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Tests and Measurements of Image Acquisition Characteristics for Image Sensors

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***Abstract*—**In the image sensors, the acquired image often differs from the real image in luminance or chrominance due to fabrication defects or nonlinear characteristics, which often lead to pixel defects or sensor failure. Therefore, the image acquisition characteristics of image sensors should be measured and tested before they are mounted on the target product. In this paper, the standardized test and measurement methods of image sensors are introduced. It applies standard light source to the image sensor under test, and the characteristics of the acquired image is compared with ideal values.

***Keywords*—**Image Sensor, Image Acquisition Characteristics, Defect, Failure, Standard, Test, Measurement.

I. Introduction

IMAGE sensor converts optical image to electrical signals in pixel basis. Each pixel implemented as a photodiode on the semiconductor substrate. During semiconductor fabrication process, some defects can be occurred in the photodiodes. Even if there is no problem in the photodiodes, the acquired image often differs from the real image in luminance or chrominance due to nonlinear characteristics of photodiodes. They often lead to pixel defect or sensor fail. Therefore, the image acquisition characteristics of image sensors should be measured and tested before they are mounted on the target product. Furthermore, it is desirable to standardize these test and measurement methods to evaluate them or remove faulty ones.

In this paper, the standardized test and measurement methods of image sensors are introduced based on the KSIA standards [1]-[4]. It applies light source to the image sensor under test, and the characteristics of the acquired image is compared with ideal values. These test and measurement methods can be applied to both image sensors and image sensor modules, and they are usually performed by lot testing.

II. Test and Measurement Procedure

There are many variations on the tests and measurements of image acquisition characteristics, but they are quite similar except the determination criteria of defect and failure. Therefore, they are often performed simultaneously with following procedure.

(1) Target image sensor is mounted in the test equipment.
(2) Light source is applied to the image sensor.
(3) Optical image is acquired and converted to R, G, B, and Y values for all pixels in the image sensor.
(4) Decision parameters are calculated from R, G, B and Y values for all pixels, regions, lines, and frames.
(5) For all pixels, regions, lines, and frames, decision parameters are compared with the predefined thresholds.
(6) From decision parameters, pixels, regions, lines, or frames are determined as normal or defect.
(7) Considering types, numbers, error values, and locations of defects, image sensor is determined as normal or fail.

Defect means that the corresponding pixel, region, line, or frame cannot correctly acquire the image. Image sensor can be used even if it has several defects in pixels, regions, lines, or frames. For example, an image sensor with several defects in pixels cannot be used in digital cameras, but it can be used in web cameras.

Fail means the image sensor cannot be used due to many or large defects in pixels, regions, lines, or frames. An image sensor is determined as fail by considering types, numbers, error values, and locations of defects.

III. Standard Test Specification

Test specification is the documentation to specify the test procedure in the predefined description style. It consists of 7 *items*, i.e. *test name*, *image sensor information*, *test object*, *test region*, *decision parameter*, *decision rule*, and *light source*.

Each item can have its sub-items, and each sub-item can have its sub-sub-items. Each item, sub-item, and sub-sub-item can have its *type* and *value*. *Type* is one of *FIX*, *DFT*, *UV*, or *NAP*, as follows.

(1) FIX (fixed): The corresponding item has a fixed value, and it cannot be modified by test user.
(2) DFT (default): The corresponding item has a default value, but it can be modified by test user.
(3) UV (user value): The corresponding item has no fixed or default value, and test user can use any proper value in the given test.
(4) NAP (non-applicable): The corresponding item should not be defined in the given test.

IV. Test Name

Test name is a name of the given test. Some standard tests have their own predefined test names, and test user can use any test name except these predefined test names.

V. Image Sensor Information

Image sensor information defines the target image sensor. It has 7 sub-items, i.e. *sensor type*, *color type*, *color pattern*, *luminance conversion*, *color interpolation*, *frame size*, and *center region size*.

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A. Sensor Type

Sensor type is hardware type of the target image sensor. It is one of *CCD*, *CIS*, or *UDD*.

(1) CCD: Target image sensor is a charge-coupled device.
(2) CIS: Target image sensor is a CMOS image sensor.
(3) UDD: Target image sensor is a user-defined device.

B. Color Type

Color type is RGB type and bit-resolution of a pixel value. It is one of *8B* or *24B*.

(1) 8B: Pixel has 8-bit value of one of R, G, or B.
(2) 24B: Pixel has 24-bit values of 8-bit R, 8-bit G, and 8-bit B.

