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# Building the Internet of Things platform for smart maternal healthcare services with wearable devices and cloud computing

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ABSTRACT

In recent years, the industry of wearable devices for pregnancies has been developing rapidly. The devices ranges from foetal monitors to multi-functional health examination instruments, which helped monitoring and management of maternal health indicators such as foetal heart rate, blood glucose, and blood pressure in home. Pregnant women and obstetricians are bounded together by wearable devices in an unprecedented way. With the universal use of the Internet of Things technology, the Smart Maternal construction started to raise people's attention. This article proposes an Internet of Things platform for smart maternal healthcare services with wearable devices and cloud computing and the key technologies. We also investigate its applications, and monitoring and management modes in home for obstetrics departments in hospitals. The Smart Maternal platform, which is based on the Internet of Things and centres on pregnant women, is able to greatly mitigate the workload of medical staffs, increase the work efficiency, facilitate the pregnant women to go to the doctors and improve the quality of obstetrical treatment.



## 1. Introduction

As one of the contents of public health, maternal and child healthcare is increasingly valued by governments. With the child-bearing policy carried out, aged tendency of population, the increasing of chronic disease and the development of economy in China in these years, birth defects such as high-risk pregnancy, foetal congenital heart disease and women with two cancers have become major public health issues in the field of maternal and child health. And governments at all levels in China invested heavily in these major health issues. In recent years, China has been experiencing rapid urbanisation and industrialisation. However, the medical treatment service, especially the obstetrical treatment is underserved. The efficiency of medical staff is reduced and the pressure of high-quality service is increasing. China is one of the countries that possess high incidence of birth defects and a great part of medical and obstetric resources are devoted to the diagnosis and treatment of perinatal birth defects and congenital heart disease.

Even though foetus is inside the pregnant woman's body and the pregnant woman is the most direct and the most dedicated guardian for the foetus. The pregnant women are not able to learn the health of the foetus even the life risks occurs without the help of external technical means. Therefore, foetal monitoring is an essential tool for obstetricians to learn the vitals of pregnant women and the health of the foetus [1]. Foetal monitoring, which is easy to operate and safe and reliable, is being widely used and mastered by maternal and child healthcare institutions at all levels in China [2–4]. However, foetal monitoring used by most hospitals in China still has followed deficiencies.

First, it is failed to achieve information sharing. Monitoring results in most hospital need to be printed, which makes them unsuitable to store, easy to lose, and cannot realise timely sharing of monitoring information and multi-person consultation. These factors cause inconvenience to the doctors' clinical work, or even delay the diseases, leading to medical accidents. Second, it is unable to realise intelligent real-time monitoring and early warning function: from the perspective of quality management, when pregnant women are in obstetrics department, they are along with problems like a mass flow of other pregnant women, high emergencies and high risk. If emergencies happen during the monitoring process and they cannot notify doctors in time, they may miss the optimal time to be rescued, which may put them at life-threatening risks and cause some serious adverse consequences. Third, it is failed to realise humanised in-home health monitoring: Nowadays, traditional healthcare systems can no longer satisfy the needs of continuously monitoring of pregnant women. As the mothers of foetus, pregnant women take an irreplaceable role in learning their babies. Therefore, in-home

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self-monitoring is a crucial content during perinatal healthcare period.

At present, healthcare based on "Internet+" and "Wise Information Technology of 120 (WIT120)" based on artificial intelligence as emerging industries, have become China's national action plan and have received great attention and strong support from all levels of government. With the comprehensive application of information platform and system, Internet, communication technology, Internet of Things (IoT), big data, cloud computing technology and wearable devices, IoT healthcare is gradually entering communities, families and grassroots levels. It provides targeted and personalised services to individuals which enables the telemedicine to progress from disease treatment to disease prevention, offering new ideas and new means for solving major public health problems in women and children's health [5–7].

Internet of Things (IoT) [8] refers to objects are connected through Internet, which means using modern information technology such as intelligent sensing, identification technology and wireless communication to realise the interconnection between objects. It is known as the third wave of information industry development after computer and Internet. M-health based on IoT is to utilise wearable medical sensors [9–11] to provide real-time feedback of the vital signs and medical information of patients and offer them with "anytime, anywhere" health services.

Architecture of healthcare software-as-a-service platform for cloud-based clinical decision support service has been designed in [12]. In [13], an interconnection framework for mHealth and remote monitoring based on the IoT has been proposed. In [14], an optimised IoT-based cloud service in next generation smart environments is given. The work [15] designed a hierarchical sensor-based healthcare monitoring architecture in wireless heterogeneous networks. Another work [16] also focused on heterogeneous wireless access networks and presented an optimised architecture for remote patient monitoring service. Regarding softwarisation, a software of Internet of Things infrastructure for secure and smart healthcare is developed in [17].

The aim of this paper is to design and develop an Internet of Things platform that provides smart maternal healthcare services with wearable devices for pregnant women and cloud computing techniques. It is able to achieve all-weather, all-round monitoring and early warning for pregnant women during the perinatal period, especially for the high-risk pregnant women. Through clinical practice such as screening, monitoring and emergency response and relevant clinical criteria, this platform will reduce high-risk conditions and adverse consequences that caused by neglect, omission or delay, making up for the perinatal care in China, especially the aspects of insufficient management of high-risk pregnancy.

This paper is organised as follows. We introduce wearable devices for pregnancies in Section 2. We describe the Internet of Things techniques used in the paper in Section 3. Then, we present the architecture and systems of the underlying platform in Section 4. The analysis of an experiment on the IoT platform based a questionnaire is given in Section 5. In Section 6, we present the challenges and opportunities of the IoT platform. Finally, the paper in concluded in Section 7.

## 2. Wearable devices for pregnancies

Wearable mobile medical devices have been widely used in clinical practice for a long time [18]. For example, the electrocardiographs that used commonly, sphygmomanometers and oximeters can all be carried and used. Computers can read and analyse the data after patient's detection. This kind of devices is called the first generation of wearable medical devices in the era of information and digitalisation. They have unquestionable professionalism and develop enormous medical value clinically. However, its comfortableness and usability are poor.

The advantages of wearable medical devices are mainly showed in two aspects from the perspective of medicine. (1) Some specific professional devices which have merits of intelligent, wearable and portable can detect health and disease status of vulnerable populations (e.g., pregnant women and elders) with low cost [19], thereby causing lower cost of money and time. For example, wearable medical devices not only saves the cost of examination for pregnant women with a history of heart disease or pregnancy and heart disease, but also declines the risk of accidents that happen in the round trip between home and hospital, improving the quality of care and medical experience. (2) By using wearable devices to accumulate long-term health data, patients with chronic diseases can avoid poor dependence of traditional disease diaries.

With the popularisation of smart mobile terminal devices and the rapid development of Internet cloud computing, and IoT, the application field of wearable mobile medical devices in maternal and child healthcare have become wider and wider [20–22]. At the same time, these devices accelerate the arrival of the era of intelligent maternal and child healthcare.

Compared with traditional maternal monitoring equipment, wearable devices break the traditional mode of physiological parameter collection and medical monitoring, and they can dynamically manage the vital signs data of pregnant women in real time. Pregnant women can use wearable devices themselves to detect their foetal heart rate, blood sugar, blood pressure, weight, pulse, blood oxygen, blood lipids, ECG, urine and other items.

