Motion Aware Camera
-Shutter and Aperture Graphics-

Masaki Suzuki*†, Ramesh Raskar*
* Camera Culture Group,
MIT Media Laboratory
Email:suzuki@media.mit.edu, raskar@media.mit.edu
† Canon Inc.

***Abstract*—This paper presents a novel camera mode called "Motion Aware Camera" that adds an animation-like effect automatically to a captured image. In this Motion Aware Camera, each pixel sensor has its own shutter and aperture.**

By changing the exposure time and the ray's passing rate independently, we are able to capture an image embedded with various time information and signal power. A motion line like those found in animation can then be seen in a captured image. In addition, this structure simplifies in a temporal post processing, because various time information distributes on one image buffer rather than on different ones and is easy to access. As a result, this camera structure not only allows users to create a new visual representation, but also decreases computational cost for on-camera processing.

Fig. 1. A simulation result of Motion Aware Camera.

I. Introduction

Current cameras have various camera modes for use in different situations. For instance, "Shutter Priority mode" allows the user to choose a specific shutter speed, and "Portrait mode" provides the user an artistic representation of a subject by using a wider aperture to render the background out of focus, thereby focusing on a human face instead of other image content.

In this paper, we introduce a novel camera mode called "Motion Aware Camera". This camera has a shutter and an aperture for each pixel sensor, allowing us the ability to capture a real world scene as an animation. By driving these factors independently, a camera has an image embedded with various time information and aperture rates. As a result, this camera ultimately provides the user motion lines as a novel visual representation.

A. Contributions and Limitations

- We proposed a novel camera structure that has a shutter and an aperture on each pixel sensor. This camera captures pictures that are similar to computer-generated effects.(Section II)
- We showed shutter patterns and aperture patterns that create various representations of a subject.(Section III)
- We demonstrated a low complex spatial-temporal processing using this camera.(Section III)
- This technique degrades the total number of output images in some cases.(Section II)

B. Related work

Fuchs et al. provided an approach for adding expressive renderings to images and videos that highlight motions and movement[1]. Other methods have also been proposed to add a motion blur[2],[3]. However, since all of these techniques rely on motion analysis, their computational costs are high. In contrast, our approach uses addition and subtraction and can be performed with a camera. B. Kim and I. Essa discussed the construction of an optimal sampling filter given the characteristics of the output video device. This system is a prerequisite for successful anti-aliasing[4]. Our goal is to capture and modify a real world scene into a comic-like expression, and in order to get such a expression, we will use aliasing effect.

One of the earliest techniques for controlling temporal filtering makes use of stroboscopes to combine multi-exposure images of high-speed motion into a single image[5]. Recently, the photo-refractive effect of photonic crystals has also been used to implement a temporal high rather than short time intervals at a very small time and space scale[6],[7]. In order to create time-lapse outputs, a virtual shutter and multi-camera arrays are proposed[8] [9]. In these techniques, only one shutter is set onto a sensor plan. In contrast, our approach sets a shutter and aperture at each pixel sensor. Raskar et al. [10] augmented a traditional camera with a high-speed ferro-electric LCD shutter to remove the blur effect, and our goal is to create such an effect in a positive manner.

II. Motion Aware Camera

In this camera, each sensor has its own shutter and aperture. (Figure. 2). As a result, it is possible to deliver light rays to each pixel sensor at various times with various power levels. A realistic implementation of this structure will involve using an electric shutter and biasing a signal that is read from the pixel sensor as a virtual aperture.

For instance, table.I(left) shows 9x9 shutters for 9x9 pixel sensors. And each index shows a timing t for the shutter's open-close. While cameras are capturing rays through the sensor, shutters open and close in this order. Eventually, captured information has spatial-temporal information based on a sensor plan, and temporal information, $t = 1, 2, 3, 4$, exists in one's spatial space. As a result, this structure creates special motion expressions in a picture.

