# Psychological and Physiological Effects of VLC using Versatile CSK Code Patterns

Takamasa Shimada1, Noriko Konno<sup>1</sup>, Atsuya Yokoi<sup>2</sup>, and Noriharu Miyaho<sup>1</sup> <sup>1</sup>Tokyo Denki University, Inzai, Japan (e-mail: tshimada@mail.dendai.ac.jp). <sup>2</sup>Atsuya Yokoi is with Samsung R&D Institute Japan, Yokohama, Japan (e-mail: atsuya.yokoi@samsung.com).

*Abstract*— Visible light communication will play a wide variety of important roles in future communication services. This paper explores color shift keying (CSK) for the modulation of visible light communication, describing the most recent developments in CSK. Also discussed are the evaluation of the psychological and physiological effects of visible light communication, and the feasibility of visible light communication providing added values by measuring arousal, healing, visual attraction, the response time for recognition, easiness of memorizing and reaction time for CSK code.

*Keywords*—CSK, Physiological effect, Psychological effect, Healing effect, VLC.

#### I. INTRODUCTION

Many different visible light communication (VLC) methods have been proposed and developed for commercial services. Visible light communication is characterized by the freedom from the constraints of laws regulating radio propagation and the ability to allow visual inspection of data transmission/reception. Visual inspection can prevent eavesdropping, which will cause a risk normally difficult to prevent from in wireless communication environments. All the light sources around us, such as room lighting, TV screens, traffic signals, and neon signs, have high potentials to serve as visible light communication devices.

This paper deals with color shift keying (CSK) for the modulation of visible light communications. Also, considering potential new communication services, this paper evaluates the psychological and physiological effects of visible light communications. There are few study reports about psychological and physiological effects of CSK code. This paper evaluates the feasibility of visible light communication providing added values by measuring arousal, healing, visual attraction, the response time for recognition, easiness of memorizing and reaction time for CSK code.

#### II. SAFE AND SECURE COMMUNICATION TECHNOLOGY REQUIREMENTS IN CYBER-SOCIETY

In today's cyber-society, the electronic information infrastructure is used not only for enterprise and government activities but also for commerce and health management.

In image sensor communication using CSK, color cells are arranged in a specific frame shape. Since each color cell blinks continuously in a different color, it is necessary to examine the effect of blinking cells on human psychology and physiology. Basic research on this subject has already begun [1][2]. We analyzed the psychological and physiological effects of CSK communication, taking these research results into account.

#### III. CSK AND ITS APPLICATION

#### A. Principles of CSK Communication Technology

CSK is one of the modulation schemes for VLC that was adopted in the IEEE802.15.7-VLC standard in 2011[1]. In CSK, information is transmitted as color symbols that are generated by multi-color light sources such as RGB LEDs. Fig. 1shows an example of a CSK color symbol mapping on CIE1931 x-y color coordinates [3].

CSK has the following advantages over the conventional OOK (On Off Keying) VLC system.

1) Good connectivity guaranteed by the color coordinates

2) High speed and variable data rate with CSK constellation design

3) Illumination dimming available because of the constant normalized total power.

Furthermore, CSK is particularly suitable for image sensor communications (ISC) from displays to cameras because it uses visible colors for its communication. All displays can be used as transmitters and all cameras can be used as receivers of CSK without additional hardware.

#### B. Application to Image Sensor Communication

A new ISC system using CSK has been proposed by Yokoi et al. [4], consisting of a transmitter with a liquid crystal display, plasma display, OLED or other color display, and a receiver with a color image sensor, i.e., a digital camera. It is assumed that the systems transfer information from TVs, PC displays, digital signage boards or other color displays to mobile terminals or others receivers with digital cameras. The main feature of this system is that it can be configured with off-the-shelf consumer products such as TVs and smartphones, without any additional hardware.

Color displays can show animations of two-dimensional images, and digital cameras can record them. Therefore, two-dimensional CSK codes can be adopted to communicate from a display to a camera. The scheme is called Space Division Multiplexing CSK (SDM-CSK) [4]. SDM-CSK is very effective for increasing the data bit rate. If we use a 16×16

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cell sized CSK code for SDM-CSK, the bit rate increases by 256 times compared with normal CSK. Examples of SDM-CSK codes in 16-CSK are shown in Fig. 2.



Fig. 1. CSK color symbol mapping on CIE1931 x-y color coordinates



Fig. 2. Two-dimensional SDM-CSK code

#### C. Color Offset CSK

The CSK symbols are offset in the color space, in order to offset the visible color carrying a message from the image colors already present [5].

This is called offset CSK. Fig. 3 shows normal 4CSK, which uses the whole sRGB (standard RGB) color space: R(0.64,0.33),G(0.30,0.60), and B(0.15,0.06)), blue offset 4CSK, green offset 4CSK and red offset 4CSK.

#### IV. PSYCHOLOGICAL EFFECTS OF COLOR OFFSET CSK

We have examined the psychological and physiological effects of color offset CSK (red, blue and green).

