Visible Light Communications: Recent Activities in Japan

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Smart Spaces: A Smart Lighting ERC Industry - Academia Day
at BU Photonics Center, Boston University

February 8, 2011

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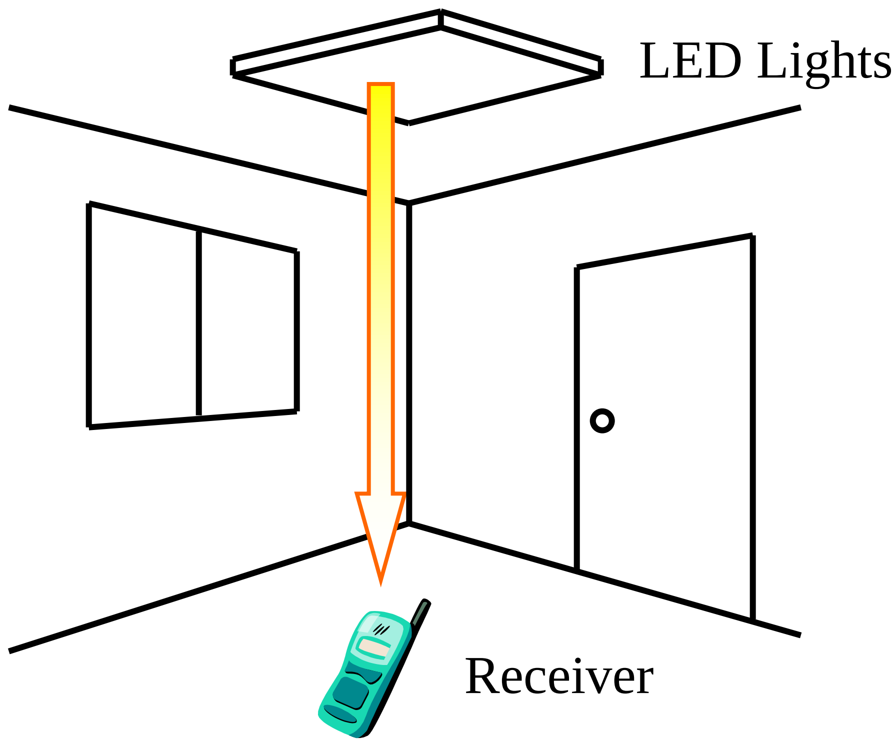
1. Visible light communication

1. Visible light communication

Visible Light communication is a wireless communication technology that uses light that is visible to humans.

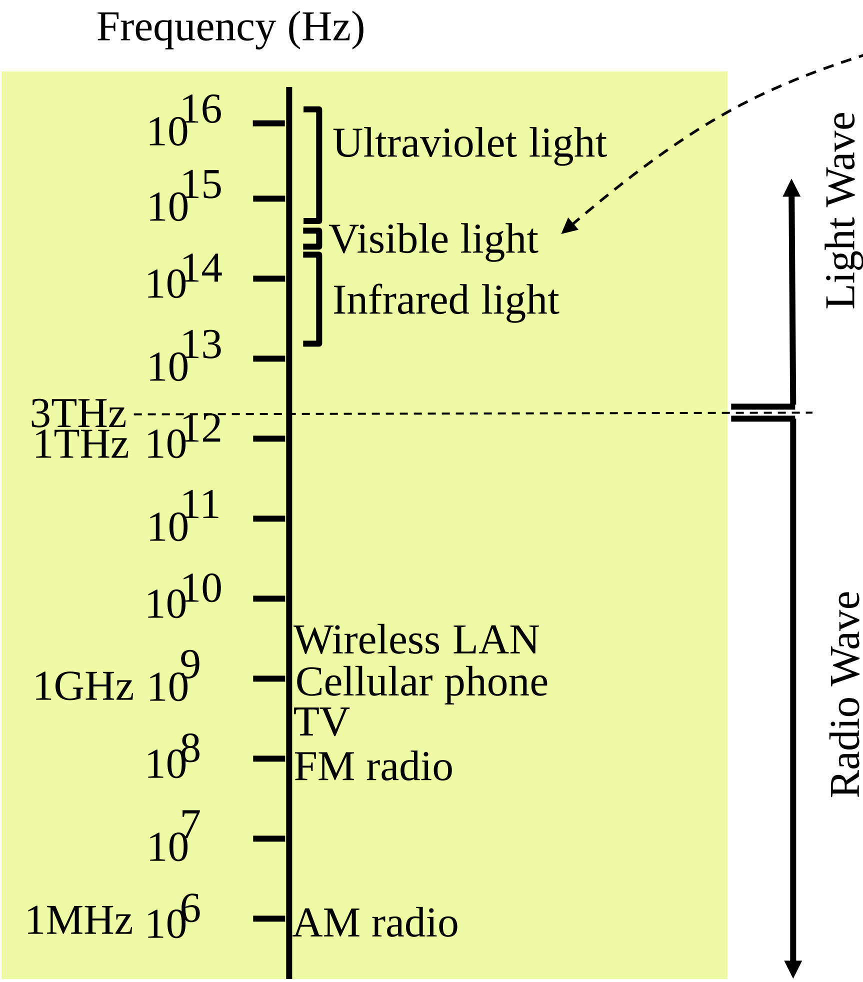
Typical example of visible light communication: the use of LED illumination as a transmitter



Why do we want to use visible light for communication?

Reason 1: Visible light communication is not regulated.

Radio Wave and Light Wave



Visible light communication

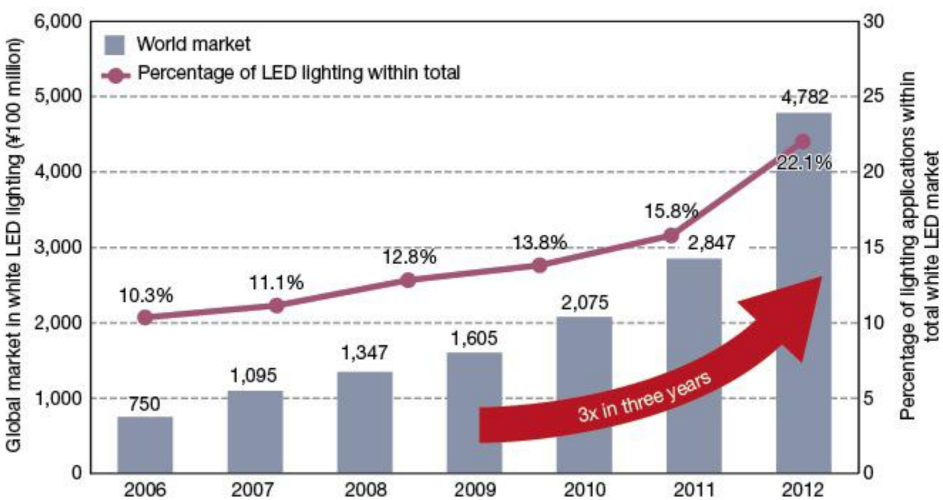
Frequency above 3THz is NOT regulated by the Radio Regulation Law .

The use of radio frequency below 3THz is regulated by the Radio Regulation Law .

Visible light communication is not regulated, so it is fairly easy to introduce new products , though safety regulation of high-power LED light has been already discussed.

