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Multiple bio-monitoring system using visible light for electromagnetic-wave free indoor healthcare

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ABSTRACT

In this paper, a multiple biomedical data transmission system with visible light communication (VLC) is proposed for an electromagnetic-wave-free indoor healthcare. VLC technology has emerged as an alternative solution to radio-frequency (RF) wireless systems, due to its various merits, e.g., ubiquity, power efficiency, no RF radiation, and security. With VLC, critical bio-medical signals, including electrocardiography (ECG), can be transmitted in places where RF radiation is restricted. This potential advantage of VLC could save more lives in emergency situations. A time hopping (TH) scheme is employed to transfer multiple medical-data streams in real time with a simple system design. Multiple data streams are transmitted using identical color LEDs and go into an optical detector. The received multiple data streams are demodulated and rearranged using a TH-based demodulator. The medical data is then monitored and managed to provide the necessary medical care for each patient.

1. Introduction

An indoor healthcare system is invaluable technology for patients with serious diseases, or for elderly people who spend most of their time in a hospital or at home [1,2]. An Internet-of-things (IoT)-based healthcare system provides useful and convenient services to both patients and medical experts, e.g., reduction of medical expenses, decrease in frequent hospital visits, early detection of critical conditions, remote patient monitoring, and stochastic medical decisions at any time [3,4].

Although radio-frequency (RF)-based technology provides usability, mobility, and flexibility, its frequent usage in healthcare and medical tests could have harmful effects on the patients' health. Considering that VLC (visible light communication) is harmless to the human body, it is a good alternative to RF wireless systems [5]. It can be employed for long-term transmission of significant vital signals (PPG, ECG, body temperature) even in RF-restricted areas. Here, PPG (photoplethysmography) is defined as volume changes in the blood and ECG (electrocardiography) means the electrical characteristics of the heart. Furthermore, VLC acts as a source of illumination and simultaneously provides wireless data connectivity with low cost, low power consumption, and security against undesired network accesses [6–8]. Therefore, it can be adopted for various smart applications, e.g., automobile collision prevention systems, indoor navigation, art gallery monitoring, and bio-medical data transmissions [9,10].

Recently, several VLC-based transmission systems have been studied to monitor vital signals [11–16]. In [11,12], an efficient indoor broadcasting, i.e., a hybrid PLC (power line communication) and VLC system was proposed for hospital applications [11,12]. With a high-priced optical receiver, a visible light channel is adopted to implement a remote health-monitoring system in [13]. A visible light uplink data transmission system was designed to observe a patient's vital signals; however, an offline process for system synchronization and evaluation was employed [14]. In [15], a WDM (wavelength division multiplexing)-based bio-medical signal transmission system was introduced to increase the data transmission rate. A multi-amplitude signaling-based medical-data transmission system with a simple system design was studied to improve the bandwidth efficiency in [16]. However, these VLC applications do not consider multiple-access transmissions.

To simultaneously transmit and manage various significant medical data with real-time monitoring, multiple-data transmission is required. In the RF communications area, a time-hopping (TH) method has been introduced to avoid signal overlap in a multiple-access system [17]. In a TH technique, a transmit pulse is placed on one of the TH slots in a symbol interval, where a symbol interval is separated by other TH slots, and the TH slot for transmission is randomly changed using pseudo-random codes. A TH-based transmission implementation is very simple

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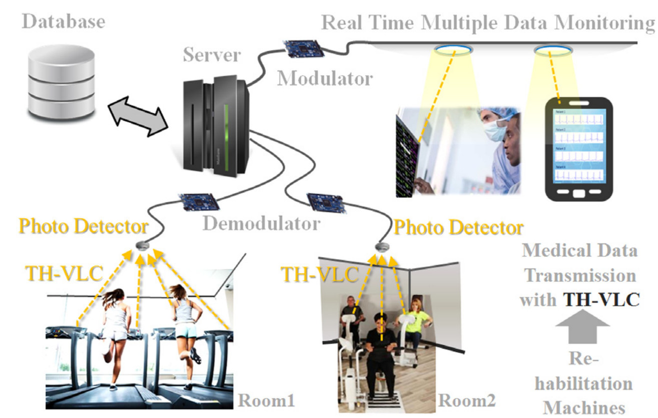

Fig. 1. TH-VLC system integrated into IoT-based rehabilitation facilities.

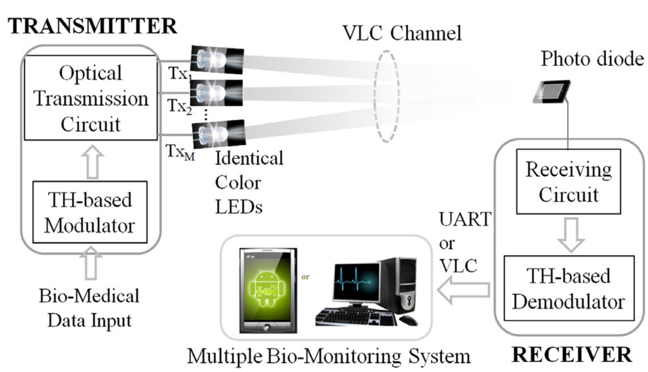

Fig. 2. TH-based VLC system architecture.

