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Real Time Biomedical Signal Transmission of Mixed ECG Signal and Patient Information using Visible Light Communication

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Abstract— **The utilization of radio-frequency (RF) communication technology in healthcare application, especially in the transmission of health-related data such as biomedical signal and patient information is often perturbed by electromagnetic interference (EMI). This will not only significantly reduce the accuracy and reliability of the data transmitted, but could also compromise the safety of the patients due to radio frequency (RF) radiation. In this paper, we propose a method which utilizes visible light communication technology as a platform for transmission and to provide real-time monitoring of heart rate and patient information. White LED beam is used as the illuminating source to simultaneously transmit biomedical signal as well as patient record. On-off Keying (OOK) modulation technique is used to modulate all the data onto the visible light beam. Both types of data will be transmitted using a single data packet. At the receiving end, a receiver circuit consisting of a high-speed PIN photodetector and a demodulation circuit is employed to demodulate the data from the visible light beam. The demodulated data is then serially transmitted to a personal computer where the biomedical signal, patient information and heart rate can be monitored in real-time.**

I. INTRODUCTION

The wide implementation of the radio frequency (RF) wireless technology in healthcare centers like hospital and nursing home has often been associated with the mobility, feasibility and high speed features of this technology to provide real-time information such as biomedical signal and patient information. However, prolong usage of the radio frequency (RF) wireless technology in the medical field has been in debate due to the emission of RF radiation that would deteriorate the health of the patients [1]. Furthermore, the intrusion of electromagnetic interference (EMI) will jeopardize the quality of medical monitoring as the accuracy and efficiency of the transmission of data is crucial for the medical staff to provide corresponding measures or treatment based on the real-time information received [2]. The disadvantages of RF wireless technology are further emphasized through the banning of RF devices such as mobile phone in the emergency room and intensive care unit (ICU) [2], [3].

Rapid progression in the light emitting diode (LED) industry has prompted continuous studies on this technology to replace the conventional RF wireless technology by transmitting digital signals via an optical channel through a method known as visible light communication (VLC). It can be used for illumination as well as transmission of data. The widespread development and deployment of LED is mainly due to the advantages it poses over traditional incandescent by having long life expectancy, generating minimal amount of heat and being energy efficient [4]. Moreover, the fast switching capability of the LED makes it a suitable candidate for high-speed wireless links [5]. The non-susceptibility of VLC towards EMI makes it immune to interference while being used in the healthcare application as a medium of transmission [5]. Also, the usage of VLC ensures the safety of the patients by not generating RF radiation.

VLC is a form of optical wireless technology that offers a large amount of unregulated and unlicensed bandwidth [6]. This allows a substantial amount of data to be transmitted over a single channel at a time. A comprehensive real-time health monitoring system can be developed by simultaneously transmitting information such as biomedical signal and patient record using a single data packet. The data packet must be carefully designed to prevent any complication in the interpretation of the data at the receiving end. Furthermore, the length of the data must be reasonable to provide a high sampling rate especially for the acquisition of the biomedical signal. The signal received can then be processed to acquire information like heart rate which may be crucial for physician in providing diagnosis.

In this paper, we propose a system using VLC as a transmission medium to concurrently transmit electrocardiography (ECG) signal and patient information in accordance with the Health Level Seven (HL7) standard protocol. An algorithm is applied to reduce the size of the data packet automatically to transmit the ECG signal only if there is no patient information to be transmitted. Certain information is then extracted from the ECG signal to evaluate heart rate. A program is designed and developed to display the information on the personal computer (PC) to provide real-time monitoring.

