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Implementation of Wireless Data Transmission Based on Bluetooth Technology for Biosignals Monitoring

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Abstract: We have implemented a wireless biomedical transmission system which used Bluetooth module in the server as the network base station. The proposed system utilizes Time Division Multiplexing (TDM) technique for transmission of multi biomedical signals simultaneously. On the other side, in the Bluetooth client, the biosignal packets are retrieved and their contaminations such as noises and interferences are removed. The application consists of Bluetooth server and remote Bluetooth client that enable real-time transmission, preprocessing, processing, monitoring and finally analyzing biosignal based on wireless technology. The significant advantage of this system is its ability for assessing vital biosignals of several patients and makes such monitoring convenient.

Key words: Biosignal · Bluetooth · Client · ECG · Feature extraction · Processing · Server

INTRODUCTION

In the recent years, because of rising costs to healthcare services, there has been an increasing trend towards the use of standby physicians supervising patients health conditions regularly. In other words, there is not equipoise between biomedical services and their costs. Over the recent years, the health monitoring has vastly extended its capabilities. For instance, wireless transmission of real–time biosignals is becoming more and more profuse. A lot of efforts have gone into wireless biosignals transmission like LAN client-server based structure. For instance the communication between server and client based on TCP/IP protocol used in web-based approach to transferring the measured biosignal data to the central depository [1], or data transmission over one of the available wireless networks technology based on GSM, GPRS are such client-server networks used in telemedicine systems [2]. In [3] the use of Body Area Networks (BANs) investigated and then Biosignals monitored and transmitted to remote healthcare centers over GPRS and UMTS.

The analysis of the ECG has been widely used for diagnosing many cardiac diseases. The ECG is a graphic record of the direction and magnitude of the electrical activity that is generated by depolarization and depolarization of the atria and ventricles. In fact, beat

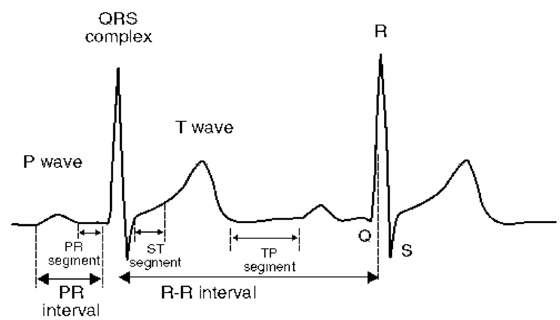

Fig. 1: A schematic representstion fo ECG signal [6]

detection is necessary to determine the heart rate and several related arrhythmias such as Tachycardia, Bradycardia and Heart Rate Variation; it is also necessary for further processing of the signal in order to detect abnormal beats [4]. Heart Rate Variability (HRV) measurements analyze how these RR intervals, which show the variation between consecutive heartbeats, change over time. Further use of ECG signal can also be Pulse Wave Transmitted time (PWTT) is used as a new non-invasive and cuffless method for blood pressure estimation [5]. A Schematic representation of normal ECG is shown in Figure 1. The raw ECG signals acquired contaminated with several noise and artifacts. Broadly speaking, ECG contamination can be classified into the following categories:

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- Power line (50 - 60 Hz) interference.
- Respiration, causing drift in the baseline known as baseline wandering.
- Noise coupled from other electronic devices, usually at high frequencies.
- Electrode pop or contact noise.
- Electromyography (EMG) noise.

Among these noises, the first three items are the most significant and can strongly affect ECG signal analysis [8].

This paper represents a progressive implementation of wireless biosignals processing and monitoring based on Bluetooth technology. By this means, biosignals from all patients confined in intensive care unit (ICU) are acquired to Bluetooth server and transmitted via Bluetooth and these signals are received in remote monitoring center known as Bluetooth client. Therefore, the specialist can attend to this center without the inconvenience incurred leaving his local practice besides, with the aids of software, diagnosis is much more accurate.

