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Development of DVS Evaluation Methods from User Perspective

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Abstract

We report measurement methods and metrics for the evaluation of dynamic vision sensor (DVS) pixels. In particular, we developed automated test environments and test metrics which can quantify the sensitivity, latency and background noise of DVS pixels. For sensitivity measurements, response probabilities of pixels were analyzed at various conditions, such as base light intensity and region of interests of a sensor. Pixel latency was measured by varying the duty of light pulse, and noise level were also characterized at different light intensities. We expect the developed methods and metrics can help to clarify the performance of DVS pixels at the user point of view

Introduction

Dynamic vision sensor (DVS) is an image sensor which captures brightness changes. Unlike conventional frame-based cameras, DVS generates asynchronous “event” signals which enables high temporal resolution, high dynamic range and low power consumption [1-4]. These properties have attracted lots of attention from computer vision and robotics applications and various types of DVS have been developed both in academia and industry [5]. Since the potential of DVS has been proven from many applications, it is necessary to standardize test methodology and specifications to evaluate and characterize the properties of DVS from user perspective. The performance of DVS should be qualified both chip performance such as power and pixel performance such as imaging quality [6-9].

In this work, we established measurement methods and metrics for the evaluation of DVS pixels. First, an automated test system was developed to acquire steady results from repeated tests. By using the developed system, we collected DVS signals at various conditions such as Region of Interests (ROIs) of DVS, DVS sensitivity, and base light intensity. Event Response Probability (ERP), latency, and stationary noise (STN) are the major properties which determine the characteristics of DVS pixel so we organized test methods for them. Finally, we defined metrics to quantify the test results. The metrics enabled the direct comparison about the characteristics of DVS pixels.

Methods

Two automated test systems were constructed (Figure 1). One is for testing ERP and STN, and the other is for latency measurement. Both was composed of a light source, a neutral density (ND) filter, and a PC. For the latency measure, a BJT and a function generator were added. We installed the test system in a dark environment to eliminate the ambient light. A light source, LED illuminator (DBL-103x103-W-V2, Youth Tech) and controller (DPS-35V2-2, Youth Tech), was used to generate brightness changes. LED controller was connected to a PC and RS232 communication between them enabled automatic control of the light source. Python scripts were used to generate sequences of light intensity changes. A function generator and a BJT was also used instead of the LED controller to control LED pulse more precisely. ND filters were applied to adjust a low light condition. By using a motorized filter wheel (FW102C, Thorlabs) which contains different types of ND filters, the light condition was controlled either manually or automatically.

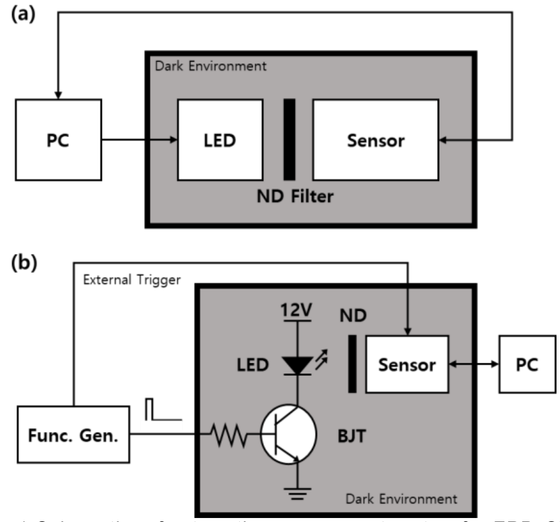

Figure 1 *Schematics of automatic measurement system for ERP, STN (a) and latency (b).*

Temporal contrast (TC), which is an input signal of DVS for testing properties, is defined as specify brightness changes. When the light intensity is changed from I_0 to I_1, TC is expressed as logarithmic ratio of I_0 and I_1 (Figure 2(a)). DVS produces “ON” events when TCs are larger than 0 and “OFF” events when TCs are smaller than 0. It should be noted that, for accurate measurements, series of square pulses were used to generate TCs.

To measure ERP, a series of TC sequence is needed. We generated continuously increasing or decreasing TCs, which amplitudes were in the range of 50% to 0% or -50% to 0%, with the amplitude interval of 2%. Each TC were repeated 10 - 100 times for acquire accurate results (Figure 2(b)). To measure pixel latency, an external trigger signal from function generator was used as a reference time. The exposure time of DVS (tExposure) was fixed as 100ms and the time interval between trigger signal and LED on timing (tDelay) was controlled (Figure 2(c)). The TC amplitude was fixed as 50% to ensure that all pixels produce events. The latency was defined as the time when more than 80% of pixels produce events. By reducing the time difference between tExposure and tDelay, the latency can be induced.

