Stop Motion Goggle: Augmented visual perception by subtraction method using high speed liquid crystal

Naoya KOIZUMI
Keio University
4-1-1 Hiyoshi,
Kohoku,Yokohama
Kanagawa, Japan
koizumi.naoya@kmd.keio.ac.jp

Naohisa NAGAYA
Keio University
4-1-1 Hiyoshi,
Kohoku,Yokohama
Kanagawa, Japan
naohisa.nagaya@kmd.keio.ac.jp

Masahiro FURUKAWA
Keio University
4-1-1 Hiyoshi,
Kohoku,Yokohama
Kanagawa, Japan
m.furukawa@kmd.keio.ac.jp

Maki SUGIMOTO
Keio University
3-14-1 Hiyoshi,
Kohoku,Yokohama
Kanagawa, Japan
sugimoto@ics.keio.ac.jp

Masahiko INAMI
Keio University
4-1-1 Hiyoshi,
Kohoku,Yokohama
Kanagawa, Japan
inami@kmd.keio.ac.jp

ABSTRACT

Stop Motion Goggle (SMG) expands visual perception by allowing users to perceive visual information selectively through a high speed shutter. In this system, the user can easily observe not only periodic rotational motion such as rotating fans or wheels, but also random motion like bouncing balls. In this research, we developed SMG and evaluated the effect of SMG on visual perception of high speed moving objects. Furthermore this paper describes users' behaviors under the expanded visual experience.

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: Theory and methods

; H.1.2 [**User/Machine Systems**]: Human information processing

General Terms

Human Factors, Design

Keywords

Motion Perception, Deblurring, Visuosensory Augmentation

1. INTRODUCTION

Manga is an important part of Japanese culture, and it shows us the dreams of its readers. Many appealing characters who display superhuman power in these stories fascinate the readers, and it is not at all unusual that people have a strong yearning to become like these heroes.

"Doragon ball"[1] is one of the most popular manga in the world. During the story's fight scenes, the main characters exchange blows at superhuman speed. Thus, ordinary people are unable to perceive the exact movements. This paper introduces a device that is able to allow one to view this kind of a high speed motion. We named the device "Stop Motion Goggle", and evaluated it.

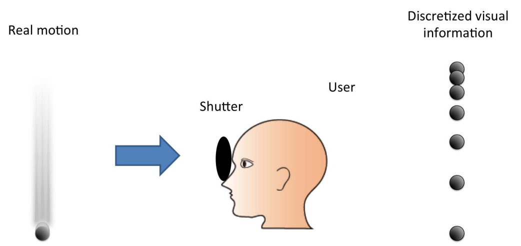

Figure 1: Concept sketch of SMG

Our hypothesis is that people will be able to perceive such motion by attaching a shutter for human eyes to reduce the motion blur. We propose SMG as an interface to augment human visuosensory ability by controlling the exposure time, frequency and phase for human eyes. Figure 1 shows the concept of SMG. The features of SMG are as follows:

1. It augments our visiosensory ability by reducing the amount of light which reaches the naked eye to a normal range.

2. It is a wearable device, thus not requiring any alterations done to the object being observed. It is also able to provide information according to each individual's needs.

3. It is able to realize very short time shuttering by the usage of Ferro-electric Liquid Crystal.

In this paper, we propose the SMG method and its design, and evaluate possibility of this.

2. RELATED WORKS

Many kinds of crystal shutter glasses have been developed as active shutter methods for the viewing of 3D displays [2]. This is called "frame sequential method", and it realizes stereoscopic vision by the usage of time division control. This device is similar to the SMG system. However, the frame sequential method involves synchronizing the image projection display timing, while the SMG synchronizes with the motion itself.

There are some similar glasses type devices. Milgram realized a commercially-available shutter for the human eye [3]. Similar to the SMG, the shutter is also made up of crystal glasses. However, it changes very slowly, and the color changes from white to transparent. The speeds of changing from white to transparent and back to white again are 4 ms and 3 ms respectively. The structure of our device is completely different because the color changes from transparent to black, and black cuts reflected light well, thus making it suitable for shuttering. The SMG also has an improved response speed specification - it changes from black to transparent, and from transparent back black within 1 ms.

