimal lens position and make the most of the performance of lenses. In the past, passive AF, which optimizes the focus only with the clarity of the image (c.f., contrast-based AF), was widely used. As camera technology has developed with the spread of mobile devices in recent years, various active AF technologies using phase detection (PD), infrared rays [1], time of flight (TOF) [2], or deep learning [3] or are being developed to compensate for the shortcomings of the passive AF [4][5]. Accordingly, the industry needs a reliable and efficient way to evaluate those novel AF technologies.

In the evaluation of AF, not only accuracy but also speed is considered as an important attribute [6]. Therefore, it is necessary to evaluate both how quickly AF has the right focus and how often it reaches the optimal focus. The basic evaluation method is to measure the time from the beginning to the end of the focusing process and measure the sharpness of the image while repeating this process. Traditionally, this process was conducted manually by covering and uncovering an object or sensor repeatedly. However, the manual process is slow and inconsistent, which can lead to unreliable evaluation results. When light is blocked, moreover, automatic exposure (AE) and automatic white balance (AWB) functions are also actively involved, making it ambiguous to specify the pure AF time.

To avoid this problem, we introduce a new device and solutions to evaluate AF performance. Instead of mechanically covering the sensor, we used a transparent display to electrically cover the front of the sensor and repeatedly induce refocusing. By electrically placing a blocking image in front of the sensor, we can dramatically shorten the time to cover the sensor, allowing us to measure the speed of AF more clearly than the conventional method. By using a dynamic blocking image, in addition, we evaluated various AF sub-performance such as contrast sensitivity and directional sensitivity, which was not available with the existing monotonous measurement method.

Method

Hardware

In this study, we used a 15-inch commercial transparent display to configure the proposed device. The device have box-shaped frame including a PC to control the transparent display. We designed the instrument so that the chart could be mounted on the back side, and implemented light emitting diodes (LEDs) inside to illuminate the chart. The specification of the transparent display is shown in Table 1.

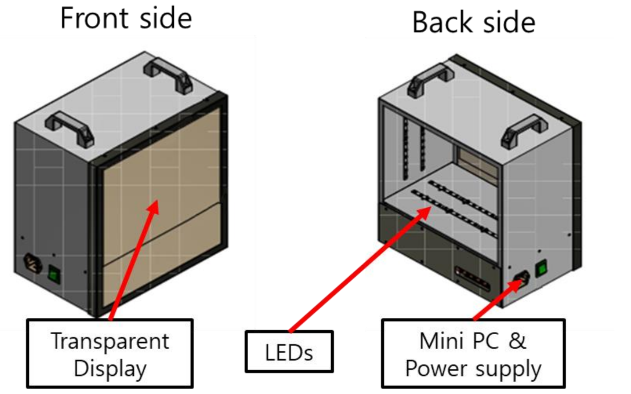


Figure 1. The configuration of the proposed AF evaluation device with a transparent display.

Table 1. Specification of the transparent display

Model name	YM-TLP-15, YAMA
Panel Resolution	1024 x 768 (4:3)
Viewing Angle	85 degree
Transparent	75% - 85%
Scan rate	60Hz - 75Hz
Contrast Ratio	700:1
Response Time	5.7ms
Active Area	304.1mm x 228.1mm (15 inch)

When deactivated, the display is transparent so that the camera can view a chart inside the box (Figure 2a). In contrast, an opaque image appears, making the sensor to refocusing on it when it is activated (Figure 2b)

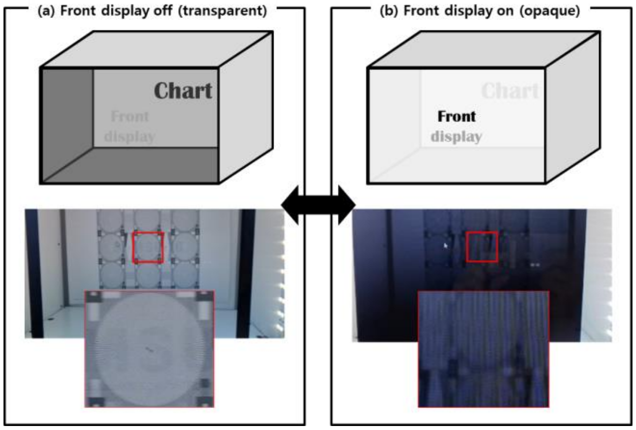


Figure 2. Two states (deactivated vs. activated) of the proposed transparent display device.