Wearable medical devices engineered for pregnant women are portable accessories that have clinical health monitoring function. This new type of medical devices, which as accessory, integrates with cutting-edge technologies including advanced materials, sensing, circuit design, information transmission and information processing. They can implement the monitoring function while providing a comfortable and convenient experience. The appearance of wearable technology and the application and management in-home and in-hospital not only remedies the shortcomings of traditional maternity monitoring equipment that failed to continuously and dynamically detect pregnant women for a long time, but also overturn the traditional health monitoring management model for pregnant women.

In the 1990s, wearable devices for pregnant women have been popularised in major hospitals in Europe and America. After 2010, they gradually were out of hospitals and entered families. They were improved with more oriented and personalised service, and combined with big data [23] and cloud computing [24,25], making the maternal and child healthcare progresses from treatment to prevention. For instance, The University of Oxford in the United Kingdom applied mobile foetal monitor to improve the quality of perinatal care. What is more, it can remotely monitor multiple pregnant women at the same time.

China has a large population while medical resources are scarce and medical allocation is not so reasonable. Besides, with the opening of the full-scale two-child policy, the whole nation is achieving the peak of childbirth and the obstetrics of hospitals are filled to capacity. Due to the limited place, the number of pregnant women that can be accommodated by hospitals is restricted. The health problems of elderly pregnant women and high-risk pregnant women are becoming increasingly prominent. Therefore, it has become a common will of the whole society that construct a new maternal health family monitoring model to optimise the allocation of limited obstetric and gynaecology resources and allow as many pregnant women as possible to receive professional medical guidance as well as services. If a pregnant

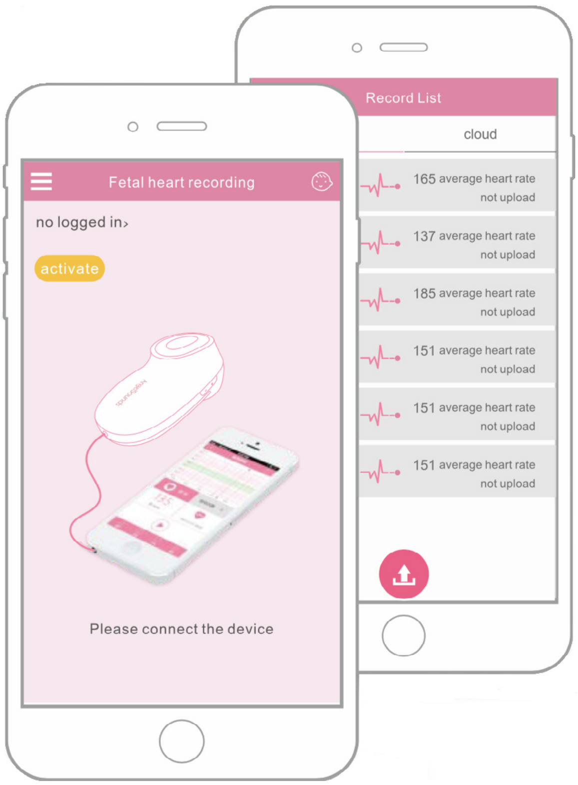


**Fig. 1.** The interfaces of a mobile application of the IoT-based computerised interpretation system for home use.

woman choose to line up in the hospital for routine check-ups, only one foetal heart rate monitoring may take about 50 min. Using wearable foetal monitoring at home can saves precious time. Moreover, it can be used anytime, effectively cutting down the incident rate of adverse pregnancy outcome.

As for pregnancy associated with high-risk factors, such as pregnancy associated with diabetes, elderly pregnant women' anaemia, gestational hypertension, placenta presentation, giant foetus, multiple pregnancy, etc. Obstetricians and gynaecologist can suggest that pregnant women should use wearable foetus-voice meter after 28 weeks of gestation to proceed self-monitoring at home for intimate dynamic detecting, then upload foetal heart monitoring online. As Fig. 1 shows, doctors are able to look over the foetal monitoring data at the mobile smart terminal APP at any time and interpret and provide targeted guidance. Additionally, for those pregnant women who are advanced age, anxious, or have received infertility treatment with artificial assisted reproductive technology to conceive, it may be more acceptable for them to use wearable remote foetal heart rate monitor at home and upload the foetal heart map to let the medical staff know the foetus's current status.

## 3. The Internet of Things platform

Internet of Things (IoT) [26–29] is a comprehensive technology, covering the whole process of acquiring, transferring, storing and disposing information. IoT has giant potential in the field of medical treatment and public health. For the patients, adhibitions like identifying patients' identifications, diagnosing with one specific card, collecting vital sighs etc. make the medical treatment more humanised. For individuals, the application of wearable health sensors make healthcare more scientific; devices like smart blood pressure monitors and thermometers, remote electrocardiographs make it more convenient for people to take care of elders [30]. For hospitals, using the IoT to execute treatment process management, equipment and instrument automation management and telemedicine can improve the healthcare services, strengthen the medical technology system, eliminate medical safety risks and etc. Therefore, IoT has a hugely vast application scenarios in medical healthcare area.

The smart maternal and child medical service platform presented in this paper is one of the application scenarios in the field of maternal and child healthcare. It is based on the core business of maternal and child healthcare and online services. And it centres on offline healthcare institutions, building a maternal and child life cycle big data centre based on Area Data Centres.

In addition, with the core of medical closed-loop service before, during and after the pregnancy, this platform utilises IoT technology to realise the integration and interconnection of families and hospitals. It integrates online and offline maternal and child healthcare services to realise foetal monitoring network, pregnancy hypertension monitoring system, pregnancy blood glucose management system, high-risk maternal management system, outpatient self-acquisition system, remote consultation system, medical treatment system, etc. These data collected by systems will be integrated in data platforms in hospitals to satisfy not only the needs of doctors, but also the personalised needs of pregnant women. Furthermore, to strengthen the management of high-risk pregnant women, the pregnant women can self-monitor their foetal heart rate, electrocardiogram, blood sugar, blood pressure, weight and so on.

The data transmission process of the remote foetal monitoring system is based on the IoT. Monitoring management system connects wearable intelligent foetal heart monitoring devices, uses mobile internet and integrates IoT technology to make the real-time seamless joint of hospitals, doctors and pregnant women come true, which on the basis of data. Hence, this platform can extent the foetal supervision service to families, which can prominently raise the level of health management during the perinatal period and decrease the maternal mortality rate. Remote monitoring management system can monitor three parameters, which are maternal foetal heart signal, uterine contraction signal and foetal movement signal. Without going to hospitals, pregnant women are able to interact with their doctors who are in hospitals by means of smart phone mobile APP and information management platform. Through data mining and analysis, interpretation and guidance from professional doctors, self health management is totally possible for pregnant women. What is more important is that wearable devices for pregnant women timely help reveal health concern and high-risks factors of pregnant women, so that hospitals can conduct timely interventions.

Through network information technology, important indicators such as maternal foetal heart rate signal and uterine contraction are collected and transmitted to the monitoring centre for analysis to help hospitals to judge the foetal survival status in utero. This helps learn the growth and development of foetus during the whole gestation period and offer timely health advice to pregnant women. Doctors can timely predict, prevent and dispose various factors affecting the foetus, such as hypoxia, intrauterine distress and so on. Intravascular Ultrasound Doppler flow mapping gains wide application and it is precision is highly recognised clinically. It meets the needs of general public pregnant women inspection and monitoring. Foetal ECG technology has advantages in portable, wearable and accurate monitoring, and it is more suitable for pregnant women who are elderly, high-risk or obese. Maternal-foetal ECG device will be developed to wearable and portable, as an upgrade of existing foetal heart monitoring.

