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Smart Fetal Care

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Abstract

The exam of fetal well-being during routine prenatal care plays a crucial role in preventing pregnancy complications and reducing the risks of miscarriages, birth defects and other health problems. However, the conventional prenatal screening and diagnosis is conducted by medical professionals in a clinical environment, which is subject to certain limitations such as manpower, medical devices and location, time and cost of services, etc. This paper presents a new approach to detect and monitor fetal movement safely and reliably without any constrains of time, environment and cost. Unlike the conventional method, our contribution includes a novel soft sensor pad which can automatically detect fetal movement and uterine contraction non-intrusively and the robust data analysis software to monitor pregnancy health and screen abnormalities with quantitative assessment. The monitoring belt embedded with the soft sensor pad is wearable, non-intrusive, radiation free and washable. The new algorithms are robust for noise removal, feature extraction, time sequence data analysis and decision support to achieve personalized care. Both the design of soft sensor pad and functions of the belt are original and unique. The results of preliminary clinical trials demonstrate the feasibility and advantages of our prototype.

Introduction

Prenatal care is important to promote a healthy birth by providing regular medical check-ups to ensure healthy pregnancy that benefits both mother and child. The exam of fetal well-being during routine prenatal care plays a crucial role in preventing pregnancy complications and reducing the risks of miscarriages, birth defects and other health problems. However, the conventional prenatal screening and diagnosis is conducted by medical professionals in a clinical environment [1-3], which is subject to certain limitations such as manpower, medical devices and location, time and cost of services, etc. By contrast, the unconventional and creative aspects of our idea of soft sensor monitoring belt aim to overcome these limitations by integrating the advanced technologies for wearable sensors, big data analytics and mobile computing for personalized antenatal care. More specifically, we develop a novel soft sensor pad which can automatically detect fetal movement and uterine contraction non-intrusively together with the robust data analysis software to monitor pregnancy health and screen abnormalities with quantitative assessment. Based on the extensive patent search, no such a product is currently available which meets all of the requirements such as safe, non-intrusive, radiation free, personalized, reliable, automatic, mobile, quick, wearable, comfortable, convenient and cheap.

System Framework

We aim to overcome the limitations of the conventional methods by integrating the advanced technologies for wearable sensors, big data analytics and mobile computing for personalized fetal care. In particular, we develop a novel soft sensor pad which can automatically detect fetal movement and uterine contraction non-intrusively together with the robust data analysis software to monitor pregnancy health and screen abnormalities with quantitative assessment. More specifically, our approach is characterized by three key components: 1) soft sensor monitoring belt embedded with a soft sensor pad, 2) control module and 3) dtata analysis software for personalized detection and mornitoring. A user-friendly mobile app is developed to assist the pregnant women to monitor fetal movement, which is shown in Fig. 1. The framework of soft sensor monitoring belt for smart fetal care is shown in Fig. 2; and the System structure of the smart fetal monitoring is shown in Fig. 3.

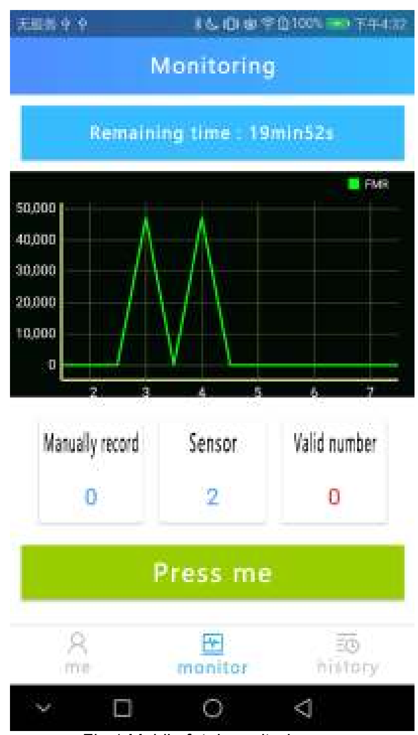


Fig.1 Mobile fetal monitoring app

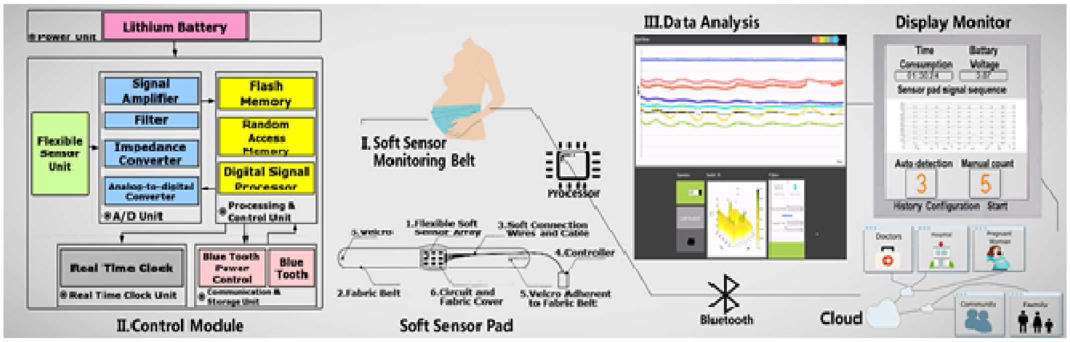


Fig.2 The framework of soft sensor monitoring belt for smart fetal care.