To remove or minimize cables requires a robust wireless link with low-power capabilities. Although many wireless standards can be used, but there are important considerations such as range, security, throughput and last not least ease of implementation and cost. The aforementioned wireless interface between our server and client is Bluetooth. Bluetooth is a low power device, which operates in the open unlicensed Industrial, Scientific and Medical (ISM) band at 2.4 GHz. The Basic Rate is 1 Megabit per second (Mbps) with an Enhanced Data Rate of 2 or 3 Mbps. The typical performance of the Basic Rate ranges from the lower hundreds to about 700 kbps. By using time-division duplex (TDD) scheme, it affords bi-directional radio transmission between devices and allows up to seven devices to be connected together, which form a piconet. A piconet is the fundamental Bluetooth network where one device is the Master (provides synchronization reference) and all the other devices are known as the Slaves [7].

The organization of this paper is as follows: In section II, the basis of Data Acquisition is described. In section III, Computer based signal processing and analysis is presented and in sections IV, V the Bluetooth Sever and Bluetooth Clint are described. Finally, we make our concluding remarks in section VI.

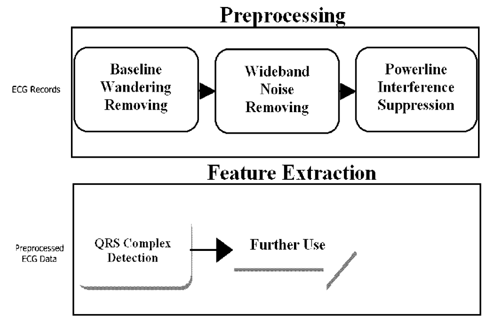

Fig. 2: General trend of computer based processing and analysis

Data Acquisition: Acquisition of the signal can be handled through LabVIEW. It enables acquisition of data seamlessly, regardless of the application. NI-DAQmx is a programming interface is used to communicate with data acquisition devices. A wide range of data acquisition cards are available that satisfy our purposes. For example, the PCI-6023E board is suitable one. It features 16 channels of analog, a 68-pin connector and 8 lines of digital I/O. It does not have any analog output [9]. Then Measurement & Automation Explorer (MAX) is used that provides access to PCI-6023E DAQ. It is necessary to settle the channel that will be used. In this project because it was not possible to make an acquisition of biosignal in real world, we used provided ECG database. However, preconfigured Analog Input (AI) VI can be replaced with ECG database block, so it makes the acquisition of an external signal with ease.

Computer Based Signal Processing and Analysis: This part is located in Bluetooth Client, which separated into four subsections. Figure 2 depicts the general trend.

Baseline Wandering Removing: Baseline wandering usually comes from respiration and body movements. It is usually in amplitude of around 15% FSD (full-scale deflection) at frequencies wandering between 0.15 and 0.3 Hz. A highpass digital filter [8] can suppress it.

A Kaiser Window FIR highpass filter is used to remove the baseline wandering. Figure 3 shows the specifications of the highpass filter and the BD of a VI for removing the baseline wandering [10].

Removing Wideband Noise: After removing baseline wandering, the resulting ECG signal is more explicit and stationary than the raw signal. However, some other types of noise might still affect feature extraction

