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Quantitative Image Quality Evaluation Method for UDC (Under Display Camera)

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Abstract

Nowadays, mobile phone set makers are implementing a full screen display by changing the mounting form factor of the front camera, which is superior in design. When it comes to smart phone front-facing cameras, the hole type front-facing camera degrade the industrial design, while pop-up style camera has also limitation in terms of waterproofness and durability. In the case of Under Display Camera(UDC) which is in its final form factor by design, where a camera is placed underneath the screen, the display panel on the light-receiving path degrades the camera optical sensitivity and causes decrease in image quality performance due to regular display panel pattern. In order to commercialize the UDC, improving image quality of the UDC and exact measurement are crucial. However, subjectively evaluating image taken through the display panel is challenging task measure the image quality performance.

This paper introduces a numeric based UDC image quantitative measurement method as a more objective evaluation way.

Introduction

With the development of the mobile industry, display and camera technologies included in mobile phones are also developing. The current display technology for mobile set is being developed to increase the screen share of the display panel. Recently, the front facing camera is being considered to be placed underneath the display panel as shown in Figure 1. Positioning the front camera under the panel has the advantage of full display without bezel, notch and/or hole structure, but the panel distract the light-receiving unit of the camera. Due to the disturbance and decreasing transmittance, the UDC image quality faces the problems of light quantity reduction and diffraction.

UDC is very good in terms of industrial design. But the image is distorted by the panel when viewed from the CMOS image sensor point of view. Therefore, achieving maximize image quality performance is challenging task. In typical cases, multiphase object effect that is not usually happen in traditional non UDC structure, are caused by the diffraction artifact. The resolution of image is reduced due to the pattern of display panel. As the amount of light decreases, the noise characteristics of the sensor essentially is worse than before. In particular, in relation to the deterioration of image quality that occurs in an UDC, it is difficult to evaluate the performance of an accurate UDC by performing a subjective comparison.

In this paper, we present image quality metrics that can evaluate camera image quality levels of the UDC technology.

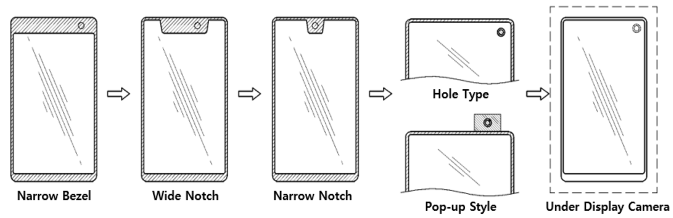

Figure 1. Trend of front camera type

Proposed approach

In order to evaluate the image quality of UDC, we define two metrics. The first is to quantify the diffraction images that occur in the image passing through the display panel. The second is to quantify the general image quality.

Diffraction

The representative artifact caused by the display panel is the diffraction. The diffraction occurs when light passing through a panel that has specific pattern as shown in Figure 2. Each display panel manufacturer has its own display panel pattern, and the shape of the diffraction image passing through the display panel varies according to the related pattern [1].

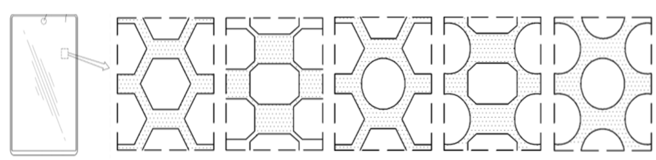

Figure 2. Regular pattern in display panel

The diffraction shape of light when taking a picture with a general mobile phone is shown in Figure 3 (a). When taking a picture with a UDC-equipped mobile phone, the diffraction of light occurs around the light source is shown as in Figure 3 (b). You can see that the image quality has deteriorated.

Figure 3. Example of the diffraction: (a) Non-UDC, (b) UDC

This section describes the metric calculation method for quantifying these diffraction phenomena. Since the diffraction of UDC occurs at the periphery of the light source, images were captured using a point light source in the dark room as shown in Figure 4. The diffraction shape of light when taking a picture with a general mobile phone is shown in Figure 4 (a). When taking a picture with a UDC-equipped mobile phone, the diffraction of light occurs around the light source is shown as in Figure 4 (b). It can be seen that the diffraction is distorted by the regular display panel pattern.