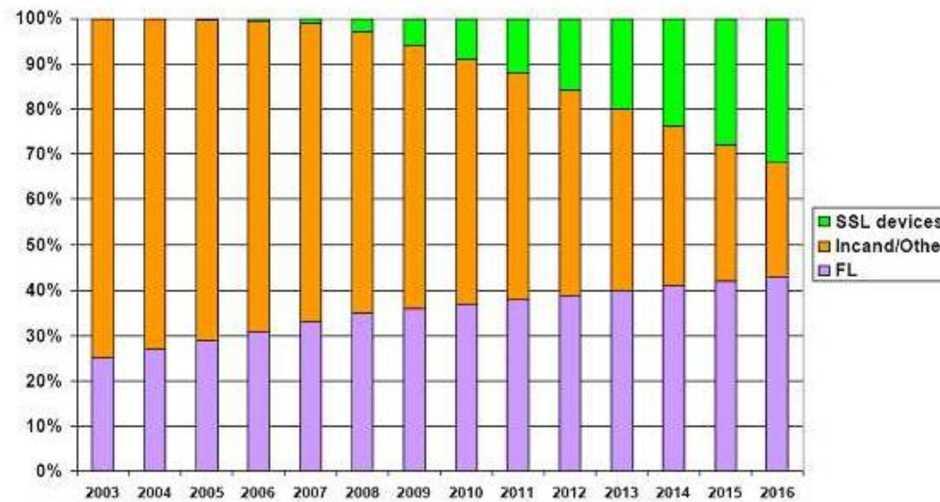
Reason 2: Visible light LED will be used everywhere.

Infrared light is already used for communication, such as wireless remote control , IrDA, Infrared wireless LAN, and infrared inter-building communication. However, visible light LEDs are beginning to be used in every home and office, which makes visible light LEDs ideal for **ubiquitous data transmitter**.



Data source: Nikkei Electronics

Prediction of LED lighting in the global market



Data source: OIDA

Prediction of market share of lighting types: SSL(Solid State Lighting or LED lighting), incandescent lamp, and fluorescent light

The growth rate of LED lighting is expected to triple from 2009 to 2012, and the market share of LED lighting will be more than 30 percent of total lighting market in 2016.

Reason 3: Image sensors can be used as receivers

The use of image sensors as receivers makes it possible detect not only incoming data, but also the accurate direction of the incoming vector from a transmitter to a receiver.

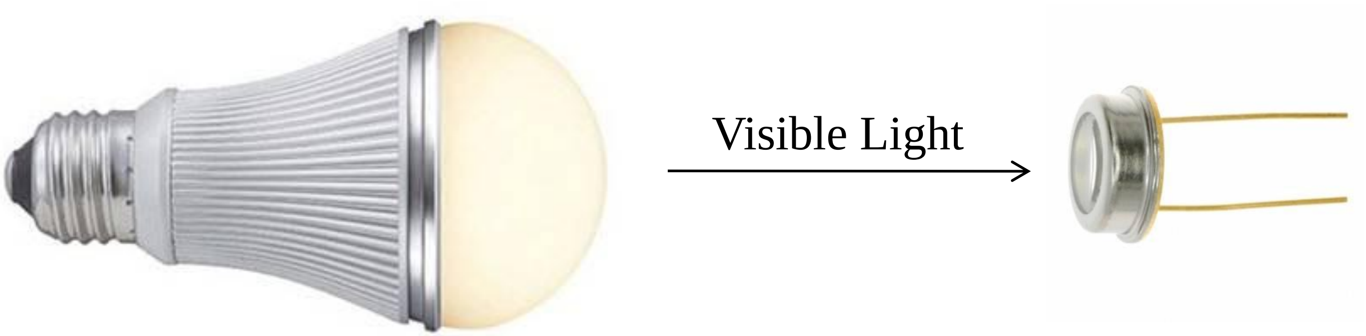
The image sensor technology will allow visible light communication to various new applications as shown below, which cannot be realized by radio wave technology:

- ◎ Indoor navigation
- ◎ Augmented reality
- ◎ Accurate control of robots or vehicles
- ◎ Accurate position measurement

2. Methods of visible light communication

2.1. Devices used for Visible Light Communication
2.2. Communication using Image Sensors

2.1. Devices used for Visible Light Communication



Transmitter device

Receiver device

Transmitter device of visible light communication

-Visible light LED

LED light intensity is modulated by controlling its current.
data rate: low speed to very high speed
(up to several hundred Mbps)

-Fluorescent lamp

FSK modulation of high frequency fluorescent light
data rate: up to several kilo bps