Introduction of health monitoring management based on wearable devices in the obstetrics and gynaecology department can realise the dynamic real-time management of vital signs data of pregnant women, strengthen the perinatal monitoring, optimise the quality of pregnancy, reduce the pressure of outpatient service and antenatal care in hospitals and relieve the work intensity of obstetricians. We can create a brand new intelligent maternal and child management model to build the bridge between hospitals and hospitals, doctors and doctors, doctors and pregnant women, doctors and intelligent medical apparatus, pregnant women and intelligent medical apparatus through the combination of wearable IoT and Hospital Information System and Internet. This model can break through the information island, optimise the medical procedures, improve the medical environment, enhance the patients' satisfaction and provide professional and efficient management tool for medical staff, hospital administrators and health authorities as well.

## 4. Architecture and systems of platform

### 4.1. Architecture design

The platform engineered in this paper mainly consists of perception layer, network layer and application layer. Its construction is shown in Fig. 2.

The sensing layer mainly be applied to realise the collection of various physiological information, automatic identification and intelligent control. Obstetrical high-risk pregnancy monitoring and early warning for the IoT-based Platform for Smart Maternal Healthcare Services needs indexes including foetal heart rate, maternal blood pressure, maternal blood glucose, maternal weight, urine analysis, etc. The network layer mainly support the information transmission, routing and control of terminals and sensing extension devices, which provides communication support between pregnant women and devices, devices and terminals for home monitoring. Wearable devices primarily employ BlueTooth wireless technology nowadays. Application layer basically refers to detailed applications of mobile medical, which includes not only public service, but also professional service. It covers disease and health management in successive eras during the perinatal period. For instance, through foetal heart monitoring, foetal hypoxia and other symptoms can be discovered in time to prevent foetal distress caused by umbilical cord around the neck and other factors.

Take Shenzhen Bao'an maternal and child healthcare hospital as an example, once the hospital deploys this platform, the pregnant women who come to hospital to set their health records and take antenatal care can learn about hospital information, medical information, maternity school schedules, etc. in their first time by means of downloading the mobile APP. Additionally, they can watch online pregnant women' school video without going out, and they can make an appointment and sign in pregnant women' school courses offline, which improve the health education coverage and strengthen doctor–patient communication. Pregnant women can record and detect their self-health status in real-time by using wearable intelligent BlueTooth medical devices and mobile APP, further build their personal digital inspection files. When the health data exceeds the normal range, the hospital workstation system will automatically alarms and alerts the pregnant woman to the hospital for medical treatment. Meanwhile, doctors can provide personalised medicare program, which aims to better monitor the health of the pregnant women and foetus. Besides, the informationisation and integration of IoT-based Platform for Smart Maternal Healthcare Services are mainly reflected in the following aspects:

(1) Self-help setup of health records: pregnant women can employ intelligent women and children mobile to realise the establishment of "mother and child healthcare manual", and then fill the information, so that pregnant women who have accomplished the setup of health records can skip this step in hospital, which saves a great deal of time. Through the data interface, the hospital HIS system can directly recall data and print the contents of the books, greatly reducing the waiting time before diagnosis and decreasing the data entry errors effectively.

(2) Self-service collection and health education in hospital waiting rooms: when weight scale, sphygmomanometer, thermometer and other routine testing equipment in hospital are connected to the intelligent maternal perinatal health management system platform, the inspection data can be straightly recorded under the name of the pregnant woman's personal health file. The HIS system can directly recall the data from the files so that it no longer needs medical staffs to record data manually, which cuts down about 10 min for waiting of one patient.

(3) Integrated foetal heart monitoring in-hospital and out-hospital: Foetal heart monitoring takes a long time, normally is 25 to 30 min, and it takes longer if abnormality exists. Therefore we put forward the integrated foetal heart monitoring based on in-hospital and out-hospital. Pregnant women can go to the foetal heart monitoring rooms to detect, but also can buy or rent the devices, use the smart terminal APP to notify the medical staffs to remotely monitor and provide accordingly guidance.

(4) Application of cloud computing: the application of cloud computing allows nurses and doctors to use portable tablets to view the medical records, so that they no longer need to make the rounds of the wards with paper medical record. At the same time, doctors can realise voice writing medical records and medical advice, voice and video consultation, and they can use their mobile phone to view patients' reports and temperature list, which is more convenient for doctors to operate. The document such as temperature list recorded by nurses can also be collected by wearable device and recorded by voice.

Reasonable application and management of wearable devices for pregnant women can decline the number of visits and hospitalisations for pregnant women, which enormously economise the expense and cut down the human cost. The management of wearable devices for pregnant women depends not only on the hardware and software technology, but also on the realisation of mobile medical and remote monitoring, and needs support of reasonable medical management model.

Nowadays, the medical model in maternal and child area in China differs from other countries, and there are two main management mode: (1) equipment manufacturing, operation companies and hospitals directly cooperate with each other; (2) enterprises construct their own telemedicine centre. The appearance of wearable devices is slowly driving the transformation of maternal and child health care industry, and posing new challenges to the existing medical mode. Though pregnant women can self-collect data in home at anytime, the data is quite different from that monitored in hospitals in accuracy. Besides, due to the reality that the industry's internal standards delay behind the development of technology, the establishment of corresponding laws and regulations is also delaying.

### 4.2. System components

The construction content of this platform includes maternal and child data integration system, perinatal health management system, maternal and child intelligent follow-up system and intelligent maternal and child management and control system. The system deployment and logical architecture are shown as Figs. 3 and 4.

Maternal and child data integration platform realises the exchange of unified data and transmission standards. It offers comprehensive standardised interface, which not only satisfies the