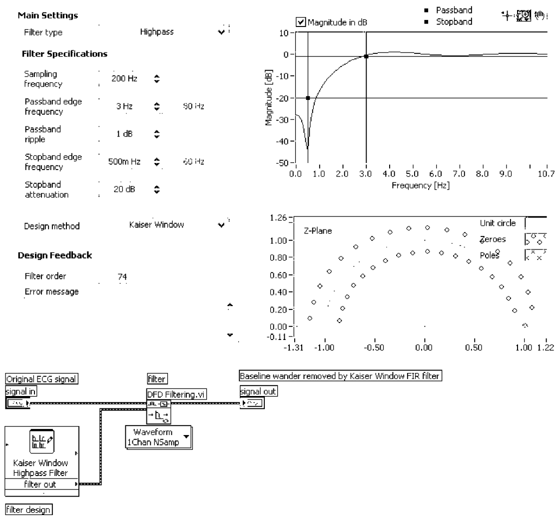

Fig. 3: Highpass filter for removing baseline wandering

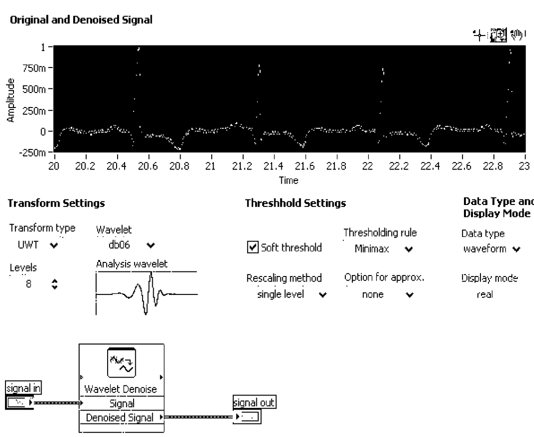

Fig. 4: Removing wideband noises from an ECG signal by applying the UWT

of the ECG signal. The noise may be complex stochastic processes within a wideband, so cannot be removed by using traditional digital filters. For removing the wideband noises, the Wavelet Denoise is used. This VI first decomposes the ECG signal into several subbands by applying the wavelet transform, then modifies each wavelet coefficient by applying a threshold or shrinkage function and finally reconstructs the denoised signal. Figure 4 shows an example of applying the undecimated wavelet transform (UWT) to the ECG signal. UWT is a wavelet transform derived by allowing the translation parameter to vary continuously, whilst restricting the scale parameter to a dyadic scale (thus, the set of time-frequency atoms now forms a frame). This leads to the undecimated wavelet transform (UWT), which for a signal s ϵ L^2 (R), is given by:

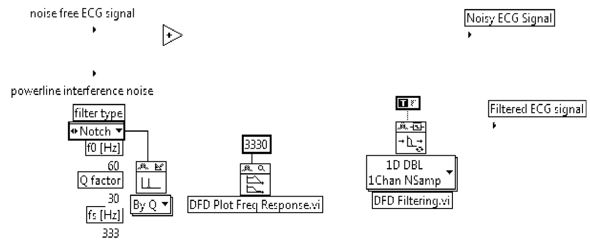

Fig. 5: Block Diagram of Notch Filter VI designed for Powerline interference suppression

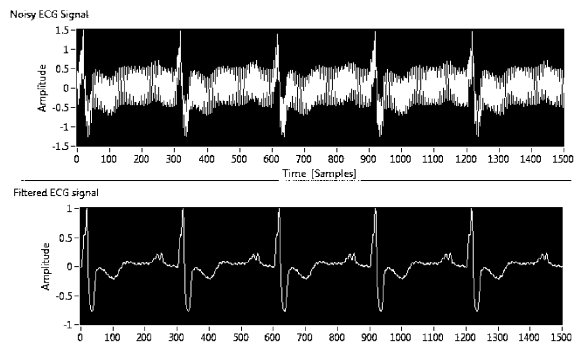

Fig. 6: The result of designed filter on noisy signal (Powerline interference removal)

$$\omega_v(\tau) = \frac{1}{\sqrt{v}} \int_{-\infty}^{+\infty} s(t)\, \psi^*(\frac{t-\tau}{v})\, dt \qquad (1)$$
$$v = 2^k, k \in \mathbb{Z}, \tau \in R$$

Where ω_v is the UWT coefficient at scale v and shift τ and ψ^* is the complex conjugate of the mother wavelet [11]. The UWT has a better balance between smoothness and accuracy than the discrete wavelet transform (DWT).

