IoT Assisted Real Time PPG Monitoring System for Health Care Application

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Abstract— **Photoplethysmography is an important area that measures heart rate and its variability for clinical diagnosis of cardiac illness and oxygen saturation level in blood. Nowadays biomedical signal transmission through IoT cloud provides an additional benefit in health monitoring especially for ailing senior citizens who are remotely located. The process of bioelectric signal transmission takes place at a very slow sampling rate. In the present work, a prototype system is proposed for PPG monitoring using Internet-of-Things (IoT). PPG data are captured by a reflectance-type PPG sensor with an embedded controller over a measured interval of time. PPG waveforms are then modeled using either Fourier or Gaussian method, the model parameters thus obtained are truly representing the sampled PPG Data. The computed model coefficients are then transmitted to the IoT cloud server (e.g. Dropbox) with WiFi connectivity. At the remote end, provision is made to access these model parameters from the cloud server and reconstructing the PPG waveform. The performance of the reconstruction process is evaluated by calculating mean square error (MSE) and percentage root mean squared difference (PRD). Experiments were performed on ten volunteers of different ages in order to assess the reliability of the entire method. Experimental results reveal the ruggedness of the proposed method, which can supplement the clinical diagnosis in cardiac ailments and facilitate the treatment of rural patients from any urban location through expert physicians.**

Keywords— ***Dropbox, IoT, MSE, PPG, PRD***

I. INTRODUCTION

Nowadays, human population and complexity of diseases are increasing rapidly which has made medical amenities beyond affordable. Health conditions of elderly and ailing people need to be monitored periodically, which poses a major challenge to the existing medical infrastructure of the country at present. The fast and accurate diagnosis of disease at an affordable price has been a major concern [1-3]. The inadequacy of the number of hospitals and health centers has aggravated the problem related to regular health checkups and timely diagnoses. In a developing country like India, the inadequate medical infrastructure in rural areas is needed to be addressed. With the rapid progress of IoT based clinical diagnosis system, treatment from a remote location with an affordable cost has become a reality. ECG and PPG monitoring is gaining much importance in cardiac disease monitoring and in research and development activities. In general, the ECG and PPG signals are recorded by stationary recorders; then the data recorded are analyzed by the doctors attached to the clinic/medical centers leading to the diagnosis of cardiovascular ailments. However, the lack of portability of necessary medical equipment and accessories; severely restricted data collection. Moreover, these devices are delicate and too expensive for home use, patients have to go to the hospital frequently, which ultimately increases the burden on hospitals/health centers and limited medical professionals attached. Therefore, the proposed IoT based cheap, portable PPG based monitoring system is timely connected. In the advent of Internet-of-Things and wire-less sensor networks (WSNs), ECG and PPG signals can be transferred to the IoT cloud server by means of wireless transmission technology, such as Bluetooth or Zigbee [4-11]. IoT technology provides an avenue for multiple connected devices to collect and share information with each other. Thus the IoT set-up consists of a centralized network of computers that can exchange data within a single framework [12-13]. A regular hospital can be turned into a smart hospital after enhancement by the IoT feature. In an IoT cloud environment, it is possible to preserve all medical transcripts of the patients and simultaneously track further information from the central database [14]. In the present article, a PPG monitoring framework based on the Internet-of-Things (IoT) is proposed. The PPG information extracted will be transferred to the IoT cloud utilizing Wi-Fi without the need for a local terminal. Contrast to Bluetooth or Zigbee, Wi-Fi ensures faster transmission rates and wider coverage areas. The PPG data captured from the volunteers using the fingertip sensor is stored temporarily on a laptop. The raw data are then filtered to remove the noise and are modeled beat wise using either Fourier or Gaussian method [15]. Thus the size PPG information gets reduced after beat-wise modeling in comparison to the raw data, which consumes less IoT cloud server storage space. These beat wise PPG model parameters are considered as the primary features of PPG waveform, which can be transmitted directly to the IoT cloud using Wi-Fi. At the multiple remotely located medical centers, a utility software can access this IoT cloud server to import the PPG model parameters to reconstruct the PPG waveform for clinical analysis by medical professionals. The performance metrics (MSE and PRD) of reconstruction has been tested with formidable accuracy by comparing it with the original PPG waveform [16].

