Fundamental Study for Optical BAN

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Abstract. For a new optical body area network (BAN) technique, a fundamental study was conducted of optical data transmission through a human body using diffusely scattered light. The frequency bandwidth for data transmission was restricted by the effect of strong scattering inside body tissues. In experiments using human bodies, the possibility of the transmission up to 100 MHz was confirmed. Using the linear equalization process, we can transmit an 800 MHz square wave signal. Data transmission of around 200 mm distance in a human hand was possible. To overcome problems of noise, multipath transmission, and the instantaneous interruption of data transmission, the space diversity (SD) technique was applied to stabilize data communications. The SD technique effectiveness was confirmed through analysis using real optical impulse responses. The feasibility of BAN using diffusely scattered light in the body was verified through these analyses.

Keywords: BAN, body area network, optical BAN, optical communication, data transmission, scattering, diffusion, space diversity.

1 Introduction

Recently, the usefulness of wearable computer has been widely recognized. Many reports describe the body area network (BAN) [1]. In most studies, the signal carrier for BAN is an electrical signal such as electric field, electric current, or electromagnetic wave [2]. Many attempts have been undertaken to use the electric BAN in medical practice [3]. However, related to the use of electrical signals for BAN, there have been restrictions of signal bandwidth, problems of electromagnetic interference, and difficulties controlling information leakage by electromagnetic radiation.

To overcome these problems, we propose the use of light as a signal carrier [4]. Few reports describe optical signal transmission through the human body for BAN. We can find few practical applications of optical BAN for medicine. When light enters our body, it is scattered diffusely. If we can use this scattered light for data transmission, then we can realize a new optical technique for BAN.

In this study, we analyzed characteristics of light transmission through body tissues and attempted a new detection technique to examine the feasibility of the optical BAN in practical applications.

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2 Optical BAN from Wrist to Fingertip

When we illuminate near-infrared (NIR) light on our body surface, some light propagates diffusely in the body tissue. When we illuminate the light on the wrist area for example, the light propagates widely in the hand area and part of it reaches the fingers. Therefore, we can make the BAN from/to a wristwatch type device to/from the fingertips. Figure 1 presents the optical BAN principle. For example, we can identify the individual with the wristwatch by just touching the door-knob with no action of the personal authentication such as fingerprint imaging or iris scanning. If another person wears the watch, then it cannot be operated by the authentication function built-in the watch. Many other applications are possible with this optical BAN from the wrist to the fingertips.

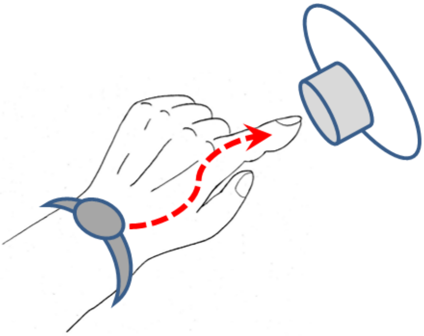

Fig. 1. Optical BAN principle

3 Data Transmission Rate

In the BAN using diffusely scattered light, the propagation path of light is spread in a wide area in the body tissue, which brings pulse broadening in the light propagation through the body. This pulse broadening restricts the data transmission rate.

To evaluate the transmission rate, the optical responses of a human arm and a human hand were measured. Short pulses of laser light (Ti:Sapphire, wavelength 786 nm, pulse width 20 ps FWHM, optical power 200 mW) were illuminated on one side of the body. The light transmitted through the body was received at the other side of the body with an optical fiber. The light was led to a streak camera (temporal resolution < 15 ps, repetition rate 2 MHz) and the broadened pulse shape was measured [5].

Table 1 shows results of pulse broadening. From this result, we can expect the signal transmission in the order of 100 MHz. With signal processing techniques such as the linear equalizing process, we were able to transmit an 800 MHz square wave signal in our experiment [5].

Table 1. Pulse broadening through living body tissue

	Thickness [mm]	Pulse width [ns FWHM]	Freq. band [MHz]
Palm	27	0.78	130
Arm	46	0.98	100

4 Data Transmission Range

Attenuation of an optical signal in our body is much higher than the electric signal, which makes the control of information leakage through unnecessary radiation easier than the electric signal. However, if the range is too small, then it is not practically useful. Consequently, the data transmission range was analyzed using a model phantom and a human body.