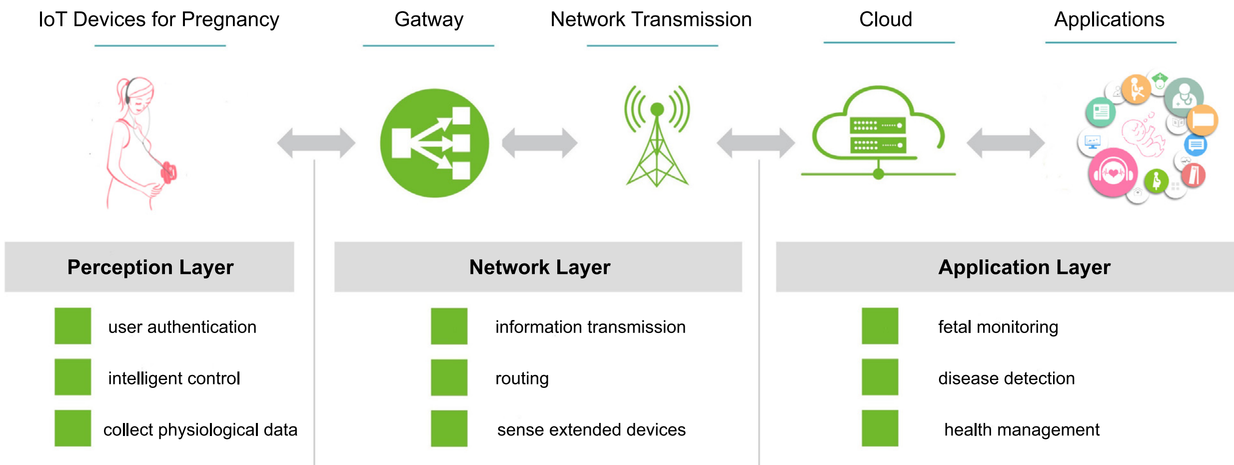


**Fig. 2.** Three Layers of Platform Architecture.

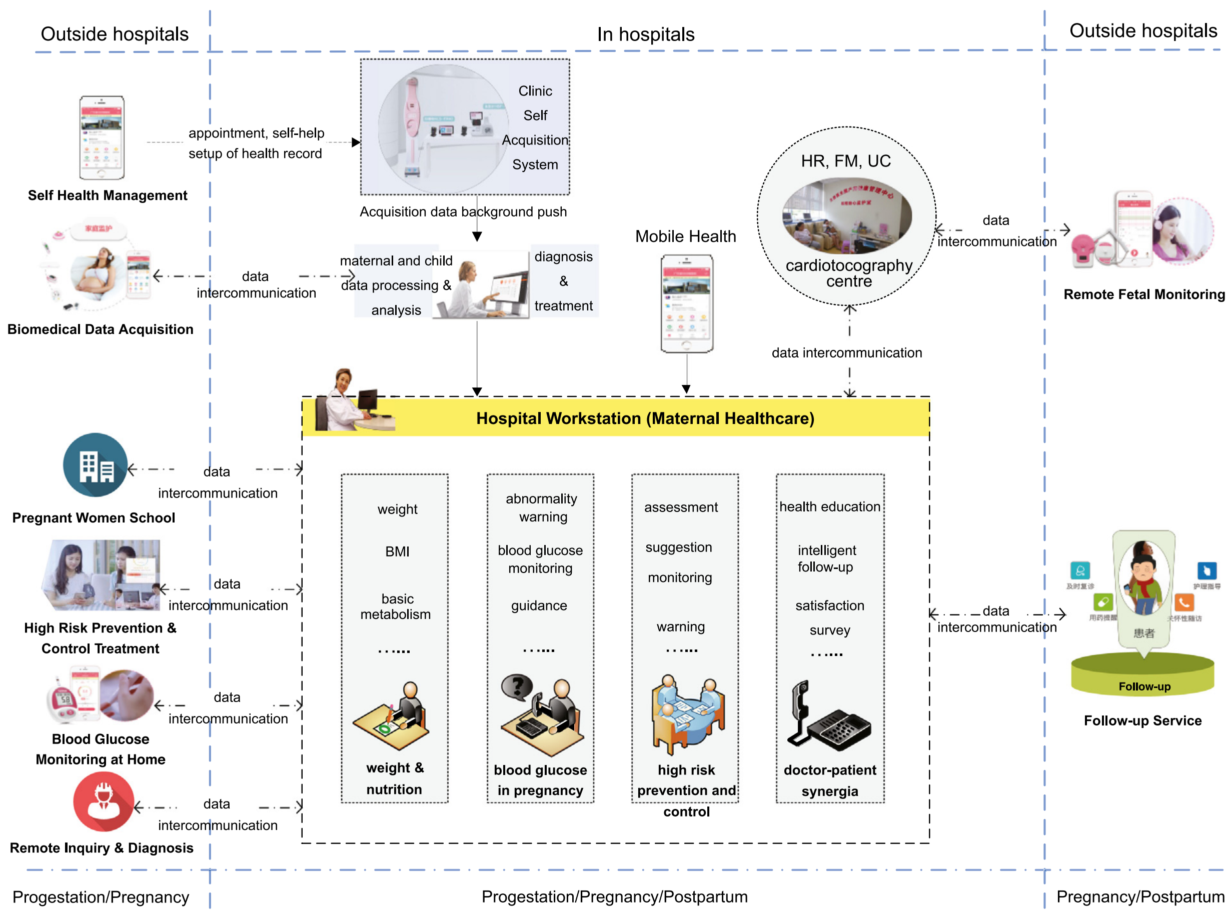


**Fig. 3.** Progestation, pregnancy and postpartum working flow of the platform.

need of vertical connection between subsystems in the system, but also meets the need of the horizontal connection with the superior departments, other systems and hospital information systems. In this way the phenomena of information isolated island and data gap can be eradicated. The maternal and child data integration system includes six primary functions, which are single sign-on, unified authentication, data standards, patient primary index, data integration, enterprise service bus and panoramic health file.

Perinatal health management system provides information platform service for hospitals, doctors and pregnant women. First, doctors and hospitals are able to manage the information of pregnant women systematically by using the database and proceed real-time monitoring during the entire process, which is particularly crucial for high-risk pregnant women. Second, through the mobile technology, pregnant women are capable to contact with the doctor at anytime, realising early discovery and early interference for high-risk factors and decreasing the occurrence