There has been research done on the sampling effect for visual information by using a stroboscope [4] or high speed camera [5]. The stroboscope is a method that controls the sampling rate of human eyes by controlling the blinking time of light. Gregory BARSAMIAN built the Juggler with this method to realize stop motion that was visible to the naked eye [6]. Morphovision is a kind of stroboscope system using a rotating object [7]. The key technology of Morphovision lies in the special light set above the rotating model. A digital projector is used to show a narrow beam of light. This light is reflected using a polygon mirror, and is applied on the model house. The rotating polygon mirror projects the line to move across the model from left to right, at high speed. As the speed is increased, the full image of the model becomes visible. This is caused by the persistence of vision effect of human vision. As the model rotates faster, the movement of the light and model are synchronized. At the moment of their synchronization, the distorted house suddenly appears. The type of distortion can be changed by selecting different lighting patterns.

A high speed camera is a device used for recording fast-moving objects. After recording, the images stored on the media can be played back in slow-motion. This camera enhances our visuosensory aspect by extending the time domain. In this way, we can perceive previously unperceivable high-speed motion such as the fluttering of birds, projectile path of a football, or deformation of baseball.

While we can view the Jugger and Morphovision with naked eyes however, both systems are highly dependent on the environment, since they need a dark setting and special equipment to project a specific kind of light to realize the visual effects. Therefore, they cannot show different things to different users simultaneously. This is the limitation of these systems. Also, high speed cameras have other limitations, such as not being able to provide information in real-time, only a recorded image. Besides, there are many equipment requirements, not only a capture system but display systems as well.

3. STOP MOTION GOGGLE

Humans perceive visual information with their eyes. Retinas receive light, and the information is then passed through the nerves to the brain. The stop motion goggles (SMG) realizes discretizing the continuous information by placing shutter goggles in front of eyes. In this research, we control the frequency and phase of exposure, and the exposure time of the visual sensor. It is possible to observe motion of objects at different intervals by controlling the exposure frequency. This method is very effective to observe periodic motion. In videos, temporal aliasing results from a limited frame rate and causes the wagon-wheel effect [8], whereby a spoked wheel appears to rotate very slowly or even backwards. The effect of aliasing has changed its apparent frequency of rotation. A reversal of direction can be described as a negative frequency. Temporal aliasing frequencies in video are determined by the frame rate of the camera, but the relative intensity of the aliased frequencies is determined by the shutter timing (exposure time) or the use of a temporal aliasing reduction filter during filming. SMG realizes the situation heretofore described for human eyes in real-time.

It is also possible to control the exposure phase to adjust the timing of light. If the frequency of exposure and the observed motion are synchronized, we can see the arbitrary state of object by tuning the phase.

It is also possible to control the flicker fusion rate of human eyes by controlling exposure time. The visual persistence of human beings is between 10ms and 200ms, and it depends on environmental brightness and spatial frequency. Thus, it is possible to reduce the visual persistence effect by using shutter goggles. This reduces the motion blur, and sharpens the outline of the object that is moving at high speed. From the view point of interface design, SMG is basically a shutter for the human eye. Because this system is very simple, it can be applied to various applications which will be described later.

4. IMPLEMENTATION

The SMG is a wearable device, similar to how one wears a pair of spectacles. Thus, it is highly mobile, and that is an important requirement of our design. We chose to use a shutter, and designed a system and circuit in order to satisfy this requirement.

4.1 System

SMG is composed of a crystal shutter and control circuit. Figure 2 shows the system block diagram and appearance. The circuit controls the shutter by a microcomputer and an operational amplifier which generates a specific duty ratio and frequency. It also controls the shutter by using a waveform data which is stored in an EEPROM. The waveform data is changed by a dial on the circuit. Furthermore, the waveform data is also controlled by an IR signal that is received by a photo-transistor. When the user tunes these parameters finely, they connect the circuit to a computer via serial communication and specify exposure phase, exposure frequency and duty ratio by entering the desired value for each crystal.