Analysis

In the experiment, the distance between the camera and the device was adjusted so that the field of view (FOV) could only show the inside of the main box. Then, we recorded a preview screen of the camera while modulating the image on the display. In the recorded preview image, we designated the region of interest (ROI) with 1/4 area of the entire screen at the center, and measured the average brightness and Tenengrad-based sharpness [7] of the ROI for each frame. The averaged brightness, B_i, and sharpness, S_i are defined as follows:

$$B_i = \frac{1}{N}\sum_{x,y}^{N} I_{x,y,i} \tag{1}$$

$$S_i = \sum_{x,y}^{N}\sqrt{S_h\left(I_{x,y,i}\right)^2 + S_v\left(I_{x,y,i}\right)^2} \tag{2}$$

where $I_{x,y,i}$ denotes the gray-scale ROI image in the i-th frame, N is the pixel size in the ROI, and (S_h, S_v) are the horizontal- and vertical-Sobel filtering operators. Note that we normalized the sharpness by dividing the results of (2) by its standard deviation after subtracting its mean value as follow:

$$S_{i,norm} = \frac{S_i - mean(S_i)}{std(S_i)}. \tag{3}$$

Results

We measured the brightness and sharpness changes along the frame of the videos acquired with the existing (c.f., manual) and the proposed (c.f., automatic) methods. In the result of the existing method, we observed that the amplitude of brightness was severely fluctuated (the blue line in Figure 3a) and the periods of both brightness and sharpness (the red lines in Figure 3a) were unstable. In the enlarged graph so that only one cycle of the graph is visible, we specified the following three points: state 1) Just before the sensor is unblocked, state 2) The point where the brightness is stabilized, state 3) Just before covering the sensor again (Figure 3b). The ROI at each state is shown in Figure 3c-e, respectively. After state 1, the brightness soared and stabilized after a few frames (state 2 in Figure 3b). During the time, the sharpness started to increase and stabilized before the state 3.

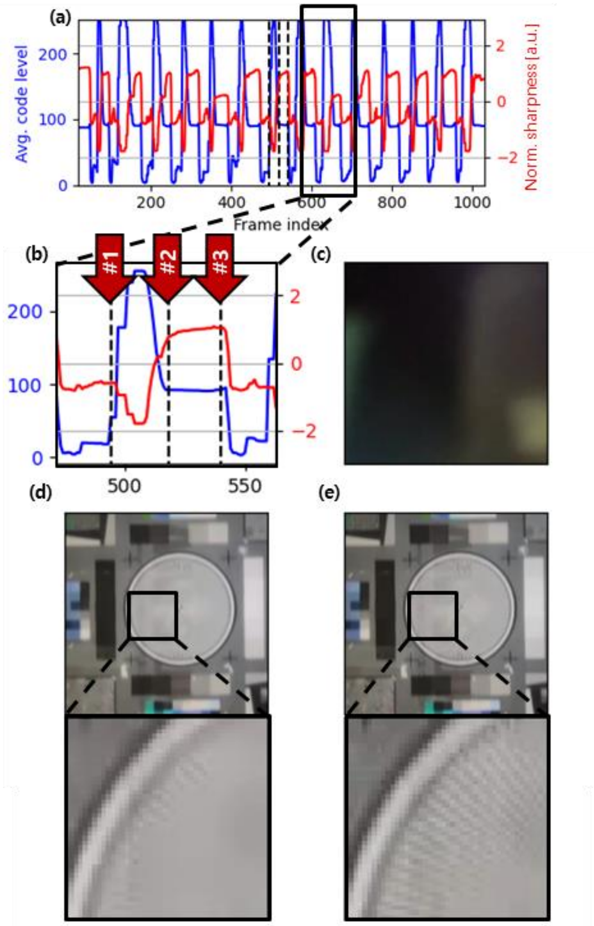


Figure 3. Result of the existing method. (a) Brightness and normalized sharpness along the frames. (b) Zoomed area including a refocusing cycle. (c) The ROI when the sensor begins to be uncovered (the state 1 in (b)), (d) The ROI when the AE process is complete (the state 2 in (b)), (e) The ROI when the refocusing process is complete (the state 3 in (b))

