Smart Light–Ultra High Speed Projector for Spatial Multiplexing Optical Transmission

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Abstract

We present a spatial multiplex optical transmission system named the "Smart Light" (See Figure 1), which provides multiple data streams to multiple points simultaneously. This system consists of a projector and some devices along with a photo-detector. The projector projects images with invisible information to the devices, and devices receive some data. In this system, the data stream is expandable to a position-based audio or video stream by using DMDs (Digital Micro-mirror Device) or LEDs (Light Emitting Diode) with unperceivable space-time modulation.

First, in a preliminary experiment, we confirmed with a commercially produced XGA grade projector transmitting a million points that the data rate of its path is a few bits per second. Detached devices can receive relative position data and other properties from the projector.

Second, we made an LED type high-speed projector to transmit audio streams using modulated light on an object and confirmed the transmission of position-based audio stream data.

1. Introduction

Recently, we developed RPT (Retro-reflective Projection Technology) for the study of augmented reality or mixed reality [1][2].

This technology uses a projector and retro-reflective material as its projection surface. In the RPT configuration, a projector is arranged at the axial symmetric position of the user's eye with reference to a half-mirror, with a pinhole placed in front of the projector to ensure adequate depth of focus. Images are projected onto a screen that is either made of, painted with, or covered with retro-reflective material. This technology has been studied for HMPD (Head Mounted Projective Display) previously [3].

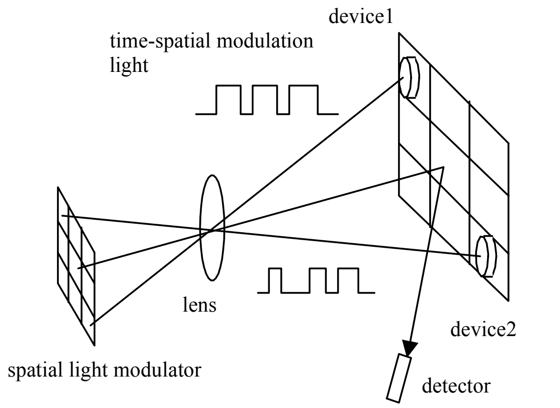

Figure 1. Spatial multiplex optical transmission

This study applies RPT to multiplex optical transmission, simultaneously using video presentation and multi-directional transmission.

The concept of ubiquitous computing is already well known, but in general it is still dependent on the use of sophisticated wireless communication technology using infrared or spread-spectrum transmission. For these methods, a time division or frequency multiplex system is necessary to transmit to devices that are omnipresent in space. Further, there is a quadratic trade-off between the number of targets and the volume of transmitted data.

To resolve this problem, in this paper we propose Smart Light, a system that uses space division multiplex transmission to project information, and describe the details of fundamental experiments conducted to confirm this concept.

2. Related work

The I/O bulb as researched by Ishii [4] refers to an optical input/output device utilizing a projector and camera substituted for the bulb. It is used in workbench type fields with marked blocks. These blocks have functions that are the result of their respective aspects, such as their mirrors and lenses, etc. In this configuration, the observer sees the property of the block or light ray on the workbench. However, the block has just a passive marker, and therefore it has no interaction with the projector or other blocks. In this study, the projected images are focused on the observer's eyes.

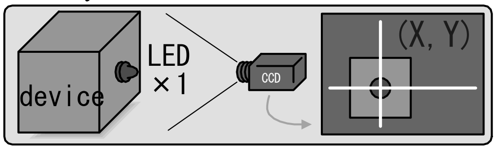

Figure 2. Basic concept of image processing

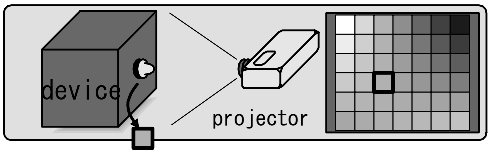

Figure 3. Basic concept of projector image processing

In the OOTF (Office of the future) [5] project, using computer vision techniques, the system can sense depth information and project dynamic images to any surface in one's office, enabling the observer to see flat images on irregular wall surfaces or desks. Thus the entire office can become part of a large immersive display. This system, however, is not intended to be used as a communication interface from the system to its detached devices.