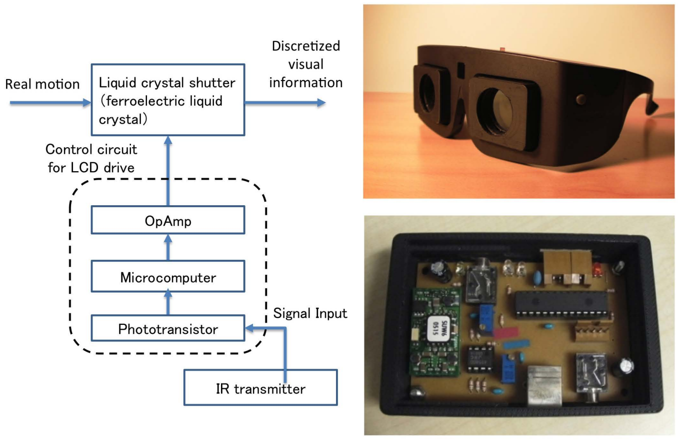

Figure 2: Block Diagram and Snapshot of SMG

4.2 Circuit

The microcomputer (PIC16F876, Microchip Technology Inc.) generates the waveforms to control the crystals. Normally the crystal works with +/- 5V, but we input +/- 15v to improve the response speed of the crystal. This high voltage is instantaneously created using a DCDC converter (SUW60515C, Coral) via pre-emphasis circuit.

4.3 Shutter

The Ferroelectric Liquid Crystal (FLC) was chosen instead of TN or IPS types in order to realize high speed shuttering for visual information. Table 1 shows the specifications of LV2500P (Micron Corp). The transmission changes from 10% to 90% within 50us. We carried out experiments to find out the optimal combination of circuit and shutter. Figure 3 shows the test conditions. The test was conducted in a dark room with a brightness of 0.02Lux. We put the FLC shutter between an LED and a photo-transistor, and checked the output voltage of the photo-transistor using an oscilloscope. Figure 4 shows the result for 10Hz with 1% duty ratio condition, and for 80Hz with 4% duty ratio condition. The red line is the input voltage for the FLC, and blue line is the output voltage of the photo-transistor. In both conditions, the photo- transistor responds within 50us delay, and it rises to 90% output within 150us. According to this result, it can cut out more than 90% of light if a voltage for over 250us (frequency 80Hz / Duty ration 2%) is applied, and can achieve the required shutter speed of within1.0 ms, as described in Section 2.

5. SMG EVALUATION

Perceptual evaluation was carried out using a moving indicator to confirm the augmentation of human vision. This experience shows the benefit of SMG, which is the augmentation of visual ability of humans by deblurring, an effect brought about by discretization. There are many researches which focus on the motion blur effect for human perception, and Takeuchi et al. discovered that the human brain has a mechanism to reduce the information during the signal transduction process [9]. As the SMG does not affect an object or the motion of object, we can thus completely remove the effect of motion blur.

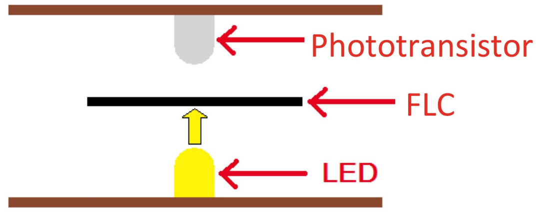

Figure 3: Characteristics of FLC measurement system

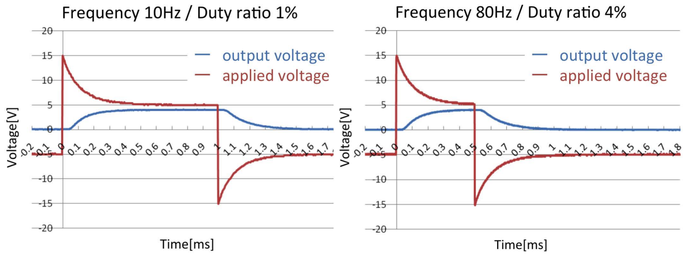

Figure 4: Characteristics of FLC measurement system

However, there is insufficient physiological knowledge on how to control SMG to find out the best parameter for reducing motion blur. Therefore, we have to evaluate the visuosensory feature using the SMG. At first, the exposure time of SMG was controlled, and an object moving at constant speed was observed. Evaluation was conducted with a Landolt ring, which is used for visual acuity tests. This test was conducted over a range of smooth pursuit eye movements to confirm the augmentation of human ability by SMG.

