EVALUATION OF CAMERA PERFORMANCE USING ISO-BASED CRITERIA

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ABSTRACT

This paper investigates the performance of a vehicular rear-view camera through quantifying the image quality based on several objective criteria from the ISO (International Organization for Standardization). In addition, various experimental environments are defined considering the conditions under which a rear-view camera may need to operate. The process for evaluating the performance of a rear-view camera is composed of five objective criteria: noise test, resolution test, OECF (opto-electronic conversion function) test, color characterization test, and pincushion and barrel distortion tests. The proposed image quality quantification method then expresses the results of each test as a single value, allowing easy evaluation. In experiments, the performance evaluation results are analyzed and compared with those for a regular digital camera.

Keywords: vehicular camera, image quality, ISO

1. INTRODUCTION

Images obtained from vehicular cameras are being increasingly used when driving a car due to their safety effect. Yet, the quality of this kind of image is an important factor to catch all possible information accurately. This image quality is determined by an integrated chain of input, image processing, and output modules, where the property of the vehicular camera, as the input module, is particularly important. However, the image quality level of current vehicular rear-view cameras is lower than that of regular digital cameras due to limited electric power, a limited internal memory, optical zoom difficulties, low color reproduction capabilities, the use of a wide-angle lens, and a limited resolution. For example, camera noise is significantly increased when the illumination environment around a vehicular rear-view camera becomes dark. Also, the distortion in the resulting image is higher than that with a regular digital camera due to the use of a wide-angle lens. Thus, to establish the requirements for a vehicular rear-view camera and produce one corresponding to such requirements, the camera performance of vehicular rear-view cameras needs to be evaluated by analyzing their image quality. Accordingly, this paper proposes an evaluation method for the camera performance of vehicular rear-view cameras based on their image quality. Using the ISO test criteria[1-6] applied to digital still cameras, the

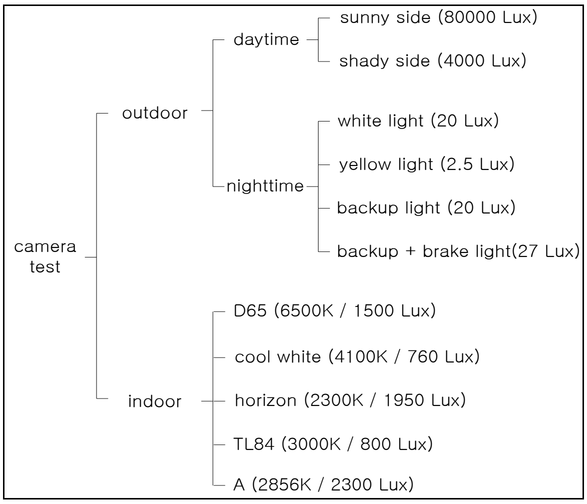


Fig. 1: Test environments used to evaluate performance of vehicular rear-view camera.

proposed evaluation factors for determining the performance of a vehicular rear-view camera include a noise test, resolution test, OECF test, color characterization test, and pincushion and barrel distortion tests.
Various experimental environments are also defined considering the conditions under which a vehicular rear-view camera may need to operate. These experimental environments are divided into two categories: outdoor environments, including daytime sunny, daytime shady, night-time white light, night-time yellow light, night-time backup light, and night-time backup and brake light, and indoor environments, including such standard illuminants as D65, cool white, horizon, TL84, and A. In experiments, the camera performances of a vehicular rear-view camera and regular digital camera were evaluated and compared the using the numerical values derived from the proposed quantitative evaluation method. As a result, the performance of the vehicular rear-view camera could be easily estimated in terms of its sensitivity to noise, resolution, OECF property, color reproduction, and degree of pincushion and barrel distortion by calculating the difference values of the test results.