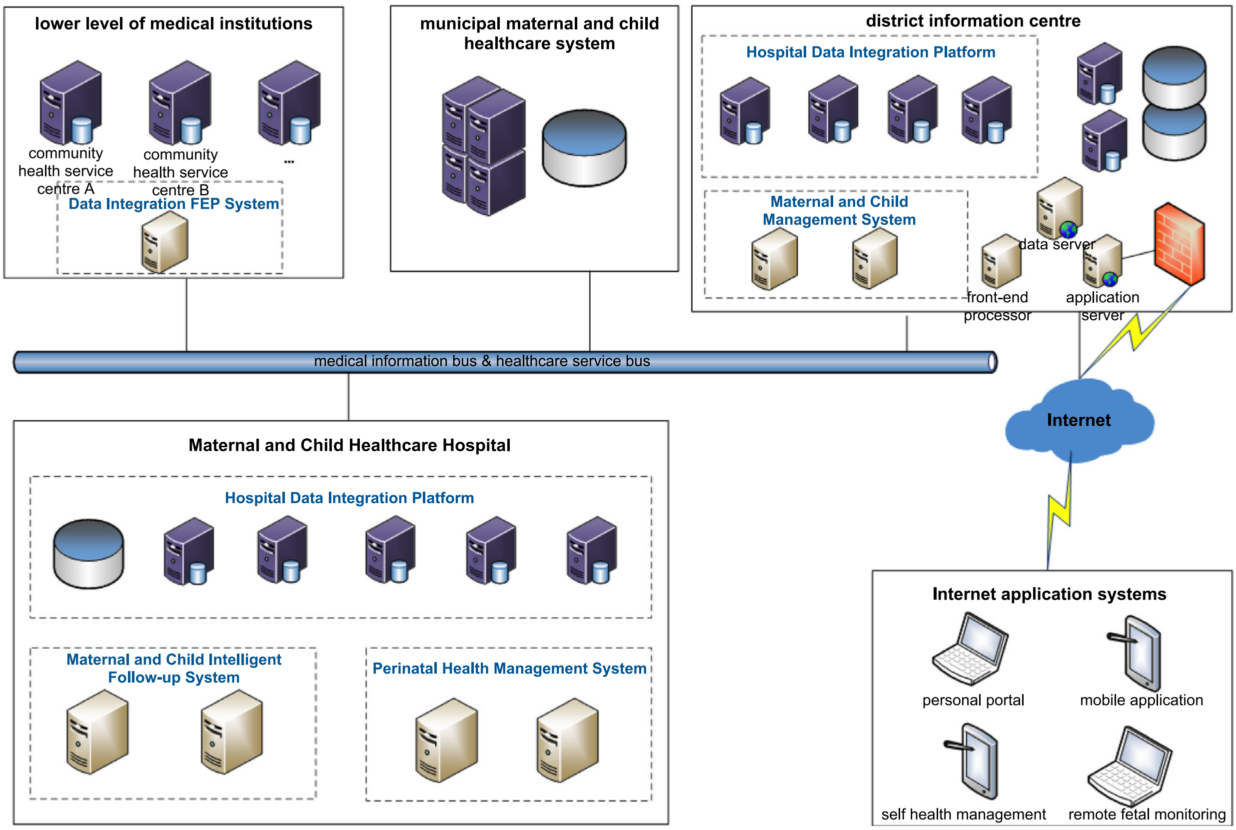


**Fig. 4.** Application deployment of different systems.

of diseases during pregnancy. Third, the health management platform with the core of big data will bring a great revolution to the medical concept and medical habits in the field of obstetric and gynaecology.

Simplifying the medical procedures and raising the medical efficiency are gradually put on the agenda by the hospitals. Especially the conflicts between doctors and patients awakens the hospitals that it is one of the highest priorities to improve patients' satisfaction with medical care. Intelligent Follow-up system can offer perfect health education and follow-up service. It has integrated post-hospital and follow-up monitoring function, which greatly meets hospitals needs. The business process of maternal and child intelligent follow-up system is depicted in Fig. 5. It is composed of holographic files of pregnant women, follow-up centres, mission centres, management centres, service centres, maternity and medical end APP.

The intelligent maternal and child management and controlling system integrated maternal and child health information resources. It rationalises and standardises maternal and child health care work and provides comprehensive and precise information for the maternal and child healthcare work. It includes pregnant women decision support system and high-risk maternal control system. The maternal and child management and controlling system mainly tracks the number of pregnant women in certain region, the number of high-risk pregnant women (number of elderly pregnant women, number of diabetes pregnant women, number of hypertension pregnant women), the number of registered women today, the number of check-ups today, the number of deliveries today, the number of weak infants and other dynamic information through data statistics and analysis. Combining with Geographical Information System (GIS), it can dynamically show the number and distribution of pregnant women in every street and the number of high-risk pregnant women. Furthermore, it is able to track the building where each pregnant woman lives and the current status by step-by-step training.

## 5. Analysis

The experimental data are collected via a third-party observational system and are only used in academic research purpose. This is due to both related human interaction issues in hospitals and the need of a large number of distributed participants in varying locations and backgrounds all over China. We have made use of questionnaires designed by ourselves. Questionnaires are delivered online and consist of a set of questions which all participants are asked to complete. The questionnaire are delivered to a group of participants who are all pregnant women with little effort via the online system.

A total number 315 samples are randomly obtained, and no general obstetrics, gynaecology and other general medical histories regarding prenatal care are screened out. The respondents of this questionnaire came from all parts of the country. They came from 27 provinces in China, including many pregnant women from the same province but different cities. Some of these places are relatively developed in economy, such as Beijing, Shanghai, Jiangsu and Guangdong, and some are relatively backward.

### *5.1. Demographic sociological characteristics of the subjects*

In the survey sample, there were 40 pregnant women aged 20–25, accounting for 12.7%, 164 pregnant women aged 26–30, accounting for 52.06%, 98 pregnant women aged 31–35, accounting for 31.11%, 10 pregnant women aged 36–40, accounting for 3.17%, and 3 pregnant women aged 41–50, accounting for 0.95%, which is shown in Fig. 6. The minimum age of pregnant women