#### A. Examination environment

Subjects are 9 arbitrarily selected able-bodied people (nine males with an average age of  $21.3\pm0.7$ ). The experiments were conducted after receiving informed consent from each subject based on the human bioethics review guidelines specified in Tokyo Denki University.

In this experiments, we used color offset CSK codes. Fig. 3shows the color offset CSK codes for normal, red, green and

blue used in the experiment. They were displayed on a 55-inch monitor (68 cm high). The size of a CSK code was around 12 cm  $\times$  12 cm (reference outer shape). The CSK code was displayed at the center of the monitor. The measured brightness of the artificial illumination at the monitor ranged from 440 lx to 480 lx, and at the subject's eye position, from 420 lx to 460 lx. The subject sat 2 meters away from the monitor (i.e. three times the height of the monitor), and faced with the monitor. This reproduced the normal distance from which people watch TV.



Fig. 3. Color offset CSK

#### B. Evaluation of psychological effects

After a CSK code was displayed for about 60 seconds, its psychological effects were measured by making use of personal psychological interviews. The measurement period continued for about 30 seconds after the display.

We used the following evaluation indicators: arousal, mental concentration assistance, rest, visibility, and visual attraction. These were evaluated on a visual analog scale ranging from none (0%) to very strong (100%).

#### C. Results of psychological evaluation

The experiments revealed the following results:

#### (1) Arousal (Fig. 4)

Arousal rose significantly above its pre-presentation level during a normal CSK presentation when the red color offset CSK was presented. It was higher with red-offset CSK than with normal CSK or other color offsets of CSK (green or blue).

(2) Rest level (Fig. 5)

The rest level fell significantly below its pre-presentation level during normal CSK and red-offset CSK. The rest level was significantly higher with green- and blue-offset CSK than with normal CSK or red-offset CSK.

(3) Visual attraction (Fig. 6)

Visual attraction was significantly higher with red-offset CSK than with green- or blue-offset CSK.

#### V. PHYSIOLOGICAL EFFECTS OF COLOR OFFSET CSK

*A. Evaluation of physiological effects (stress and relaxation)* For evaluating physiological effects, stress and relaxation, we

characteristic EEG. We EEG used used two (electroencephalogram) features, the alpha and beta brain waves, as indicators. It is known that the activity of each wave is associated with certain human mental states, as shown in Table I. The EEGs were measured using the unipolar method with the average value at the two earlobes as the reference. The measured EEGs were sampled at 200 Hz and stored as digital data in a computer. The power spectrum was calculated from data in each of the analyzed sections, consisting of 256 samples. Next, a fast Fourier transform was applied for spectrum calculation. The F3, F4, C3, C4, P3, P4, O1, and O2 electrodes of the international 10-20 electrode placement system were used to analyze the alpha and beta waves. The alpha waves were measured while the subject was at rest with closed eyes. Measurements made in the first 10 seconds (the time needed for the EEG to become stable) immediately after the presentation of the CSK code were excluded. The averages of the data over approximately 20 seconds before and after the presentation of the CSK code were calculated and compared. For the beta waves, the measurements during approximately the first 10 seconds and the last 10 seconds of the CSK code presentation time were averaged and compared.



Fig. 4. Results for arousal. Number ① to ⑤ shows ① Before presentation, ② Normal CSK, ③ Color offset CSK (green), ④ Color offset CSK (red), ⑤ Color offset CSK (blue), respectively.



Fig. 5. Results for rest level. Number ① to ⑤ shows ① Before presentation, ② Normal CSK, ③ Color offset CSK (green), ④ Color offset CSK (red), ⑤ Color offset CSK (blue), respectively.





TABLE I. Human states as determined from characteristic brainwaves

Characteristic waves	State
Alpha waves	At rest, eyes closed
Beta waves	Eyes open; pain; mental
	calculation, tension, stress

## *B.* Results of physiological evaluation (stress and relaxation)

The experiments revealed the following results:

(1) Alpha wave power (Fig. 7)

The alpha wave power with green-offset CSK was significantly higher from the forehead electrode (t-test,  $\alpha = 0.05$ ) than with red- or blue-offset CSK or normal CSK, indicating an elevated rest level in the subjects.

(2) Beta wave power (Fig. 8)

The beta wave power with green-CSK was significantly lower from the electrode at the center to the back of the head (t-test,  $\alpha = 0.05$ ) than with red- or blue-CSK or normal CSK, indicating that the stress level of the subjects was low.

## *C.* Evaluation of physiological effects (recognition, memory and reaction)

The time for recognition, easiness of memorizing and reaction time for CSK were measured by P300, event-related potential of EEG. P300 is induced with high probability during experiment using oddball paradigm [6]. In oddball paradigm, one of several stimuli is randomly selected and shown every constant period. Subject reacts when he/she recognizes the specific stimulus called target we assigned before. In this experiment, normal 4CSK, blue-offset 4CSK, green-offset 4CSK and red-offset 4CSK were used as stimuli for oddball paradigm. The total number of displaying CSK code in one experiment is 60. The duration time of one CSK code is 200ms. Inter-stimulus interval (ISI) is 800ms and black screen was shown in ISI. Then, the duration time of one experiment. The subjects reacted by turning on the push button switch held on the right hand as soon as he recognized the target was shown. P300 reflects the higher brain function, recognition and judgment.