Powerline Interference Suppression: Improper grounding of the ECG equipment and interference from nearby equipment mostly causes powerline interference (50/60 Hz). Such interference can be removed in many situations by means of linear or nonlinear filtering. The IIR Notch Peak Design VI is used to design a notch filter. It uses the notch filter to remove single frequency noise (50/60 Hz) from ECG signals [12]. Figure 5 and Figure 6 show BD of this VI and its result on the contaminated ECG signal respectively. As BD manifests, the Q factor equals the quotient of center frequency and corresponding bandwidth.

Feature Extraction: For the purpose of diagnosis, there are various features extracted from the preprocessed ECG data, including QRS intervals, QRS amplitudes, PR intervals, ST intervals, etc. This section mainly discusses QRS complexes detection.

The detection of the R-peaks and consequently of the QRS complexes in an ECG signal provides information about the heart rate, the conduction velocity, the condition of tissues within the heart as well as various abnormalities. It supplies evidence for the diagnoses of cardiac diseases. Due to this cause, it has drawn extensive attention in the ECG signal-processing field. However, the presence of time-varying morphology and various type noises makes the detection more difficult.

The peaks in ECG signals usually are damaged by environment noises and cannot be detected properly by conventional curving-fitting methods.

The wavelet-based peak detection technique is naturally immune to noise and can distinguish both sharp and mild peaks/valleys accurately. Since well-chosen wavelet can extract main features from noisy signals by multi-resolution analysis, many wavelet-based detection methods have introduced recently. We have used the WA Multiscale Peak Detection VI to detect the Q, R and S points in an ECG signal and computes the QRS duration. Before the peak/valley detection, the Multiresolution Analysis VI is used to decompose the ECG signal by 8 level Daubechies6 (db06) wavelets and then reconstruct the signal with D4 and D5 subbands. D4 and D5 subbands will be kept for reconstruction because almost all QRS details are within these two subbands, which will make the QRS detection more accurate.

This VI performs undecimated discrete wavelet decomposition with the biorthogonal wavelet bior3_1 on the input signal. The width input controls the decomposition level. Then Searches for zero-crossing points in the detail coefficients at all levels and selects the zero-crossing points at the largest scale as the coarse estimation of the real peaks. It searches the finer scale for the corresponding nearest zero-crossing point for each detected point. Until this VI reaches the finest scale, which is the first level, the last step will be repeated [13].

After extraction of the features by performing QRS complex detection, we can analyze the features with other methods. For example, performing Heart Rate Variability (HRV) analysis on the R-R interval signal to demonstrate the state of the heart and nerve system.

Bluetooth Server: Preparing acquired signals whether from real-time acquisition or from ready database, is the main task of Bluetooth server application. In the following steps we will develop a Bluetooth server application.

Retrieving Machine Bluetooth Address: Via indicator blocks placed in FP of program retrieve this machines Bluetooth address and device name and display it on the FP. This is done by passing a timeout value of zero to the Bluetooth Discover function. Also for preventing probable problems that may occur by other insecure Bluetooth devises, Bluetooth Set Mode function is used to make server Bluetooth devise not discoverable.

Create a Bluetooth Service: Bluetooth Create Listener function is used to create a Bluetooth service identified by a Bluetooth UUID. A UUID is a universally unique identifier that is guaranteed to be unique across all space and all time. UUIDs can be generated in a distributed fashion independently. It does not require any central registry of assigned UUIDs. Listener ID is returned by this function, which refers to this server through LabVIEW application. The Bluetooth Create Listener function also returns a reserved Bluetooth channel. It enables the server to listen for inbound connections. A Bluetooth channel is a global resource with only 30 channels available on any Bluetooth device. If no server channel is available, the function returns an error.

Waiting for Incoming Connection Request: Bluetooth Wait on Listener function is used to wait for specified timeout and accept an incoming connection request from a client. This function returns a connection ID used to exchange data with the client.

