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A Joint PQRST Detection and Data Compression Scheme for Wearable Sensors

(LI-FI Technology)

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Abstract: This paper presents a novel electrocardiogram (ECG) processing technique for joint data compression and PQRST detection in a wireless wearable sensor using LI-FI. The proposed algorithm is aimed at lowering the average complexity per task by sharing the computational load among multiple essential signal-processing tasks needed for wearable devices. The desired output is the location of the P wave and the T wave and QRS detection. The accuracy of location of features is essential for the performance of other ECG processing such as signal Analysis, Diagnosis, Authentication and Identification. The algorithm was tested using MIT-BIH arrhythmia database. The compression algorithm, which is based on an adaptive linear data prediction scheme, achieves a lossless bit compression.

Index Terms—ECG Sensor, PIC16f877A, PQRST detection, UART, LI-FI wireless kit.

I. INTRODUCTION

The **E**lectrocardiogramis the electrical manifestation of the contractile activity of the heart. It is a graphical record of the direction and magnitude of the electrical activity that is generated by depolarization and repolarization of the atria and ventricles. It provides information about the heart rate, rhythm, and morphology. The importance of the Electrocardiography is remarkable since heart diseases constitute one of the major causes of mortality in the world. ECG varies from person to person due to the difference in position, size, anatomy of the heart, age, relatively body weight, chest configuration and various other factors. There is strong evidence that heart's electrical activity embeds highly distinctive characteristics, suitable for various applications and diagnosis. The ECG is characterized by a recurrent wave sequence of P, QRS, T and U wave associated with each beat. The QRS complex is the most striking waveform,

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caused by ventricular depolarization of the human heart. A typical ECG wave of a normal heartbeat consists of a *P* wave, a *QRS* complex, and a *T* wave. Fig. 1 depicts the basic shape of a healthy ECG heartbeat signal with P, Q, R, S, T characteristics and the standard ECG intervals QT interval, ST interval and PR interval.

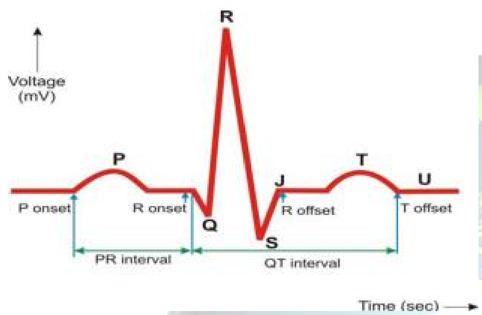

Fig. 1 an ECG waveform

A number of techniques have been devised by theresearchers to detect the characteristics in ECG [1]-[6]. Recently wavelet transform has been proven to be useful tool for non-stationary signal analysis. The wavelet transform based technique can be used to identify the characteristic features of the ECG signal to a reasonably good accuracy, even with the presence of high frequency and low frequency noises. Among the existing wavelet approaches, (continuous, dyadic, orthogonal, bi-orthogonal) we use real dyadic wavelet transform because of its good temporal localization properties and its fast calculations. Discrete Wavelet Transform (DWT)can be used as a good tool for analyzing non-stationary ECGsignal.

This can be achieved by proactive and long term monitoring of individual's cardiovascular health using low-cost wearable electrocardiogram (ECG) sensor devices. The main features of the ECG, i.e., the P, Q, R, S, and T points, give information about the cardiac health of the person. A wearable ECG sensor, as shown in Fig. 2, can be used to acquire, process, and wirelessly transmit ECG signal to a monitoring center. The main challenge involved in the development of the sensor is to make the device low profile, unobtrusive, easy to use with long battery life for continuous usage. A high level of integration with inbuilt signal acquisition and data conversion is required to minimize the size, cost, and power consumption of such a sensor. The major source of power consumption in such a system is the wireless transceiver, and hence, it is desirable to carry out preliminary ECG analysis tasks like QRS detection [4] and *RR* interval estimation locally. This allows the transmission to be triggered only when it is deemed necessary based on cardiac rhythm analysis.

II. METHODOLOGY

In order to extract information from the ECG signal, the raw ECG signal should be processed. ECG signal processing can be roughly divided into two stages by functionality: Preprocessing and Feature Extraction as shownin Fig. 2.