C. Color Pattern

When a pixel has only one of R, G, or B value, 2×2 pixels consist of a pixel group covering all R, G, and B. *Color pattern* describes this color configuration. For example, RGGB means that upper-left, upper-right, lower-left, lower-right pixels have R, G, G, and B values, respectively. When *color type* is 24B, *color pattern* is not defined.

D. Luminance Conversion

Luminance conversion is a conversion equation in the test equipment to calculate Y value from R, G, B values

E. Color Interpolation

Color interpolation is a conversion equation in the test equipment to calculate missing R, G, and B values of all pixels when *color type* is 8B. When *color type* is 24B, *color interpolation* is not defined.

F. Frame Size

Frame size is horizontal and vertical size of a frame. It consists of 2 sub-sub-items, i.e. *fr_X* and *fr_Y*. Its unit is pixel.

(1) fr_X: Horizontal size of a frame
(2) fr_Y: Vertical size of a frame

G. Center Region Size

Center region size is horizontal and vertical size of a center region. Many tests are separately performed on center and border regions, since these regions often have different image acquisition characteristics due to optical lens. It consists of 2 sub-sub-items, i.e. *cr_X* and *cr_Y*. Its unit is pixel. When both cr_X and cr_Y are 0, it does not distinguish center and border regions.

VI. Test Object

Test object defines the target pixel, region, line, or frame to be determined as normal or defect. It consists of 2 sub-items, i.e. *test object type* and *test object size & position*.

A. Test Object Type

Test object type is one of FRM, PIX, LINE, or BLK.

(1) FRM (frame): Defect is determined in each frame.
(2) PIX (pixel): Defect is determined in each pixel.
(3) LINE (line): Defect is determined in each line.
(4) BLK (block): Defect is determined in each rectangular region.

B. Test Object Size &Position

Test object size & position is the number, size, and position of test objects. It consists of 4 sub-sub-items, i.e. *to_N*, *to**n**_X*, *to**n**_Y*, and *to**n**_P*. ***n*** is a serial number of the test object, and it does not appear when *to_N* is 0 or 1.

(1) to_N: Number of the test objects. When *to_N* is 0, a frame is divided into rectangles with horizontal size of *to_X* and vertical size of *to_Y*, and all rectangles are used as test objects, and *to**n**_P* does not appear. When *to_N* is 1, only one test object is used, and *to**n**_P* appears only when the test object is not a frame.
(2) to***n***_X: Horizontal size of ***n***-th test object.
(3) to***n***_Y: Vertical size of ***n***-th test object.
(4) to***n***_P: Horizontal and vertical positions of ***n***-th test object.

VII. Test Region

Test region defines the pixel regions to calculate decision parameters for each test object. It consists of 3 sub-items, i.e. *test region type*, *test region format*, and *test region size & position*.

A. Test Region Type

Test region type is one of FRM, PIX, REG, BLK or LINE.

(1) FRM (frame): Decision parameter is calculated from all pixels in a frame.
(2) PIX (pixel): Decision parameter is calculated from one pixel.
(3) REG (region): Decision parameter is calculated from some regions in a frame.
(4) BLK (block): A frame is divided into equal-sized blocks, and decision parameter is calculated from these blocks.
(5) LINE (line): Decision parameter is calculated from a horizontal or vertical line.

B. Test Region Format

Test region format is one of RGB or Y.

(1) RGB: 3 decision parameters are calculated from each R, G, and B.
(2) Y: 1 decision parameter is calculated from Y.

C. Test Region Size & Position

Test region size & position is the number, size, and position of test regions. It consists of 4 sub-sub-items, i.e. *tr_N*, *tr**n**_X*, *tr**n**_Y*, and *tr**n**_P*. ***n*** is a serial number of the test region, and it does not appear when *tr_N* is 0 or 1.

(1) tr_N: Number of the test regions. When *tr_N* is 0, a frame is divided into rectangles with horizontal size of *tr_X* and vertical size of *tr_Y*, and all rectangles are used as test regions, and *tr**n**_P* does not appear. When *tr_N* is 1, only one test region is used, and *tr**n**_P* appears only when the test region is not equal to the test object.
(2) tr***n***_X: Horizontal size of ***n***-th test region.
(3) tr***n***_Y: Vertical size of ***n***-th test region.
(4) tr***n***_P: Horizontal and vertical positions of ***n***-th test region.

VIII. Decision Parameter

Decision parameter defines the required parameters to determine the target pixel, region, line, or frame as normal or defect. It consists of 4 sub-items, i.e. *decision parameter name*, *decision parameter type*, *decision parameter unit*, and *decision parameter description*.