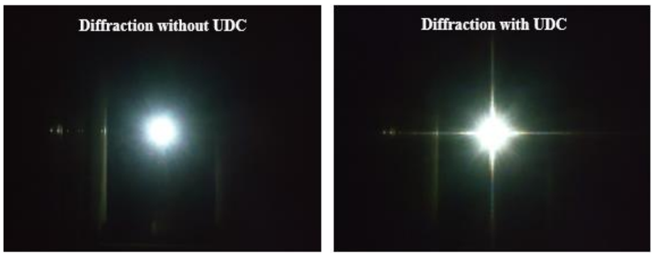

Figure 4. Image of point light source in the dark room testing: (a) Non-UDC, (b) UDC

The method of evaluating the diffraction performance of the UDC is as follow. The first step is to create a reference image by the light output from light source. In the second step, a reference value obtained by quantifying the degree to which the outline of the reference image is closed to original shape is calculated. In the third step, light output from the light source passing through the display panel is captured by a set including an image sensor to generate an evaluation image. In the fourth step, a value corresponding to the reference value is calculated from the evaluation image and a performance evaluation result is output by comparing calculating value with the reference value.

The Figure 5 shows diffraction quantification step. First, the original image is converted to gray scale, hereafter binary processing and contour processing have been performed. By processing a step of converting the original image into a grayscale and binary step to generate a contour image, it is possible to improve the accuracy of contour image analysis.

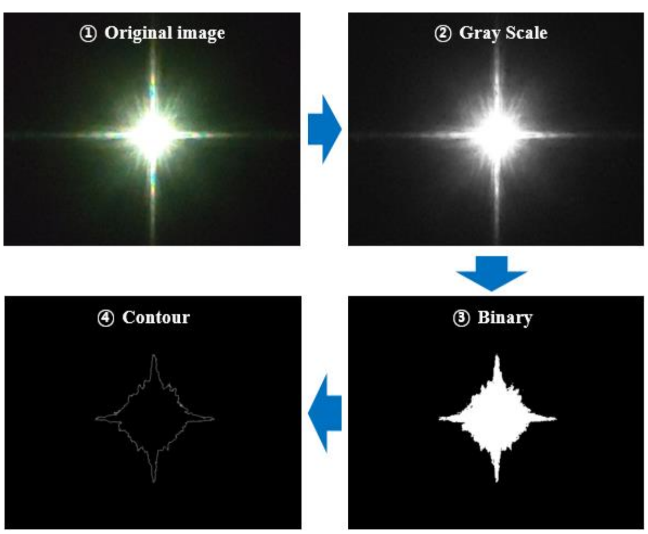

Figure 5. Diffraction quantification step

The Figure 6 shows the enlarged contour image. In each of the plurality of positions having the coordinates of (x_i, y_i) on the contour image, the phase angle(θ_i) with respect to the center of the contour image having the coordinates of (x_c, y_c) and from the center of the contour image to the plurality of positions the target value can be calculated based on the distance(D_i).

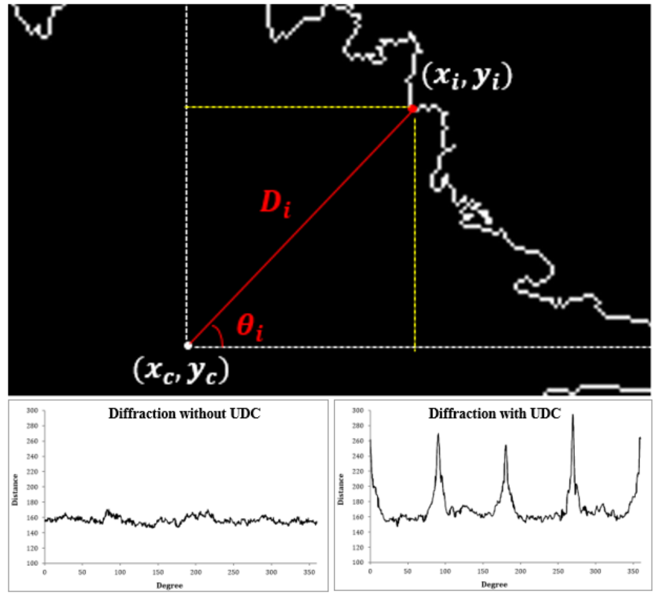

Figure 6. Enlarged contour image and its analysis

By using the acquired contour image, standard deviation ($STDEV_{(diffraction)}$), mean ($Mean_{(diffraction)}$) and amplitude ($Amplitude_{(diffraction)}$) can be obtained according to the following equations (1).

$$\theta_i = \operatorname{atan}\left(\frac{x_i - x_c}{y_i - y_c}\right) \quad D_i = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2}$$

$$STDEV_{(diffraction)} = \sqrt{\sum_{i=1}^{n}(D_i - \bar{D})^2 \times \frac{1}{n}}$$

$$Mean_{(diffraction)} = \sum_{i=1}^{n} D_i \times \frac{1}{n} \tag{1}$$

$$Amplitude_{(diffraction)} = D_{max} - D_{min}$$

General image quality components

In the UDC, when the light passes through the panel and reaches the CMOS image sensor, the amount of light decreases by at least 80% and affects the image quality. The resolution is reduced due to the panel's regular pattern and transmittance. Therefore, it is necessary to check the level of the general image quality as shown in Figure 7. In the test chart, we defined the several quantitative metrics, such as visual noise, resolution, contrast of texture and sharpness, respectively [2].