2. DEFINITION OF REAL-WORLD SITUATIONS

Various illuminant conditions considering real-world situations are defined to evaluate the camera performance, and Figure 1 shows the test environments. In the case of outdoor environments, the illuminant conditions are classified into daytime sunny, daytime shady, night-time white light, night-time yellow light, night-time backup light, and night-time backup and brake lights. Meanwhile, for indoor environments, five standard illuminants are used: SpectraLight III Lighting Booth with D65, cool white, horizon, TL84, and A. The average illuminance and color temperature are also represented for each environment.

3. QUANTIFICATION OF IMAGE QUALITY

For an intuitive evaluation and estimation of the performance of a vehicular rear-view camera, five evaluation tests are proposed to quantify the image quality.

3.1 Noise

The noise test is an algorithm that calculates the amount of noise in an image taken by a vehicular rear-view camera. Plus, the von Kries model[7] is applied to the algorithm to consider the human visual system. As the noise test results are expressed as vertical and horizontal noise values for each luminance level of the noise test chart, the results are quantified by calculating the average noise value σ_{avg} for each luminance level as follows:

$$\sigma_{avg} = \frac{1}{L_{\max} - L_{\min}} \left(\sum_{i=L_{\min}}^{L_{\max}} \sigma_i \right) \tag{1}$$

where $L_{\max}$ and $L_{\min}$ denote the maximum and minimum luminance values, respectively, and σ_i denotes the noise value for luminance level i.

3.2 Resolution

This test is an algorithm that analyzes the details in an image taken by a vehicular rear-view camera and uses the MTF (Modulation Transfer Function)[8], which represents the ratio of the output spatial frequency to the input spatial frequency. The results of the resolution test are expressed as the variation in the MTF values according to an increase in the spatial frequency for the RGB channels. In the case of a regular digital camera, the MTF values gradually decrease to almost zero. If a digital camera has a good resolution performance, the spatial frequency values are high when the MTF values are near zero. In other words, the smoother the MTF slope, the better the camera performance. On the basis of repeated resolution tests, the quantitative value for the resolution test was determined as the value of the spatial frequency when the MTF curve decreased to a point of 0.05(5% of MTF), as the MTF value never reaches zero due to the effect of noise.

3.3 OECF

This test is an algorithm that analyzes the relationship between the luminance and the digital values in an image taken by a vehicular rear-view camera, and the OECF test results are expressed as the relationship between the input log-scaled luminance and the camera output value for the RGB channels. A straight line represents the shape of the OECF for an ideal digital camera. Therefore, to quantify the OECF test results, the average difference Δd_{avg} is calculated between the ideal digital values and the real digital values as follows:

$$\Delta d_{avg} = \sqrt{\frac{1}{N}\left(\sum_{i=1}^{N} (L_i - O_i)^2 \right)} \tag{2}$$

where *N* denotes the number of patches, and L_i and O_i denote the ideal and real digital values for the ith patch, respectively.

3.4 Color Characterization

The color characterization test results are expressed as the color difference[9] ΔE^*_{ab}, which is already widely used in color image processing.

$$\begin{aligned} \Delta E^*_{ab} &= \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \\ \Delta L^* &= L^*_2 - L^*_1 \\ \Delta a^* &= a^*_2 - a^*_1 \\ \Delta b^* &= b^*_2 - b^*_1 \end{aligned} \tag{3}$$

where L^*_1, a^*_1, and b^*_1 denote the CIELAB value of the original color, and L^*_2, a^*_2, and b^*_2 denote the CIELAB value of the test color.

3.5 Pincushion and Barrel Distortion

To quantify the results of the pincushion and barrel distortion test, the degree of warping is compared with a straight line using a specially developed test chart, as a standard chart evaluating the pincushion and barrel