Data Transmission: The connection ID if fed into loop structure and data transmission will continue while no error accrues during data transmission between server and client or none of server and client terminates the connection. Data sent to client consist of several raw ECG signals that acquired from patients. Time division multiplexing (TDM) is used to concatenate all signals' samples. So first, of all each signal that belongs to the specific patient upsampled five times. The number of times for upsampling depends on number of acquired signals. For instance, this project is designed for five ECG patients' signal, so each acquired signal should be upsample for five times. Then each one shifted by the leading zeroes and all of them is added together. The result will be multiplexed signal. Figure. 7 demonstrates this method. Finally, this concatenated vector data is cast into string data and sent via Bluetooth Write functions to exchange data with the client.

$1st\ patient\ \ [a_1\ a_2\ a_3\ a_4\ a_5 \ldots a_n]\ \underline{upsample}\ [a_1\ 0\ \ 0\,0\,0\,0\ a_2\ 0\ 0\ \ 0\,0\,0 \ldots a_n]$

$2nd\ patient\ [b_1\ b_2\ b_3\ b_4\ b_5 \ldots b_n]\ \_\_\_\_\_\_\_\_\ [0\ \ b_1\ \ 0\,0\,0\,0\,0\ \ b_2\ 0\ 0\,0\,0\,0 \ldots 0\ b_n]$

$3rd\ patient\ [c_1\ c_2\ c_3\ c_4\ c_5 \ldots c_n]\ \_\_\_\_\_\_\_\_\ [0\ 0\ \ c_1\,0\,0\,0\,0\ \ 0\ c_2\ 0\,0\,0\,0\,0 \ldots 0\ c_n]$

$4th\ patient\ [d_1\ d_2\ d_3\ d_4\,d_5 \ldots d_n]\ \_\_\_\_\_\_\_\_\ [0\ 0\ \ 0\ d_1\ 0\ \ 0\,0\,0\,0\ \ d_2\ 0\,0\,0\,0\,0 \ldots 0\ d_n]$

$5th\ patient\ [e_1\ e_2\ e_3\ e_4\ e_5\ \ldots e_n]\ \_\_\_\_\_\_\_\_\ [0\ \ 0\ \ 0\ 0\ e_1\ 0\,0\,0\,0\,0\ \ e_2\ 0\,0\,0\,0\,0 \ldots 0\ e_n]$

$$\oplus\Downarrow$$

$$[a_1\ b_1\ c_1\ d_1\ e_1\ a_2\ b_2\ c_2\ d_2\ e_2\ \ldots a_n\ b_n\ c_n\ d_n\ e_n]$$