Receiver device of visible light communication

-PIN photo diode 

-high speed reception up to 1Gbps

-Avalanche photo diode 

-very sensitive reception

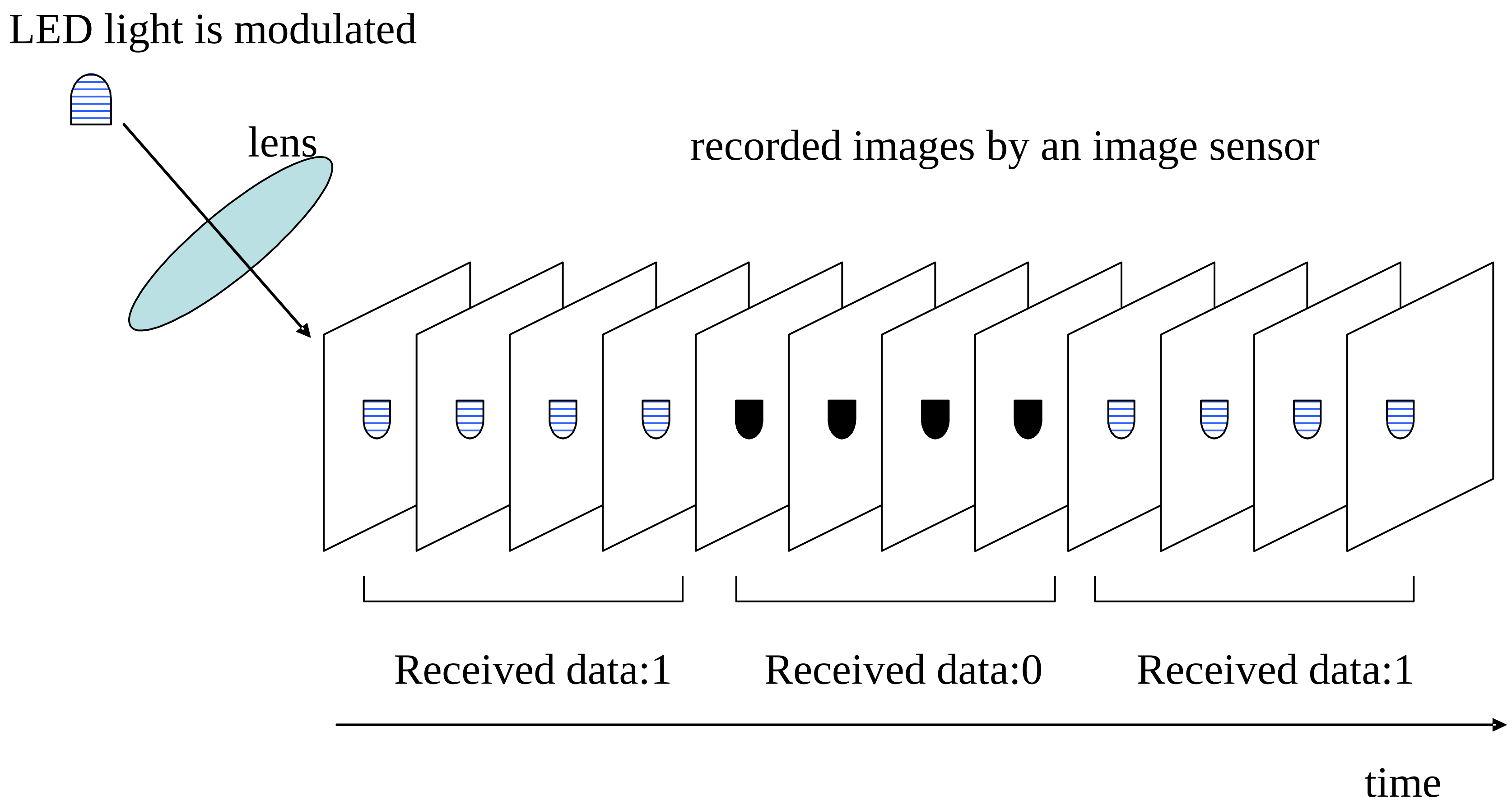
-Image sensor 

-simultaneous image acquisition and data reception

2.2. Communication using Image Sensors

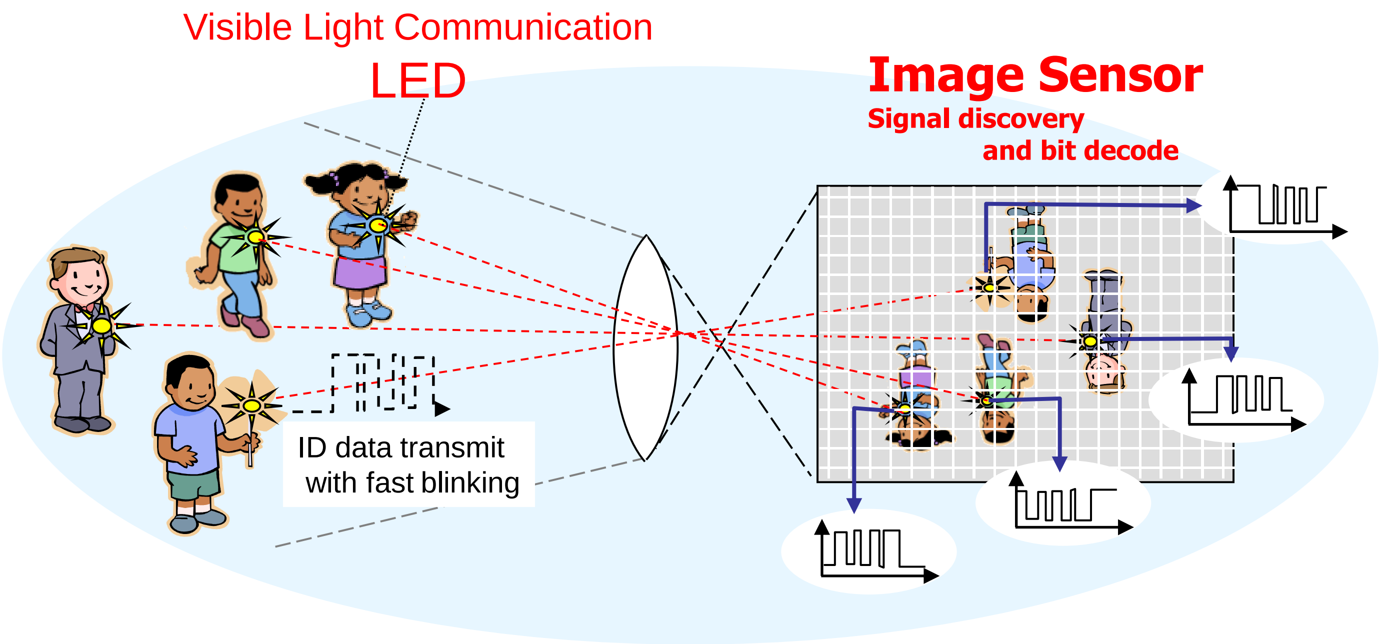
Data can be received with image sensors.

Principles of communication using image sensor



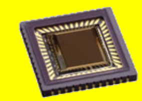
Camera (receiver) continuously takes images of a scene with an LED light and a receiver detects the optical intensity at a pixel where the LED light is focused on.

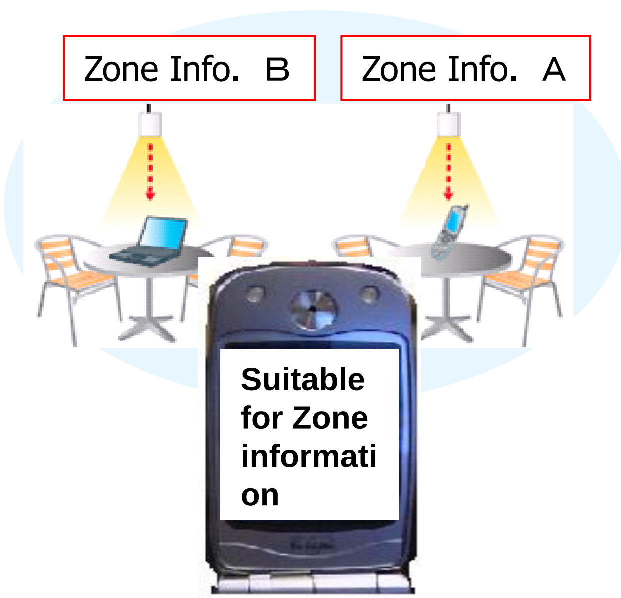
Principles of communication using image sensor (continued)

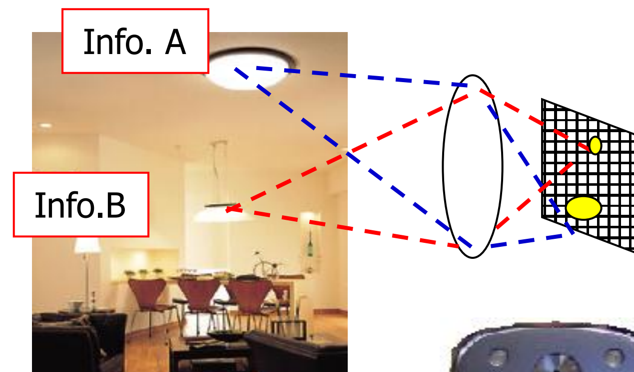


Even if multiple visible light sources send data simultaneously, an image sensor is able to receive and demodulate all the data simultaneously without any interference between them.

Merits of communication using image sensor

	Photo diode communications 	Image sensor communications 
Number of signal	△ Single	○ Multiple
Robustness	×	○ (no cross talk/ no Interference)
Distance	△ ~ 10m	○ Very Long（2km）
Space Resolution	△ Direction	○ Each pixel