5.1 Equipment

Test equipment was developed to realize a uniform linear motion for the Landolt ring. This equipment is composed of three items: RS-380PH-4045(MABUCHI MOTOR CO., LTD.) as an actuator, a pulley that converts rotation motion into linear motion and a belt as a transfer mechanism. A Landolt ring marker with diameter 6mm was fixed on the

Table 1: FLC Specifications data sheet

Parameter	O.C.	Guaranteed O.C.
Transmittivity (close)	28 - 30%	> 25%
Transmittivity (open)	< 0.03%	< 0.05%
Contrast ratio	1000:1	500:1
Response time	35μs	< 50μs
Transition time	70μs	<100μs
Guaranteed operating temperature	10 - 50 °C	
Shape	Circlur	
Size(dia)	34mm	

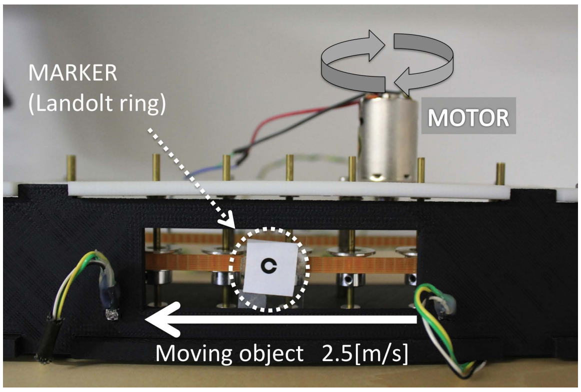

Figure 5: Accelerator unit for motion marker

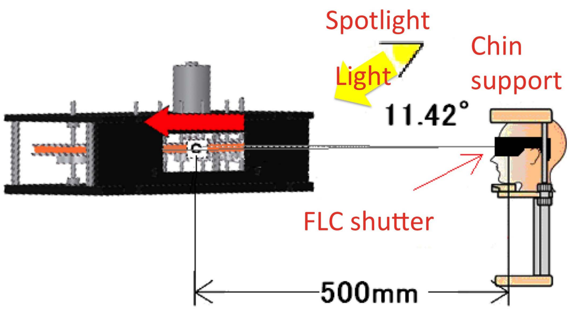

Figure 6: Accelerator unit for motion marker

belt. The speed of this equipment was controlled by a feedback system consisting of a photo-reflector on the box, and retro-reflective material on the belt.

5.2 Design

We fixed the head position of the subject 500mm away from the test equipment. The subject wore an eye-patch to reduce the effect of congestion. The marker speed was set to be 2.5m/s, which is equivalent to over 200deg/s in angular velocity. This speed is very much faster than the limitation speed of smooth pursuit eye movement. According to Miles, the limitation speed of smooth pursuit eye movement is from 40 to 60deg/s [10]. The interior of the box is lit by an incandescent light bulb, and Table 2 shows the average luminance of the marker for the naked eye and FLC. These values were recorded using luminance meter(SANWA's LX2). These luminance values depend on the duty ratio of SMG, because the meter measures the luminance with integral characteristic in time domain.

Table 2: Luminance status

	Drive condition	illuminance
ambient light		181.9
SMG	open	7.87
	25Hz / 2%	0.48
	25Hz / 10%	1.51
	25Hz / 3%	0.51
	25Hz / 12%	1.54

5.3 Procedure

This test was conducted with 5 (male) subjects. Before the test, we confirmed that the subjects could not recognize which side (4 sides: up, down, right and left) of the Landolt ring was up by looking through the gap using both the naked eye and corrected vision. The frequencies of the FLC were 25Hz and 50Hz. When the frequency was 25Hz, 9 different exposure time were selected, with exposure times between 0.80ms and 4.0ms, in increments of 0.4ms. In other words, the duty ratio was between 2.0% and 10% in increments of 1.0%. When the frequency was 50Hz, 10 different exposure times were selected, with exposure times between 0.60ms and 2.4ms, in increments of 0.2ms. This equates to a duty ratio of between 1.0% and 10%, in increments of 1.0%. The gap position of the Landolt ring was chosen randomly, and each position appeared 3 times (altogether, 12 trials are conducted for each subject). Subjects were allowed to look at the test equipment to determine the position of the gap for 5sec for each trial.

5.4 Result

Figure 7 and Figure 8 shows the experiment result of 25Hz and 50Hz. The horizontal axis is the exposure time, and the vertical axis is the percentage of correct answers. In all subjects, the percentage of questions answered correctly declined with increasing exposure time. This trend was observed not only during the 50Hz condition but also during the 25Hz condition. Figure 9 shows the average data of whole subjects for each frequency.

