Fetal Electrocardiography and Web based Out-of-Hospital Monitoring System

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ABSTRACT
Recently, healthcare monitoring systems have utilized the modern wireless networks and internet technologies. One of the most developed applications in the healthcare monitoring systems is the fetal heart beat detection. The fetal heartbeat signal contains potentially precise information. This information could assist clinicians in making more appropriate and timely decisions during pregnancy period and labour. The continuous change in the fetal heartbeat signals during the pregnancy period pushes the researchers to focus on building the out-hospital monitoring system. This paper proposes an implementation of out-of-hospital fetal electrocardiogram (FECG) monitoring system. The proposed monitoring system comprises of an acquisition part and data transfer part. The acquisition part acquires FECG signal through use a Least Mean Square (LMS) based adaptive filter. In addition, this part has been written in MATLAB graphical user interface (GUI) to simplify the system usage by pregnant women. The other part uses the internet based web page to transmit FECG data to physicians for monitoring, diagnosis and pregnant care at a significantly low cost, regardless the location of pregnant women. Moreover, a database could be built at the hospital to manage the patients and physicians reports and decisions.

Keywords
Fetal electrocardiogram (FECG), fetal heart rate (FHR), out-of-hospital, health care monitoring.

1. INTRODUCTION
The Fetal Electrocardiogram (FECG), which is a part of the Electrocardiogram (ECG), simulates the electrical activity of the fetal heart inside the mother belly [1]. FECG produces such significant information about the physiological state of a fetus heart conditions during the pregnancy duration. Therefore, an early detection of any problem before delivery increases the effectiveness of the treatment [2]. The obtained FECG signals are a collection of low power sources and noise. This noise at the received fetal signals is the amplitude of mother ECG as a high amplitudes signal in comparison with fetus [1]. Numerous methods and approaches have been proposed and used for detecting of the FECG signal; such as adaptive filtering [3], wavelet analysis [4], and blind source separation (BSS), independent component analysis (ICA) [5]. Normally, pregnant women are required to frequently visit hospitals to monitor the health of fetuses and conduct the test of fetal's heart beat rate, and dynamic behaviors [6]. This pushed the researcher to find an alternative system based on remote monitoring health schemes. The remote health care monitoring of patients can be done using the internet that has played an important role in addition to wireless technology. Thus, instead of having to move patients to their caregivers, the patient can transmit medical information through the wireless network to the physicians regardless of geographical barriers and socioeconomic status [7]. The trend and desire is to allow pregnant women to receive ambulatory monitoring of FECGs at home through wireless telemedicine. Telemedicine is a new area of remote health care and a convenient way for patients to avoid frequent hospital visits, which leads to save more time of patients, doctors and medical expenses [6].

2. RELATED WORKS
Recent research showed numerous methods and approaches that dealt with FECG extraction. In addition, several health care projects are in full swing in different universities and institutions, with the objective of providing more and more assistance to the patient or fetus. The related work can be categorized into the three main parts described in the following subsection:

2.1 Fetus ECG
The FECG describes the electrical physiological activity of a fetal heart. It contains important indications about the health and condition of the fetus [8]. The fetal ECG extraction is an interesting and challenging problem in biomedical engineering. Therefore, many approaches have been proposed to get the FECG. In [2], the authors proposed neuron fuzzy logic technique namely Adaptive Neuron Fuzzy Interface System (ANFIS) to cancel the Mother ECG (MECG). They combined the advantages of neural network and fuzzy logic technique in order to prove the efficiency. While in [9], the authors demonstrated a system simulation to compare the performance of Recursive Least Square (RLS) and Normalized Least Mean Square (NLMS) adaptive filters, for detecting the Fetal Heart Rate (FHR). According to the results, the Recursive Least Square Adaptive Noise Canceller (RLS-ANC) technique gave better results compared with NLMS in realizing FHR monitoring. The proposed method of [10] went to highlight the clinical importance of applying this algorithm in understanding the health state of pregnant women and fetal heart, such as fetal maturity, fetal position. Thus, RLS blind signal separation algorithm of natural gradient and Empirical Mode Decomposition (EMD) has been combined to extract FECG. The proposed algorithm has been compared with the Fast Independent Component Analysis (ICA) algorithm.