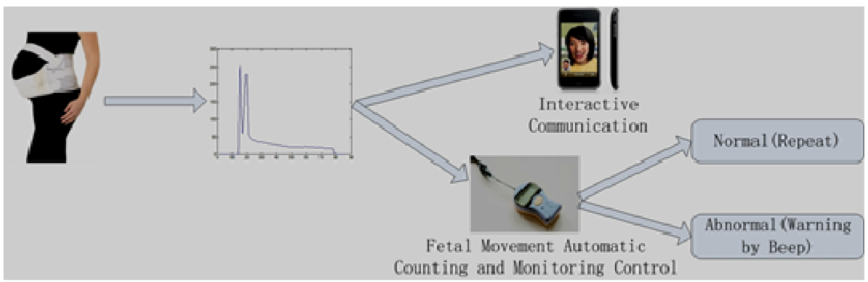


Fig.3 System structure of the smart fetal monitoring

Method

Our approach is originated from the collaboration with medical doctors to develop a new model of hand-held Doppler fetal monitor with mobile facilities for prenatal care. Clinically a reduction or absence of fetal movement is an alarming sign of fetal compromise or even death. To overcome the limitations of Doppler fetal monitor with ultrasound exposure and other sensors and devices, we developed a soft sensor monitoring system which consists of three components as shown in Fig. 2 – I. Soft Sensor Monitoring Belt, II. Control Module and III. Data Analysis. The soft sensor monitoring belt is embedded with a soft sensor pad to capture signals of fetal movement, or uterine contraction. The control module processes the data in a real-time fashion to achieve personalized detection and monitoring with the embedded robust data analysis software. The data analysis software provides robust algorithms including deep learning and ensemble learning for data enhancement, fusion, pattern classification and time series of pattern analysis. The control module provides reliable online service for real-time monitoring and issuing warning signals if any abnormalities occur. The following highlights the functionalities and implementation of the three key components of the system.

1) Soft sensor pad
Our new design of soft sensor pad is made of a two-dimension array of soft pressure sensor strings. The connection of different sensor components is arranged in a flexible structure so as to make the sensor pad robust to disturbances with the expected signal by applying competitive algorithm to enhance signal. The innovative aspect of our new soft sensor pad is to enhance the system performance by a control module with an embedded DSP for data processing.

2) Control module
A special control module with embedded DSP is for system control and performance enhancement, which provides robust algorithms for data enhancement, representation, storage, analysis, transmission and security protection.

3) Robust Data Analysis for Personalized Healthcare
The software development of smart fetal care by fetal health monitoring resolves around the new methods and robust algorithms including deep learning and ensemble learning to handle the three fundamental issues: multiple feature extraction and fusion, detection of movement, classification for abnormities detection. The original signal is enhanced by autocorrelation and scale production. Through simple thresholding, the signal could be classified as fetal-movement signal and non-fetal movement signal. Using the initial detection result as feature vector, better result could be achieved by supervised learning. We propose an ensemble learning framework here. First, multi-channel feature vectors of fetal signals are extracted by simple thresholding. Second, the framework adopts data transformation techniques, such as bagging, to generate a set of new training datasets $\{D^1, \ldots, D^B\}$ (where B is the number of new training datasets) to maximize their diversity. Third, a set of oracles $\{O^1, \ldots, O^B\}$ are trained by the newly generated training set. A confidence factor α_j ($j \in \{1, \ldots, B\}$) can be calculated based on these two prediction results in terms of suitable measure. Finally, a consensus function Φ is designed to combine the prediction results $\{P^1, \ldots, P^{2B}\}$ and the confidence factor $\{\alpha_1, \ldots, \alpha_B\}$ from multiple classifiers, and predicts the labels of the fetal movements in the test set.

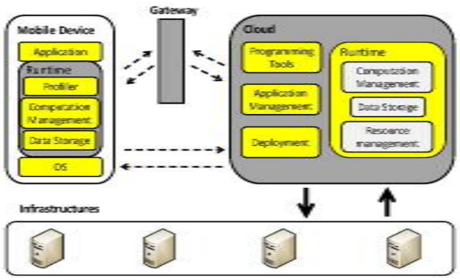
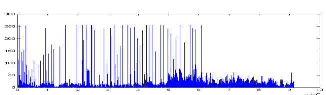


Fig.4 The workflow between mobile devices and the cloud server

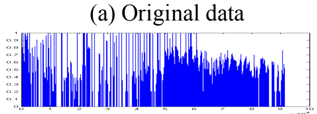
Experimental Results

A preliminary clinical trial was conducted at Guangzhou Women & Children Medical Center and Guangzhou No. 3 Hospital, China. Four groups of volunteer subjects participated in the trial. The testing includes both the automatic counting of fetal movement by signal analysis and the manual counting by over 80 volunteer subjects over 3-month data tracking and comparison studies.