A. Decision Parameter Name

Decision parameter name is a name of the given decision parameter. Test user can use any decision parameter names.

B. Decision Parameter Unit

Decision parameter unit is a unit of the given decision parameter. It is one of CODE, %, and ARBT.

(1) CODE (code): Unit is 8-bit pixel value.
(2) %: Unit is percentage.
(3) ARBT (arbitrary): Unit is arbitrary.

C. Decision Parameter Description

Decision parameter description is a calculation method of decision parameter. It can be described as mathematical equations, pseudo-codes, verbal sentences, or any other styles.

IX. Decision Rule

Decision rule is a rule to determine the target pixel, region, line, or frame as normal or defect. It consists of 4 sub-items, i.e. *defect decision type*, *defect decision limit*, *fail decision type*, and *fail decision limit*.

A. Defect Decision Type

Defect decision type is a comparison method of a decision parameter to determine defect. It is one of OV, UV, OR, IR, EV, or NV.

(1) OV (over-value): Target pixel, region, line, or frame is determined as defect when the decision parameter exceeds DUL.
(2) UV (under-value): Target pixel, region, line, or frame is determined as defect when the decision parameter falls short of DLL.
(3) OR (out-of-range): Target pixel, region, line, or frame is determined as defect when the decision parameter exceeds DUL or it falls short of DLL.
(4) IR (in-range): Target pixel, region, line, or frame is determined as defect when the decision parameter is between DLL and DUL.
(5) EV (equal-value): Target pixel, region, line, or frame is determined as defect when the decision parameter is DPV.
(6) NV (non-equal-value): Target pixel, region, line, or frame is determined as defect when the decision parameter is not DPV.

B. Defect Decision Limit

Defect decision limit is a threshold limit to determine defect. It has 3 sub-sub-items, i.e. DLL, DUL, or DPV.

(1) DLL (defect decision lower limit): Lower limit of defect decision. It is used when *defect decision type* is UV, OR, or IR.
(2) DUL (defect decision upper limit): Upper limit of defect decision. It is used when *defect decision type* is OV, OR, or IR.
(3) DPV (defect decision parameter value): Exact value of defect decision. It is used when *defect decision type* is EV or NV.

C. Fail Decision Type

Fail decision type is a comparison method of a decision parameter to determine fail. It is one of ADE or OV.

(1) ADE (any-defect-exists): Target image sensor is determined as fail when it has any defects.
(2) OV (over-value): Target image sensor is determined as fail when the number of defect test object exceeds FUL.

D. Fail Decision Limit

Fail decision limit is a threshold limit to determine fail. It has only 1 sub-sub-item, i.e. FUL.

(1) FUL (fail upper limit): Upper limit of fail decision. It is used when *fail decision type* is OV.

X. Light Source

Light source defines the color spectral distribution and light intensity of a light source in the given test. It consists of 2 sub-items, i.e. *color temperature type* and *illuminance type*.

A. Color Temperature Type

Color temperature is the numerated value of color. It is the temperature of a black body with same spectral distribution, and its unit is K. *Color temperature type* is the color spectral distribution of light source. It is one of A, B, C, D50, D55, D65, D75, or T***n***.

(1) A: Standard illuminant defined in [5]. Its color temperature is 2856 K and it represents light bulb.
(2) B: Standard illuminant defined in [5]. Its color temperature is 4874 K and it represents direct sunlight at noon.
(3) C: Standard illuminant defined in [5]. Its color temperature is 6774 K and it represents north sky daylight.
(4) D50: Standard illuminant defined in [6]. Its color temperature is 5003 K and it represents horizon daylight.
(5) D55: Standard illuminant defined in [6]. Its color temperature is 5503 K and it represents mid-morning and mid-afternoon daylight.
(6) D65: Standard illuminant defined in [6]. Its color temperature is 6504 K and it represents noon daylight.
(7) D75: Standard illuminant defined in [6]. Its color temperature is 7504 K and it represents north sky daylight.
(8) T***n***: Arbitrary illuminant whose color temperature is ***n*** K.

B. Illuminance Type

Illuminance is the numerated value of brightness. It is the light flux per unit area, and its unit is lux. *Illuminance type* is the illuminance of the light source. It is one of D, W, and L***n***.

(1) D: Dark light source. Its illuminance is near 0 lux.
(2) W: White light source. Its illuminance is near 500 lux.
(3) L***n***: Arbitrary illuminant whose illuminance is ***n*** lux.

XI. Conclusion

In this paper, the standardized test and measurement methods of image sensors are introduced. It applies standard light source to the image sensor under test, and the characteristics of the acquired image is compared with ideal values.

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