In contrast, the both brightness and sharpness graphs from the proposed method showed highly consistent frequency (Figure 4a). In the enlarged graph (Figure 4b), we set the 3 points as same as Figure 3b. Compared to the existing method, the time to stabilize the brightness (c.f., state 1 to state 2) was significantly shorter. In the brightness graph from the proposed method, in addition, we cannot find the overshoot nor undershoot, which were observed in that from the existing method just after each state 2 and 3. The sharpness started to increase at the state 2 point, while it began to increase before reaching the point in the existing method.

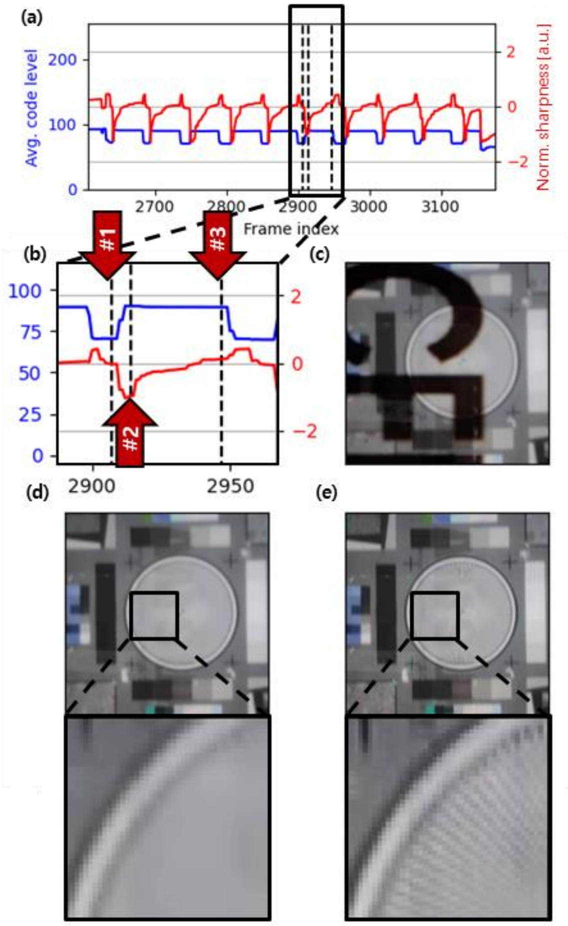


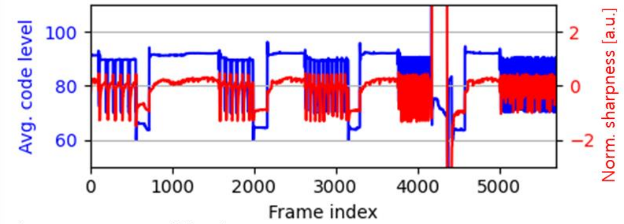
Figure 4. Result of the proposed method. (a) Brightness and normalized sharpness along the frames. (b) Zoomed area including a refocusing cycle. (c) The ROI when the sensor begins to be uncovered (the state 1 in (b)), (d) The ROI when the AE process is complete (the state 2 in (b)), (e) The ROI when the refocusing process is complete (the state 3 in (b))

Discussions

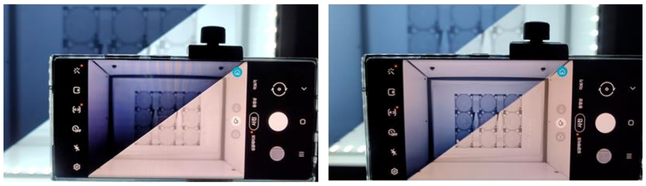
In this study, we compared the two AF evaluation methods by measuring the sharpness. We used the Tenengrad focus function to quantify the sharpness in this experiment, but it would be possible to use another focus function such as variance or Laplacian-based functions. This is because they yield the maximum values where the focus is optimized regardless of their types [8]. What is important in our application is not the absolute level of the sharpness, but the time when the relative sharpness is maximized, which is why we normalized the sharpness.