Suitable for Object Information with position

3. Areas to which visible light communication technology may be applied

3. Areas to which visible light communication may be applied

3.1. Applications that do personal area communication

3.2. Applications that enable users to know users' locations in several meter accuracy

3.3. Applications that enable users to know users' locations in several millimeter accuracy

3.4. Applications that use augmented reality

3.5. Applications that cannot be achieved by radio-wave technology

3.1. Applications that do personal area communication

Download of needed information for digital signage applications

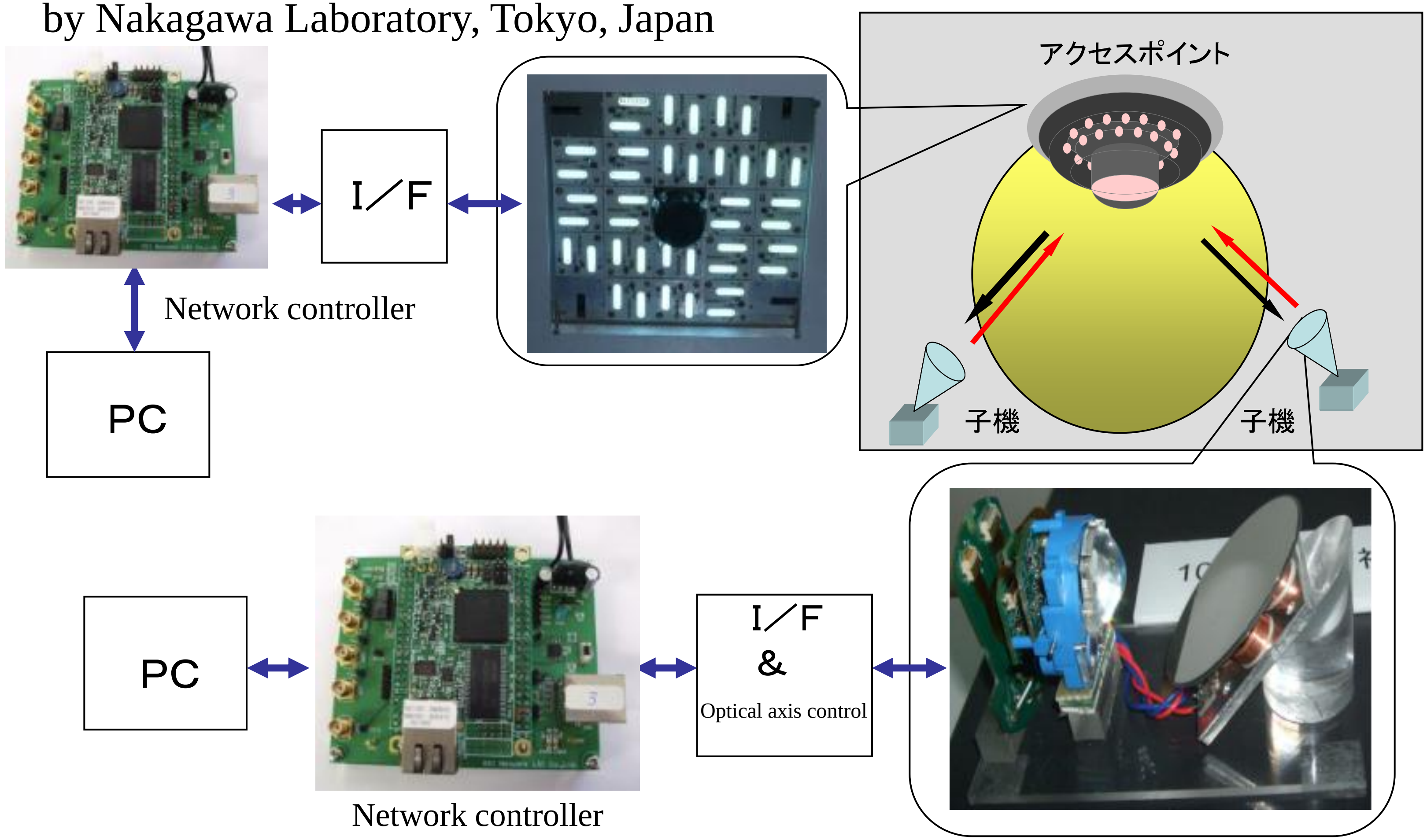
Prototype made by VLCC (Visible Light Communications Consortium) in Tokyo September 2009

User downloads information from a digital signage board whose backlight LEDs sends data

The Infrared Data Association (IrDA) (located in California, USA) and Visible Light Communications Consortium (VLCC) (located in Tokyo, Japan. Chairman: Prof. Haruyama of Keio University) has been working together since September, 2008 for a visible light communication using IrDA protocol stacks. [1]

100Mbps Full-duplex multi-access visible light communication system[2]

by Nakagawa Laboratory, Tokyo, Japan



Optical CSMA/CD (carrier sense multiple access with collision detection) method is used for accesses from multiple terminals. The communication distance is 3 meters. This technology was based on 100Mbps infrared LAN system whose standard was proposed by ICSA (Infrared Communication Systems Association) of ARIB (The Association of Radio Industries and Businesses), Japan.

High-Speed Parallel Wireless Visible Light Communications System Using 2D Image Sensor and LED Transmitter [6]

by Keio University and Sony Kihara Laboratory

Each of 64 (8 x 8) LEDs transmits different data, which are projected onto a different pixel of a high-speed image sensor. About 50 times increase of data rate was achieved. (Because of the overhead, 64 times increase was not possible.)

Communication using LED spotlight

“Hikari Guide System” by Shimizu Corporation, Japan

Spot lights sends data such as picture information in a museum as shown above and a receiver guides guests by voice sound.

Visible light information broadcast system

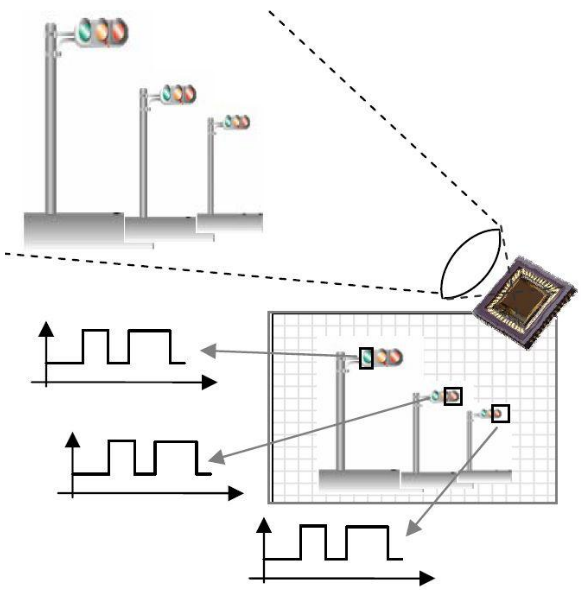
Prototype made by NEC and Matsushita Electric Works, members of VLCC

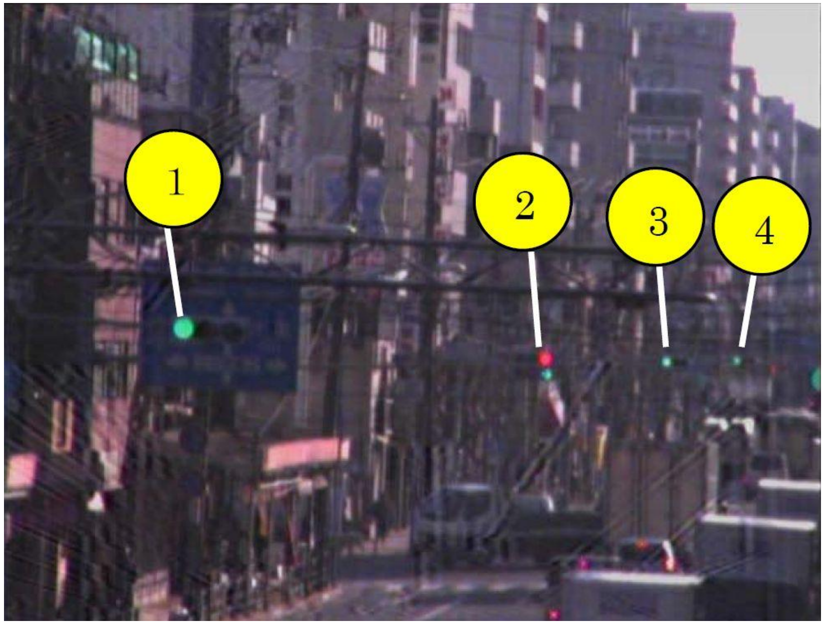
Information of products at a supermarket is obtained by a visible light receiver that is installed in a shopping cart.

Application of visible light communication to ITS (Intelligent Transport System)

System with LED traffic light transmitter and image sensor receiver [3]

by VLCC (Visible Light Communications Consortium, Japan) and
The Japan Traffic Management Technology Association





VLCC (Visible Light Communications Consortium), March 2010

Data from multiple LED traffic lights are received by an image sensor receiver.