The Smart Dust [6] project creates a ubiquitously distributed sensor network. "Smart Dust" devices are tiny wireless micro mechanical devices that sense vibrations or light. Communication, however, is only possible with nearby devices, while distant device receive relays. Thus it is unknown whether great amounts of data can be transmitted through this system.

Another related field of study is known as "Smart Pixel" [7]. The system has a photo-detector, LED, and operation chip on a silicone board. There is a currently much research anticipated related to Smart Pixel in optical computing fields, but there is not yet much research which applies this system to communication in the real world.

RFIGs [8][9] use a RFID (Radio Frequency Identification) tag system, computer vision and graphics, and HCI by using a portable projector with a RFID reader to allow for geometric operations such as finding the location of wireless tags.

This system is different from Smart Light because it requires microwave resources to communicate with RFID tags, and thus the number of simultaneous users is restricted and the communication capacity is inadequate.

The CoBIT [10] project can project various kinds of information according to their positions, and the future course of this project appears to be similar with that of the Smart Light system introduced in this paper. However, the functions of this project that have been thus far implemented have been limited, such as the sensing of the position of a device by using laser radar and simply projecting one type of musical data to a nearby space.

In the "HIEI Projector" [11] project, a projector with an infrared-pass filter can transmit information with many attributes. It projects 2D-ID data or some character information to an observer indirectly. However, the projected information is static and therefore there is no time-division modulation. Further, this system in only for observer-handled devices and not distributed devices.

Finally, "Realizing ultrasound-guided needle biopsies" [12] use HMDs in medical procedures, projecting ultrasound probe data using a stereo video-see-through HMD. A physician can see volume visualization of the ultrasound data directly. This system, however, cannot transmit some data to detached devices.

3. Principle

3.1. Camera vs. projector

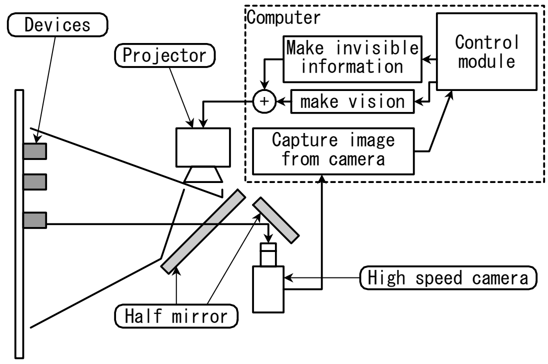

Figure 4. General application of Smart Light

The basic purpose of a video camera is to acquire images. It is also a type of high-speed information capturing equipment used by image-processing systems such as a high-speed video camera, the Vision Chip [13], etc. Figure 2 describes how to obtain a LED's position in a camera coordinate system. (1) The camera receives an image with luminescent spots, (2) the controller makes a binary image to determine the position of the spots from the camera image, and then it (3) calculates the center of the binary image and the output (X, Y) position. In this condition, the camera can receive some information from the LED. A projector may also be used in place of a camera, although they are currently seldom used for "information" projection. Figure 3 describes how to obtain a photo-detector's position in a projector coordinate system. (1) By using a conventional projector, colored images can be projected according to their X-Y coordinate positions. Next, (2) a device acquires the RGB color values through its color sensor, and then it (3) translates the color values to positions to