2.2 Wireless Patient Monitoring System

Different studies have been proposed to address the issues of transmitting information for medical evaluation. Group of them went to discuss the implementation of health-related monitoring applications using technology and protocol ZigBee. The introduced system consisted of end units carried by patients that collect sensed data (health sign readings) and transmitted wirelessly to a coordinator unit [11]. The design and testing of a wireless ECG system was proposed using a wireless ECG device, as well as software to display the waveform remotely on a computer web page. The aim of this system was to serve as a means for a doctor or physician to check up a patient away from a hospital setting. The use of the internet and smart phone allows for this freedom. In addition, the author of [12] proposed wireless bio-sensing with smart phone based monitoring system. The proposed system was aimed to provide personal home telehealth system by using sensor integrates ECG front-end analog block to transmit the ECG signal, a micro-controller and a Bluetooth link to any smart phone which supports the Bluetooth low energy technology.

2.3 Wireless FECG Monitoring System

The core of wireless fetal ECG monitoring system is the design of wireless monitoring terminals. These terminals are used to transmit information for medical evaluation and take the suitable medical decisions to ensure the safety of the fetus during pregnancy. Therefore, the FECG is became an important branch in telemedicine. Recent research papers have been included: In [14] simple and portable emergency medical care for fetal ECG monitoring system was implemented. This work included both hardware and software. The hardware part was used to collect data acquisition system utilizing microchip called CARDIC. While, the software part was used to write algorithms and customized application for the networking and Fetal Heart Rate (FHR) monitoring systems. In [15] the system named, telefetalcare was built, to guarantee a deep continuous screening of fetal monitoring. Additionally, the proposed system allowed the pregnant women to monitor health state at home without moving to the hospital or asking for clinicians support. While the authors in [6] introduced the Block Sparse Bayesian Learning (BSBL) framework to reconstruct non-sparse FECG signal with high quality/explore and exploit correlation structure of signals. These two unique abilities made the acceptance of BSBL framework successful in wireless FECG telemonitoring and a challenge for compressed sensing (CS) algorithms.

3. PROPOSED SYSTEM DESIGN

During recent years, FECG monitoring systems become one of the important factors in ensuring the safety of the fetus during pregnancy. Therefore, the continuous FECG monitoring through a wireless system is highly desirable to ease the fetal well-being. In this paper, the propose system consists of measuring device that has been is simulated using MATLAB based Graphical User Interface (GUI) to ease its use. Moreover, a home server is considered as the base station or mobile terminals as well as the structure of database inside designed web pages. This section is divided into two main parts as follows:

3.1 Extraction FECG and Design GUI

The extraction method of fetal ECG and converting it to GUI in MATLAB to facilitate its use have been explained in the following sub-section.

3.1.1 FECG Extraction

The FECG extraction has a vital role in medical diagnosis during pregnancy using electrodes placed on the maternal abdomen and chest. The abdominal is a composite signal, consisting of the contributions from maternal electrocardiogram (MECG) and the FECG, while the chest contains MECG only [16]. No current standards exist for electrode location, but concentric circles on the abdomen, covering all available angles will provide the maximal coverage. Fig. 1 illustrates the lead positions that are proposed to probe the mother's signals [17].

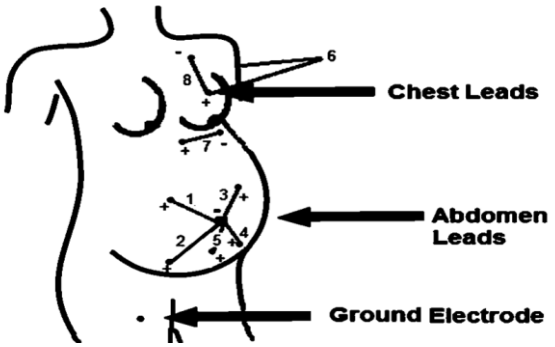

Fig 1: Proposed lead locations [17]