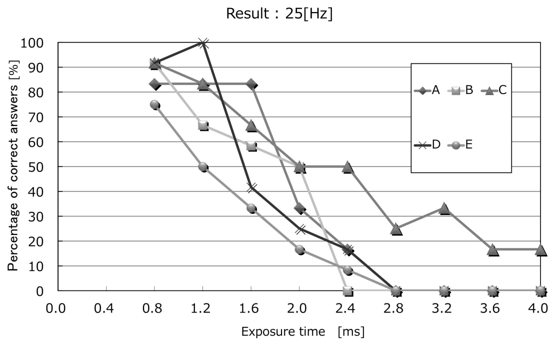

Figure 7: Percentage of correct answers: 25Hz

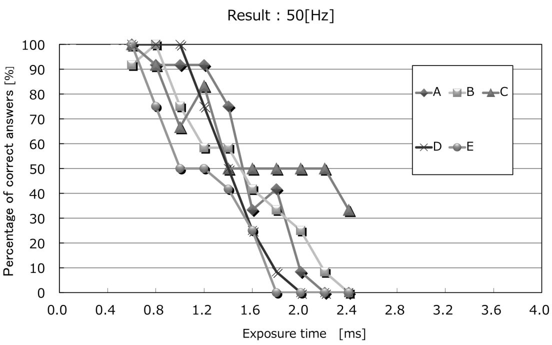

Figure 8: Percentage of correct answers: 50Hz

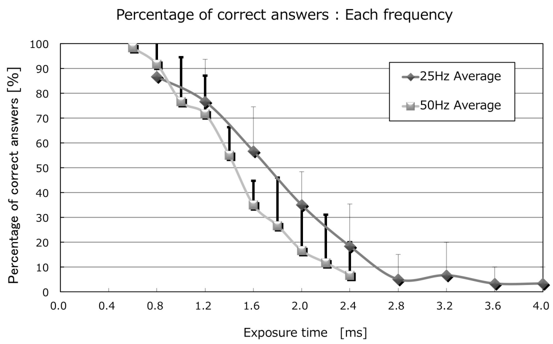

Figure 9: Percentage of correct answers: Each frequencies

5.5 Discussion

From the results, we can see that the shorter exposure time is, the better the percentage of correct answers. Thus, we can conclude that the SMG augments motion perception. Moreover, using lower frequency yielded better results than higher ones, even if exposure times remained the same.

In particular, it was observed that if the exposure time was greater than 1.2ms, subjects found it easier to see using a lower frequency. This reason might be related with Bloch's law [14]. According to Bloch's law, it is possible to exchange the amount of light for the duration and maintain a constant effect under an approximately 100ms stimulus duration. Therefore, the subject is able to retain more visual images under a higher frequency situation as compared to a lower one. This makes it difficult to distinguish the position of the gap, since there is some overlay.

6. DOUBLE FREQUENCY METHOD

Some subjects gave feedback that it was difficult to recognize the motion using SMG, because it reduced the motion blur in the previous experiment. Motion blur shades off the outline of motion object but it helps to recognize the motion's trajectory. Motion blur is caused by the persistence of vision (POV) and there are some displays while utilize POV. LED POV utilizes line LED which moves as display, while the Saccade Display also utilizes line LED as a display, but is immobile [11]. Users can see the display with the smooth pursuit of human eyes. In this way, while reducing blur or POV has its good points, there is trade-off between the ability of being able to clearly visualize motion object and motion trajectory. Therefore, we developed the double frequencies method to solve this trade-off. SMG has two FLC: one FLC is set at a high frequency for shutter control to see POV or blur, and the other is set at a low frequency to see the clear outline of the object in motion. We control duty ratio of both FLC to be the same value, so as to keep the same luminance for each eye.

6.1 Equipment

The test equipment is composed of a motor, bar, printed Landolt ring and LED POV display. Subjects see the rotating marker from over 600mm away. The rotation speed is 7rps. The position of printed Landolt ring is 230mm from the rotation center, and the LED POV display is 10mm from the center. The diameter of the printed ring is 75mm, and the thickness of the bold marking is 15mm. The diameter of the POV LED display is 40mm, and is composed of 16 LEDs. Figure 10 shows the difference between a long period shutter and a short period one. The right side is a photo of the short period shutter, and the left one is with a long exposure time.

Figure 10: The difference of shutter speed

6.2 Design

We controlled SMG under three conditions:

1. Frequency is 20Hz and duty ratio is 99% for both eyes.
2. Frequency is 200Hz and duty ratio is 99% for both eyes.
3. Frequency is 20Hz and duty ratio is 99% for right eye, frequency is 200Hz and duty ratio is 99% for left eye.