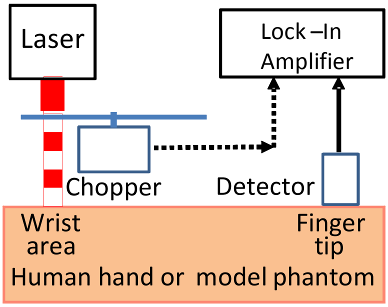

Fig. 2. Measurement of transmission range

Figure 2 depicts the experimental setup schematically. The light beam from the laser (Ti:Sapphire, wavelength 800 nm, optical power 1 W) was made intermittent with a mechanical chopper for the lock-in detection of received light. It was illuminated on the surface of a model phantom which simulated the human hand tissue. The agar phantom was produced with intralipid and black ink added to simulate the respective scattering and absorption coefficients of mammalian tissues: $\mu_s'=1.0$ /mm and $\mu_a=0.01$ /mm. The light propagated through the phantom was detected using a Si photodiode placed at a specific distance away from the light incident point. The intensity of the received light was measured using a lock-in-amplifier. The noise unsynchronized with the chopper was eliminated in the process of phase-sensitive detection.

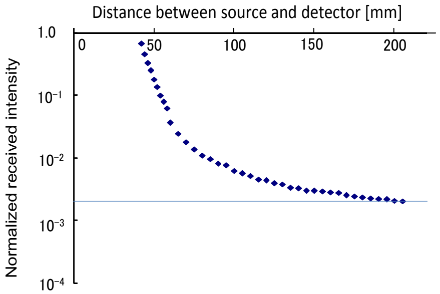

Fig. 3. Attenuation of optical signal with source-detector distance: horizontal line indicates a noise level

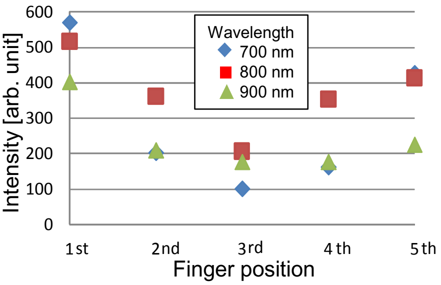

Fig. 4. Received optical signal intensity at different fingers and wavelengths

Figure 3 presents measurement results, which suggest that the transmission around 200 mm surface distance was possible. Using the same experimental setup, the transmission range was evaluated using a human hand. To reduce the optical power density on the body, the incident light beam (optical power 250 mW) was expanded to 40 mmϕ using an optical beam expander. The received light intensity at the tip of each finger was measured using different wavelengths in the NIR range. Figure 4 shows the result of measurements. Results show that optical data transmission from the wrist is possible to all fingers. Among the wavelengths examined, the highest performance was obtained with the 800 nm wavelength.

5 Application of Space Diversity Technique

In optical BAN, signal attenuation attributable to the strong scattering in the body is severe, and data transmission is vulnerable to optical and electrical noises. To address this problem, we introduced the space diversity (SD) technique. For this technique, we placed some detectors on the body surface at separate positions, and applied an operation to the outputs of some detectors. For the SD operation, the following three methods were used.

1) Selection method: Instantaneous signal intensities from all detectors are compared. Then the largest signal is selected.
2) Equal-gain combining method: Signal intensities from all detectors were summed with the same weights.
3) Maximum-ratio combining method: Signal intensities from all detectors were summed with the weight of each signal intensity.

To compare the performance of SD operation methods described above, noise of different kinds was added to the signal. Table 2 presents different noises, and Figures 5 and 6 show them. Figure 7 portrays the arrangement of the detectors. Five detectors were aligned along a line with 20 mm separation. The distance of the line from the light-incident point was 100 mm.

Table 2. Different type of noises

#	Distribution	Synchronism	Appearance
1-1	Uniform distribution (0-1)	Asynchronous	Fig. 5(a)
1-2			Fig. 5(b)
1-3			Fig. 5(c)
1-4		Synchronous	Fig. 5(c)
2-1	Normal distribution (m=0.5, σ^2=0.5)	Asynchronous	Fig. 6(a)
2-2			Fig. 6(b)
2-3			Fig. 6(c)
2-4		Synchronous	Fig. 6(c)

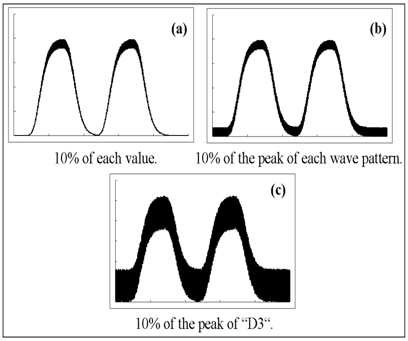

Fig. 5. Noise-added wave shape (uniform distribution noise)