As shown in this figure, the navel is considered as the reference electrode of the leads, which is connected to the negative line of the instrumentation amplifier [17]. The data collecting electrodes (1, 2, 3 and 4) are located in 7cm away from the navel, whereas electrode 5 is only 5cm below the navel. The ground electrode is located on the top of the right thigh. Although there are many other lead configurations, this suggested one guarantees a full encirclement of the fetus heart because the leads are set as close as possible to the fetus. For thoracic leads, lead 6 is located such that the positive electrode is set 18cm away from the navel, whereas the negative electrode is put on the opposite side of the positive lead, i.e., on the back. For lead 7, the positive electrode is located 15cm away from the navel, and then moved to the left 10cm to the negative electrode. Finally, lead 8 starts from the same point of positive lead 6, then moves up 6cm to its negative electrode [17]. The extraction of FECG from the mixed (mother and fetus) signal can be reframed in a well-organized manner using various signal processing techniques. This paper adopts adaptive filter and Least Mean Square (LMS) Algorithm. As shown Fig. 2, a basic Adaptive noise cancellation (ANC) system has been considered. The noise canceller needs a reference signal generated from the maternal electrocardiogram to perform this task. The primary signal is FECG signal added with MECG signal and the secondary signal is the reference signal which is the noise to be canceled i.e., MECG signal. The secondary noise signal must be well-correlated with the noise in the primary signal. Adaptive filters are used in fetal electrocardiography, in which a maternal heartbeat signal is adaptively removed from a fetal heartbeat signal [16].

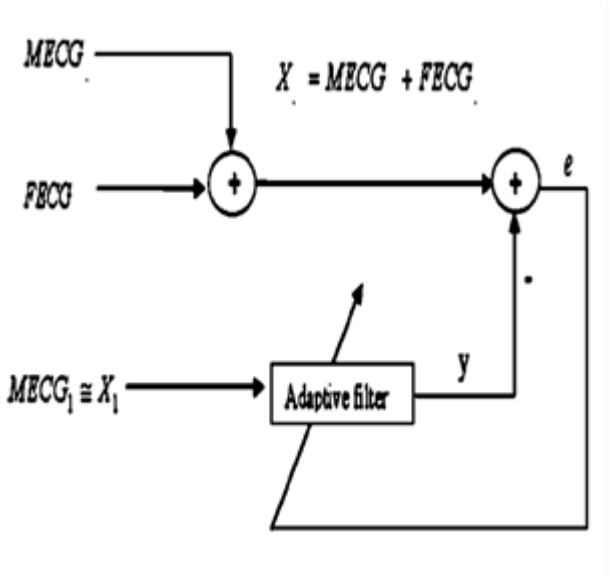

Fig 2: Adaptive noise canceller [16]

The basic steps of implementing FECG extraction are shown in Fig. 3 as a flow chart. Recorded ECG signal is obtained from real pregnant woman's chest and abdomen, or Daisy dataset can be obtained from sista website [18]. Adaptive noise cancellation process exploits the principle of LMS adaptive filters to extract FECG. Not all the database abdominal signals embrace fetal signals with the same power; therefore, sometimes the extracted FECG still contains maternal spikes which are in fact the mother QRS (MQRS) wave of the mother's ECG which deforms the FECG.

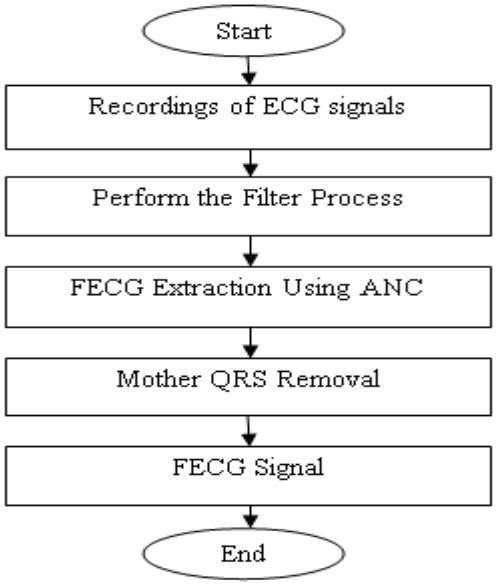

Fig 3: Steps of FECG Extraction

3.1.2 MATLAB GUI Design

A graphical user interface (GUI) is a graphical display in one or more windows containing controls, called components, to enable a user to perform interactive tasks. The GUI is kept waiting for the user to manipulate the required control, and then responds to each action sequentially. The user of a GUI is not need to understand the details of how the tasks are performed unlike code programs to accomplish tasks [19]. These tasks helped the patients to learn how to use the device. Figure 4 shows the designed GUI. This GUI consists of a set of steps to reading pulse of the mother and fetus at different locations used in this work shown in Fig. 1. In addition, it consists of a set of different control buttons such as a "close" button to close the program, "help" button to guide patients on the proper use of the program. Then, the collected readings are transferred to the computer as images using "collect" button. These images to be sent to the doctor through the internet.