II. METHODOLOGY

The "Internet of Things" provides a means to enable us to sense and control a variety of parameters and objects through the wireless Internet. Research in related fields has revealed that remote health monitoring is feasible to monitor the health condition of non-critical patients at home

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rather than in a hospital, relieving the burden on hospital resources such as doctors and beds. It is evolving as a successful means to provide better access to healthcare for those living in rural areas, or to enable elderly people living independently at home for longer. In a cloud-based architecture, there must be a reliable cloud service provider who provides cloud storage facility to store a patient's healthcare information. The service provider can make use of public, private, or hybrid cloud infrastructures to store information about a patient's physiological conditions that are monitored with the help of the wearable sensors. The cloud server gets updated with all collected data over time. A real-time PPG Monitoring System is implemented using cloud computing and Web as shown in Fig. 1.

A. PPG Data Acquisition

The PPG data acquisition unit consists of a typical reflectance type PPG sensor (HRM2511E Easy Pulse Plug-in V1.1 module) and ATMEGA328 embedded controller shown in Fig. 2. The analog signal is fed to one analog input channel of an embedded controller. The PPG data is captured by an embedded C program with a sampling rate of 250 Hz. The embedded controller transfers the data to the computer via USB connectivity for saving into a data file (.txt) containing a sampled PPG signal.

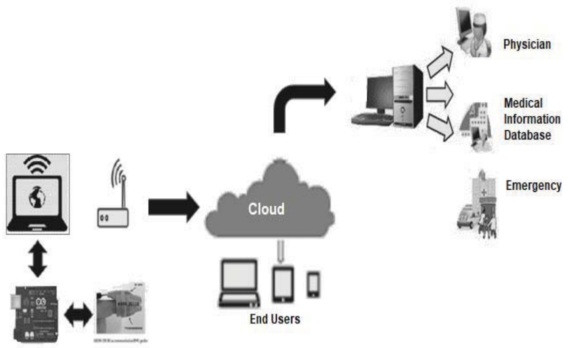

Fig. 1. Architecture of the IoT-based PPG monitoring systems

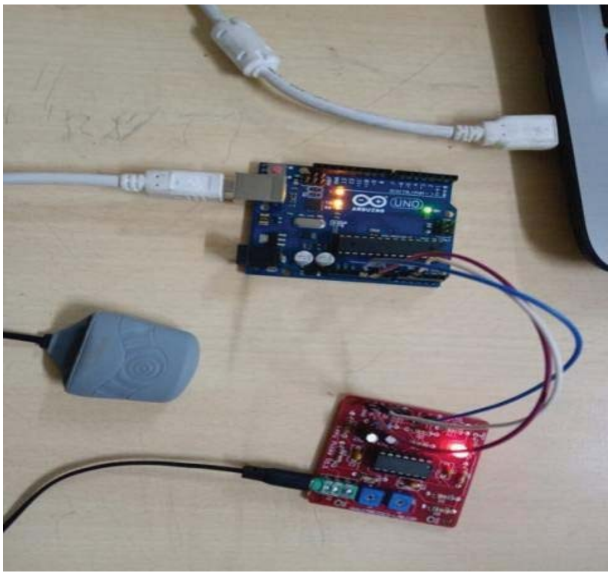

Fig. 2. Experimental set up of PPG Data Acquisition

B. Prepossessing PPG Signal

The sample data files of PPG data sets of different subjects are prepossessing by MATLAB program using different stages. The normal frequency range for PPG signals is 0.5 to 4 Hz, while for motion artifacts it is 0.01 to 10 Hz. Therefore, it is not easy to obtain a clean signal by applying a general filter to a PPG signal contaminated by motion artifacts. A band pass filter has been used to remove the motion artifacts and noise. The steps are as follows: - i) Removal of high-frequency noise and baseline wandering from PPG signals using a band pass filter (having cut –off frequency as 0.75Hz and 8 Hz for PPG signals), ii) Limit the signal level using AGC (Automatic gain control) the technique in Fig. 3. shows a noisy and filtered PPG signal.