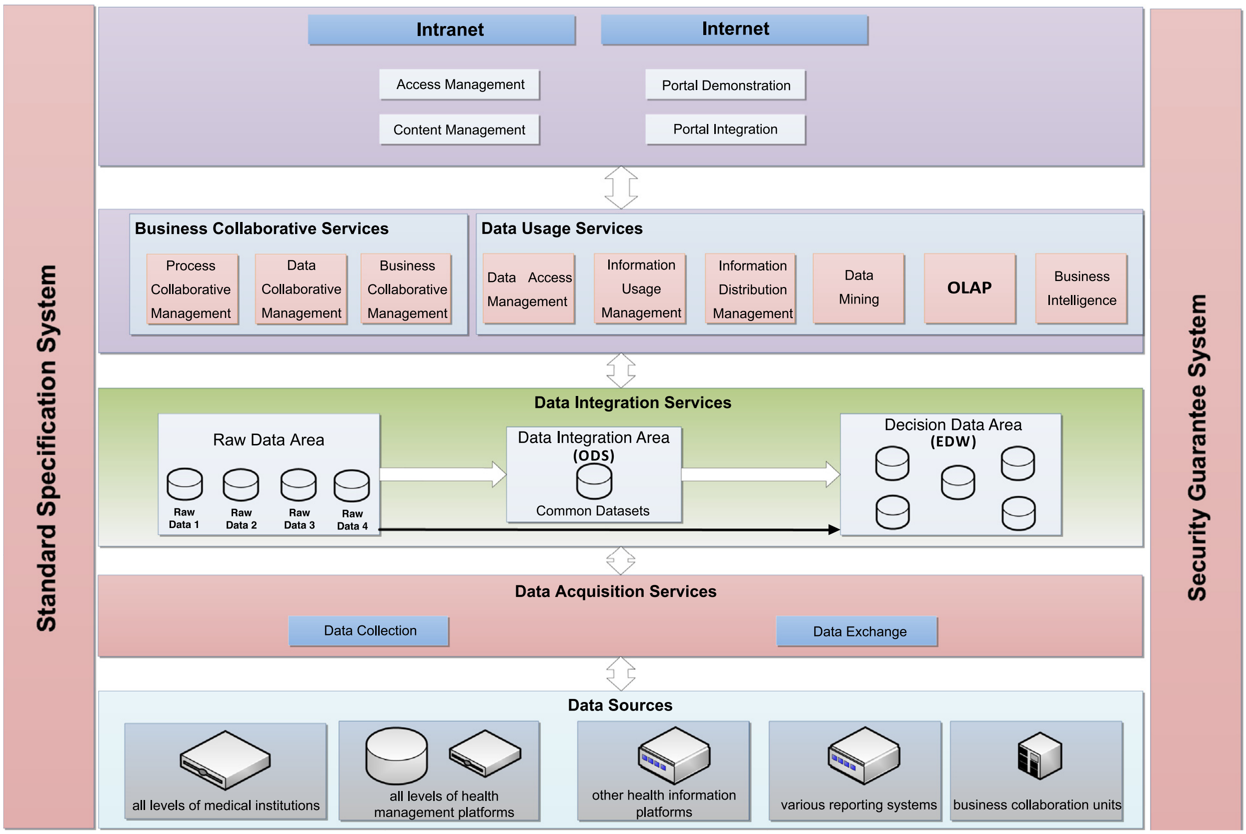


**Fig. 5.** System architecture.

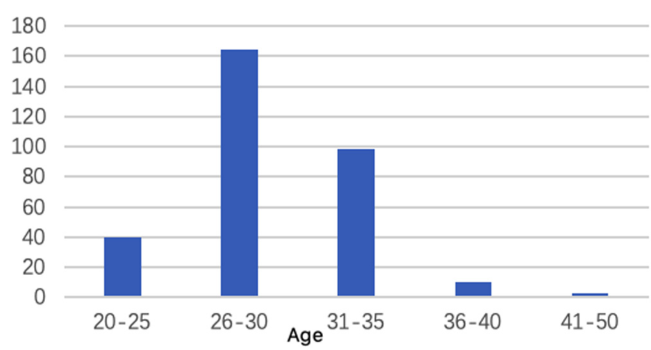


**Fig. 6.** Age distribution of pregnant women.

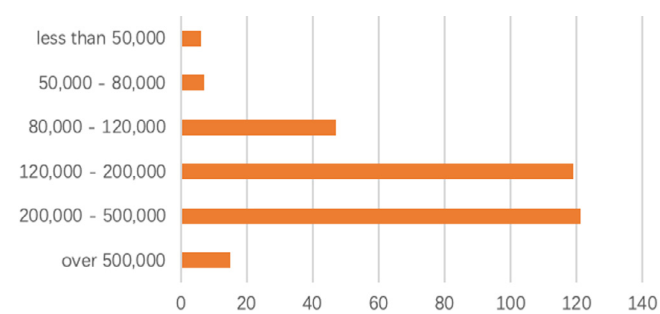


**Fig. 7.** Annual household income (CNY) of pregnant women.

is 20 years old and the maximum is 49 years old, covering the age of most pregnant women. The average age is 29.38 years old. Among them, the age range of 26–30 years accounted for the largest proportion of samples, this age group was the best age of childbearing for women, followed by the proportion of 31–35 years old pregnant women.

The annual family income of the respondents is shown in Fig. 7. The comparatively well-off standard, which indicates the degree to which the basic needs of people's material and cultural life are well met, is an important indicator to measure the economic status of a family. In 2020, China's comparatively well-off standard annual income is CNY 80,000–300,000. There are 6 pregnant women with annual family income less than CNY 50,000, accounting for 1.90%, 7 pregnant women from CNY 50,000 to 80,000, accounting for 2.22%, 47 pregnant women from CNY 80,000 to 120,000, accounting for 14.92%, 119 pregnant women from CNY 120,000 to CNY 200,000, accounting for 37.78%, 121 pregnant women between CNY 200,000 and 500,000, accounting for 38.41%, and 15 pregnant women with more than CNY 500,000, accounting for 4.76%. For the respondents, the annual family income of them is concentrated in CNY 80,000–500,000, and 95.87% of them have reached the standard of comparatively well-off family or above.

In terms of educational background as shown in Fig. 8, there are 5 pregnant women with junior high school or below, accounting for 1.59%, 10 pregnant women with high school or secondary vocational technical school, accounting for 3.17%, 265 pregnant women are undergraduate or with college education, accounting for 84.13%, and 35 pregnant women are postgraduate or above, accounting for 11.11%. In this survey, the number of pregnant women with college degree or above is the majority, accounting for 95.24% of the total.

We also have some understanding of the pregnant women's pregnancy. For instance, 1. 81% of the pregnant women who participated in the questionnaire survey are pregnant for the first time. Moreover, pregnant women's pregnancy risk assessment

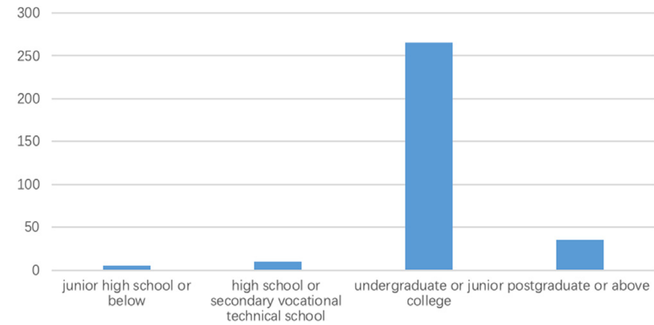


**Fig. 8.** Educational background of pregnant women.

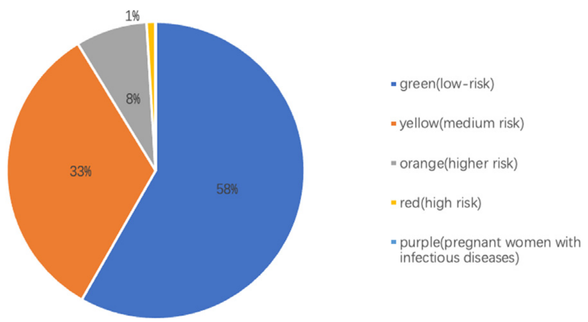


**Fig. 9.** Pregnancy risk categories of pregnant women.

and management refers to the screening, assessment, grading and management of pregnancy related risks for women from pregnancy to 42 days after delivery, timely detection and intervention of risk factors affecting pregnancy, prevention of adverse pregnancy outcomes, and protection of maternal and child safety. Pregnant women with risk categories of "orange", "red" and "purple" were included into high-risk pregnant women as key groups. As shown in Fig. 9, 57% were "green (low risk)" and 36.68% were "yellow (general risk)". The proportion of high-risk pregnant women was 8.57% among the survey samples.

The existing wearable IoT devices on the market have been able to collect the health data of some pregnant women and their foetuses. The indicators in the questionnaire above can be detected by certain devices. To be specific, foetal movement can be measured by home foetal movement instrument and foetal heart meter. Body temperature can be measured by Bluetooth thermometer, Bluetooth temperature gun and electronic temperature paste. What is more, Foetal heart meter can not only measure the heart rate of pregnant women and foetus, but also measure foetal movement and uterine contraction. Bluetooth weight scale can be used to measure weight. Bluetooth electronic blood glucose meter can be used to measure blood glucose, and finger clip oximeter can be used to measure blood oxygen saturation. Additionally, Blood pressure can be measured by Bluetooth electronic sphygmomanometer. Breath rate can be measured by finger clip oximeter. With these IoT devices, the data obtained can be transmitted to the intelligent terminal conveniently and quickly. What is worth mentioning is that the prices of these household equipment are acceptable to the general public, and they are also relatively easy to obtain.

For example, they can be purchased directly in physical stores or online. However, as shown in Fig. 10, only 7.94% of pregnant women know that wearable IoT devices could measure blood oxygen, 17.14% know uterine contraction, 19.37% know respiratory rate, 21.59% know foetal heart rate, 28.89% know

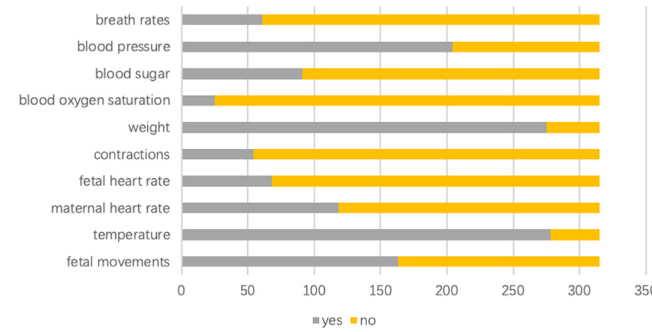


**Fig. 10.** Question about whether the respondents know the monitoring of physiological parameters can be completed at home during pregnancy.

blood glucose and 37.46% know maternal heart rate, respectively. Some indicators are relatively high degree of cognition, for example, 51.75% of pregnant women know that wearable devices can be used to measure foetal movement at home, 64.76% of pregnant women know that blood glucose can be measured at home, 87.30% of pregnant women know body weight, 88.25% of pregnant women know temperature can be measured at home. Nevertheless, the overall understanding of wearable IoT devices is not high enough. Even though 95.24% of the respondents have a college degree or above, and most of them were under 35 years old, means that this group of people have more understanding and interest in advanced equipment, the results show that many pregnant women have limited knowledge of functions of wearable IoT devices, which greatly affected the popularity and application of the devices.

