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# Optical Wireless Transmission of ECG during effort

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**Abstract.** In the context of contactless diagnostics of human bio-parameters, wireless transmission are generally based on radio-frequency technologies. This can be a problem regarding interferences with other equipments or with interactions for human body as for example people wearing pacemakers. We present in this paper the realization of a portable device able to perform distant ECG (electrocardiogram) monitoring during physical activities based on optical wireless communications. Our system is designed using on-the-shelf components and imposes constraints on sampling frequency. Therefore, even if the sampling frequency in the proposed system is not sufficient for medical diagnosis, our study shows the potentiality of using optical wireless for transmission and distant analysis of ECG data. We illustrate the performance by experimentally evaluating packet error rate of the optical wireless transmission of ECG data and we show that the heart rate is correctly evaluated when the person is moving inside a room.

**Keywords:** Optical wireless communication, wireless ECG transmission, packet error rate.

## 1 Introduction

Nowadays, there is a rapid development of medical technology. One of the most developing branches is contactless diagnostics of human bio parameters. With the help of technology, we can track many of the characteristics of a human condition, for example - the bio potentials of the heart, temperature, heart rate and physical activity. Electrocardiography is one of the oldest and most common methods of studying the heart. Performing the electrocardiogram requires specific equipment. In hospitals, ECG is generally still interpreted using a recorder, which has several drawbacks: it is difficult to conduct a comparative analysis of the electrocardiogram at different periods, it is necessary to use special chart paper, there is no automated diagnosis and storage of patient data. Existing devices able to record ECG data are generally based on wired solutions and based on several leads using more than 3 electrodes for medical diagnosis. This type of device is not adapted to be used during daily life activity with body motion. Therefore, there is a need to develop inexpensive and accurate portable electrocardiograph.

In this context, in order to enhance comfort of use and reduce disturbance due to cables, the development of wireless devices for monitoring and recording human physical activity is relevant, not only to be able to record history of the data numerically but also to represent and analyze data during efforts. In order to wirelessly transmit ECG data, several challenges have to be taken into account: frequency sampling (so transmission rate) sufficiently high in order to ensure a good ECG quality [1-2] and miniaturization of circuits for emission and reception in order to integrate them near from the electrodes. Typically, a sampling frequency of minimal 250Hz is required for medical purpose since most of the diagnostic information is contained below 100 Hz for adults [1]. For heart rate evaluation, the sampling frequency can be much lower since the fundamental frequency for the QRS complex is around 10 Hz [1].

Several works have been done on wireless monitoring of ECG based on radio frequency (RF) technologies [2-5]. RF communications (Bluetooth, zigbee, wifi, ...) reliability is not always ensured especially due to interference with other technologies using same band frequencies. In addition, radio wave impact on health is controversial but unknown, so it is interesting to investigate alternative solutions such as optical wireless communications (OWC). Provided that the constraints about eye safety are satisfied, OWC are safe and not subjected to RF interference.

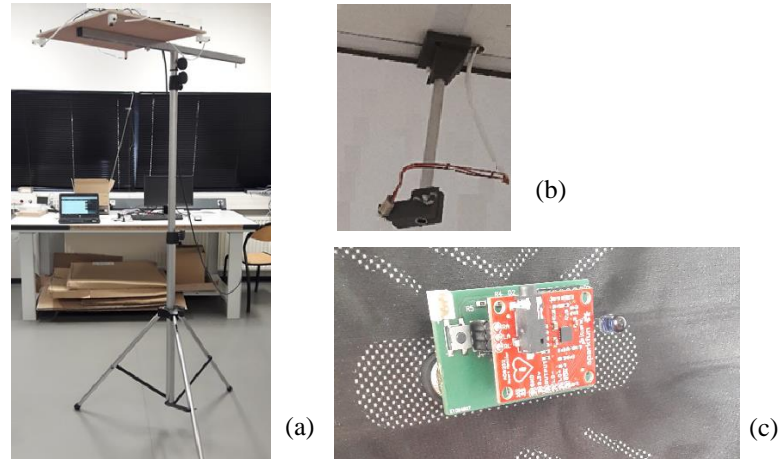
Published works about optical wireless ECG devices are all dealing with visible light communication (VLC) [6-8]. One limitation is potential discomfort when visible signal is emitted from sensors worn by a user. VLC is more suitable for downlinks when illumination and communication are coupled. In addition, the constraints on size and portability are not treated in these studies.

In this work, we propose a portable device able to do distant ECG monitoring during physical activities based on optical wireless communications in infrared (IR) range. We present in part 2 the optical wireless ECG monitoring system, then in part 3 the results and performance before concluding in the last part.

## 2 Optical wireless ECG monitoring system

### 2.1 Hardware realization

In order to transmit ECG data, the practical transmission system is designed with off-the-shelf components. The goal is to be able to transmit data while the person is making exercise inside a room, so with mobility. For this, we propose a configuration with spatial diversity including several optical receivers placed in the ceiling. They are at the corners of a central panel, which can be a lighting device as shown in Figure 1 (a). In addition, we have fixed the receivers orientations to  $45^\circ$  thanks to pieces shown in Figure 1 (b) in order to ensure good coverage area. For the emission, we have designed a system able to be worn on electrodes integrated in a shirt, with the emitting diode oriented perpendicularly to the body (see Figure 1 (c)). As we can see in this picture, the designed device has reduced dimensions in order to be worn upon a cardiac belt (space between electrodes is 5cm). Therefore, the ECG signal amplitude may differ from classical ECG monitor.