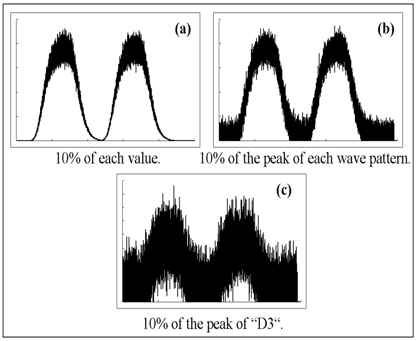

Fig. 6. Noise-added wave shape (normal distribution noise)

The impulse response of light propagation from the incident point to each detector was measured using a laser (Ti:Sapphire, wavelength 800 nm, pulse width 20 ps FWHM, optical power 1 W) and a streak camera. As a scattering medium, chicken breast meat was used. Figure 8 shows the measured pulse shapes at different detectors. These were regarded as impulse responses. The waveform received at each detector was calculated as the convolution of the impulse response and the input rectangular waveform. Figure 9 presents the signal waveform deformed by the scattering effect. Noises of different kinds shown in Table 2 were added to these deformed signals, and the three kinds of SD operations described above were applied.

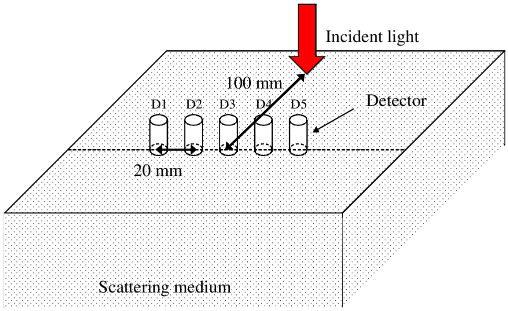

Fig. 7. Arrangement of photodetectors for space diversity techniques

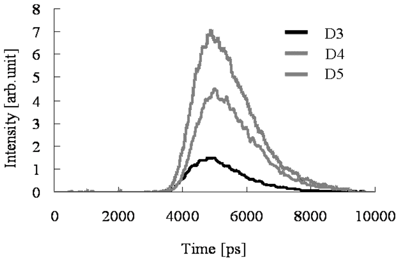

Fig. 8. Measured pulse shapes

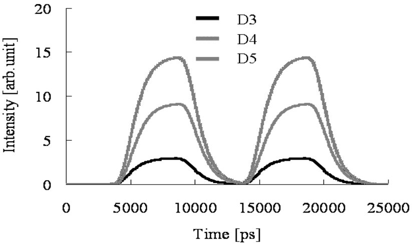

Fig. 9. Signal waveforms obtained from measured impulse response

Table 3. Comparison of signal-to-noise ratio for different synthesis methods of space diversity [rms dB]

#	Selection	Equal-gain combining	Max-ratio combining
1-1	24.8	24.9	**25.6**
1-2	**19.5**	16.5	18.7
1-3	20.8	20.9	**21.7**
1-4	**19.5**	15.5	17.8
2-1	21.3	23.5	**24.0**
2-2	17.3	19.6	**20.1**
2-3	16.0	15.2	**17.3**
2-4	**16.0**	11.9	14.2

Table 3 presents the signal-to-noise ratio of the resultant waveform after the SD operations. Bold figures denote the largest signal-to-noise ratio in the noise category.

As expected, the SD performance differed for different noise types. Results suggest that the maximum-ratio combining method had superior noise suppression ability to that of other methods.

6 Conclusions

An optical BAN technique was proposed using near-infrared light as a data transmission carrier. It offers different merits over conventional BANs with electrical carriers.

The frequency bandwidth for data transmission was evaluated in the experiment with a human arm and a human hand. The possibility of the transmission on the order of 100 MHz was confirmed. Using the linear equalizing process, we were able to transmit an 800 MHz square wave signal.

The transmission range through body tissue was analyzed in experiments. Data transmission around 200 mm surface distance was possible. The data transmission from the wrist area to each fingertip was confirmed. The feasibility of the optical BAN from the wristwatch-type device to the fingertips was verified.

To overcome problems in practical use, the space diversity (SD) technique was applied to stabilize data communication. The SD technique effectiveness was confirmed in the analysis using real optical impulse responses. For the SD technique, data-synthesis methods of different kinds were compared. Among them, the maximum-ratio combining technique was found to be the most appropriate for the SD method of this purpose. Results of these analyses verified the feasibility of optical communication through the human body using diffusely scattered light.

This study was conducted with the approval of the Ethics Committee of Graduate School of Engineering, Hokkaido University.

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