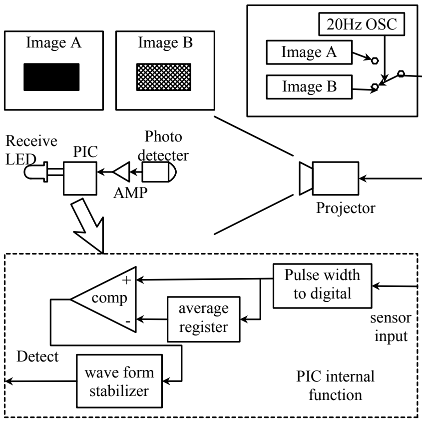

Figure 5. Preliminary experimental set-up

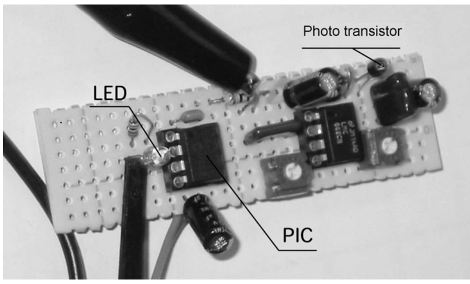

Figure 6. Close-up of a receiver

Table 1. Results of preliminary experiment

Luminance of A and B (cd/m^2)	Response from detector	Response from subject
82;82	No	No
82;88	Yes	Yes
82;95	Yes	Yes
77;77	No	No
77;72	Yes	No
77;67	Yes	Yes

obtain the (X, Y) data. In this condition, the projector can also transmit some other "information" to the device. We call this "information projection."

Summarizing this section, we can understand a projector as having dual functionality when compared to a camera in the sense that it can also project "information."

3.2. Smart Light

Many studies of projector systems focus on projecting "images." This paper focuses on projecting "information" which includes images. We call this system Smart Light, which consists of a kind of projector that can project not only images but also unobservable information.

Figure 4 shows the implementation of Smart Light, indicating some of the workbench. One characteristic of this system is its use of only light for communicating technology, positioning technology, and vision technology. Thus the system has the possibility of being simple and compact. The structural procedure of this system is as follows:

1) Projection image is made with invisible information.
2) Image is projected to a wall.
3) Devices receive some invisible information and make some responses with LED.
4) Camera receives the responses from the devices.

In this system, only one projector projects images for the observer, and it communicates with the detached devices simultaneously.

3.3. Preliminary experiment

This experiment shows that commercially produced projectors can project not only images but also "information." The common frame-rate of the projector can be set up to 60Hz, and though it can be fit to the characteristic features of human perception, when set at high speeds there is no time for blinking for the processing of invisible information. We therefore decided to add very little luminance movement as invisible information (See [14] for details).

Figure 5 shows a block diagram of the 2-part experimental setup. One part is a signal generator that makes 20Hz luminance movement images. The name of the projector is PLUS-V1100 (1000 ANSI lumen). The other part is a receiver that can detect 20Hz photo power movement. Figure 6 shows the details of the receiver. In this experiment, we recorded the reactions

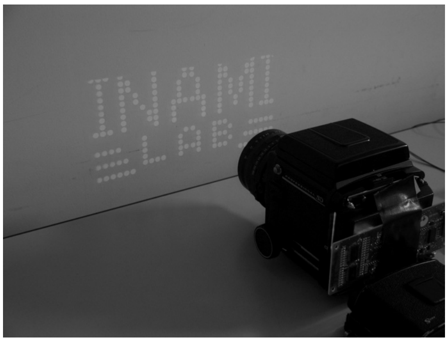

Figure 7. Example of a LED projector

of the receiver that can sense the blinking and reaction responses of the subject.

3.4. Result of preliminary experiment

Table 1 shows the results of the preliminary experiment. We found some different thresholds from the detector to the subject, indicating that with Smart Light it is possibility to project invisible information with a normal projector. In some conditions, the detector can receive data even when the subject does not subjectively sense any flicker.

In this configuration, however, the data rate is just a few bits per second, and there is too little room to apply this system to general applications. Therefore a high-speed projector is needed.