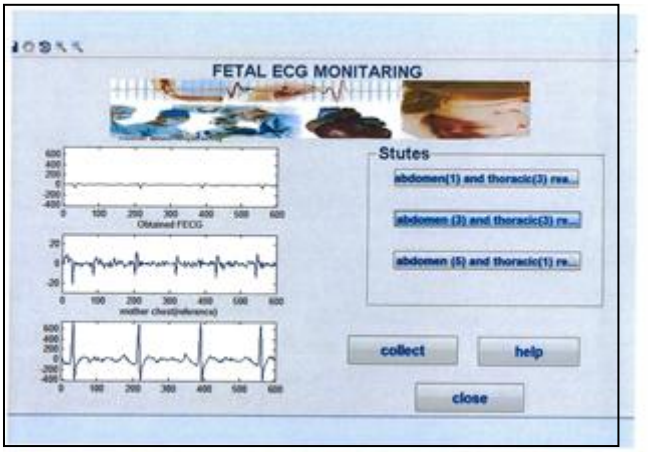

Fig 4: GUI design

3.2 Web Page Design

This sub-section explains the design of the hospital web page. The designed web page is responsible for controlling data flow between the pregnant and physician to take the appropriate medical intervention. The web page design, as show in Fig. 5, consists from different sections such are: main, departments, doctors, patients, help, contact us. Each section has a job to do: such as "main" part explains the location and function of web page. Additionally, "departments" show medical departments and prominent doctors enrolled in the terms of reference on the site and the possibility to send them. Moreover, the "doctors" are a special section of physicians, which is protected by password specified for each doctor to access his/her own page and access to the messages of patients and recording new patients. Furthermore, "patients" is a special section that is protected by serial numbers. This serial numbers is given to the patient by the physician to access a particular page and correspondent the doctor. On the other hand, the "help" section assists the patients to know all the sections of the website. "Contact us" is a reporter officials for the site in the event of a line certain. All information related to physicians and patients he/she joined in the site are stored in a database designed for this purpose.

This page represents a home page to the hospital monitoring system. In medicine, monitoring is the observation of a disease, condition or one or several medical parameters over time. It can be performed by continuously measuring certain parameters by using a medical monitor.

Fig 5: Web page design

The flow chart of Fig. 6 explains the procedure of sending FECG data from patient to the doctors and takes an appropriate medical interaction as shown in.

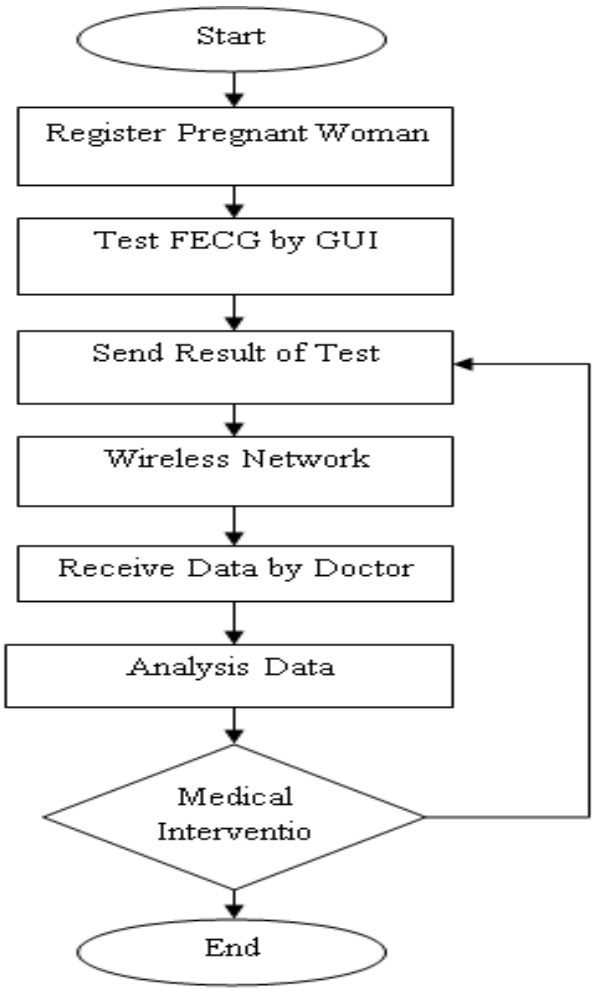

Fig 6: The flow diagram of system

4. THE RESULTS

The results consist two sections the first section is GUI to extract pulse of fetus and send the result to doctor, the second section is web page to receive the data by internet and take medical intervention.