In addition, 1.97% of the respondents said that they had downloaded or would download mobile phone software specially developed for pregnant women. It can be inferred that most pregnant women are very concerned about the maternal and foetal health during pregnancy, and they are willing to use the Internet and intelligent devices to obtain health science, personalised services and suggestions and other things about pregnancy.

As for the survey of pregnant women's willingness to use wearable devices, we divide them into two types. One is smart bracelet, watch and so on. It is more compact and portable, and almost does not cause trouble to pregnant women's daily life. Pregnant women do not have to spare a specific period of time or space to use them for monitoring. The other is to wear smart flexible wearable fabrics such as clothes and abdominal belts with sensors or electrodes hidden, the area of such products is larger, but it is also very convenient for pregnant women to use, and the burden on pregnant women is acceptable.

As shown in Fig. 11, 64.76% of pregnant women are strongly willing or willing to wear smart and flexible wearable fabrics during pregnancy, 21.59% of pregnant women are unwilling, and 3.81% of pregnant women are strongly unwilling. In the survey of pregnant women's attitude towards wearing smart watches and bracelets during pregnancy, 79.68% of pregnant women said they were strongly willing or willing, 13.65% of pregnant women said they would not, and only 0.63% of pregnant women said they are strongly unwilling.

It can be seen that pregnant women's recognition and acceptance of using wearable IoT devices during pregnancy are relatively high, and pregnant women's acceptance of wearing intelligent flexible wearable textiles is lower than that of smart watches, bracelets and other devices. The reasons may include the high popularity of smart watches and bracelets nowadays, and there are more people using smart watches and bracelets than the smart and flexible fabrics. In addition, for the large contact area between the smart wearable fabrics and the skin of pregnant

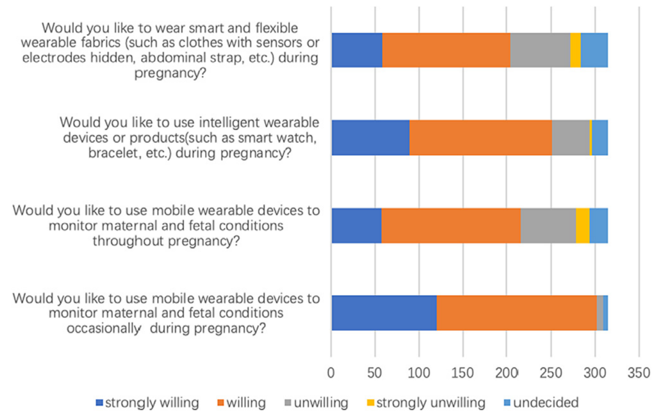


**Fig. 11.** Question about pregnant women's willingness to use wearable devices.

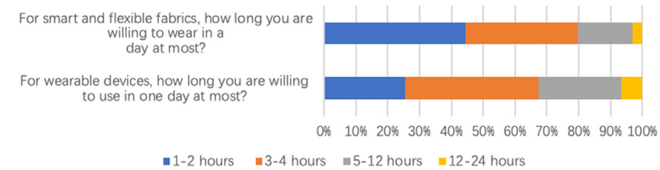


**Fig. 12.** Questions about the maximum daily usage time that pregnant women are willing to use in one day at most.

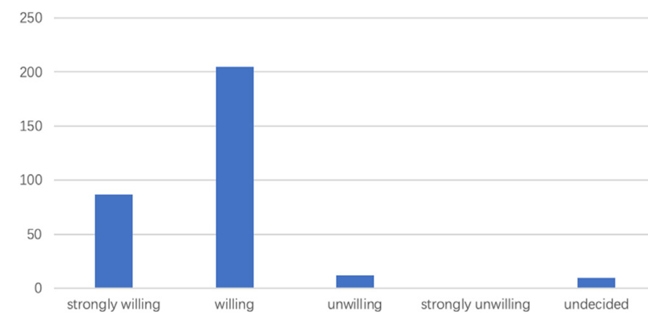


**Fig. 13.** Questions about pregnant women's willingness to accept the intelligent advice provided by wearable devices based on monitoring results, and then make corresponding behavior changes.

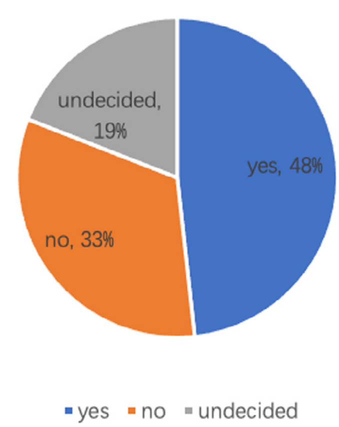


**Fig. 14.** Question about whether pregnant women concern about wearable devices will violate their privacy.

women, pregnant women may have concerns about their safety, such as whether there is radiation effect, etc. In addition, they also have higher requirements for their comfort and appearance.

38.1% of the respondents were very willing to use the wearable device occasionally to detect the maternal and foetal condition, 57.78% of the pregnant women were willing to do so, only 2.22% of the pregnant women said they were not willing and only 1.9% of the pregnant women were not sure. However, the number of pregnant women who are strongly willing and willing to use mobile wearable devices to detect maternal and foetal status throughout pregnancy is reduced. 18.1% of pregnant women indicated that they were strongly willing, while 50.16% of pregnant women indicated that they were willing. The proportions of very unwilling and unwilling were 5.08% and 20%. Generally speaking, most pregnant women are willing to use mobile wearable devices during pregnancy, but more pregnant women will be more receptive to occasional use. There might be many concerns for the pregnant women, for example, whether it is necessary to use wearable devices continuously in the early stage of pregnancy, whether it is convenient to use these devices for a long time, whether the operation is simple, and whether it will bring too much trouble.

As shown in Fig. 12, 41.9% of respondents said they would wear 3–4 h a day at most, 26.03% said they would wear 5–12 h a day at most, and a quarter of pregnant women said they would wear up to 1–2 h a day for smart watches, bracelets and other devices. Only a very small number of pregnant women, that is, 6.67% of pregnant women would like to wear 12–24 h a day. For smart flexible wearable fabrics, nearly half of them, that is, 44.44% of pregnant women said that they would wear up to 1–2 h a day, 35.24% of pregnant women said they could wear up to 3–4 h a day, only 17.14% of pregnant women said that they could wear up to 5–12 h a day, and only 3.17% of pregnant women said they could wear up to 12–24 h a day. It can be seen that whether it is smart watches, bracelets and other smaller devices, or wearable fabrics, pregnant women prefer to use them for a shorter time. Most pregnant women would like to use them for 1–4 h per day. If pregnant women use smart flexible wearable fabrics, they are willing to wear them for a shorter time than smart watch and bracelets.