C. PPG Beat Extraction

The filtered sampled data are loaded into an array. The local minima points, indicating the foot of PPG waveform points located in terms of index number and the corresponding amplitudes are stored in two new arrays shown in Fig. 4. The sampled data points between two successive time index values will form one complete beat of the PPG waveform shown in Fig.5. If there are N number of foots then the number of beats will be (N-1). The sampled data set of all beats are stored in two dimension array and is stored in a data file.

The algorithm in the form of pseudo-code is shown below:

1. Read sampled data values from 'ppg_filtered.txt' file and store these values to array 'X'.
2. Find the local minima (amplitude and sample no.) of all data points in array X and store it into two arrays called min_ peak and loc. Find the size of the array 'min_peak' and store it to S.
3. K= (S-1), where K is the number of beats.
4. Set beat counter (I) to 1
5. Loc1=loc(I); Loc2=loc(I+1)
6. N=(Loc2-Loc1) +1, where N is the number of data points in a beat. Set data index pointer J=1;
7. ppg_beat(J, I)=X(J,I)
8. J=J+1
9. If J<=N go to step 7.
10. I=I+1
11. If I <=K go to step 5.
12. Save the array ppg_beat into the file ppg_beat_matrix.txt.
13. Stop

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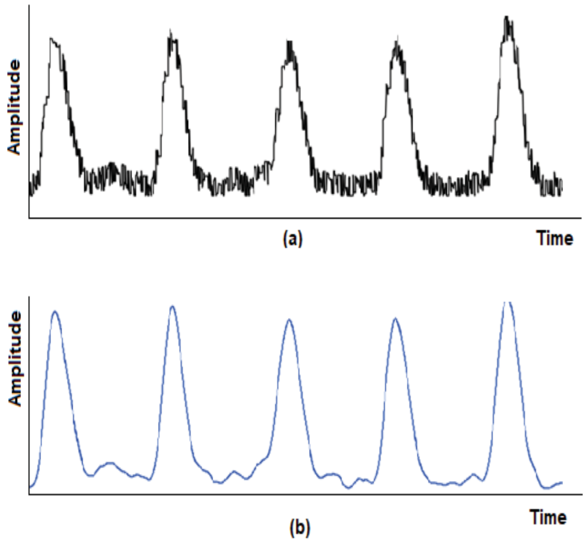