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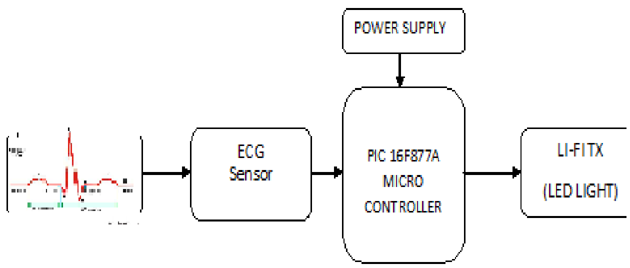

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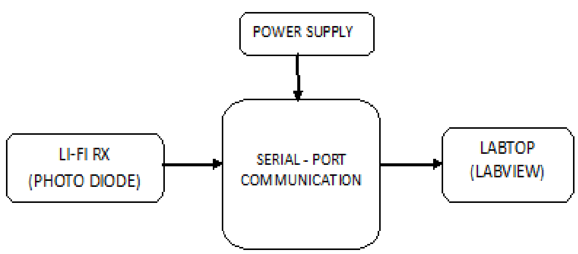

Fig. 2 Structure of ECG Signal Processing.

Feature Extraction is performed to form distinctive personalized signatures for every subject. The purpose of the Feature Extraction process is to select and retain relevant information from original signal. The Feature Extraction stage extracts diagnostic information from the ECG signal. The Preprocessing stage removes or suppresses noise from the raw ECG signal. A Feature Extraction method using Discrete Wavelet Transform (DWT) was proposed by Emran et al [7] - [8].

A. Pre-processing

ECG signal mainly contains noises of different types, namely frequency interference, baseline drift, electrode contact noise, polarization noise, muscle noise, the internal amplifier noise and motor artifacts. Artifacts are the noise induced to ECG signals that result from movements of electrodes. One of the commonest problems in ECG signal processing is baseline wander removal and noise suppression.

1) Baseline Drift Removal

- Baseline wandering is one of the noise artifacts that affect ECG signals. We use the median filters (200-ms and 600-ms) [9] to eliminate baseline drift of ECG signal. The process is as follows
- The original ECG signal is processed with a median filter of 200-ms width to remove QRS complexes and P waves.
- The resulting signal is then processed with a median filter of 600-ms width to remove T waves. The signal resultingfrom the second filter operation contains the baseline of the ECG signal.
- By subtracting the filtered signal from the original signal, a signal with baseline drift elimination can be obtained.

2) Noise Removal

After removing baseline wandering, the resulting ECG signal is more stationary and explicit than the original signal. However, some other types of noise might still affect Feature Extraction of the ECG signal. To remove the noise, we use Discrete Wavelet Transform. This first decomposes the ECG

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signal into several subbands by applying the Wavelet Transform, and then modifies each wavelet coefficient by applying a threshold function, and finally reconstructs the denoised signal.

The high frequency components of the ECG signal decreases as lower details are removed from the original signal. As the lower details are removed, the signal becomes smoother and the noises disappears since noises are marked by high frequency components picked up along the ways of transmission.

B. QRS-Detection

QRS detection is one of the fundamental issues in the analysis of electrocardiographic signals. The QRS complex consists of three characteristic points within one cardiac cycle denoted as Q, R and S. The QRS complex is considered as the most striking waveform of the electrocardiogram and hence used as a starting point for further analysis or compression schemes. The detection of the QRS complex is based on modulus maxima of the Wavelet Transform. The QRS complex produces two modulus maxima with opposite signs, with a zero crossing between them shown in Fig. 3. Therefore, detection rules (thresholds) are applied to the Wavelet Transform of the ECG signal.