Fig. 7: Procedure of signal multiplexing

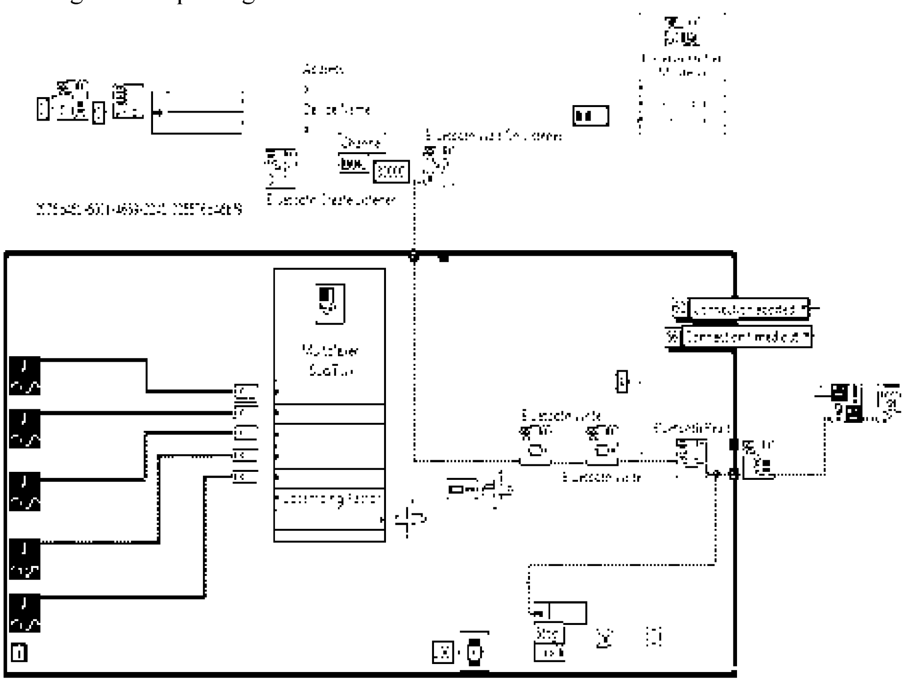

Fig. 8: Block Diagram of Bluetooth Server application

The first Bluetooth Write sets the amount of data to send and the second Bluetooth Write sends the data. The Bluetooth read waits until the client is done reading and sends a confirmation (This is there to make sure that the server and client are in sync). Error checking in the loop will stop the loop if a connection error occurs.

This procedure is repeated in every iteration for new set of acquired signals.

Close Connection: Bluetooth Close Connection function is used to close connection to the client and to stop listening for incoming connections. Figure 8 shows BD of Bluetooth server.

Bluetooth Client: Bluetooth client application is located in monitoring station. All the operation consists of preprocessing, processing and feature extraction are done in this application.

The following steps show how to develop a Bluetooth client application.

Requesting a Connection to Bluetooth Server: For connecting to service on a Bluetooth server, Bluetooth Open Connection function is used.

The channel number is set to zero and a Bluetooth UUID for identifying which service to connect to, is specified. The Bluetooth Open Connection function performs a Service Discovery in Bluetooth (SDP) inquiry to make a connection to the first service found with matching UUID. Internally, RFCOMM channel number will be the result of an SDP query. The SDP query is a tool for translating UUID to a channel number. Specifying a nonzero channel number avoids the internal SDP query operation thus reducing the amount of time it takes to connect to the service. If the channel number is nonzero, LabVIEW will ignore the UUID input parameter.