Application of visible light communication to ITS (Intelligent Transport System)

Information broadcast system using LED traffic lights

The Nippon Signal Co., Ltd. and VLCC, at Japan Shop 2006

The transmission method is based on Japan JEITA CP-1222 standard.

Multiple transmission using multiple colors

Joint project of Keio University and JVC

"Sound Spot"

Different color lights send different data

Application of visible light communication to amusement

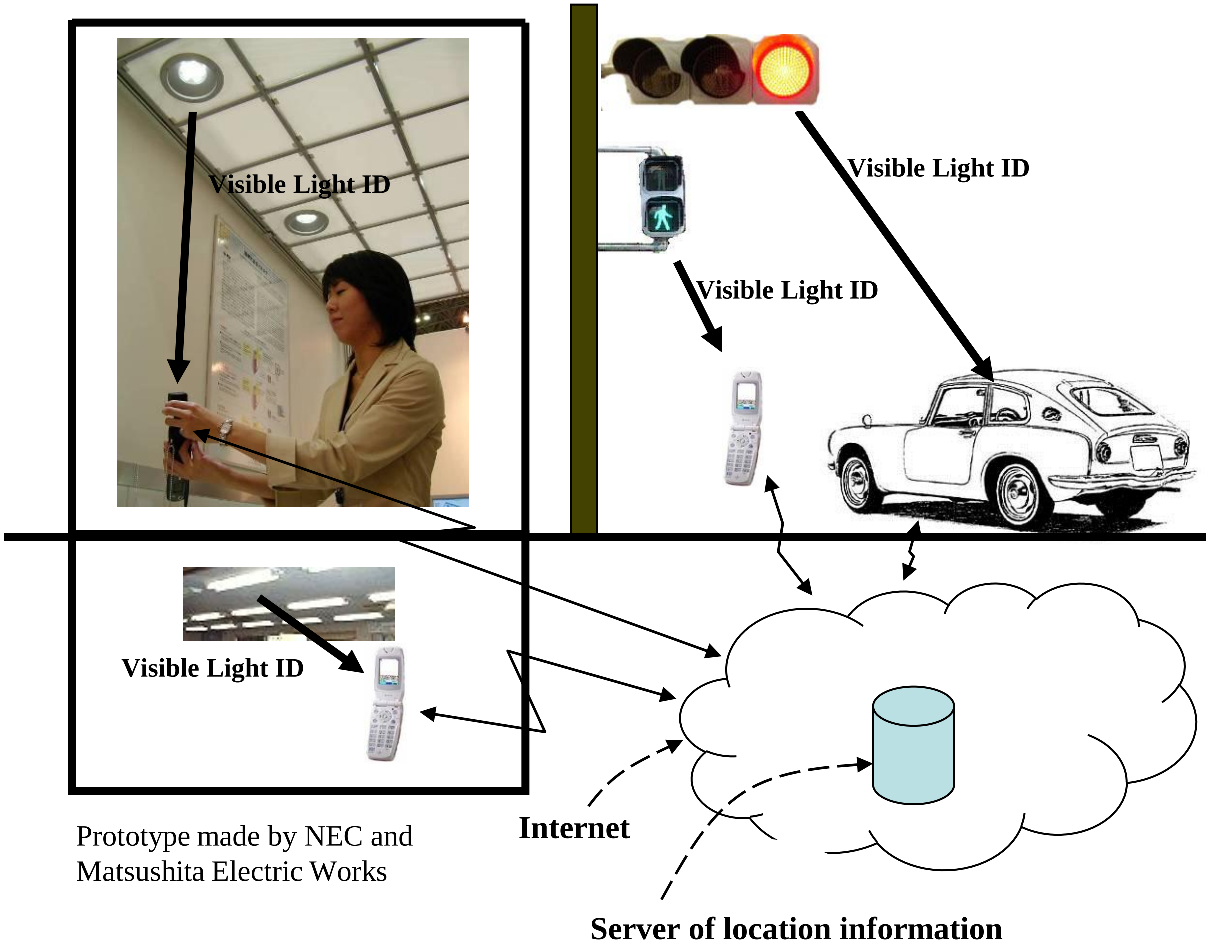
By Sony and Agilent at CEATEC 2004, Japan

SoundSpot

Demonstration of music broadcast system

3.2. Applications that enable users to know users' locations in several meter accuracy

Global location service that uses visible light ID system

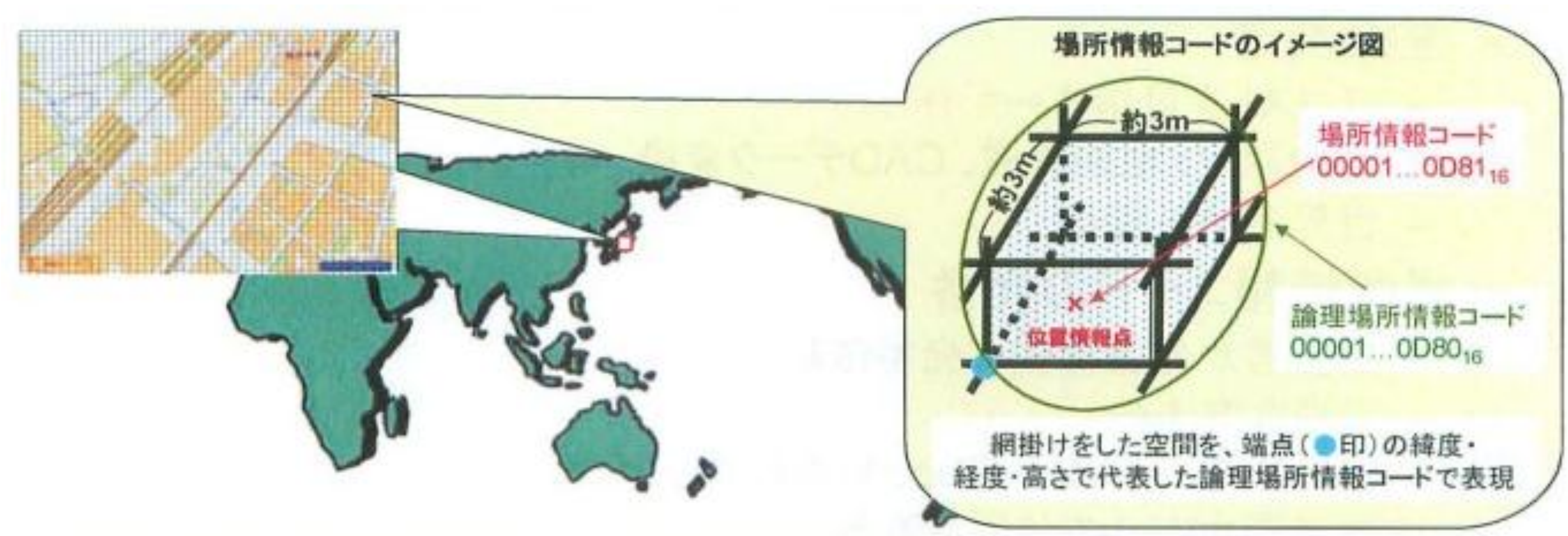


Prototype made by NEC and Matsushita Electric Works

It accesses the Internet by first obtaining code from a visible light source such as LED lights. It then accesses the location server from the cellular phone in order to obtain location-related information.