The key of the design is the exposure frequency and brightness. In this test, we only controlled it to compare the effect of shutter frequency for human eyes but the duty ratio does not change. We would like to confirm that it is effective for the human visuosensory system to provide different frequency visual information for each eye to augment in this test.

6.3 Procedure

There were a total of 6 subjects (1 female, 5 male). Their eyesight was normal, with the right eye as the dominant eye. The experiment was carried out under conditions (1), followed by (2), then (3). The direction of the Landolt ring was changed randomly.

6.4 Result

Figure 11 shows the results of this experiment. The red shows the accuracy ratio for the printed Landolt ring direction, and the blue is the accuracy ratio using the LED POV display. According to this result, people are able to recognize visual information for different frequencies and coordinate them in their brains.

6.5 Discussion

We confirmed that this double frequencies method was effective. However, it seemed better to either assign a low frequency shutter speed to the dominant eye, or change the frequency in turn. According to this result, we can see that it is possible to design multi-frequency vision. In the future, we would like to determine the relation between using high and low frequencies.

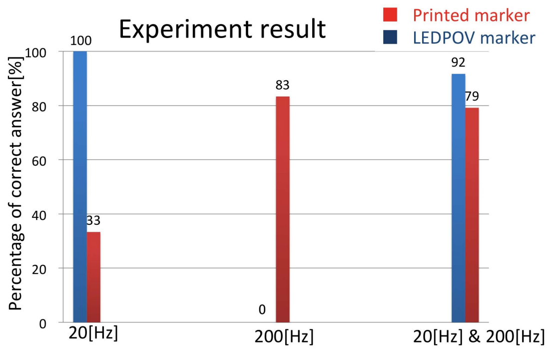

Figure 11: The graph of experiment result

7. DISCUSSION

7.1 Application

We demonstrated SMG at several events to observe users' reaction. At SIGGRAPH 2008 and Interactive Tokyo 2008, we demonstrated a "coin spinning"application [12]. Users can see the engraved design on the spinning coin using SMG. Figure 12 shows what was demonstrated.

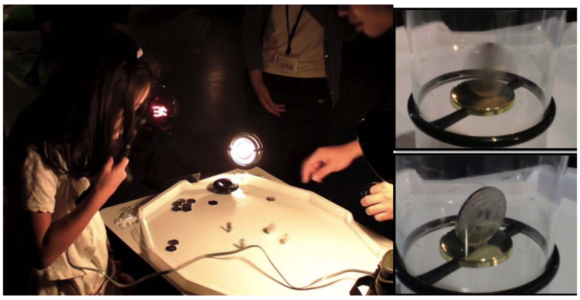

Figure 12: Snapshot of the coin through SMG

At Laval Virtual 2009 and Ars Electronica Center, we demonstrated a "blinking night view"application [13]. Since the light was blinking at the frequency of A.C. power (such as 50Hz or 60Hz), users can see the blinking night view with SMG by tuning the exposure frequency and phase. Figure 13 shows what was demonstrated. This demonstration is done in the room at that time. And of course we can use this outside since SMG is wearable device. For example we can see "blinking night TOKYO"from tower building.

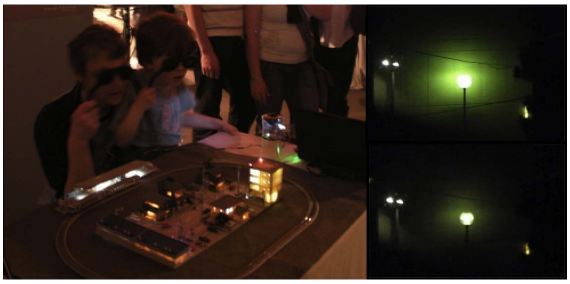

Figure 13: Miniature night view

7.2 Limitation

After several test and demonstrations, we found the following three limitations of SMG:

1. SMG cuts light, therefore making it is useless when viewing low luminance objects or in a dark environment.
2. SMG does not work for still objects, because there is no change in time domain.
3. SMG requires the tuning of the exposure parameter, depending on the motion of the object being observed.

The first limitation is obvious, since SMG is a device which cuts light. However, sunglasses are also commonly worn with the purpose of reducing luminance for eyes, in order to augment a dynamic range of luminosity sensitivity. Therefore, we can see that this limitation of SMG is not an important one.