3.2. Ultra high speed projector

A normal projector has a maximum frame-rate of 60 frames per second. This modulation rate is too slow for transmitting audio or video streams, and therefore in this study we consider a projector that can modulate at high frequencies. In such a setup, we can choose DMDs (Digital Micro-mirror Device) or LEDs that generate high-speed spatial light modulation. A DMD projector can modulate about 10,000 times per second when set at maximum levels. We call such a projector a "High Speed Projector." A LED is a low-cost, bright light source that can modulate at lightning speed. We decided to use a LED device for our Ultra High Speed Projector because of this fast modulation rate. This allows the projector to transmit multiple data streams simultaneously. Of course this system is expandable to enable the transmission of high rate data streams such as video, etc.

4. Primary LED projector

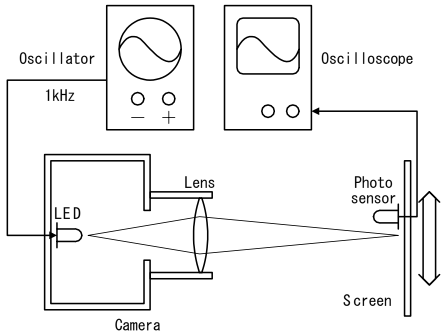

Figure 8. Experimental setup using one LED projector

For sending audio and video streams, we decided to make a LED projector. First we evaluated the characteristic features of single-LED projectors, observing how signals are transmitted or how they spread (See Figure 7).

4.1. One LED experiment

4.1.1. Experimental setup As shown in Figure 8, we prepared a film camera body (MAMIYA RB67-S), a camera lens (MAMIYA-SECOR-C F4.5/50mm), and one LED device (on the focal plane) for the projector because the mechanism of the projector is similar to that of the camera. Therefore in this experiment we used this camera unit as a projector by placing a LED on the focal plane. This camera system is a medium format, so the diameter of lens and the film size is larger than that of a 35mm camera. As an advantage, however, its light volume is sufficient for projection, and its focal plane is wide enough to create an LED array. On the other hand, this camera is large and difficult to handle, with a weight of about 2 kilograms. We also prepared an oscillator that generates a 1 kHz square wave with a 5V wave height, and we used an oscilloscope (Tektronix TDS2012) to observe and read the wave height of the photo sensor.

Figure 9 describes the circuit of this setup and its observation condition. As for the LED, the angle of half power width is 20 degrees, the diameter of the spot is 2mm, and the current of the LED is 1.5mA. The photo sensor used is a TOSHIBA TPS603. It detects light with a pull upped by 20 kilo-ohms and is fixed to the height gage in order to modify the height of the sensor. The location of this experiment was a room with illumination of about 500lux.

4.1.2. Experiment We set the photo sensor on the screen in front of the lens. The distance from lens to photo sensor was 300mm. We then connected the wires between the LED and the oscillator and placed the LED in the center of the focal plane in the camera. Next, we adjusted the focus of the camera and opened its shutter. When the focus was adjusted to 300mm ahead, the distance from the lens to the focal side became 60mm. We measured the voltage of both ends of the “20 kilo-ohms” register with a moving photo sensor of about 20mm, showing the intensity of illumination at the sensor’s point. We recorded the value every 2mm.

4.1.3. Result of experiment In this configuration, white noise of about 25mV height occurs when the LED is off. As for measured voltage, the noise voltage is added to the signal voltage. Therefore it can be explained by the following equation (1):

Nn: Noise value
Sn: Signal value
Dn: Measured value

$$D_n = \sqrt{S_n^{\ 2} + N_n^{\ 2}} \qquad (1)$$

Figure 10 shows the signal values Sn calculated by equation (1), and their plots. The illumination intensity of the LED is a single peaked pattern. We can read out that the diameter of the half power of the max illumination intensity is about 10mm from this figure. This ideal value is computable from the magnification of the lens parameter.