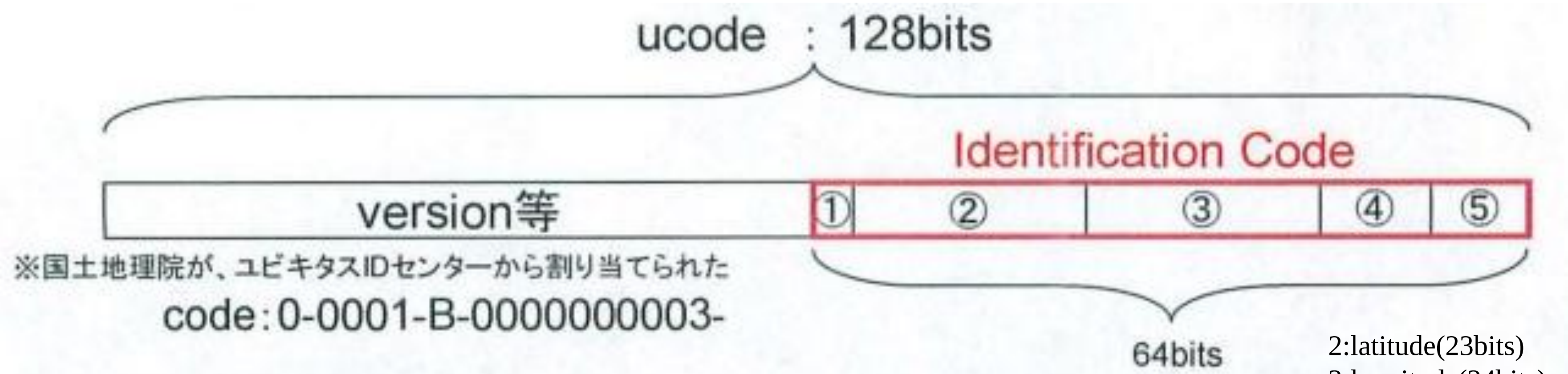
Standardization of format of location information

Geospatial Information Authority (GSI) of Japan’s Ministry of Land, Infrastructure, Transport and Tourism started the activity of standardization of format of location information in 2010. 17companies including Keio University has been doing research collaboration with GSI until 2012.



Standardization of format of location information

The idea is to assign a unique number for 3 meter by 3 meter square everywhere. If such a unique code is used for IC tag, ubiquitous location services will be possible. At outdoor locations, GPS and other GNSS satellites can be used to detect user's location. However, it is still very difficult to detect user's accurate position indoor. If this standardized format is widely used for IC tag, ubiquitous indoor navigations infrastructure will be made.



2:latitude(23bits)
3:longitude(24bits)
4:height(9bits)

Location code proposed by GSI

Keio University is working with GSI to use this format as GSI's code of sending location information from visible light source such as LED lighting.

Flow planning survey system for a store

Visible light ID from LED lights is received by a receiver attached at the bottom of a shopping cart. LED light transmitters are installed in each passage in a supermarket. Shoppers’ movement is analyzed based on the received ID history.

Nakagawa Laboratories, Inc.

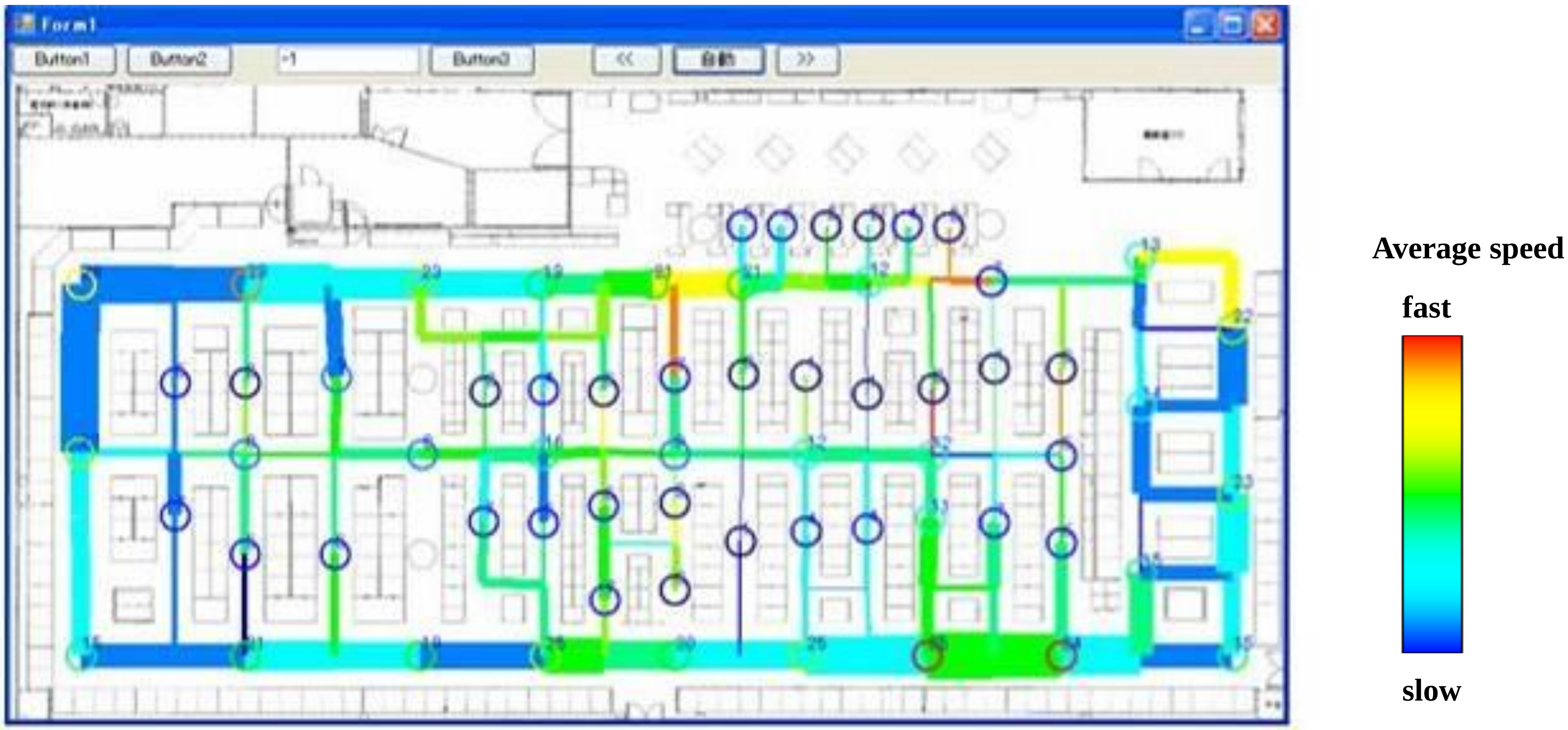
Visible light transmitter using LED light

Nakagawa Laboratories, Inc.