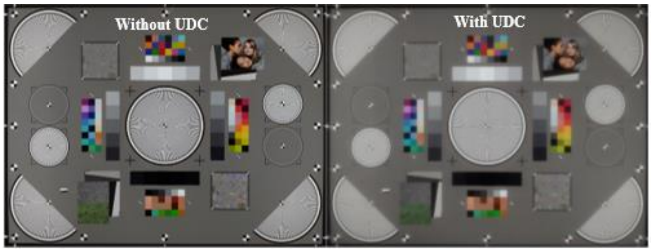

Figure 7. Test Chart for General Image Quality

How to Evaluation Method

For UDC Image quality evaluation, a set equipped with an image sensor, which is 0.8um based 32Mega pixel CMOS image sensor, in the form of a smartphone is prepared, and set-based evaluation is experimented. The Figure 8 shows test set equipped with UDC. Capture conditions are defined, target charts and the form-factor set are required for image quality evaluation. Finally, the acquired images are analyzed.

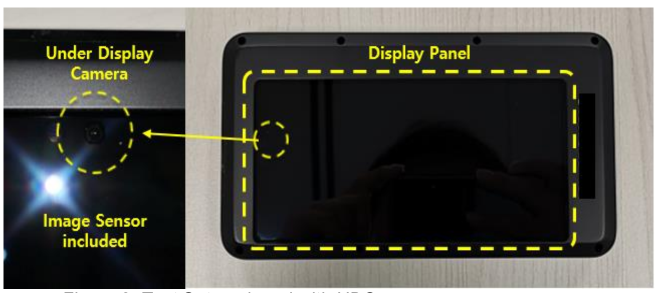

Figure 8. Test Set equipped with UDC

The lighting device is a point light source. A point light source is placed inside the shielding box as shown in Figure 9. The slit of the shielding box has a width of 2mm (a). The lighting device can output light that goes straight in one direction through the slit of the shielding box. The output light is incident at a right angle to the test set to acquire the evaluation image.

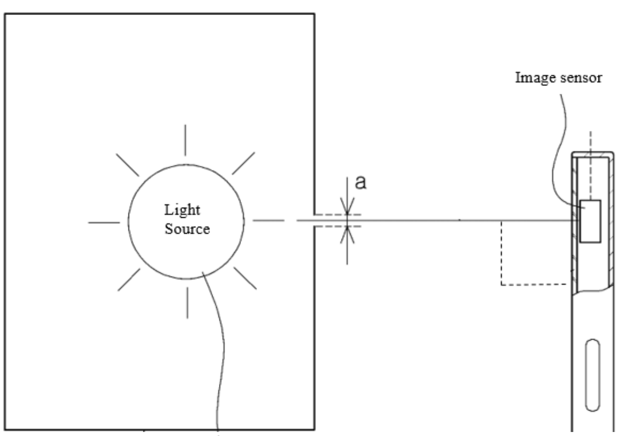

Figure 9. Design of Lighting Device

With the following lighting device as shown in Figure 10, the UDC mounted set and the general set are sequentially mounted and captured to obtain an image capable of quantitative analysis of diffraction.

Figure 10. Lighting Device for Test

Result

The Table 1 shows UDC image quality result with score. At the outdoor scene, the image quality of UDC is 54.8% of conventional front-facing camera (shown as Ref. Non UDC), while in indoor scene this became 46.2%. It can be seen that the larger the amount of light, the less deterioration of the image quality. In general IQ components, since the visual noise level is 34.7% of outdoor and 23.7% of indoor, it can be seen that a high sensitivity sensor with good signal to noise ratio(SNR) performance is advantageous for UDC mounted mobile sensor.