II. SYSTEM DESCRIPTION

Fig. 1 shows the overall system architecture of the VLC system. The proposed system consists of three parts: A transmitter module that acts to modulate the data on a visible

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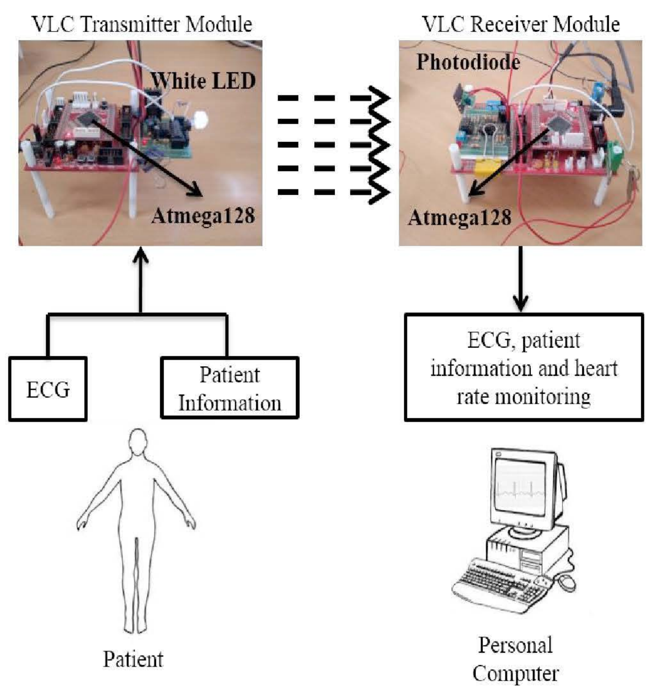


Figure 1. VCL system architecture.

light beam for transmission, a receiver module that functions to demodulate the received signal, and processing which interprets the incoming data packet and converts them into useful information such as ECG signal and patient information to be displayed on the PC. This includes the evaluation of heart rate through the ECG signal.

A. Transmitter

On-off keying (OOK) non-return-to-zero (NRZ) modulation technique is employed to modulate the data onto the visible light beam. OOK is the simplest modulation scheme and is a form of amplitude-shift keying (ASK). It represents the presence of digital data with a binary one and the absence of digital data with a binary zero through the presence or absence of the carrier wave respectively. The advantage of using NRZ format over other formats like return-to-zero (RZ) or short pulse is that the usage of bandwidth by the signal is half of that used by the other formats. The simplicity of the OOK modulation methodology reduces the power consumption as compared to other modulation technique like phase shift keying (PSK) such as binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK).

A LM555 timer is used to produce the carrier wave at 100 kHz. The high frequency is required to prevent the white LED from flickering and appears to be in constant illumination. The microcontroller Atmega128 acts as the interface between the data to be transmitted and the transmitter module. The ECG signal as well as the patient information that are to be transmitted is modulated using a NAND gate. An optical driver consisting of a transistor is built to control the current flow through the LED and to prevent current overflow which would burn out the LED.

B. Receiver

A surface-mount silicon PIN photodiode S5107 from Hamamatsu with a wavelength detection range of 350 – 1100nm is used. The wide range of detectable wavelength is chosen to allow visible light with different wavelength to be detected. The received signal is first converted into electrical signal. However, signal conditioning has to be applied before any further processing due to the attenuation and noise corruption during transmission. The signal is first passed through an amplifying circuit to boost up the intensity of the signal. Then, it is fed into an envelope detector circuit to demodulate the data from the carrier signal. A low pass filter is then used to eliminate any remaining high frequency noise. At the final stage, a voltage comparator is used to convert the data signal into a digital format. The received data packet is decoded using Atmega128 before being serially transmitted to the personal computer for further processing.

C. Data packet

The design of the data packet has to be done according to the standard framework to ensure the accuracy of the data received and also to prevent any data loss. In order to maintain a high sampling rate for the ECG signal, four bytes of data representing two data points of the ECG signal is transmitted in a single data packet. Patient information contains the American Standard Code for Information Interchange (ASCII) characters and each character can be represented with two bytes. The function of the sync byte is to notify the system that there is an incoming data packet while the header byte represents the starting of the data packet. A byte is allocated at the end of frame to signify that the data packet ends there.