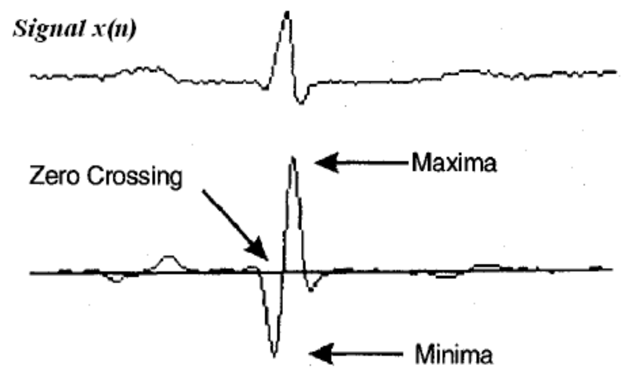

Fig. 3 Maxima, Minima, and Zero crossing of Wavelet Transform at scale

Most of the energy of the QRS complex lies between 3 Hz and 40 Hz [10]. The 3-dB frequencies of the Fourier Transform of the wavelets indicate that most of the energy of the QRS complex lies between scales of 23 and 24, with the largest at 24. The energy decreases if the scale is larger then 24. The energy of motion artifacts and baseline wander (i.e., noise) increases for scales greater than 25. Therefore, we choose to use characteristic scales of 21 to 24 for the wavelet to detect QRS complex (Fig. 4). The *Q* and *S* waves are high frequency and low amplitude waves and their energies are mainly at small scale. So, the detection of these waves is done with WT at lowscale. The onset and offset of the QRS complex are detected by using scale 22. From the modulus maximum pair of the *R* wave, the beginning and ending of the first modulus maximabefore and after the modulus maximum pair are detectedwithin a time window. These correspond to *QRS* onset and offset points.

C. Detection of P and T waves

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1) P wave detection

The P wave generally consists of modulus maxima pair with opposite signs, and its onset and offset correspond to the onset and offset of this pair. This pair of modulus maxima is searched for within a window prior to the onset of the QRS complex. The search window starts at 200 ms before the onset of the QRS complex and ends with the onset of the QRS complex.

2) Onset and off set of P wave

To find the onset, a backward search is made from the point of modulus maxima that is on the left of the zero crossing, to the start of the search window, until a point is reached becomes equal to or less than 5% of the modulus maximum. This point is marked as the onset of the P wave. Similarly a forward search is made from the point of modulus maxima that is on the right of the zero crossing, to the end of search window, until a point is reached becomes equal to or less than 5% of the modulus maximum (modulus minimum). This point is marked as the offset of the P wave

3) T wave detection

A normal T wave and its transform clearly display a modulus maxima pair with opposite signs . The T wave isfound at the zero-crossing between the two modulus maxima. The T wave's energy is mainly preserved between the scales 23 and 24. Therefore it was more appropriate to turn away from the dyadic scales and to choose the scale 10 for the WT. The next step consists of the search for modulus maxima. At scale 10 we analyzer a signal and search for modulus maxima larger than a threshold□. This threshold is determined by using the Root Mean Square (RMS) of the signal between two R-peaks. When there are two or more modulus maxima with the same sign, the largest one is selected. After finding one or more modulus maxima, it is possible to determine the locationand character of the T wave.

The first situation occurs when there is a modulus maxima pair with opposite signs. This indicates a small hill when the signs are +/- and a small inverted hill when the signs are -/+. When there is only one modulus maxima present, the + sign indicates a T wave that consists only in a ascending. When the sign is -, we see a T wave formed by an descending. The zero crossing between the modulus maxima pair corresponds to the peak of the T wave (Fig. 6).

4) Onset and off set of T wave

The T wave has characteristics similar to the P wave. The modulus maxima correspond to the maximum slopesbetween the onset of the T peak, and the offset of the T peak. The search for the onset of the T wave is carried out between the first modulus maxima corresponding to the T wave and the QRS offset. The detection procedure is the same as that for the P wave, except that the search window follows the QRS complex. The T wave onset is considered to be same as the offset of proceeding QRS complex.

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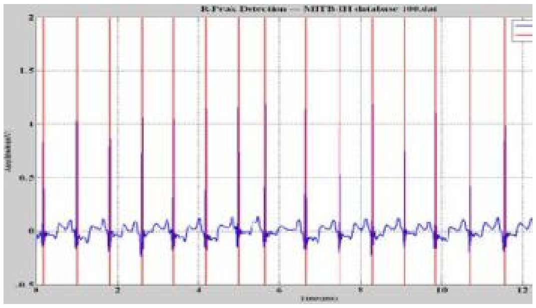