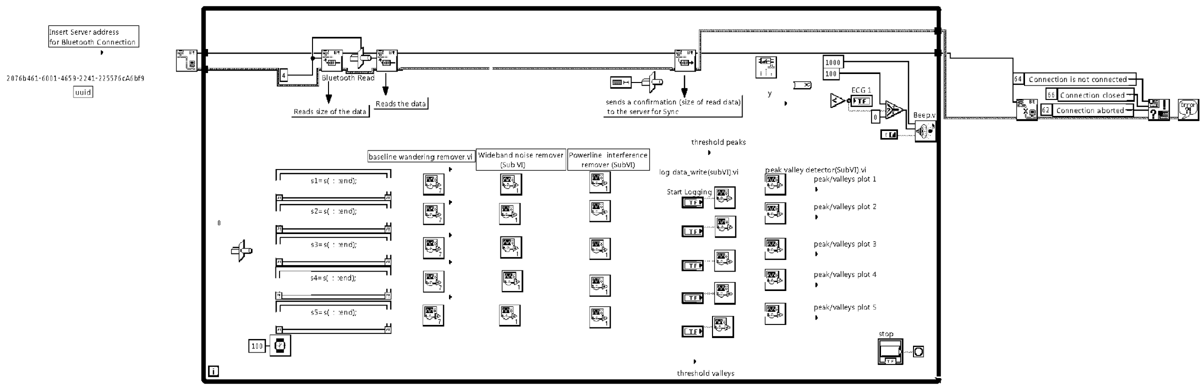

Fig. 9: Block Diagram of Bluetooth Client Application

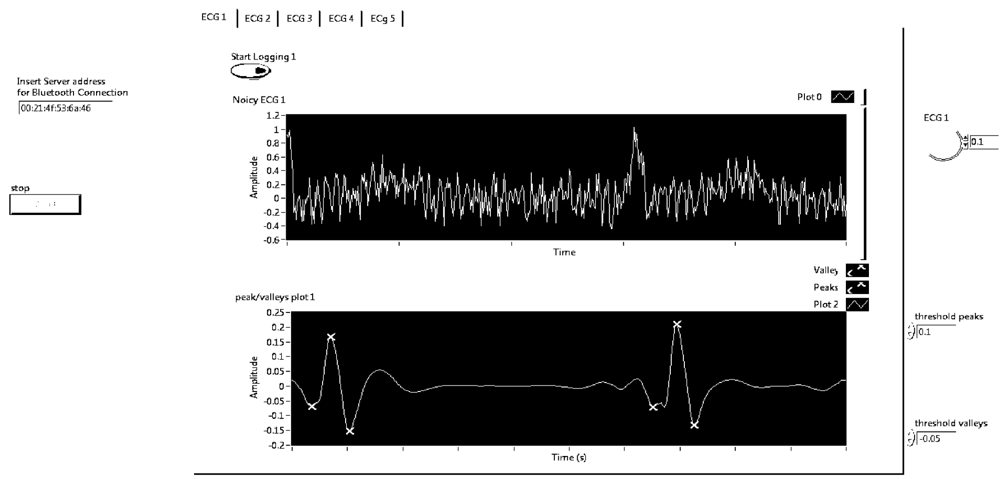

Fig. 10: Front Panel of Bluetooth Client Application

The Bluetooth RFCOMM Service Discovery VI is used to search for a valid channel number that is associated with a service on a remote Bluetooth device. This VI performs an SDP RFCOMM service discovery resulting in a usable channel number for connecting to the corresponding service on the remote Bluetooth device [14]. In Bluetooth client as the same in Bluetooth server, This VI uses Bluetooth Set Mode Function to set Bluetooth installed module in client not visible to other Bluetooth devises.

Data Transmission Between Server and Client: Using Bluetooth Read and Bluetooth Write functions makes it possible to exchange data with the server. Bluetooth Read Function reads the data on the specified channel and casts the data into a numeric representation. First Bluetooth Read acquires the size of the data and the second Bluetooth Read reads the data and passes it to demultiplexing stage. Then the Bluetooth write sends a confirmation to the server. (This is there to make sure that the server and client are in sync). Error checking in the loop will stop the loop if a connection error occurs. After demultiplexing there are five separated signals that each one belongs to corresponding patient. Subsequently they will be passed into preprocessing stage comprises three cascaded filters which are baseline wander removing, wideband noise cancelation and elimination of power line interference. Afterwards the noise free signals enter feature extraction and analysis stage that denotes ECG characteristic points. In addition, a short beep is placed for hearth beat detection. These enable us to analysis them for further diagnostics. Figure 9 and Figure 10 demonstrate the BD and FP of Bluetooth client application. As it is apparent in FP both raw ECG data and processed signal of each patient is placed in one tab that supervisor can select desired tab. In all tabs, a button named "Start Logging" is devise that enables user to log preprocessed ECG signal. It saves date, time and ECG data into file. Therefore, the software scheme is more powerful and feasible for offline assessment at a convenient time. Finally, Bluetooth Close Connection function is used to terminate connection to the Bluetooth server.

CONCLUSION

This paper showed the application of a novel approach toward wireless data transmission based on Bluetooth technology for biosignals monitoring. The important specification that must be considered in this project is real-time biosignal monitoring. Potentially, our proposed hardware/software setup applied to a LAN or used as an Internet server to share real-time data on the Web.

A summary of the important issues of this paper are listed below:

- Higher accuracy in diagnosing abnormalities.
- Usability, affordability and interoperability of the designed system.
- Offline analysis is provided.
- Prevention of using cables for networking.
- Can be generalize for any number of patients' signals with ease.

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