The noticeable differences in the graphs from the existing and proposed method are the period consistency and the point where the brightness is stabilized. The inconsistency would be due to the act of manually covering the sensor by hand in this experiment. Thus, this problem can be easily solved if we utilize an automatic system. However, the traditional method is difficult to achieve brightness stabilization as fast as the proposed method. In the traditional way, besides, a significant amount of light is blocked, resulting in strong intervention of the AE and AWB accompanied by the extra delay and over/undershoot in the brightness. The other disadvantage of the mechanical method is that it makes us to need an additional delay to move the blocking object from anywhere else to the middle of the field of view (FOV). On the other hand, the proposed method blocks the sensor electrically. Hence, we can minimize both the temporal delay and the intervention of the AE/AWB. We can confirm this advantage in the fact that the point where the sharpness starts to increase is close to the point where the brightness starts to be maintained (state 2 in Figure 4b). Accordingly, we can more obviously determine the range where AF operates with the proposed method, resulting in more precise and accurate results than the existing method.

(a) Speed modification



(b) Contrast modification



(c) Direction modification

(d) Location modification

Figure 5. Examples of detailed AF performance evaluation. (a) Measured averaged code level and sharpness change with the different screening speed. (b-d) Example of AF performance evaluation according to contrast, direction, and position change, respectively.

In addition to the evaluation reliability, the proposed method could assess the additional AF performance through image modulation. The additional measurable AF attributes are as follows: 1) agility, 2) contrast sensitivity, 3) directional sensitivity, and 4) positional sensitivity. In the situation where a scene changes rapidly, the PD signals should quickly respond to give the correct feedback to the lens actuator frame-by-frame. While gradually increasing the repetition frequency of the blocking object, we could evaluate the reactivity of the AF by counting how often the AF fails to reach the maximum sharpness along the repetition rate (Figure 5a). We can also evaluate the contrast sensitivity. If the contrast of the blocking object is not sufficient, the AF could not able to distinguish the phase disparity. Thus, by using blocking images with various contrasts, we can measure the contrast sensitivity by checking in which contrast the sensor fails (Figure 5b). The third application is directional sensitivity. Generally, PD consists of two subpixels, causing anisotropic AF sensitivity. To assess this attribute, we can use stripe-patterned image with a variety of angles (Figure 5c). The last application is positional sensitivity. A typical photograph contains multiple objects at various distance. Hence, a reference area of focus must be set automatically or manually, so that each location have difference AF sensitivity. By positioning the blocking object at various positions, it is possible to measure the relative sensitivity according to the position of the blocking object (Figure 5d).

Conclusions

We developed a device using a transparent display to evaluate AF performance more accurately and comprehensively than the existing method. Compared to the existing method, our solution can provide users with the following advantages: 1) Fast and consistent cover/uncovering time, 2) Minimal AE and AWB intervention, and 3) Various additional evaluation functions. With these advantages, we can expect more reliable results and assess the detailed AF performance such as response time and pattern-/contrast-/location-dependency, which are unavailable in the monotonous existing method. Thus, we expect that the proposed solution will contribute to both the development and marketing of next-generation sensors.

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Author Biography

Seungwan Jeon was born in Republic of Korea in 1989. He received the B.S. degree in biomedical engineering from Yonsei University in 2014, and the Ph.D. degree in creative IT engineering from POSTECH in 2020. His Ph.D. research focused on photoacoustic/ultrasound imaging techniques using image/signal processing, beamforming, and deep learning. Since 2020, he is with Samsung Electronics, Republic of Korea, as a Staff engineer. His current research interests include camera sensor, computer vision, and image quality assessment.