For the quantitative comparison between measurement conditions, the ERP curves were fitted to logistic curve as follows:

$$y = \frac{L}{1 + e^{-k(x - x_0)}}$$

'k' represents how steep the curve is. Ideally, the steepness of the ERP curve should be 1, so larger absolute k values means DVS is more sensitive to light intensity changes. 'x_0' is the TC value when the response probability is 50%. As DVS is more sensitive to brightness changes, x0 gets closer to zero.

In the experiment, we used a DVS manufactured from Samsung, which is 231Y (640 x 480 resolution), for the whole evaluation tests.

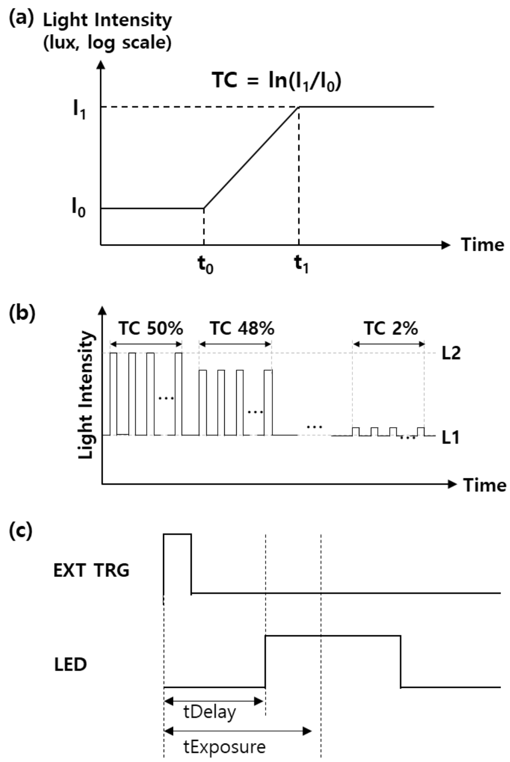

Figure 2 (a) The definition of a TC. (b) A TC sequence for ERP measurement. (c) An example TC input for latency measurement.

Results

ERP

ERP of DVS, which is related to the pixel sensitivity, were measured at different DVS sensitivities, base illuminations, and ROIs (Figure 3). The ERP curves varied according to DVS sensitivities and base illumination. The ERP characteristics were maintained regardless of ROIs of DVS. In detail, the sensitivity of DVS were changed from 'sen1' to 'sen7' by controlling the register of DVS. The absolute value of 'k' and 'x_0' value increase at higher pixel sensitivity. As the base illuminance was lowered than 1lux, 'k' and 'x_0' values decreased notably. All 'k' and 'x_0' values are in Table 1 and 2.

Table 1 ERP curve fitting results according to pixel sensitivities

ON	L	x_0	k	R^2
sen1	99.8	23.5	0.620	1.000
sen4	99.9	18.3	0.528	1.000
sen7	100.1	10.8	0.393	1.000
OFF	L	x_0	k	R^2
sen1	100.1	-21.8	-0.434	1.000
sen4	100.2	-16.2	-0.389	1.000
sen7	100.2	-9.4	-0.367	1.000

Table 2 ERP curve fitting results according to base illumination

ON	L	x_0	k	R^2
1000lux	99.9	18.4	0.436	1.000
100lux	99.9	18.6	0.381	1.000
10lux	99.9	17.7	0.415	1.000
5lux	99.9	17.8	0.443	1.000
OFF	L	x_0	k	R^2
1000lux	100.2	-15.8	-0.350	1.000
100lux	100.3	-15.9	-0.294	1.000
10lux	100.3	-16.6	-0.272	1.000
5lux	100.4	-17.8	-0.245	1.000