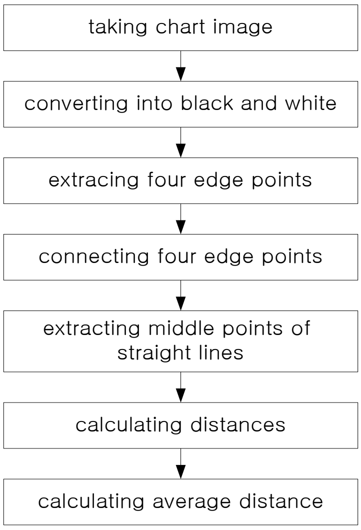
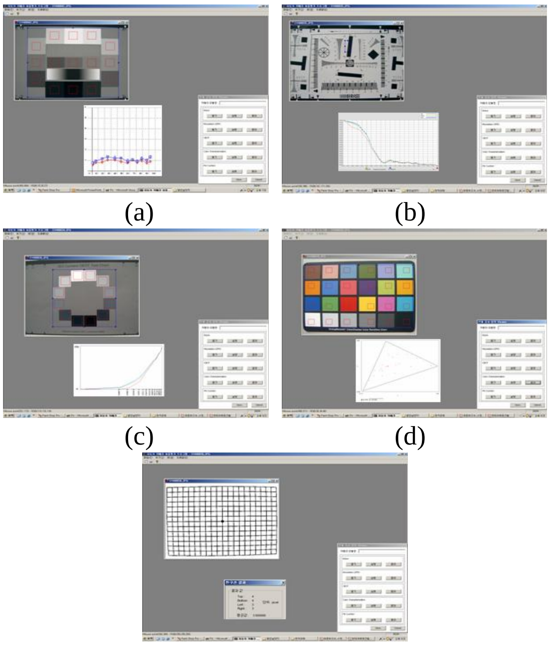


Fig. 2: Flowchart of pincushion and barrel distortion test.

(a) (b)

Fig. 3: Examples of camera images: (a) image obtained from vehicular rear-view camera and (b) image obtained from regular digital camera.



(a) (b) (c) (d) (e)

Fig. 4: Example of camera performance evaluation program: (a) noise evaluation, (b) resolution evaluation, (c) OECF evaluation, (d) evaluation of color characterization, and (e) evaluation of pincushion and barrel distortion.

distortion has not yet been specified. Therefore, the following algorithm is applied, as shown in Figure 2. First, an image of the chart is taken by a vehicular rear-view camera, and the resulting image converted into a black and white image. The four edge points are then connected by four straight lines, and the distance between the middle point of the straight line and the distorted line calculated in the black and white image. The distance is expressed by the number of pixels. Finally, the average distance is calculated to quantify the pincushion and barrel distortion test results.

4. EXPERIMENTAL RESULTS AND DISCUSSION

To evaluate and compare camera performances using the numerical values derived from the proposed quantification method, images were obtained using a vehicular rear-view camera and regular digital camera under various environments, as shown in Figure 3. Figures 3(a) and 3(b) show example images taken by the vehicular rear-view camera and regular digital camera, respectively.

Table 1: Comparison of noise test results.

Test environments		Vehicular camera	General camera
Out-door	Daytime-sunny side	2.5	1.0
	Daytime-shady side	2.0	1.0
	Night-time-white light	8.0	1.25
	Night-time-yellow light	10.0	1.25
	Night-time-backup light	7.5	1.25
	Night-time-backup and brake light	6.0	1.75
In-door	D65	2.0	1.0
	Cool white	2.5	1.0
	Horizon	2.5	1.0
	TL84	2.0	1.0
	A	2.5	1.25

Table 2: Comparison of resolution test results.

Test environments		Vehicular camera	General camera
Out-door	Daytime-sunny side	0.5	0.9
	Daytime-shady side	0.5	0.9
	Night-time-white light	0.3	0.85
	Night-time-yellow light	0.3	0.3
	Night-time-backup light	0.46	0.85
	Night-time-backup and brake light	0.39	0.9
In-door	D65	0.5	0.85
	Cool white	0.5	0.85
	Horizon	0.5	0.85
	TL84	0.3	0.87
	A	0.35	0.87

Table 3: Comparison of OECF test results.