Ds: Diameter of spot on the LED (=2mm)
Dt: Diameter of spot on the screen
Ls: Focal length of a lens (=60mm)
Lt: Distance to the screen (=300mm)

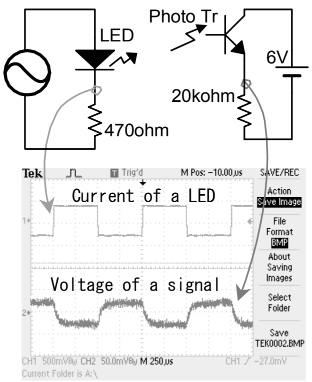

Figure 9. Waveform of signals

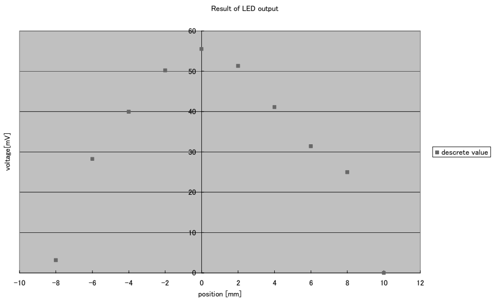

Figure 10. Intensity of LED

$$\frac{Ds}{Ls} = \frac{Dt}{Lt} \qquad (2)$$

The Ds is calculated from equation (2). In this configuration, the ideal diameter of a spot on the screen is 10mm and nearly equal to the real diameter of half the power of the maximum illumination intensity. Thus a camera lens is sufficient for use as a projection lens.

4.2 Two LED experiment

The prototype projector basically projected multiple audio streams.

The FM (frequency modulation) modulation method was used to stabilize the levels of audio. If the modulation method were AM (amplitude modulation), then the power of illumination on the screen would be jaggy, making the levels of audio unstable. The carrier of this system is self-excitation, and in order to gain the signal to noise ratio, it used infrared LEDs in the room. The LEDs were a 5mm round type of 15mA per device.

We prepared 3 sets of this transmitter and LED for placement in the camera body. The camera body used was a MAMIYA RB67PRO-S, and the lens used was a MAMIYA-SEKOR-C F4.5/50mm.

We also prepared a receiver to demodulate one audio stream that included a wired photo sensor that can select the position (audio stream). The advantage of this system is that there is little cross talk between different audio signals because of its FM modulation.

4.2.1. Experimental setup We aimed to confirm in this experiment whether this system has good spatial selectivity. First, we set the lens to the center of the bench. We used two LED units (A and B) and set the focal plane as shown in the diagram in Figure 11. Two LEDs were connected to different modulator so that we could hear the different sounds from each unit. Next, we placed a screen at a distance of 300mm from

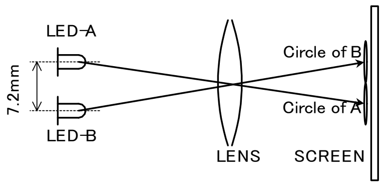

Figure 11. Experimental set up using two LEDs

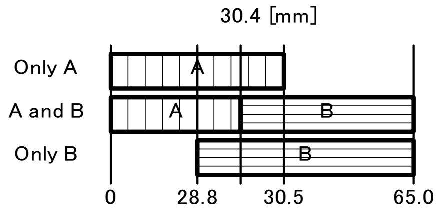

Figure 12. Results of experiment 2

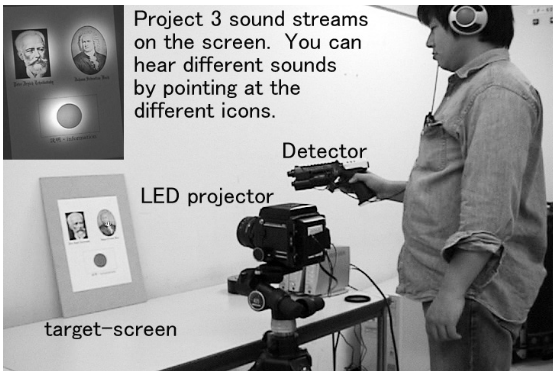

Figure 13. Using primary LED projector

the points of the lens and adjusted the imaging screen. In such a setup, there are two luminescent spots on the screen caused by the light of the LEDs. We call the spot illuminated by LED-A "CIRCLE-A" and the spot illuminated by LED-B "CIRCLE-B." We set the detectors on the luminescent spots and could hear the audio for "CIRCLE-A" and "CIRCLE-B." We measured the ranges of "CIRCLE-A" and "CIRCLE-B" by moving the photo detector in the level-containing axis of the lens.