A large data packet containing both the ECG signal and patient information could lead to a higher probability of data loss. This can be observed through the packet loss during transmission. Packet loss is a function of packet error rate (PER) which can be measured using (1). An algorithm as shown in Fig. 2 is used to check for the presence of any text data to be transmitted before the construction of the data packet. In a situation where the patient information has been transmitted and there are no characters to be sent, the packet size can be reduced to contain just the ECG signal. The dynamic design of the data packet allows the system to transmit only what is necessary. Fig. 3(a) and Fig. 3(b) show the structure of the data packet with and without patient information respectively.

$$\text{PER} = \frac{\text{Number of incorrectly received data packets}}{\text{Number of transmitted data packets}} \quad (1)$$

D. Heart rate

ECG represents the electrical signal in our heart and is defined as one of the major vital signal to be monitored in the healthcare industry due to the wealth of information that can be derived from it. One of the important features that can be useful for the evaluation of heart rate is the consecutive R to R peak (RR) interval of the ECG signal as shown in Fig. 4 [7]. It is proven that this characteristic can be used in the calculation of heart rate. The distance is measured in seconds

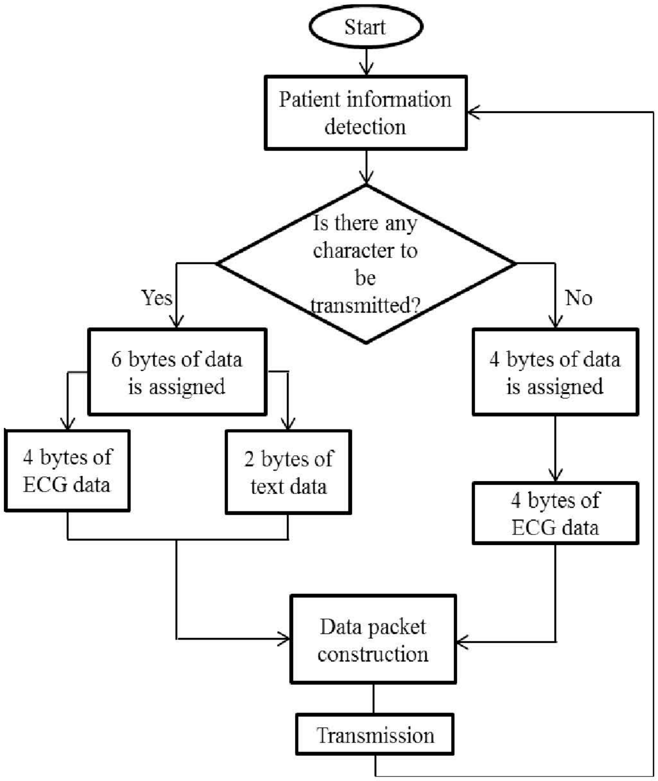
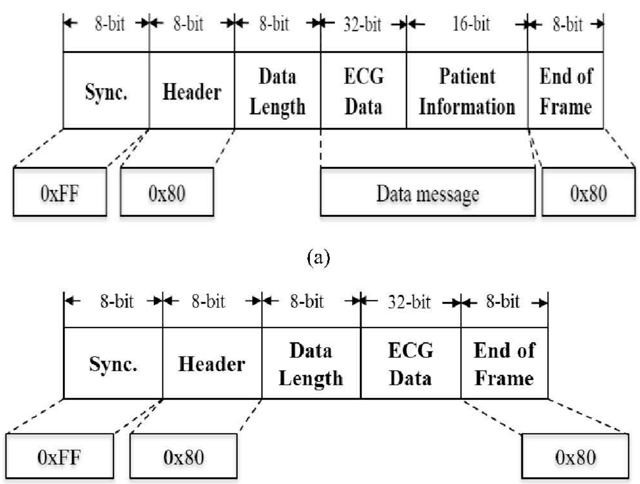


Figure 2. Data packet design algorithm.



(a)

(b)

Figure 3. Data packet (a) with patient information and (b) without patient information.