The second is the limitation in time base. SMG augments just only motion perception, and therefore does not have any effect on still objects.

The third is the limitation with regards to usage. Users must tune the exposure parameter in order to augment visual ability. Therefore, we need to measure the speed of motion or rotation before using SMG. This limitation will be resolved by using measurement tools.

7.3 Contribution

This paper has three contributions towards augmented human research.

1. We proposed a method to see motion clearly.
2. We designed the device to realize our idea.
3. We evaluated the sensory property of human with our device.

The first contribution is our methodology. There are already many systems to realize stop motion viewing in the real world, such as the stroboscope. However, there is no system without light. Our proposal method is shutter for eye. This idea is novel and realizes our vision.

The second contribution is our device design. To realize our idea, we designed SMG. The key of the design is the FLC. It realizes portability and high operationality of exposure parameter, and enables us to demonstrate our idea to others.

The third contribution is towards basic perceptual psychological knowledge. L. Gregory Appelbaum et al. also found basic psychologic knowledge with similar device developed Nike[15]. We show not only that our shuttering method is effective at augmenting human visual ability, but also the result of the double frequencies controlling method. One of our novelty is double frequency method.

8. CONCLUSION

In this paper, we proposed Stop Motion Goggle as a shutter system for human eye to augment visuosensory, especially motion perception. We designed SMG and evaluated it. The result showed that SMG augments motion perception, and users can see not only outline of motion object but also motion blur with same brightness by the double frequency test.

9. ACKNOWLEDGMENTS

This reaserch is suppported by Grant-in-Aid for Young Scientists A, KAKENHI(23680012) .

10. REFERENCE

[1] Akira TORIYAMA, Doragon ball, vol 34, p36, Shueisha, 1993

[2] Lenny Lipton, et al.: Achromatic liquid crystal shutter for stereoscopic and other applications, U.S. Patent 4884876, Dec 1989.

[3] Andrew B. Watson and A. J. Ahumada Jr., A look at motion in the frequency domain, *NASA Technical Memorandum 84352*, 1983.

[4] http://www.translucent.ca/plato.html (accessed Jan 10th 2012)

[5] Edgerton, Harold E. and James R. Killian, Jr., Flash!: Seeing the unseen by ultra high-speed photography, Hale, Cushman Flint, 1939.

[6] Gregory BARSAMIAN, Juggler, 1997.

[7] Takashi Fukaya, Toshio Iwai, and Yuko Yamanouchi: Morphovision, *ACM SIGGRAPH 2006 Emerging technologies*, 2006.

[8] Finlay D, Dodwell P, Caelli T, The waggon-wheel effect, *Perception*, 13(3) pp.237 - 248, 1984.

[9] T. Takeuchi and K. K. De Valois: Sharpening image motion based on the spatio-temporal characteristics of human vision, *Proceedings of SPIE-IST Electronic Imaging: Human Vision and Electronic Imaging X* , 5666, pp.83-94

[10] F.A.Miles, K.Kawano and L.M.Optican: Short latency ocular following responses of the monkey: dependence on temporospatial properties of visual input, *Journal of Neurophysiology*, 56,1321-2354, 1986.

[11] Junji Watanabe, Taro Maeda, Susumu Tachi, Time Course of Localization for a Repeatedly Flashing Stimulus Presented at Perisaccadic Timing, *Systems and Computers in Japan*, Vol. 36, No. 9, pp.77-86, 2005.

[12] Naohisa Nagaya, Fabian Foo Chuan Siang, Masahiro Furukawa, Takuji Tokiwa, Maki Sugimoto, and Masahiko Inami: Stop motion goggle, *ACM SIGGRAPH 2008 new tech demos*, 2008.

[13] Naohisa Nagaya, Masahiro Furukawa, Maki Sugimoto, and Masahiko Inami: Surrounding of Firefly: Stop Motion Goggle for Luminary Objects, *Laval Virtual 2009*, 2009.

[14] Bloch, A. M. Experiences sur la vision. *Soc . BioI. Mem.* , 27, 493-495, 1885.

[15] L. Gregory Appelbaum, Julia E. Schroeder, Matthew S. Cain and Stephen R. Mitroff, Improved visual cognition through stroboscopic training, *Front. Psychology* 2:276. , 2011.