Fig. 3. (a) Noisy PPG signal, (b) filtered PPG signal

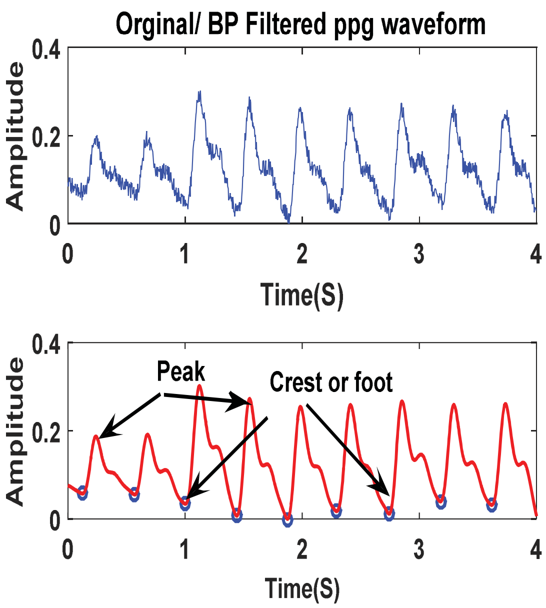

Fig: 4(a) Original PPG waveform, (b) Filtered PPG waveform

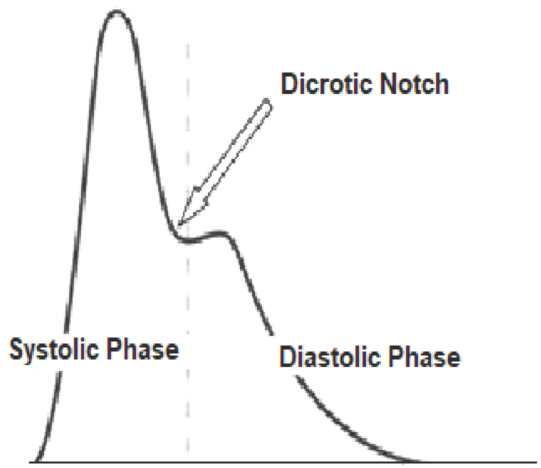

Fig. 5. Single Cycle of PPG waveform

D. Modeling of PPG waves

Each beat of the PPG signal is now modeled according to one of either Fourier or Gaussian methods as follows[7-8] .

a) Fourier Model:

As PPG is a periodic signal and it may be mathematically expressed by the following equation containing.

Fourier harmonic components as given by:

$$y(t) = C_0 + \sum_{n=1}^{n} A_n \sin(n\boldsymbol{\omega}_0 t) + B_n \cos(n\boldsymbol{\omega}_0 t) \quad (1)$$

$$A_n = \frac{2}{T}\int_0^T x(t)\sin(n\boldsymbol{\omega}_0 t)\, dt$$

$$B_n = \frac{2}{T}\int_0^T x(t)\cos(n\boldsymbol{\omega}_0 t)\ \mathrm{dt}$$

where, *y(t)*= time-instantaneous value of PPG signal,

C_0 =average value of PPG signal,

ω_0 = angular frequency of fundamental component 2Π/T,

T = time period of PPG wave

n = total number of data points.

Assuming, $A_n = C_n\cos\theta_n$ and $B_n = C_n\sin\theta_n$, equation (1) may be written as

$$y(t) = C_0 + \sum_{n=1}^{n} C_n \sin(n\boldsymbol{\omega}_0 t + \theta_n) \quad (2)$$

Where, $C_n = \sqrt{A_n^2 + B_n^2}$ and $\theta_n = tan^{-1}(\frac{B_n}{A_n})$

The model parameters are considered as ω_0, C_0, and θ_n.

b) Gaussian Model:

PPG signal were modeled of a set of independent Gaussian functions called GC:

$$GC(x) = \sum_{i=1}^{N} a_i e^{-\left(\frac{x-\mu_i}{2\sigma_i}\right)^2} \quad (3)$$

where, μ_i and σ_i are mean and standard deviation of i^{th} component of Gaussian model combination. The model parameters (a_i, μ_i, and σ_i) were determined and reconstructed over time period of recording.

E. PPG Model Parameters uploading and importing to and from IoT cloud

"The cloud" refers to resources that are accessed over the Internet, the servers, the software, and databases that run on those servers. These include the underlying infrastructure and mechanism needed for processing and storing IoT data, whether in real-time or not IoT. IoT Cloud servers are located by the IoT service providers all over the world. With the help of cloud computing, users and organizations don't require physical servers themselves or run software applications on their own machines. Cloud users are able to access i.e. import and export files and applications from any devices at remote ends. It saves the local storage space for storing large data as computing and storage take place on servers in a data center. A new application is made at dropbox.com/developers. In current work, the MATLAB application is used to write and read data from our IoT project. The Token generated is used in the file transfer to send the data generated to the appropriate account. With the help of programming in MATLAB platform obtained PPG coefficients values, 4th order Fourier model (PPG_Fourier_Model.txt) and 2nd order Gaussian model

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(PPG_Gaussian_Model.txt) from real-time PPG sensor is uploaded to a global server platform in Dropbox using transmission program with proper internet data speed also store the different subject of PPG to further analysis. The beat wise model parameters are transferred or uploaded to the Dropbox file for further access at the remote end. Thus uploading model parameters of all beats corresponding to PPG waveform data of a given patient serves as a data compression method which saves the time of transfer. In the remote center, provision is made to import model parameter (Fourier and Gaussian) from a global server platform in Dropbox cloud with proper internet data speed for the reconstruction of PPG waveforms containing all beats of PPG waveform of a given patient.