This camera achieves not only a new visual representation ability, but also a low complexity of image construction because spatial-temporal manipulation of the pixels can be accomplished by simple spatial convolution. For instance, in general cases of calculating the average value of four pixels temporally, four image buffer memory areas are required to save four different time images. And in order to access four different pieces of time pixel data, a software program has to run for a long time in buffer memory areas.

On the other hand, the Motion Aware Camera regards $s_{i,j}$ as a captured luminance through each pixel that is spatially located at i, j position, a calculation of DC component $f_{n,m}$ (n, m is the position of an output image.) of four pixels is just a summation of $s_{2i,2j} + s_{2i,2j+1} + s_{2i+1,2j} + s_{2i+1,2j+1}$ with a passing rate of aperture of 25%(right of table.I).

With such temporal processing, the number of total pixels in a final image may be less than one of its sensor. For instance, in calculating an average value of four pixels temporally as discussed above, the total pixel count of a final image would be a quarter of that of its sensor.

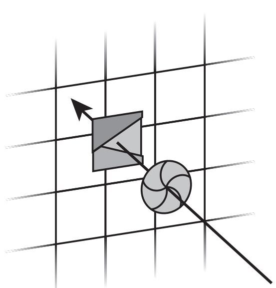

Fig. 2. A structure of the Motion Aware Camera. Each pixel sensor has its own shutter and aperture.

1	2	1	2	1	2
3	4	3	4	3	4
1	2	1	2	1	2
3	4	3	4	3	4
1	2	1	2	1	2
3	4	3	4	3	4

25	25	25	25	25	25
25	25	25	25	25	25
25	25	25	25	25	25
25	25	25	25	25	25
25	25	25	25	25	25
25	25	25	25	25	25

TABLE I
Timings of an each shutter(left) and Passing rate of an aperture(right)

III. Simulation

We confirmed the effect of Motion Aware Camera through a software simulation. At first, 150 frames were captured in 7/10 seconds by CASIO EX-FC-100. The format of the captured pixels was 480x360, rgb, 8bits. Secondly, the captured frames were processed on MATLAB, which simulated the Motion Aware Camera. In this simulation, the software derived pixel data from captured frames according to pre-formed shutter patterns and created a final image with bias using aperture pattern. In case 3, a simple post-processing was applied to a captured image.In contrast, no post-processings were used for cases 1, 2 and 4.

A. Case 1: Two shutters

The shutter pattern is in Table. II(left), and the aperture ratio is 100% anytime. There are two pieces of time information in each picture. The left half is the first frame and the right part is the sixtieth frame. Fig. 3 shows the final result.

Fig. 3. Case 1: Shadow game.

B. Case 2: Continuous shutters

A shutter pattern is in the center of Table. II. In area "A", each shutter is a vertical pixel line and does open-close from the left to right. Fig. 1 shows the final result. If each shutter opens-closes from right to left, the result would be Fig. 4.

1	60

1	A	150

A	B

TABLE II
SHUTTER PATTERN OF CASE 1(LEFT), CASE 2(CENTER) AND CASE 4(RIGHT). A NUMBER OF PATTERNS SHOWING TIMING.

16	16	36	16	16	36
16	16	0	16	16	0
16	16	36	16	16	36
16	16	0	16	16	0
16	16	36	16	16	36
16	16	0	16	16	0

30	31	60	30	31	60
50	51	0	50	51	0
30	31	60	30	31	60
50	51	0	50	51	0
30	31	60	30	31	60
50	51	0	50	51	0

TABLE III
APERTURE PATTERN(LEFT) AND SHUTTER PATTERN(RIGHT) FOR A SLOW MOTION LINE. THE NUMBER OF APERTURE PATTERNS SHOWS A PASSING RATE AND THE NUMBER OF SHUTTER PATTERNS SHOWS THE TIMING FOR EACH PIXEL'S SENSOR.