Fig. 7. Difference in  $\alpha$  wave power before and after CSK code presentation



Fig. 8. Difference in  $\beta$  wave power before and after CSK code presentation

Peak latency is duration between the time, which CSK code starts and the peak time of P300. The shorter the time for recognition, the shorter the peak latency of P300. The peak latency negatively correlates with the capacity of working memory. [7]

Amplitude positively correlates with the consumption of brain resource and capacity of working memory. People can easily memorize the CSK code that induces P300 with high amplitude. [7]

Reaction time is a duration between the time, which CSK code starts and the subject turns on the push button switch. Short reaction time means that people can respond to that CSK code depending on its meaning.

The EEGs were measured using the unipolar method with the average value at the two earlobes as the reference. The measured EEGs were sampled at 500 Hz and stored as digital data in a computer. The Cz electrode of the international 10-20 electrode placement system was used to analyze the P300 wave. The measured EEGs were sampled at 500 Hz and stored as digital data in a computer. For each target CSK code, every data measured during 1s from the time which target CSK code starts were averaged for extracting P300.

The Amplitude was defined as the voltage of peak of P300

which was detected as the maximum value of the data averaged from 250ms to 500ms. The peak latency was defined as the duration between the time which the target CSK code starts and the time of the peak. The reaction time was defined as the duration between the time which the target CSK code starts and the time subject turns on the push button switch.

### *D.* Results of physiological evaluation (recognition, memory and reaction)

#### (1)Peak latency (Fig. 9)

The peak latency with red-offset CSK was significantly shorter (t-test,  $\alpha = 0.05$ ) than with normal CSK, and the peak latency with green-offset CSK was significantly shorter (t-test,  $\alpha = 0.05$ ) than with normal CSK. These results showed that subjects could recognize red-offset CSK and green-offset CSK in shorter time compared with normal CSK. The color effects of red and green may raise the performance for oddball paradigm because Sandra et al. reported that peak latencies of the people who showed relatively high performance for the task that required high speed were short [8].



Fig. 9. Peak latency of P300 for CSK presentation

(2)Amplitude (Fig. 10)

The amplitude with red-CSK was significantly larger (t-test,  $\alpha = 0.05$ ) than that with normal CSK. Maratos et al. and Kate et al. reported that some images which raise person's arousal induce higher amplitude compared with the other images [9][6]. Red has color effects of making people feel heat and expansion of objects colored red. Therefore, red gives people stronger impression than the other colors. Moreover, red has psychological color effects of making people feel passion, love and energy [10][11]. These effects may raise arousal and, as a result, make P300 amplitude larger. The fact that psychological investigation showed that arousal rose when subjects see red-offset CSK (Fig. 4) supports our hypothesis.

(3)Reaction time (Fig. 11)

The reaction time with red-, green- and blue-offset CSK were significantly shorter (t-test,  $\alpha = 0.05$ ) than that with normal CSK. Results showed that red-, green- and blue-offset CSK induced the faster response of subjects compared with normal CSK. Robert et al. reported that shorter reaction time

relates higher attention [12]. Therefore, red-, green- and blueoffset CSK may raise the attention of subjects.



Fig. 10. Amplitude of P300 for CSK presentation



Fig. 11. Reaction time of oddball paradigm with CSK presentation

#### VI. DISCUSSION

It is thought that we can use CSK code properly by considering the results of psychological and physiological investigations.

The results of arousal and visual attention of psychological investigation and the P300 amplitude of physiological investigation showed that red-offset CSK has effects of giving strong impression, attracting attention and making people easily memorize the CSK code. Therefore, red-offset CSK is suitable for commercial advertisements. Rest level of psychological investigation and alpha and beta power of physiological investigation showed that green- and blue-offset CSK have effects of calming down and decreasing stress. Therefore, green- and blue-offset CSK are suitable for wireless communication environments in a hospital. Peak latency of physiological investigation showed that red- and green-offset CSK have an effect of raising people's performance for tasks. Red- and green-offset CSK are suitable for wireless communication environments in business occasions. Reaction time of physiological investigation showed that red-, greenand blue-offset CSK have an effect of inducing fast response. Red-, green- and blue-offset CSK are suitable for intelligent transport system (ITS).

#### VII. CONCLUSIONS

It is necessary to study the psychological and physiological effects of visual stimuli on humans under a wide variety of conditions. As part of such studies, we have analyzed some basic CSK code patterns that can be used in CSK communication services.

Looking ahead, new communication services will be conceived by combining psychologically and physiologically proper kind of CSK code with our various communication environments, such as sharing a patient's physiological information exchange between the patient and the doctor using bedroom lighting, information delivery using traffic lights or neon signs on a street, and driving support in next-generation ITS.

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