F. Reconstruction PPG Waveform from model parameters and performance analysis

The coefficients as obtained by Fourier and Gaussian modeling are synthesized to reconstruct the PPG waveforms over defined period .The Fourier harmonic components (ω_0, C_0, and θ_n) and Gaussian harmonic components (a_i, μ_i, and σ_i) were utilized to reconstruct the PPG wave by the equation (1) and equation no (3). The quality of reconstruction of PPG waveform were expressed by computing mathematical indices as: i) Percentage root mean squared difference (PRD), ii) Mean square error (MSE). They are defined as:

$$PRD = 100 \times \sqrt{\frac{\sum_{n=1}^{N}(x[n]-\hat{x}[n])^2}{\sqrt{(x[n])^2}}} \tag{4}$$

$$MSE = \sqrt{\frac{\sum_{n=1}^{N}(x[n]-\hat{x}[n])^2}{N}} \tag{5}$$

Where N = total number of samples in waveform data set

$x[n]$ = Actual value of n-th sample

$\hat{x}[n]$= Corresponding reconstructed value of n-th sample

III. RESULT & ANALYSIS

Experiments were performed under the proposed scheme for capturing PPG signals from 5 male and 5 female patients, two from each age groups between 10-20 years, 20-30 years, 30-40 years, 40-50 years, and 50-60 years. The PPG waveform was filtered for noise removal and the beats were extracted from these stored filtered PPG waveform data files using the MATLAB program. Only five beats of PPG waveforms were extracted and modeled through 4th order Fourier and 2nd order Gaussian methods. The model coefficients were stored in the PPG model data file with the appropriate patient ID. A typical data file of 55 years of the patient was uploaded into a Dropbox folder with file ID. The model coefficients are shown in TABLE-I. Once the file got uploaded, it could be accessed from the remote end Dropbox folder and used for PPG waveform reconstruction. The reconstruction of PPG waveform using Fourier and Gaussian modeling of the original signal is shown in Fig.6 and Fig.7, respectively. In each case, the residual plot is shown, which indicates better results with the Gaussian model. By careful observation from the figures, it can be concluded that GM performs better compared to the FM. It was observed that better reconstruction results using 2nd order model for most of the cases. For the specified data set, the PRD and MSE were found to be 1.98 and 10.005 respectively with Gaussian model. The same data set for the Fourier model, PRD and MSE were 2.01 and 11.75 respectively.