Table 1. Experimental result with quantitative score

		Normalization		Apsolute Value			
Items	**Sub Items**	**Direct Lightsource**		UDC		Ref(Non UDC)	
Diffraction	Mean	**83.2%**		188.4		156.8	
	STDEV	**13.3%**		33.8		4.5	
	Amplitude	**16.6%**		147.6		24.5	
Sub Score		**37.7%**					
General IQ Components		**Outdoor**	**Indoor**	Outdoor	Indoor	Outdoor	Indoor
Visual Noise	Noise (Mean)	31.8%	12.8%	3.845	5.856	2.286	3.129
	Noise (Max)	37.5%	34.5%	6.245	8.767	3.844	5.297
Sub Score		**34.7%**	**23.7%**				
Resolution	MTF25	77.8%	73.8%	910.5	844.2	1170.7	1144.5
	MTF50	66.5%	61.0%	689.3	623.1	1036.2	1021.4
	vMTF (center)	65.1%	61.3%	0.571	0.525	0.877	0.856
Sub Score		**69.8%**	**65.4%**				
Texture (high Contrast)	Full vMTF	59.0%	40.1%	0.457	0.317	0.775	0.791
	Full MTF10	68.6%	61.6%	774.5	630.0	1128.6	1022.3
	Full MTF50	61.1%	32.5%	481.7	230.1	788.3	707.8
Sub Score		**62.9%**	**44.7%**				
Texture (Low Contrast)	Low vMTF	51.7%	36.8%	0.341	0.245	0.659	0.665
	Low MTF10	70.9%	65.8%	672.8	567.3	949.1	862.3
	Low MTF50	50.2%	25.5%	317.9	150.8	633.5	590.5
Sub Score		**57.6%**	**42.7%**				
Sharpen	MTF50 High	64.7%	71.3%	638.7	650.0	987.9	912.1
	High vMTF	73.8%	74.0%	0.620	0.615	0.841	0.831
	MTF50 Low	56.7%	49.7%	617.5	528.8	1089.3	1063.1
	Low vMTF	69.8%	58.0%	0.650	0.552	0.931	0.952
Sub Score		**66.2%**	**63.2%**				
Total Score		**54.8%**	**46.2%**				

Conclusion

It is very difficult to know the exact image quality performance by subjective evaluating of the image taken through display panel. To solve this problem, this paper proposes a novel numerical based quantitative evaluation method. Objective image quality performance evaluation is possible for images captured through UDC. When developing a set equipped with UDC, if the following methodology is introduced, it is easy to set the development direction, and from a sensor point of view, it is possible to set the direction of diffraction correction IP tuning for performance improvement. We expect the proposed methodology to contribute to the UDC camera quality, which will be released in the market in the near future.

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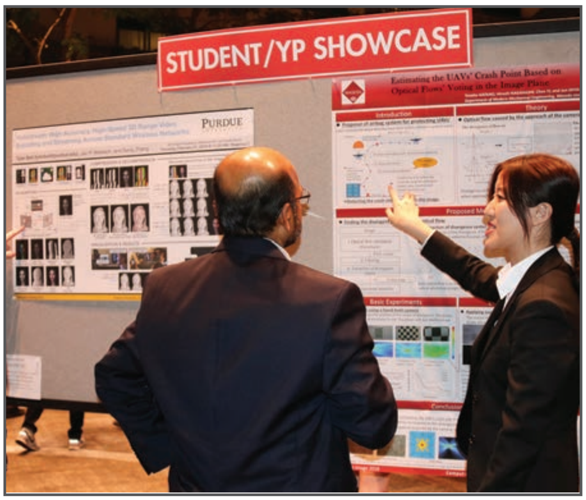

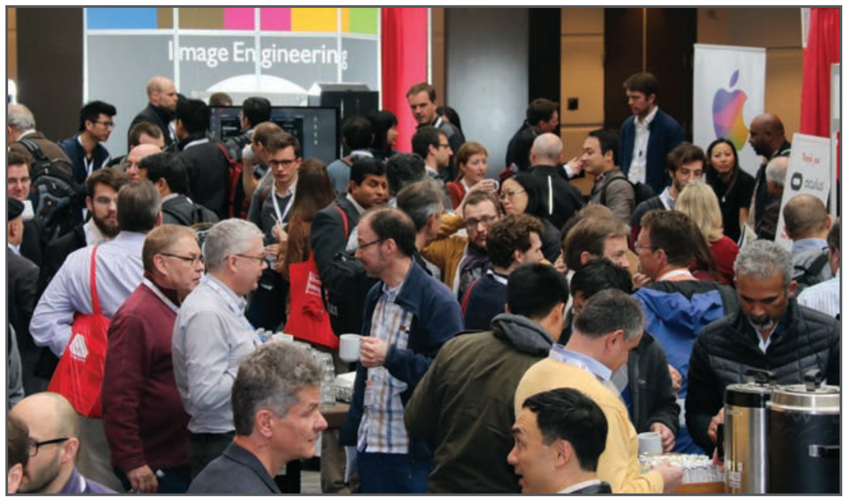

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