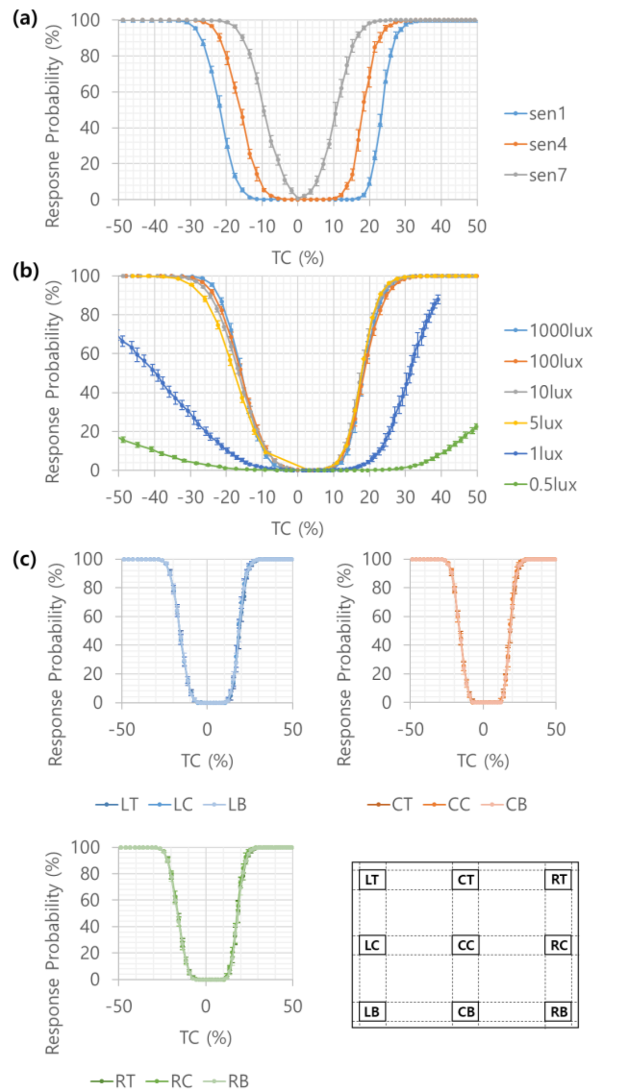

Figure 3 ERP curves according to pixel sensitivities (a), base illuminances (b), and ROIs (c).

Latency

Pixel latency was evaluated by changing base illuminations and ROIs (Figure 4). Base illumination highly impacted on pixel latency.

At 1000 lux, pixel latencies were 42.5µs and 74.7µs, respectively but at 10 lux, latencies were increased to 3000µs. ROIs was not a major factor of latency. Detailed latency values are in the table 3.

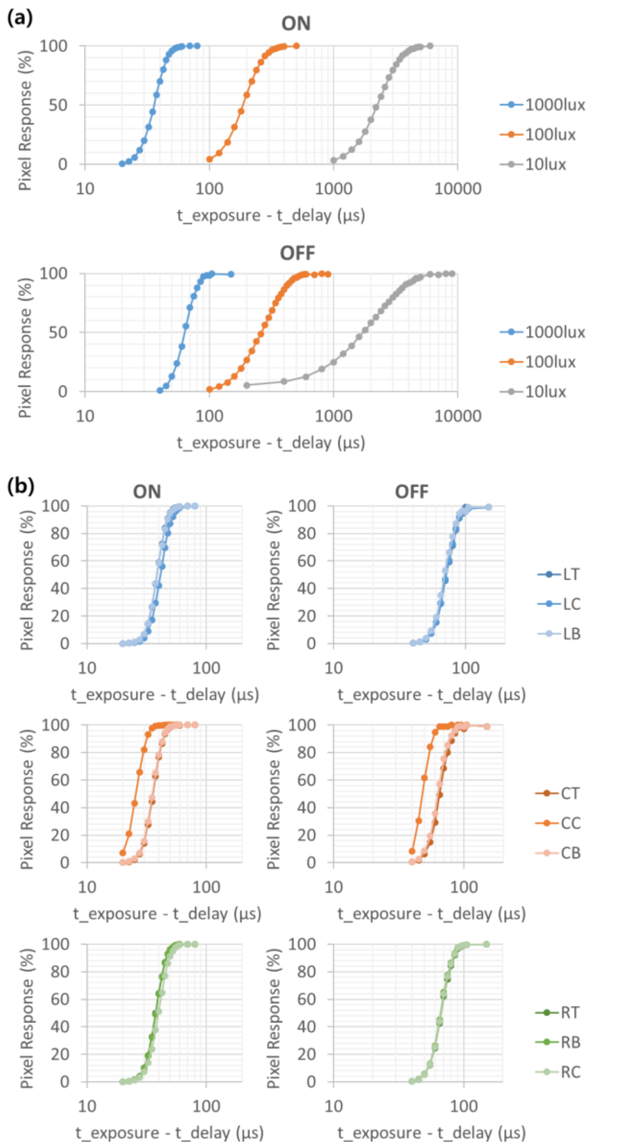

Figure 4 Pixel responses according to base illumination (a) and ROIs (b)