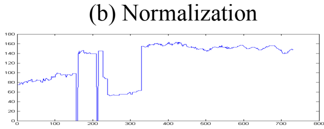
The fetal movement and other interference signals (human movement, breathing, etc) are simulated using a specially designed water channel. Gaussian noises are generated using the largest amplitude of the fetal movement. Fig. 5 illustrates the effect of noise removal on a sequence of signals. The SNRs are recorded in Table 1. The signal power is calculated including the interference signals. Fig. 6(a) shows the data distribution, where the fetal movement was captured and recorded in the 7th and 8th signal channel while the marker set by the volunteer subjects is recorded in the 9th row. Fig. 6(a) shows the fetal movement detected in different channels. able 2 presents some detail performance values. Better results are achieved by adopting the ensemble learning algorithm.



(a) Original data

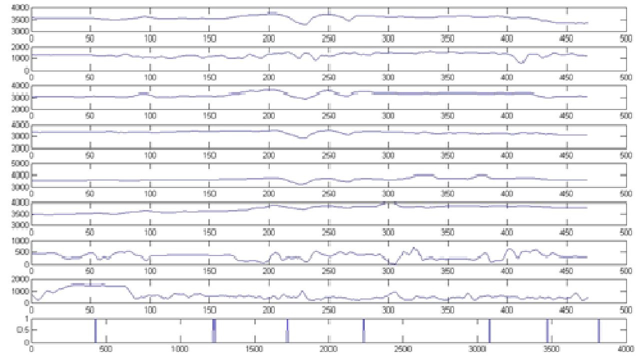


(b) Normalization

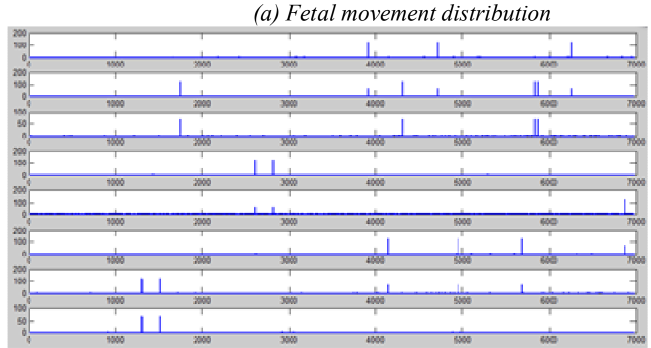


(c) De-noised result

Fig. 5 Noise removal and signal enhancement testing.



(a) Fetal movement distribution



(b) Fetal movement detected

Fig.6 Fetal movement detection.

Table 1. SNR record.

	Original signal	De-noised signal
SNR (dB)	12.6	140.1

Table 2. Performance Matrix.

Data Set (No. of data)	Method	Accuracy (%)	FPR (%)	Sensitivity (%)	Specificity (%)
120600	KNN	82.8	1.7– 17.5	76.1–88.2	82.6–99.8
	Ensemble	84.9	1.4– 17.8	77.1–89.2	83.6–99.8
252739	KNN	79.1	7.1– 16.2	61.3–68.2	63.3–66.7
	Ensemble	79.8	6.5– 16.1	62.1–69.4	64.4–67.9
26777	KNN	85.9	1.3– 13.5	72.5–83.7	76.6–96.8
	Ensemble	87.3	1.1– 12.7	73.4–84.5	78.2–98.3
40924	KNN	80.2	1.2– 18.3	55.2–93.7	79.1–98.7
	Ensemble	80.8	1.1– 17.8	56.0–93.9	79.7–98.7

Conclusions

We aim to overcome conventional limitations by integrating the advanced technologies for wearable sensors, big data analytics and mobile computing for personalized antenatal care. The novelty of the reported work in this paper is summarized as follows: 1) a new wearable/waterproof/radiation free belt embedded with a soft sensor pad to capture signal of fetal movement or uterine contraction; 2) a unique design of control module to achieve personalized detection and monitoring in a real-time fashion; 3) robust algorithms for signal enhancement, fusion of multi-channel data, automated detection of abnormalities and pattern analysis of a time series of data; 4) interactive communication via internet/mobile network.

The significance of the work is demonstrated by its impact on a wide range of aspects such as healthcare service (enhancing medical service to families and reducing workload of doctors); scientific and technological impact (new findings for healthcare and other services); economic growth (a new healthcare product with excellent market potentials); and social benefits (quality of living and family life).

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Author Biography

Jane You is currently a professor in the Department of Computing at the Hong Kong Polytechnic University. Prof. You obtained her BEng. in Electronic Engineering from Xi'an Jiaotong University in 1986 and Ph.D in Computer Science from La Trobe University, Australia in 1992. Prof. Jane You has worked extensively in the fields of image processing, medical imaging, computer-aided detection/diagnosis, pattern recognition. So far, she has more than 280 research papers published. She has been a principal investigator for two ITF projects (Innovation Technology Fund), four GRF projects (General Research Fund) supported by Hong Kong Government and many other joint grants since she joined PolyU in late 1998. Her research output has led to three US patents, technology transfers and international awards. Prof. You is also an associate editor of Pattern Recognition and other journals.

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