Visible light receiver attached at the bottom of a shopping cart

Flow planning survey system for a store (continued)

Example of flow planning of shoppers in a supermarket



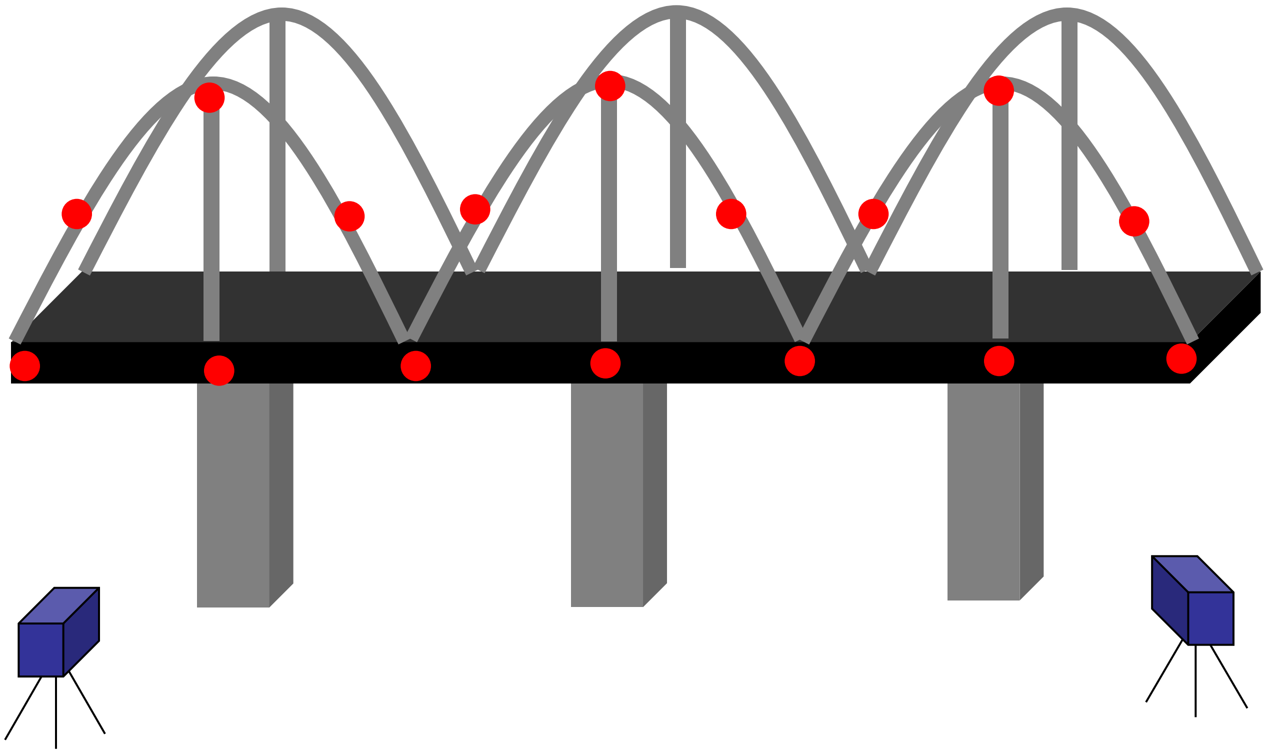
The thickness of lines indicate the traffic amount in each passage, and the color indicates how fast shoppers walked on the average.

This system is able to analyze how many shoppers passed in each passage and how fast they walked.

3.3. Applications that enable users to know users' locations in several millimeter accuracy

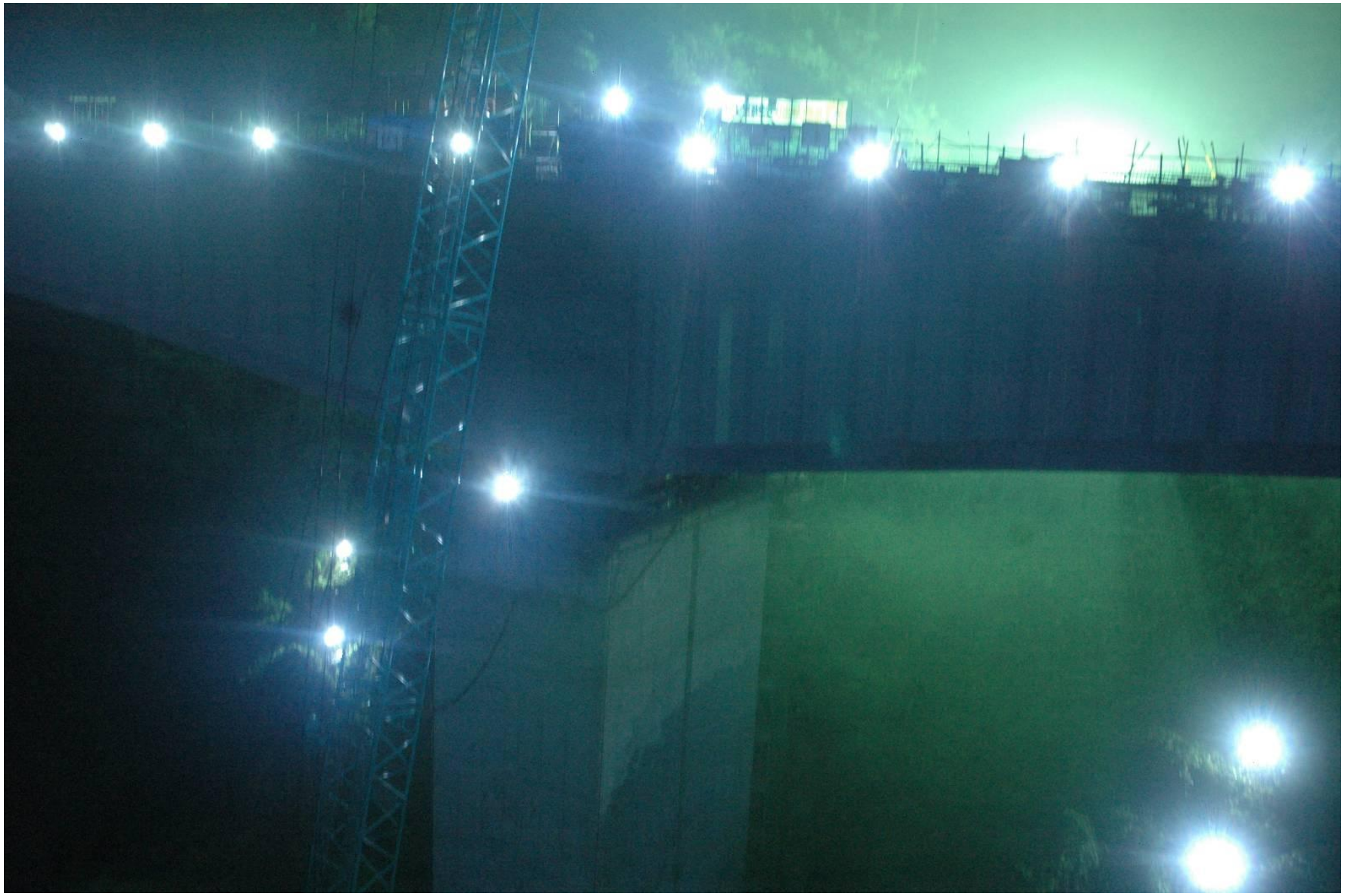
Three dimensional position measuring system using visible light communication [4]

by Keio University, Sumitomo Mitsui Construction Co., Ltd., and Nakagawa Laboratory, Japan



Objects can be measured by receiving and detecting the direction of visible light signal with an image sensor.
The error of position for a 100 meter object such as a bridge in the photo is about 5mm.

Example of three dimensional position measuring system using visible light communication



August, 2008

LED lights attached to a highway bridge under construction in Japan

When an object in located in the 40 meter by 40 meter area, this technology is able to measure three-dimensional position of the object in several millimeter accuracy.

Another example of three dimensional position measuring system using visible light communication

November, 2009

The technology is applied to measure the displacement which is caused by the increase of temperature of the aluminum dome roof due to the sunshine in the daytime. 12 LED lightings were attached to the roof. We were able to do automatic measurement of every 20 minutes for 24 hours and confirm the displacement of several millimeters.

Advantages of three dimensional position measuring system using visible light communication

- It can measure positions automatically
- It can measure temporal change of positions by continuous measurement.
- It can measure positions even at night.
- It can measure multiple positions at the same time.
- Its system is inexpensive than conventional survey equipments.