Table 3 Overall pixel latencies according to base illuminations and ROIs

ON	Latency (µs)		
ROI	1000lux	100 lux	10 lux
Whole	42.5	243	3022
CB	40.4	221	2731
CC	29.7	139	1583
CT	40.8	218	2678
LB	44.3	254	3132
LC	47.4	289	3614
LT	44.2	242	2958
RB	43.4	251	3242
RC	45.8	285	3756
RT	43.3	248	3208
OFF	**Latency (µs)**		
ROI	1000 lux	100 lux	10 lux
Whole	74.7	364	3002
CB	72.3	350	3108
CC	54.1	184	1160
CT	74.9	394	3716
LB	81.2	451	4107
LC	83.4	417	3343
LT	83.9	507	5081
RB	76.9	379	3167
RC	76.5	330	1905
RT	77.8	405	3483

Noise

While exposing DVS to constant level of light, event signals were collected for 10 seconds and average number of events per second was calculated. STN increased as light intensity decreased to 50lux, and decreased until the light intensity of 0.5lux and increased again at dark condition. Each ROIs showed different level of STN.

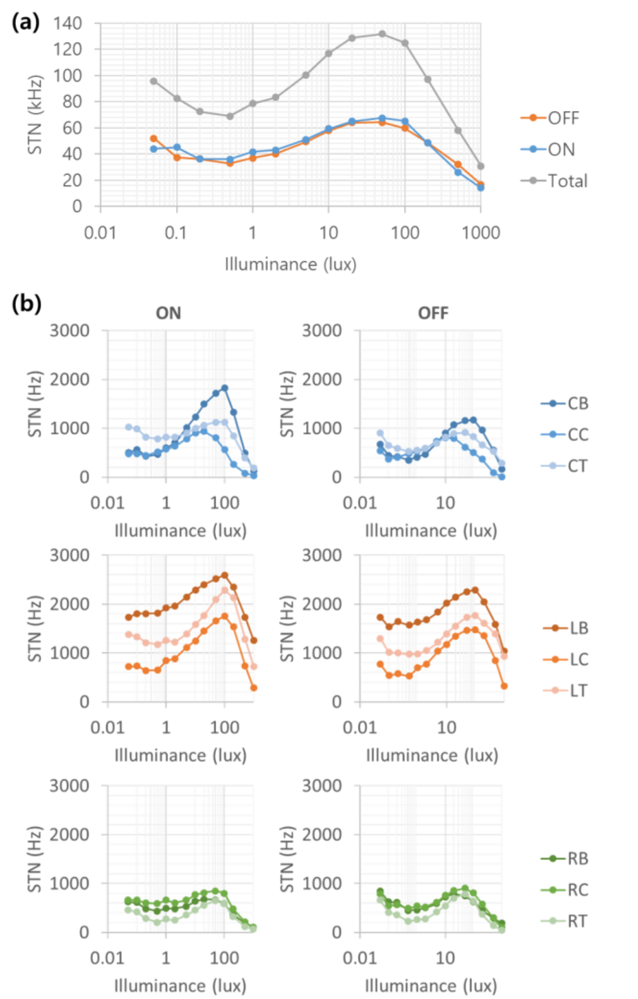

Figure 5 STN according to light intensity (a) and ROIs (b)

Conclusion

In this work, we have shown detailed measurement methods and metrics for DVS pixel performance analysis. Although it is important to standardize methods and metrics of measurement to compare properties of each sensors and find out ways of improvements, the standard methods or metrics for DVS pixel were lacked. By measuring performance of DVS pixels in three perspectives, which are sensitivity, latency and noise, using established test environments and methods, we could quantify the properties of DVS pixels systematically.

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Raeyoung Kim received her BS (2011), MS (2013), and PhD (2019) in Bio and Brain Engineering from the Korea Advanced Institute of Science and Technology. Since then she has joined in Sensor Development Division at Samsung Electronics. Her work has focused on the development and evaluation of novel types of imaging devices.