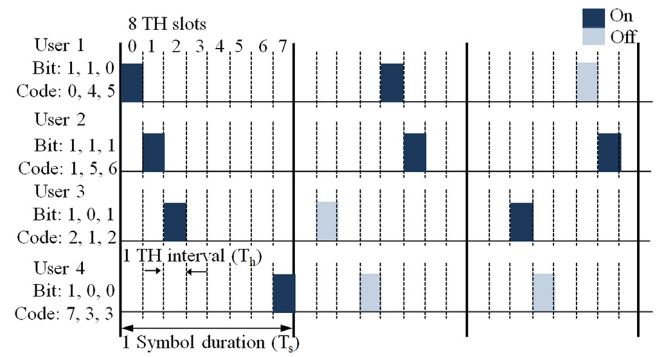

Fig. 3. Multiple-data transmission with TH technique (4 users, 8 TH slots).

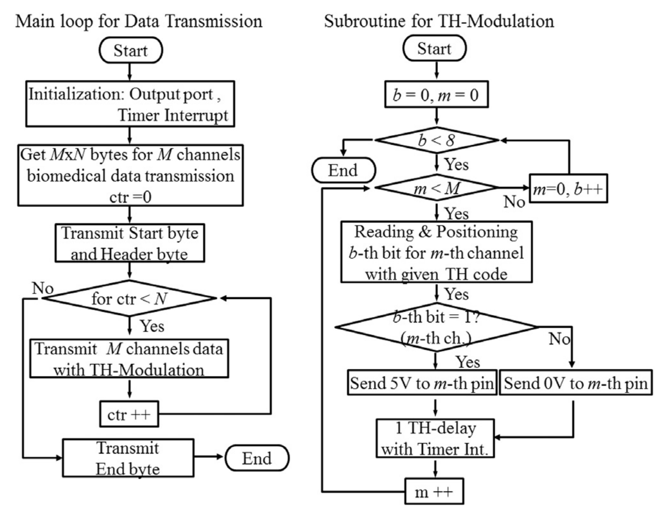

Fig. 4. Modulation algorithm for TH-based VLC.

as well as cost-effective. Here, the TH technique can be applied to optical communication for multiple medical-data transmission.

In this study, a multiple medical-data transmission technique using VLC for an electromagnetic-wave-free healthcare system is introduced. To prevent the health hazards that potentially come from RF radiation, adopting an electromagnetic-wave-free system, e.g., VLC, is important. We focus on implementing a simple and cost-effective multiple medical-data transmission system to provide high-resolution healthcare information with a low error rate in real time.

Fig. 1 illustrates the conceptual idea of an IoT-based VLC system in a rehabilitation training center. Bio-medical data or rehabilitation progress from each patient is transferred through the VLC medium with a specific TH code and is stored in the database server in real time. Then, a medical professional can keep track of each patient's condition and progress at any time through a user interface, e.g., a PC or mobile device. The proposed system is designed to be suitable for low cost, low speed sensor communication. Furthermore, a simple TH-based VLC system adopting identical color LEDs (light-emitting diodes) and a single photodiode has yet to exploited for multiple medical-data transmission.

This paper is organized as follows. Section 2 introduces TH-based multiple medical-data transmission. In Section 3, the multiple medical-data monitoring system is described and the characteristics of optical channel propagation are analyzed. The proposed system is evaluated in Section 4. Finally, conclusions are drawn.

2. TH-based multiple medical-data transmission

2.1. System model

The overall system architecture for transferring multiple medical data based on a TH scheme consists of three parts, as shown in Fig. 2: (i) Transmitter (TH-based modulator and optical transmission circuit), (ii) Receiver (Receiving circuit and TH-based demodulator), and (iii) Multiple bio-monitoring system. First, patient-generated medical data (ECG, PPG, temperature) are modulated by a given TH code and are transmitted by identical color LEDs. Here, we assume that each transmitter is synchronized perfectly. The TH-based data from the optical channel go through a photodiode and the optical signal is converted to a voltage signal at the receiver circuit. The reconditioned signal is then demodulated to a digital signal in the signal-processing module, and is observed at the monitoring system to determine appropriate care.

2.2. TH-based data transmission

To avoid pulse collisions in a multiple-access system, a TH scheme is employed [17]. In a TH-based data transmission, a bit of information is modulated by placing a pulse on a given time position during a symbol interval (T_s), where a symbol interval consists of various TH slots (T_h). The TH-based pulse example is illustrated with assumptions of four users and eight TH slots in Fig. 3.

In this study, the TH-based transmission is implemented by microcontroller-level programming; the transmission algorithm is shown in Fig. 4. Here, one packet of data consists of a start byte, a header byte, data bytes, and an end byte. First, 0xFF and 0x80 (start byte and header byte) are sent as sync. bytes. Then, data bytes with a length of $M \times N$ (M: number of channels for multiple medical data, N: number of data for one channel) are modulated with the given TH code and sent.