4.1 FECG Extraction

The results of FECG extraction from composite signals are taken with different parameters and different sources of raw abdominal data. These data are used as a source data to implement FECG extraction. In this paper, the daisy sample is adopted as a source data to get FECG as shown in Fig. 7.

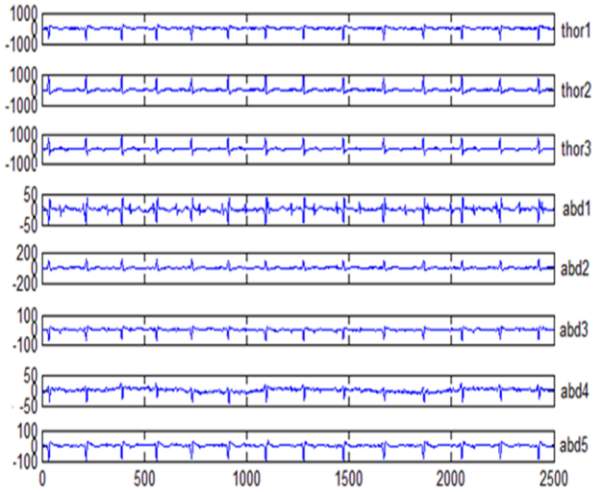

Fig 7: Daisy database

To get the pulse of the fetus, two signals are taken, one from mother chest (mother pulse) and the other from the mother's abdomen (mother and fetus pulse) as defined locations in Fig.1. Finally, FECG is obtained by applying processing filtering on both mother chest and mother abdomen. Parameters of adaptive filter can be changed to give the best reading of the pulse of the fetus, as show in Fig. 8 and Fig. 9. These figures explain three different signals to two different cases, which are saved in personal computer to send it to doctor by internet.

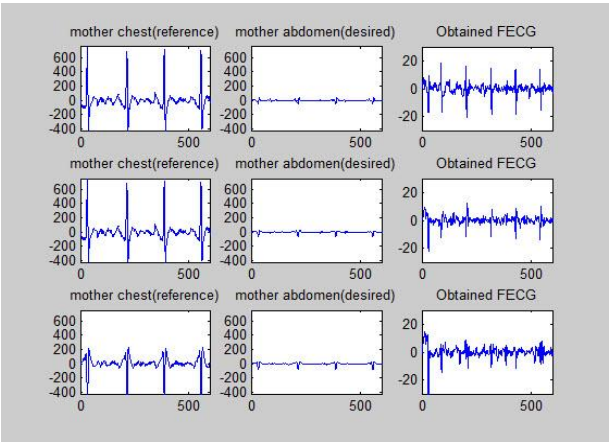

Fig 8: Three different signals, case one

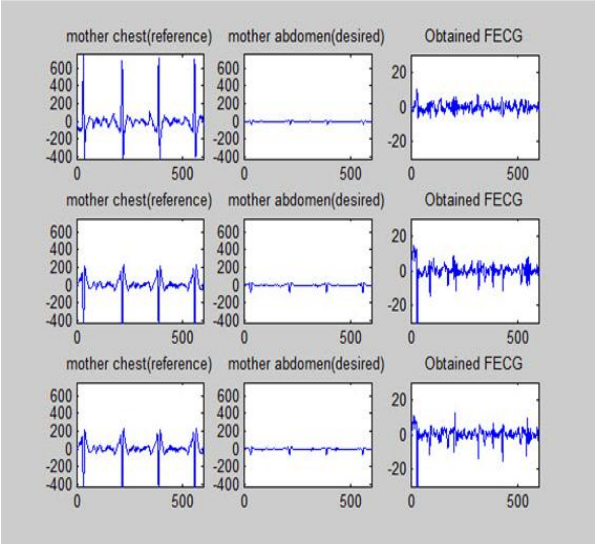

Fig 9: Three different signals, case two

4.2 Web Page

This section explains the web site and database used to save information for patients. When the pregnant women visit the hospital, the doctor registers their on the database of the medical site. Additionally, all relevant data and the health status experienced by the pregnant women are involved in the database. The proposed system has the ability to change the situation, and give number to enter it into the pages of registered patients to contact the doctor and see the results. When, the doctor sign in to inbox messages, the found messages are highlighted by colors to adopt red for emergency medical condition, yellow for an critical and the green natural state. Figures (10)-(11) explains the patients register method to different cases done by the supervisor doctor. All the entered data is stored in a table based data base. This table as shown in table 1.