Test environments		Vehicular camera	General camera
Out-door	Daytime-sunny side	25.94	34.79
	Daytime-shady side	28.93	34.08
	Night-time-white light	24.43	41.53
	Night-time-yellow light	39.04	26.02
	Night-time-backup light	43.56	26.62
	Night-time-backup and brake light	44.28	24.91
In-door	D65	29.30	34.96
	Cool white	34.21	29.59
	Horizon	34.12	36.02
	TL84	30.86	35.79
	A	31.76	32.67

The vehicular rear-view camera selected for the experiments is already widely used by the Hyundai motor company, while the regular digital camera was a Samsung Digimax 4V. Figure 4 shows the camera performance evaluation software, which was programmed using the proposed method.

Table 1 shows the noise evaluation results, where the noise values for the vehicular rear-view camera were found to be at least two times higher than those for the regular digital camera, regardless of the test environment. Plus, when comparing daytime with nighttime, the noise values increased when the illuminance was decreased. Table 2 shows the resolution evaluation results, where the values

Table 4: Comparison of color characterization test results.

Test environments		Vehicular camera	General camera
Out-door	Daytime-sunny side	11.5	4.9
	Daytime-shady side	11.6	6.5
	Night-time-white light	16.0	14.6
	Night-time-yellow light	53.6	40.9
	Night-time-backup light	16.9	14.9
	Night-time-backup and brake light	24.4	17.8
In-door	D65	11.7	5.3
	Cool white	14.9	8.7
	Horizon	18.8	9.3
	TL84	16.3	8.2
	A	14.6	7.7

Table 5: Comparison of pincushion and barrel distortion test results.

Test environments		Vehicular camera	General camera
In-door	D65	9.5	2.25

Table 6: Overall comparison of test results using average values.

Evaluation factors	Ideal camera	Vehicular camera	General camera
Noise test	0	4.32	1.27
Resolution test	1	0.42	0.82
OECF test	0	33.31	32.45
Color characterization test	0	19.12	12.62
Pincushion / barrel distortion test	0	9.5	2.25

for the regular digital camera were almost two times higher than those for the vehicular rear-view camera, regardless of the test environment. However, for the case of nighttime yellow light, the two resolution values were the same, as the illuminance of the nighttime yellow light was too dark to evaluate the resolution performance of the regular digital camera. The OECF evaluation results are shown in Table 3, where the values for the vehicular rear-view camera and regular digital camera were similar and high for the most part, as the OECF curves were gamma-shaped. The color characterization evaluation results are shown in Table 4, where the color difference values for the vehicular rear-view camera were higher than those for the regular digital camera, due to the much narrower gamut of the vehicular rear-view camera. However, for the case of nighttime yellow light, the two color difference values were both high, as the illuminance of the nighttime yellow light did not allow any discrimination of the test chart colors. Finally, table 5 shows the pincushion and barrel distortion evaluation results, which were only measured under a general standard illuminant of D65. Here, the distortion value for the vehicular rear-view camera was almost four times higher than that for the regular digital camera, as the vehicular rear-view camera uses a wide-angle lens to guarantee a wide viewing angle. For an overall evaluation of the performances of the vehicular rear-view camera and regular digital camera, the average values were calculated for the five evaluation tests, as shown in Table 6. As a result, the proposed method was demonstrated to provide a clear estimate of the performance of the vehicular rear-view camera as regards its sensitivity to noise, resolution, OECF property, color reproduction, and degree of pincushion and barrel distortion.

5. CONCLUSION

This paper proposed a method for evaluating the performance of a vehicular camera through quantifying the image quality based on several objective criteria established by the ISO. In addition, various experimental environments are defined considering the conditions under which a vehicular rear-view camera may need to operate. The factors used to evaluate the performance of a vehicular rear-view camera include a noise test, resolution test, OECF test, color characterization test, and pincushion and barrel distortion test. The proposed image quality quantification method then expresses the results of each test as a single value to enable a fast and intuitive performance evaluation. In experiments, the performances of a vehicular rear-view camera and regular digital camera were compared and analyzed. As a result, the proposed method was demonstrated to produce an effective estimate of the performance of the vehicular rear-view camera. In addition, the proposed method establishes the key requirements for a vehicular rear-view camera, allowing a focus for further improvements in the image information generated from vehicular rear-view cameras.

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