We recorded the range by under the following three conditions:

1) Transmit A only.
2) Transmit both A and B.
3) Transmit B only.

4.2.2. Result of experiment The results of this experimental are shown in Figure 12. The radii of the circles on the screen were about 30mm and 43mm. Although ideally the circles should be the same size, in actuality they were different. The reasons for this difference are the following. Although the focus of the lens was adjusted by visible light, since infrared rays were used in the experiment, the focal plane may not have been adjusted properly. In addition, there may have been an influence of reflection on the LED substrate. There was no non-signal area between LEDs, which are mounted separately. This result is positive for making a projector.

4.3. Application of audio stream projector

The following applications were realized based on the results of the above experiment (See Figure 13). This system projects 3 different audio streams to different icons on the screen. We made a LED array board that was embedded in the camera and can project 3 different sounds simultaneously. If a subject changes a direction of the detector to a different icon, he/she can hear a different sound. There is no noisy-sound area between the 3 icons, and there is little cross talk among the different signals. Further, there is no time delay in this system (i.e., using magnetic position sensors), as slight changes in the direction of the detector will change the sound accordingly.

We confirmed through this experiment that subjects could select different audio streams by moving the photo sensor close to different icons. We plan to use this system in the guidance-machines of museums. Visitors can carry a little guidance-box and point to different parts of the items on display, thereby listening to the appropriate audio guide for each display item. This system can transmit multiple data streams to multiple points at the same time.

5. LED Projector

We developed a second LED projector having the following features:

1) The pixels of a photo-source are aligned on a grid.

2) Each pixel can project one set of data from a multiple data stream.

3) The projector can project information for humans and information for the device simultaneously.

5.1. Design of the second LED projector

We designed the second projector so that it could project alphabetic characters as information for humans and pulse modulation as information for the device. It therefore has 20 discrete LED devices on the focal plane. As shown in Figure 14, the LED devices are arranged in a 4 by 5 matrix in a plane, and each

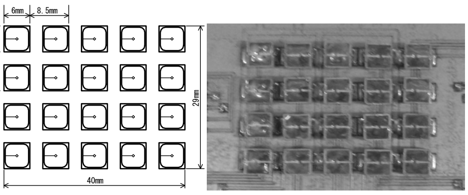

Figure 14. LED board

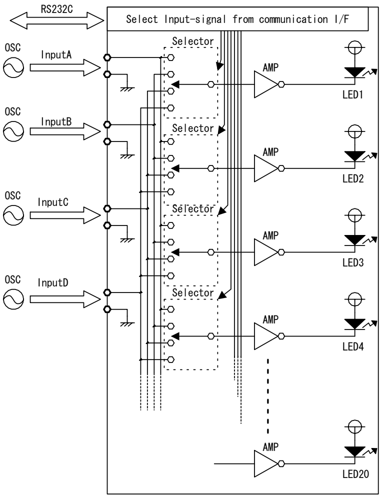

Figure 15. Block diagram of LED driver

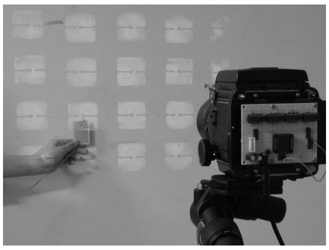

Figure 16. Using second LED projector

device emits light separately. That there are spaces between LEDs is a technical problem with the hardware. Figure 15 shows a block diagram of the LED driver board. There are three modules on the circuit board of the LED-driver.

1) Function as a select switch from 4 input signals.
2) Function as a driver for the LEDs.
3) Function as a selection control unit through serial communication with a PC.