**Fig. 1.** Receivers and emitter designs: the receivers placed at the corner of a central panel (a), pieces for orientation of receivers (b), the emitter on the T-shirt (c)

The system has been designed considering the particularities of the optical receivers, which are integrated photo-detection modules (TSOP 34338), composed of PIN photo-detector and preamplifier. They are able to detect data frames when the signal is modulated following a subcarrier of 38 kHz with a minimum of 6 cycles per burst. The receiver peak wavelength detection is around 940 nm, it has a Field Of View (FOV) of 45° and a typical minimal irradiance of 100 $\mu$ W/m<sup>2</sup> depending on the ambient noise level, which allows detecting very low power signal. The physical surface of PIN photodiode is 34.5mm<sup>2</sup>.

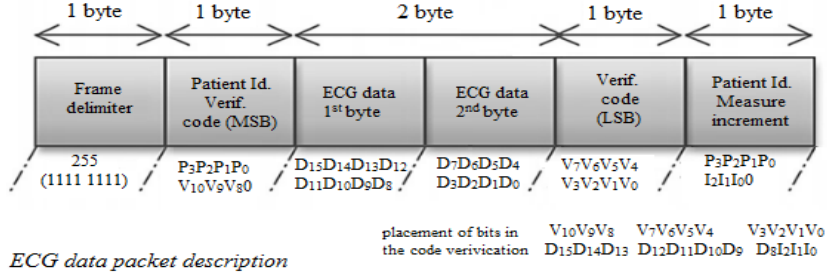
The output signal after the photo-detection module is directly connected to a FTDI module so that a computer can detect frames and evaluate packet error rate (PER) and save raw data. The serial transmission baud rate is chosen among normalized serial baud rates, and satisfying the fact that we must have at least 6 periods of the modulated signal at 38 kHz inside one useful digit. The raw data rate is consequently chosen at 4.8 kbps, which is the maximal one considering the 38 kHz sub-carrier.

With these considerations, the emitter is designed with a microcontroller generating two output signals; one is a PWM signal at 38 kHz, the other one the serial output at 4.8kbps containing useful data. The outputs are linked to an electronic circuit making logical operation and driving an infrared LED source (TSAL 6400) having a peak wavelength around 940 nm and half-power angle of 25°.

## 2.2 Optical wireless frame description

In order to be able to decode data at the receiver side and to count errors and lost packet, the frames have to follow a given format, with frame delimiters, packet numbering and redundant information. For this aim, we have developed a home-made protocol, defining a 6-byte frame as described in Figure 2. Each sampled raw data of ECG are over 2 bytes, but we add a frame delimiter byte, a patient identifier code over 4 bits,

a measure increment code from 0 to 7 (3 bits) for numbering the packets. Last transmitted data are a verification code calculated from raw data byte combination as well as redundant information of patient identifier. These two elements are used in order to detect erroneous data at reception side. We can notice that a more sophisticated protocol could be used if there was a constraint about data security or a multi-user context, but it is not treated in this study.



**Fig. 2.** Data packet description

In order to ensure a low average IR transmitted power satisfying eye safety and considering the maximal forward current of the LED, we have made the choice to transmit data only 1/3 of time. For this, we add a delay between two transmitted frame equal to twice the time of transmission of one packet (here equal to 12.5ms because of the baud rate of 4.8kbps). Therefore, this means that the packet is transmitted each 37.5ms. In addition, we have designed the electronic circuit to emit an instantaneous optical power of 51mW. Taking into account the emitting time ratio of 33.3 %, and the hypothesis of equiprobable data emission with the OOK modulation, the average IR transmitter power is around 4 mW.

### 3 Results and Performance

#### 3.1 Performance evaluation principle

The computer serially receives data, and a Python program decides from redundant information whether there is an error of transmission or if at least one of the receivers correctly received the packet. Number of errors can be counted thanks to the packet number compared to the previous correctly decode packet number, but if there are more than 8 consecutive errors, it is not possible to correctly evaluate it. For this aim the python program also take into account time of arrival of correctly decode packets. More precisely, it computes the time that has passed between the previous correct packet and the correct one just received and compare it with the normal transmission time given by the equation:

$$T_T = \frac{\text{Data (bits)}}{\text{Baudrate}} + T_{\text{delay}} \quad (1)$$

$T_{delay}$  is the delay after sending packet information (here twice the time of transmission, i.e. 25ms).  $Data$  corresponds to the number of bits per packet (here 60 bits because of the 6 bytes serially transmitted, where each bytes is composed of 8 data bits, 1 start bit and 1 stop bit) and  $Baudrate$  is the serial data rate (here equal to 4.8 kbps). So in this configuration  $T_T=37.5$  ms.