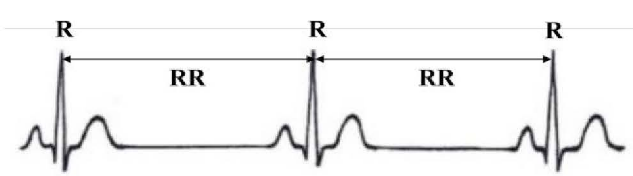


Figure 4. RR interval extracted from the ECG signal for heart rate evaluation.

and the heart rate can be computed using (2).

$$\text{Heart rate (beats per minute)} = \frac{60}{\text{RR interval (s)}} \quad (2)$$

E. HL7

HL7 is a protocol defined for the exchange of information between medical applications. It is accredited by the American National Standards Institute (ANSI). An HL7 message contains multiple segments, with each segment representing one specific category of information. Information that is included in an HL7 message depends on the message type, which is indicated on the first line under the MSH segment. Any health-related information such as patient visit data, patient diagnosis, and patient admission and discharge can be represented by an HL7 message. Hence, the transmission of the patient information in accordance with the HL7 protocol is crucial to provide the medical staff with the information used for diagnosis and management purposes.

III. EXPERIMENTAL RESULTS

To test the feasibility of the VLC system in transmitting ECG signal and patient information, a real-time transmission environment is emulated using ECG data from the PhysioNet database [8]. The patient information used in this experiment is in accordance with the HL7 protocol. A transmitter module and a receiver module is designed and fabricated as a printed circuit board (PCB). Line-of-sight (LOS) configuration is used in an indoor environment with all external lighting turned on. The experiment is conducted with a 50cm distance between the transmitter and the receiver. The data transfer rate is fixed at 3.3 kbps and it can be increased by reducing the delay between the transmission of each bit of data.

Initially, the ECG signal and the patient information are being passed into the microcontroller. Each time before the size of the data packet is determined, presence of any characters from the patient information is being checked. This is to ensure that the size of the data packet will only be increased to include characters from the patient information if there are any to be transmitted. Then, the data packet will be sent for modulation and transmission. At the receiver end, the signal received undergoes a series of conditioning and filtering before being fed into the microcontroller for further processing. The microcontroller will be on standby for any incoming packet by looking for the sync byte. Once a packet has been detected, the data contained within the data packet will be serially transmitted to the PC.

The received data in the PC is in hexadecimal format where the first four bytes represent the ECG data points and another two bytes represent an ASCII character from the patient information. Conversion has to be done to change the hexadecimal characters to their corresponding values. The sampling rate of the ECG signal is 70 samples/second. Successive RR interval for the ECG signal is always being tracked and recorded to calculate the heart rate in real-time. The full monitoring program is shown in Fig. 5.

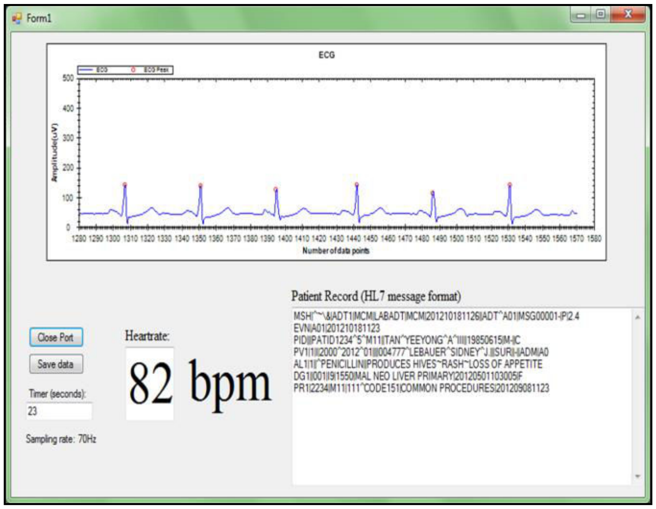


Figure 5. Screen snapshot of the real-time monitoring program.

The PER for the two different data packet sizes are determined by transmitting 1000 data packets each using the same experimental setup. Incorrect data packets or loss of the data packets at the receiving end is documented. The PER for the data packet with patient information and without patient information are 0.029 and 0.013 respectively. This shows that a larger data packet size attributes to more packet loss at the receiving end.

IV. Conclusion

A comprehensive real-time health monitoring system using commercially available white LED and VLC is successfully developed to simultaneously transmit clinical healthcare text information along with physiological signal. Furthermore, heart rate can be computed and monitored in real-time using the information transmitted. In future application, the communication distance can be increased by using collimating lens to focus the light over a distance. A higher power LED such as a 3W LED array can also be used to increase the distance of the communication.

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