The number of input sources is four, the signal level is TTL, and the frequency range of the signal is zero to ten MHz. Types of data sources can include pulse width moderated voice, FM modulated video stream, and some types of LAN (local area network).

Table 2. LED and other part specifications

Name		Value
LED	Directivity	9 degree
	Brightness of center	25 cd/m^2
	Emission wavelength	530 nm (green)
	Saturation voltage	3.6 V
	Maximum Current at a chip	20 mA
Buffer	AC type standard logic IC	TC74AC04P
Switch	CPLD by Xilinx	XC9572-15PC44C
Controller	Embedded-CPU by MicroChip	PIC16F88

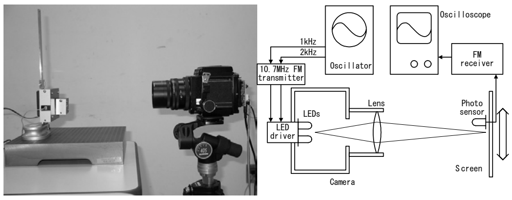

Figure 17. Experimental setup

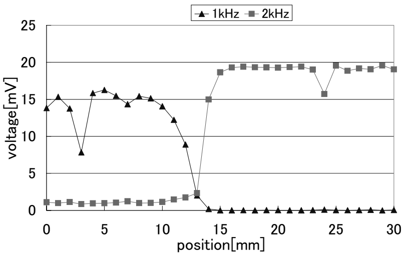

Figure 18. Result of Experiment

The LED device used was made by "Opto-device," and its model number was OP3-5305T1. This device was selected because of its extremely high level of brightness (See Table 2 for more specification).

The projector body and lens were identical to the first LED projector introduced in this paper.

This projector has the potential to project multiple sounds and/or video streams along with alphabetic characters (See Figure 16).

5.2. Experiment

Using this projector, we investigated the basic signal separation characteristics. The signal sources were two types of 10.7MHz pulses with modulated FM of different frequencies (See Figure 17).

5.2.1 Experimental setup The sound sources were 1kHz and 2kHz, and the distance from the LEDs to the receiver was 500mm. The receiver moved from one pixel (1kHz) to the next (2kHz). We recorded the output voltage of the FM receiver and plot. The luminance of the room was 600lux.

5.2.2 Results of experiment Although there are spaces between the LEDs, the separation of the signals was good,. and the range of the noisy areas was narrow with little cross-talk (See Figure 18). In Figure 18, the difference of the signal level between 1kHz and 2kHz is a characteristic of the demodulator.

6. Future Work

This projector could only project four kinds of sounds, and the positions of the LEDs were basically fixed. Thus there are a few areas where this system could be improved. We believe that this can be done by taking the following steps. First, it is necessary to research the arrangement of the LEDs so that the projecting patterns are dynamically changed. It is hoped that eventually such a projector can be equipped with 10,000 LEDs. Since high luminosity LEDs of an angle of about 2mm are currently available, it is feasible that an ultra high-speed projector about the size of a handheld computer can be made. Moreover, we would like to include a mechanism in which a reply is sent back to the user that will extend the system to include mutual communication. As an example of such an application, we plan to create a guidance system for museums (See Figure 14), in which the LED projector transmits guidance voice data separately. A visitor can point to an item with the detector device to hear a guidance voice.

7. Conclusion

This paper presented concepts related to an information projector system named "Smart Light," which can provide not only images but also information. A basic experiment was conducted using a normal projector, and the results confirmed that it was possible to actually embed information in a projection in addition to an image. However, since the rate of data transmission is very slow, the experiment using the normal projector showed that this concept could not be employed efficiently. As a solution, the use of a high-speed projector was suggested, and a way for realizing such a high-speed projector system was discussed. For this study, an ultra high-speed projector using Light Emitting Diodes was considered, and an actual basic LED projector was made as an experiment. An experiment on the nature of fundamental selection was also conducted.

Finally, this system is expandable to colored LEDs or integration units.

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