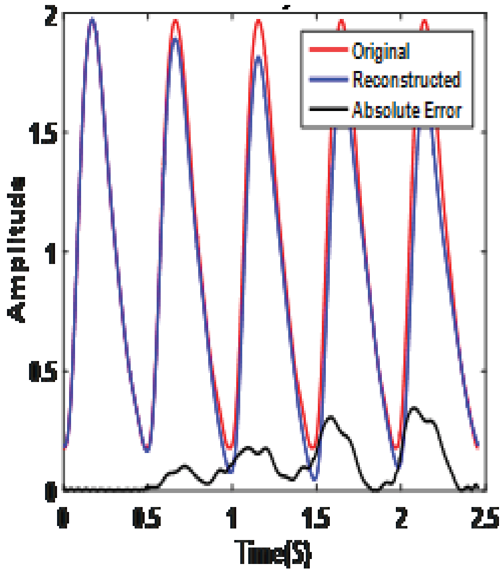

Fig.6. Reconstruction PPG waveforms with absolute error based on Gaussian Model

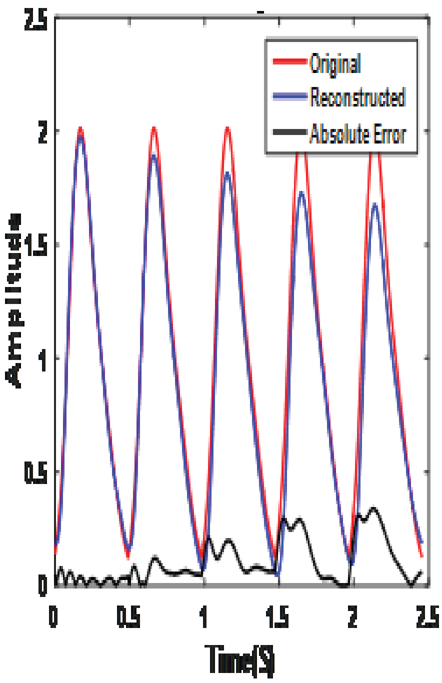

Fig.7. Reconstruction PPG waveforms with absolute error based on Fourier Model

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TABLE-I. BEAT WISE MODEL PERFORMANCE OF PPG SIGNAL

Patient-ID	Beat No	Model Parameters						Gauss Model		Fourier Model	
		Fourier (Order=4)			*Gaussian (order=2)*			*MSE*	*PRD*	*MSE*	*PRD*
		C_0	θ_n	ω_0	a_i	μ_i	σ_i				
55 Yrs.	1	1.00E+00	4.00E-02	1.29E+01							
		8.50E-01	4.75E-01	1.00E-02							
		2.10E-01	8.21E-01	0.00E+00	1.30E	1.40E-01	8.90E-02				
		4.80E-02	1.40E-01	0.00E+00							
		2.00E-02	-1.32E+00	0.00E+00	1.00E	2.50E-01	1.40E-01				
	2	8.80E-01	0.00E+00	6.8EE+00							
		5.40E-01	3.71E-01	0.00E+00							
		6.50E-01	5.60E-01	0.00E+00	1.28E	1.45E-01	8.75E-02				
		5.50E-01	1.83E-01	0.00E+00							
		1.50E-01	-2.50E-01	0.00E+00	1.00E	2.50E-01	1.41E-01				
	3	8.88E-01	0.00E+00	1.40E+01							
		7.80E-01	-5.60E-01	0.00E+00				10.005	1.98	11.75	2.01
		2.10E-01	6.60E-01	0.00E+00	1.20E	1.41E-01	8.01E-02				
		5.45E-02	-1.30E+00	0.00E+00							
		1.04E-02	-1.38E+00	0.00E+00	1.00E	2.45E-01	1.29E-01				
	4	7.28E-01	0.00E+00	8.10E+00							
		5.70E-01	1.38E+00	0.00E+00							
		4.50E-01	4.80E-01	0.00E+00	1.40E	1.38E-01	8.00E-02				
		3.00E-01	3.99E-01	0.00E+00							
		8.75E-02	3.40E-01	0.00E+00	9.80E-01	2.54E-01	1.39E-01				
	5	7.60E-01	0.00E+00	7.79E+00							
		3.45E-01	9.70E-01	0.00E+00							
		4.66E-01	4.55E-01	0.00E+00	1.10E	1.36E-01	8.29E-02				
		3.24E-01	2.75E-01	0.00E+00							
		9.56E-02	1.75E-01	0.00E+00	8.65E-01	2.56E-01	1.45E-01				

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IV. DISCUSSION

The present work has illustrated the basic scheme for IoT assisted PPG monitoring system. The proposed architecture can be implemented for patient health monitoring at the remote end, which could facilitate PPG, blood pressure, and oxygen saturation level measurement in clinical diagnosis. Thus PPG waveform data were transmitted to the IoT cloud using high-speed Wi-Fi networks over wide coverage areas. The IoT cloud could store the PPG model parameters with minimum storage space and may be accessed by users for aiming towards diagnostics and prognostics of cardiovascular diseases. The proposed system can be augmented by incorporating PPG signals thus enabling the determination of heart rate variability parameters. The performance of IoT cloud service depends on the reliability of the wireless networks by network service providers.

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