In this case, at each received packet number  $i$ , the following quantity is determined:

$$nb_{lost}^i = \frac{(T_{pr}^{(i)} - T_{pr}^{(i-1)} - T_T)}{T_T} \quad (2)$$

$T_{pr}^{(i)}$  is the time of arrival of correctly received packet and  $T_{pr}^{(i-1)}$  the time of arrival of the previous one. If  $nb_{lost}^i$  is not null, then it corresponds to the number of errors at this time of arrival. Finally, the PER for a transmission with  $n$  received packets and  $nb_{lost}$  packets is expressed as:

$$PER = \frac{nb_{lost}}{n + nb_{lost}} \quad (3)$$

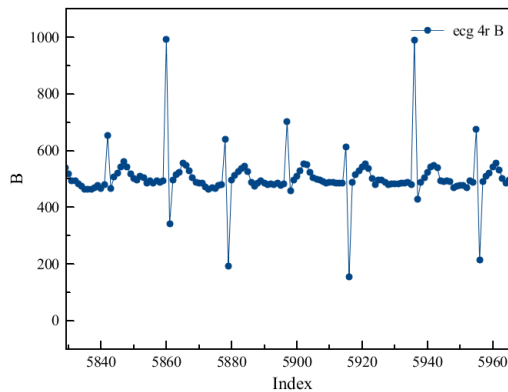
where  $nb_{lost} = \sum_{i=1}^n nb_{lost}^i$  is determined using (2).

The program computes this metric and prints this value and the number of errors at each received packet so that we can make experiments until a given number of errors is reached.

### 3.2 Results

The experiments consisted in walking in a room of size 6.6mx6.7m wearing the optical wireless ECG device, with optical receivers in the center of the room at the corners of a central panel at a height of 2.5m.

After 5 minutes, the PER converged to a value of 8.6%. This value is interesting because it is still possible to get a correct shaping of ECG as shown in Figure 3. However, with the baud rate of 4.8kbps, the sampling frequency is too small (26 Hz) to extract medical information from the ECG.



**Fig. 3.** Example of ECG from received data

Moreover, for heart rate determination, this sampling frequency is sufficient, and we verified that with a packet loss of 8.6%, the heart rate is well evaluated. This has been validated by simultaneously wearing a reference heart rate monitor, i.e. Polar V800 cardiac belt evaluating R-R period and a connected watch.

Finally, in order to increase the sampling frequency, we have investigated same scheme using another receiver (TSOP 7000), working with a subcarrier of 455 kHz instead of 38 kHz. In this case, it is possible to use baud rates from 4.8kbps to 38.4 kbps. Increasing the baud rate allows reducing the packet emission time. By keeping a delay equal to twice the packet emission time, the corresponding time between each packet  $T_T$  is determined in Table 1 in addition to the corresponding sampling frequency. We can note in this case that only the baud rate of 38.4 kbps permits reaching approximately the minimal sampling frequency of 250 Hz.

The photodiode included in the TSOP 7000 receiver is not centered in the same wavelength as the previous one, but the sensitivity at 940 nm is 0.8. In addition, one limitation of using this device is the minimal irradiance able to be detected, which is 10 times higher. Therefore, experiments have been conducted with mobility in a smaller area inside the room, with radius 1.8m from the center of the panel.

In order to transmit data with a subcarrier of 455kHz, the transmitting device has been adapted, especially the LED (SFH 4346), logical gate and mosfet having lower response time have been used. In addition, a higher speed microcontroller has been used in order to be able to generate a precise PWM clock at 455 kHz.

The PER obtained for the different baud rate are shown in Table 2. We can note that the PER is higher when the baud rate increase, which can be a problem for an accurate ECG since a PER lower than 1% is recommended [2]. However, regarding the heart rate, we have verified that its evaluation is not impacted; even with 30% of lost packets, we are able to recover the correct heart rate value for these sampling frequencies.

**Table 1.** Sampling frequency corresponding to different baud rates at 455 kHz

Baudrate	$T_T$ [ms]	sampling frequency [Hz]
9600	18.7	53,3
19200	9.37	106,7
38400	4.7	213,3

**Table 2.** Experimental PER obtained with 455 kHz carrier frequency

Baudrate	PER, [%]
9600	12,6
19200	29,5
38400	26,5



## 4 Conclusions

The work presented in this paper answers to a problematic of distant monitoring and proposes a portable device able to perform distant ECG monitoring during physical activities. The proposed device is based on optical wireless communications and is designed using on-the-shelf components. More particularly the optical receiver working with a carrier frequency imposes constraints on raw data rate. Therefore, the sampling frequency in the proposed system is not sufficient for medical diagnosis of ECG but permits evaluating heart rate. Actually, we experimentally evaluate transmission quality when a person wearing the realized device is moving inside a room. We determine packet error rate of the ECG optical wireless transmission and we show that the heart rate is correctly evaluated even if packet error rate increases with data rate. Finally, our study shows the potentiality of using optical wireless for transmission and distant analysis of ECG data provided the development of specific component platforms.

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