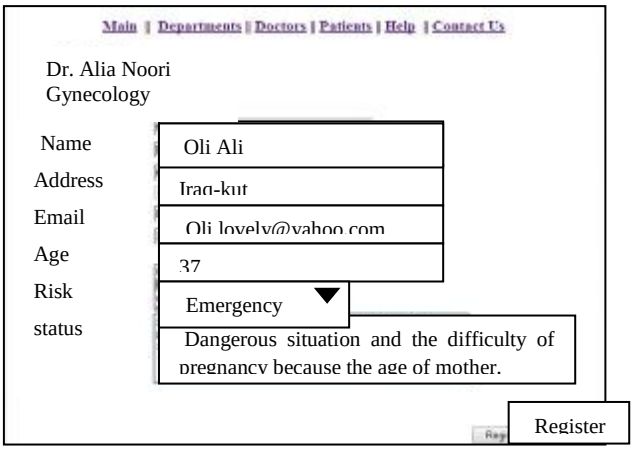

Fig 10: Register method, case one

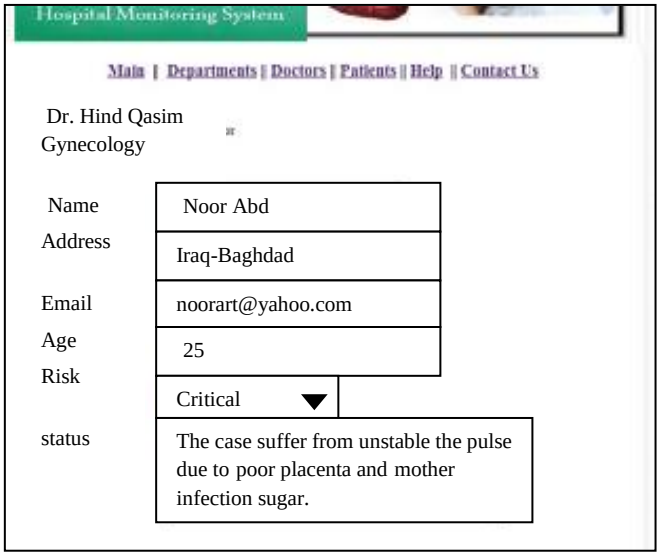

Fig 11: Register method, case two

Table 1. Stored data base of patients

No.	Patient name	Doctor name	Risk	Status
1	Oli Ali	Alia Noori	emergency	Weak pulse of fetal
2	Noor Abd	Hind Qasim	Critical	Stable situation somewhat but need more attention
3	Hba Rame	Ahmed Mosa	Normal	Situation stable and pulse normal fetus

Patient name represents a web link to shows all the register details. Figure 12 show examples of received messages.

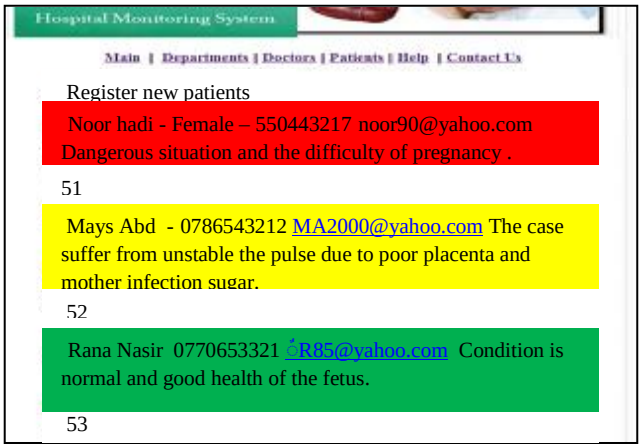

Fig 12: Received email from patient

5. CONCLUSIONS

In this paper, the architecture of an e-health system that can be used to remotely monitor the health status of pregnant women has been proposed. The monitoring can be performed even at pregnant women's house. The proposed approach of using adaptive filter to extract fetal ECG was successfully designed. The remote FECG monitoring system was also developed and tested successfully. The web page system enabled transfer of FECG, dislay, retrieves, update and create patient's medical record database. Thus, FECG extraction and the real time implementation of FECG data transfer are achieved. This system represented an important in the treads of efficiency of the primary care and cost reduction of him continues monitoring of the patients.

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