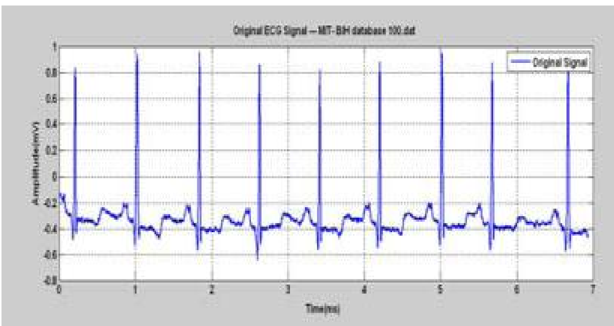

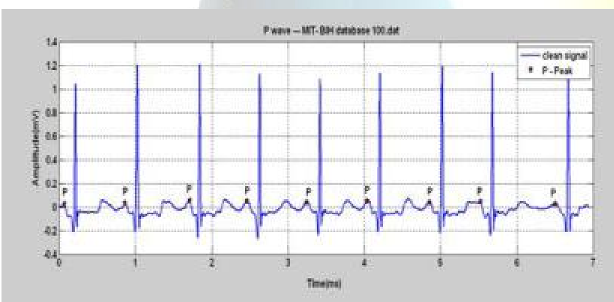

Fig. 5 P- Peak

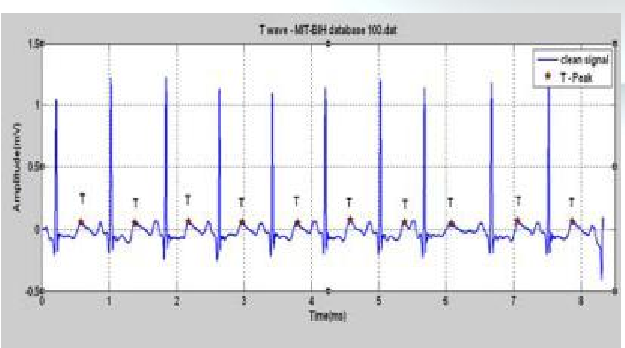

Fig. 6 T- Peak

III. LI-FI Technology (light –fidelity)

The visible light communication (VLC) refers to the communication technology which utilizes the visible light source as a signal transmitter, the air as the transmission medium, and the appropriate photodiode as a signal receiving component. Visible light communications (VLC) can provide cable free communication at very high bit rates as high as 100Mbps. In addition, it has a major advantage that it causes no interference to RF-based devices. This made wireless communication possible in RF hazardous areas such as hospitals and space station. In addition to these two key advantages, safety, simple installation procedures and band licensing-free characteristic also helped to increase VLC's potential to be developed as an alternative, or even a new standard to the wireless communication scheme. VLC uses white Light Emitting Diodes (LED), which send data by flashing light at speed. Undetectable to the human eye. In this case, high speed data can be carried by the modulated light from the LED, which makes information transmission possible while lighting our life. When signals reach the receiver through the indoor wireless channel, the photodiode will convert the optical signals to electrical ones and the original information will be recovered. The visible light communication based on LED is a novel developing technique in the optical wireless communication field.

Now a day's Wi-Fi is widely used in all the public areas like home, cafes, hospital, hotels, airports. Due to this radio frequency

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is getting blocked day by day, at the same time usage of wireless data is increasing exponentially every year. Everyone is interested to use wireless data but the capacity is going down. Wireless radio frequencies are getting higher, complexities are increasing and RF interferences continue to grow. In order to overcome this problem in future, light – fidelity (Li-Fi) technology came into existence since 2011. Li-Fi is a wireless communication system in which light is used as a carrier signal instead of traditional radio frequency as in Wi-Fi. Li-Fi is a technology that uses light emitting diodes to transmit data wirelessly. Visible light communication (VLC) uses rapid pulses of light to transmit information wirelessly that cannot be detected by human eye. This paper will focus on Li-Fi technology over Wi-Fi technology and challenges for the new VLC technology. [13]. Li-Fi can produce data rates faster than 10 megabits per second which is speedier than your average broadband connection.