Fig. 4. Case 2: Cubism

Fig. 5. Slow-motion lines

C. Case 3: Slow motion

In this case, the camera captures a subject by the shutter and aperture pattern that is shown in Table. III. Then, an after-image of the subject is added to a picture by temporal FIR filter(Equation. 1). s and f are signals of a captured image and a final image respectively, and n, m are the position of a signal on the image.

$$\begin{aligned} f_{n,m} \quad = \quad & -s_{3n,3m} + s_{3n,3m+1} - s_{3n+1,3m} \\ & +s_{3n+1,3m+1} + s_{3n,3m+2} \end{aligned} \tag{1}$$

Generally, in the case of processing temporal FIR, a camera has a several image buffers to save time informaton. On the other hand, a Motion Aware Camera embeds different pieces of time infomaton in a 2D plan, so this camera requires only one image buffer and achieves temporal FIR through spatial processing in a 2D plan.

D. Case 4: Fast motion

In this case, sensor pixels are divided into areas A and B (Right of TableII). Each area is processed using a different pattern. As far as area B is concerned, a shutter opens-closes just one time with an aperture's passing rate of 100%(Fig. 6). On the other hand, in area A, an aperture's passing rate is increased gradually from $t = 35$ to $t = 0$, and a shutter keeps the opening and closing from $t = 35$ to $t = 0$. (Fig. 7) After the processing of the shutter, an electrical charge will accumulate into digital data through an analog/digital transformation. (Fig. 8).

IV. CONCLUSION

In this article, we propose a novel camera called "Motion Aware Camera" that adds an animation-like effect automatically to a captured image. With this camera each pixel sensor has its own shutter and aperture. In software simulation, we showed four shutter patterns, four aperture patterns, and one post-processing pattern. As a result, the structure makes a contribution to creating new visual representations and low-complexity computations for on-camera processing. Other combination can be found from the sensitivity of each person. For example, a motion estimation of subjects could create another expression of the subjects. This camera can capture a novel picture with just a slight modification of an existing camera, and allows a standard camera to see the world around us in our own unique way. We believe that this camera releases the limitations of user experience by allowing users to customize parameters of aperture and shutter patterns.

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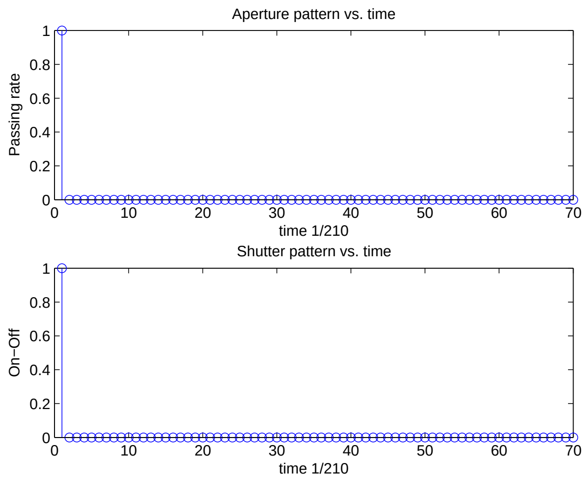

Fig. 6. An Aperture pattern and a shutter pattern for area B.

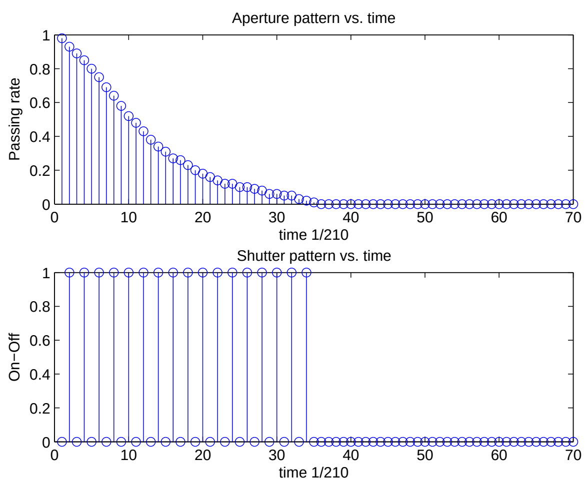

Fig. 7. An aperture pattern and a shutter pattern for area A.

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Fig. 8. Fast-motion lines

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