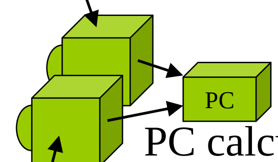
Accurate position detection of a transmitter or a receiver[5]

by Keio University

Control of a robot by detecting its accurate position using visible light and image sensor

Position data is transmitted from visible light LEDs

High resolution image sensor detects accurate direction of incoming light sources



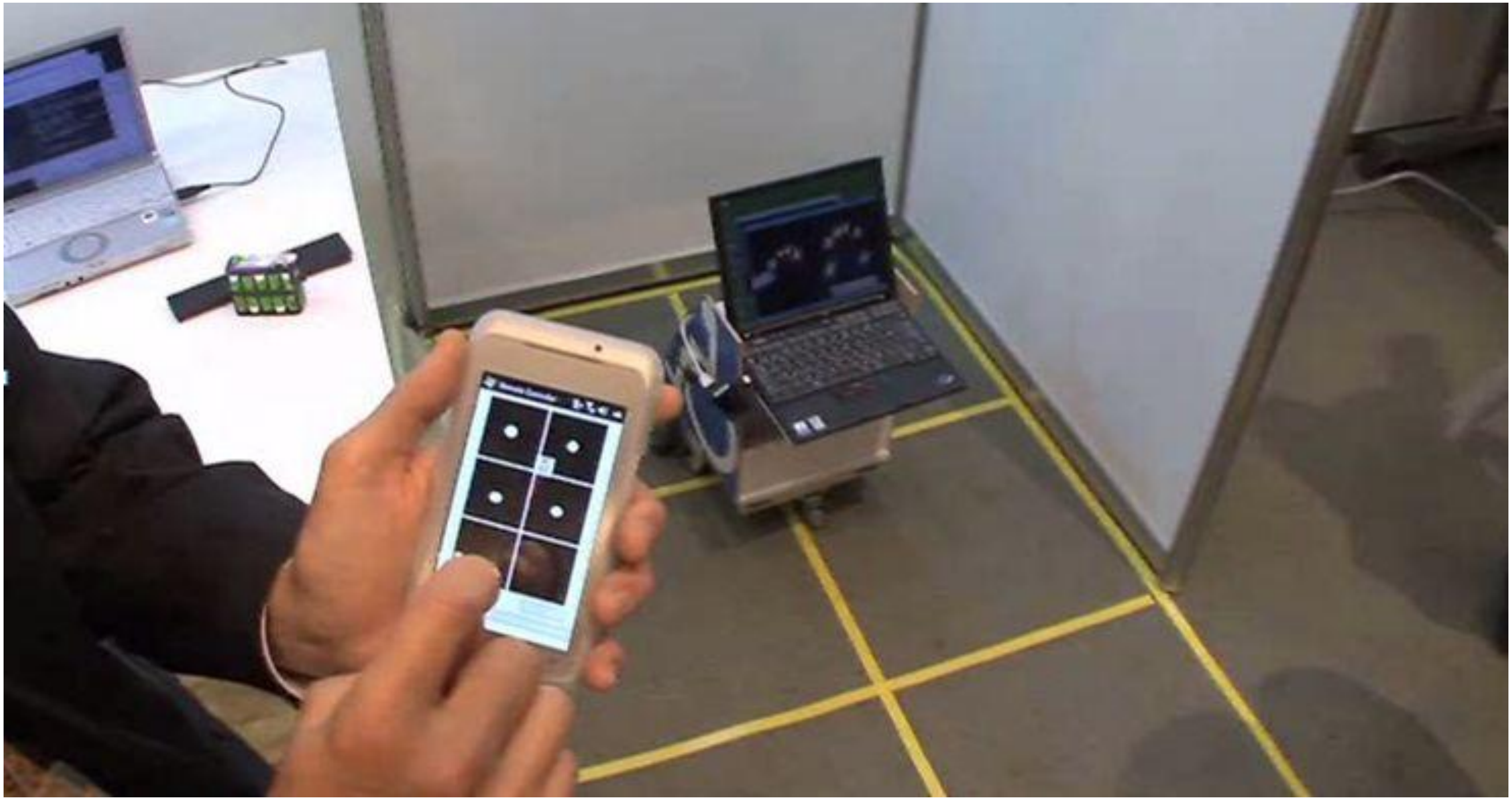
PC calculates three-dimensional position

High speed image sensor demodulates data sent from LED lightings

LED lighting with a transmitter

A robot with two image sensors calculates its three-dimensional position in real time.

Video of the accurate position detection of a transmitter or a receiver



LED lights send position data, and an image sensor of a robot receives the data as well as the image. The robot then does image processing to do phtogrammetry calculations to figure out its own position.

3.4. Applications that use augmented reality

Augmented Reality of real world image added with personal information

by Casio Computer Co., Ltd., Japan

Casio Computer Co., Ltd., September 2009

Data from LED badges are received by an image sensor which records images at the same time

Lighthouse visible light communication
by Visible Light Communications Consortium (VLCC)

Maritime Safety Agency Research Center of the Japan Coast Guard requested VLCC (Visible Light Communications Consortium) to do research about visible light communication using lighthouse or buoy lights in 2008, and VLCC member companies (Casio Computer Co., Ltd., NEC, and Toshiba) are doing experiments.

We succeeded in the experiment of 2km communication using an image sensor in September, 2008.

Lighthouse visible light communication (continued)

LED light in a photograph image

LED light for a buoy

LED light attached to a buoy

Received image and data

1300 kilo bits per second
2780 frames of pictures per second

Casio Computer Co., Ltd.

The purpose of this project is to develop a new technology that enables the visible light communication using visible light from lighthouses and buoys. An image sensor of a camera on a boat demodulates the incoming data from lighthouses and buoys and displays its content on a display monitor.

3.5. Applications that cannot be achieved by radio-wave technology

Underwater Visible Light Communication[7]

By Rise, Nakagawa Laboratories, Inc., Keio University, October 2010

Radio waves do not propagate for a long distance under water.
We were able to demonstrate that the flashlight visible light transmitter was able to transmit signals for 30 meter distance. A diver can communicate with a buddy diver using voice. LED flashlight's light is intensity-modulated. A photo diode is attached next to LEDs. Rise is planning to sell the product in 2011.

4. Conclusion

There are many applications that can be realized using visible light communication. Careful consideration will be needed to introduce it into a market.

References

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[2] Hirohashi, Ikawa, Lin, "High-Speed Full-Duplex Multiaccess System for LED-Based Wireless Communications Using Visible Light", International Symposium on Optical Engineering and Photonic Technology: OEPT 2009, July 2009, Orlando, Florida, USA

[3] http://www.tmt.or.jp/research/pdf/kashiko_21.pdf (in Japanese)

[4] Uchiyama, Yoshino, Saito, Nakagawa, Haruyama, Kakehashi, Nagamoto, "Photogrammetric system using visible light communication", IEEE 34th Annual Conference of Industrial Electronics (IECON), pp.1771 – 1776, November 2008, Orlando, Florida, USA

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[6] Masanori Ishida, Satoshi Miyauchi, Toshihiko Komine, Shinichiro Haruyama, Masao Nakagawa: "An Architecture for High-Speed Parallel Wireless Visible Light Communications System Using 2D Image Sensor and LED Transmitter" Proc. of International Symposium on Wireless Personal Multimedia Communications (WPMC'05) (CD-ROM). 1523-1527 (2005)
[7] Yousuke Ito, Shinichiro Haruyama, Masao Nakagawa, Rate-Adaptive Transmission on a Wavelength Dependent Channel for Underwater Wireless Communication using Visible Light LEDs, IEICE technical report, SIP, 105(636), 127-132, 2006-02-28