IV. DESIGN AND IMPLEMENTATION

A. System architecture

The input data from ECGsensor into a string of pulse electrical signals by microcontroller unit (MCU) though the interface circuit. Then, the electrical signals drive LED source directly through a LED driver circuit, with which electronic to optical conversion is achieved. Because of the high on-off speed characteristic of LED, people cannot perceive the twinkling phenomena so that both lighting and information transmitting can be realized simultaneously. The generated optical signals carrying original information then delivered into the indoor wireless channel. At the receiver, pin photodiode will detect the optical signal and do the optical to-electronic conversion. Then the detected weak electrical signals are delivered into a receive circuit which contains preamplifier for signal amplification to meet the need of the following signal processing. The output data from receive circuit will be decoded into primary signal, and then sent to the PC receiver though the RS -232 interface [12], [13]. The prototype was designed to demonstrate serial communication between two computers with RS-232 interface .The voltage regulator supplies constant voltage to the level shifter from the power supply by maintaining constant DC voltages and avoiding unwanted spikes in current. The level shifter helps to convert the high voltages of RS-232 to transmitter and receiver circuit levels (which 0 arête +5V). The electrical data from the computer is converted into optical data using LEDs and transmitted over light; the optical data is captured by the receiver, converted into electrical data by the photodiode and sent it to the client computer [13].

B. System design

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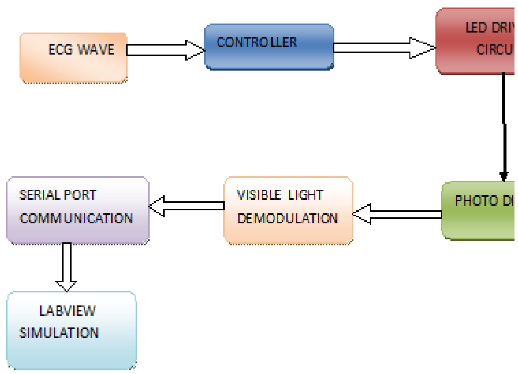

Transmitter

Every kind of light source can theoretically be used as transmitting device for VLC. However, some are better suited than others. For instance, incandescent lights quickly break down when switched on and off frequently [15]. These are thus not recommended as VLC transmitters. More promising alternatives are fluorescent lights and LEDs. VLC transmitters are usually also used for providing illumination of the rooms in which they are used. This makes fluorescent lights a particularly popular choice, because they can flicker quickly enough to transmit a meaningful amount of data and are already widely used for illumination purposes [10]. However, with an ever-rising market share of LEDs and further technological improvements such as higher brightness and spectral clarity, LEDs are expected to replace fluorescent lights as illumination sources and VLC transmitters.

Receiver

The receiver consists of an optical element to collect and concentrate the radiation onto the receiver photo detector; photodiode convert visible light into an electrical signal biased the photodiode operates in the photoconductive mode generating a current proportional to the collected light. This current is of a small value and a preamplifier is used to convert it into a voltage. This preamplifier should have low distortion and a large GBW. The resulting voltage is then applied to a low-pass filter to remove any high frequency noise. The resulting voltage signal is then further amplified in the final voltage amplifier stage. Amplifying and filtering stages, which helps reduce the DC noise component of the captured signal as well as low-frequency components. The final voltage signal should correspond to the received light pulses which are then decoded in the final decoder block, thus extracting the digital data [13],[14]. This final block performs the inverse function of the emitter's encoder block, but it can also be implemented with a microprocessor.

C. System Implementation

The current prototype is shown in figure2. It consists of PIC18F877A microcontroller, MAX232 level converter which converts RS-232 voltage level to TTL voltage level and TTL voltage level to RS-232 voltage level, white LED for the transmission of data, LED driver circuit in order to limit the current through the LED also it performs electronic to optic conversion, and

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Photodiode for detecting the data from the visible light,

V. APPLICATIONS

- Li-fi wireless communication is High speed, as high as 500mbps or 30GB per minute.
- Li- Fi uses light rather than radio frequency signals.
- Integrated into medical devices and in hospitals.
- Under water in sea Wi-Fi does not work at where Li-Fi will work.
- There are around 19 billion bulbs worldwide, they just need to be replaced with LED ones that transmit data. We reckon VLC is at a factor of ten, cheaper than WI-FI.
- Security is another benefit, he points out, since light does not penetrate through walls.
- By implementing the Technology worldwide every street lamp would be a free access point.
- 10. Li-Fi may solve issues such as the shortage of radio frequency bandwidth.

VI. CONCLUSION

This paper has presented a novel scheme for joint PQRST detection and lossless data compression aimed at wearable ECG devices. The PQRST detection algorithm achieves a high sensitivity of 99.64% and positive prediction of 99.71% with the MIT/BIH Arrhythmia database. The algorithm enables the sharing of computational load among multiple critical functions needed in a wearable sensor. To our best knowledge, this is the first joint algorithm that implements PQRST detection and lossless data compression.

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