As shown in Fig. 13, 79.05% of the pregnant women who completed the questionnaire indicated that they would like to use wearable devices to provide remote monitoring and intelligent diagnosis functions outside the hospital. There are 27.62% and 65.08% of pregnant women indicated that they were strongly willing and willing to accept the personal intelligent suggestions provided by wearable devices according to the test results. Subsequently, they could make corresponding behavioural changes (such as diet, sleep, physical fitness, etc.). Only 3.81% of pregnant women said they were not willing to do so and 3.17% of them were not sure.

In Fig. 14, it is about the personal privacy of pregnant women involved in this kind of IoT devices. Nearly half of them, that is, 48.25% of the pregnant women expressed concern that the wearable IoT devices would infringe on their privacy. There are 32.7% of the pregnant women said they were not worried, while 19.05% of the pregnant women were not sure about this.

Nearly half of them, that is, 48.25% of the pregnant women expressed concern that the wearable IoT devices would infringe on their privacy. There are 32.7% of the pregnant women said they did not concern about it, and 19.05% of the pregnant women were not sure about this.

The question related to Fig. 15 is "if you use mobile wearable devices to detect the maternal and foetal condition during pregnancy, would you like to upload the monitoring data to a third party (such as equipment or service provider, non-hospital institution)", and only 7.3% of pregnant women said they were strongly willing to do so. In contrast, 29.52% of pregnant women said they would like to, and 36.51% of pregnant women said they

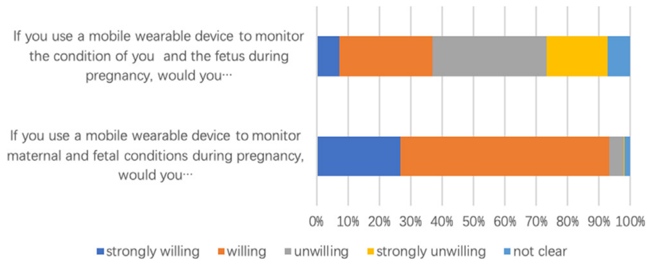


**Fig. 15.** Questions about pregnant women's willingness to share the monitoring data with a third party or obstetricians.

were unwilling. The pregnant women with attitude of strongly unwilling also accounted for 19.37%. Another question is "if you use mobile wearable devices to detect maternal and foetal conditions during pregnancy, would you like to share the monitoring data with obstetricians?" The results are very different from the previous question. There are 26.67% of pregnant women showed that they are strongly willing and 66.67% of pregnant women are willing. Only 4.44% and 0.32% of pregnant women are unwilling and strongly unwilling.

It can be seen that pregnant women attach great importance to the protection of their personal privacy. Nearly half of them are worried about whether the wearable devices will reveal their privacy. More than half of them are not willing to share their data with the third-party platform outside the hospital. They may be worried that their personal information will be used by illegal elements. It will lead to cyber crime, such as the Internet Network fraud, damage to the interests of pregnant women themselves or others. They also worried that due to the information leakage, they will receive some advertising messages, e-mail, etc. , which they are not willing to receive. However, the vast majority of pregnant women are willing or hope to share the data with hospitals and obstetricians. The advantage is that even if pregnant women stay at home, obstetricians can provide professional and personalised monitoring analysis and suggestions to pregnant women after obtaining the data.

There are mainly five factors that affect pregnant women's choice of a wearable device: safety, price, comfort, appearance and function, respectively. As shown in Fig. 16, the average scores of the five factors were 4.83, 3.64, 4.69, 3.28 and 4.57, respectively. The three factors with the highest score of 5 are safety, comfort and product function. In addition to these three factors, pregnant women also pay more attention to the price, they consider that the relatively less important one is the appearance of the product, which got the lowest score. Medical devices refer to the instruments and equipment directly or indirectly used for human body, especially wearable devices which have direct contact with pregnant women. Some devices are used frequently and some even need daily monitoring to obtain scientific and accurate data. These are directly related to the health and safety of pregnant women and foetus.

Therefore, safety is the first factor taken into account for pregnant women, the average score of the survey reached 4.83. Second, as a special medical device, the comfort is also of great importance, for the reason that pregnant women have already caused certain inconvenience to daily life, and there will be certain pregnancy reactions causing discomfort. Therefore, wearable devices should pay more attention to the design of product comfort to give pregnant women a more comfortable experience and not make them add extra burden. In addition, the function is the core of the product, which corresponds to the needs of pregnant women and foetuses. Products with larger market demand or products with more complete functions will be more popular.

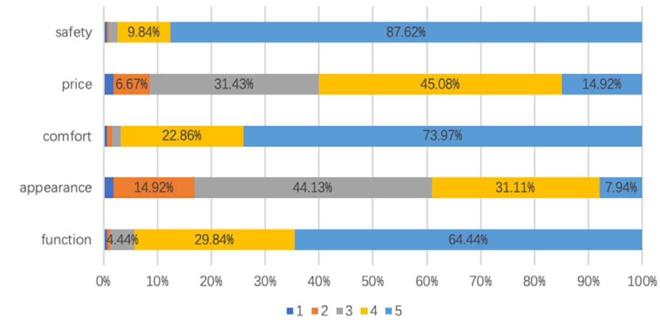


**Fig. 16.** Scores given by respondents according to the importance of the factors in choosing wearable devices for pregnant women.

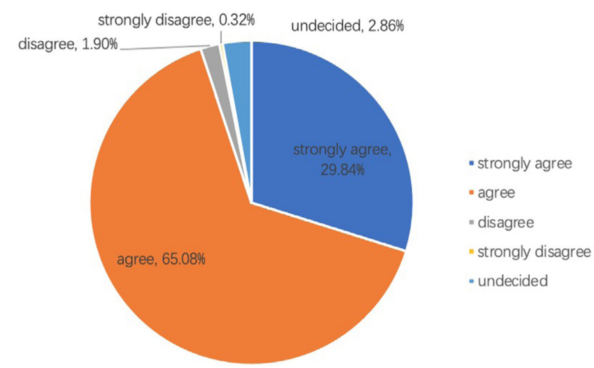


**Fig. 17.** Question about whether respondents consider that wearable IoT technology will be widely and deeply used in the field of healthcare in the future to monitor and diagnose pregnant women and foetuses remotely.

Although the price and appearance scores are lower than the other three factors, it does not mean that pregnant women do not care about it. Products with high cost performance and better appearance will definitely have greater competitive advantages.

The last question of questionnaire is "do you think wearable IoT technology will be widely and deeply used in the field of health care in the future to monitor and diagnose pregnant women and foetuses remotely?". The results are depicted in Fig. 17. As we can see, 29.84% and 65.08% of the pregnant women expressed their strong agreement and agreement, and only 1.90% of the pregnant women said they did not agree. Furthermore, 0.32% of the pregnant women said they did not agree, and 2.86% of the pregnant women said they were not sure. It can be seen that the vast majority of pregnant women showed faith and support in wearable devices and increased use of IoT technology in the medical field.

### 5.2. Correlation analysis

We used the SPSS statistical software to help analyse the result we had collected from the questionnaire. Chi-square analysis is used to analyse the demographic and sociological characteristics of the research subjects and their understanding and use of wearable IoT devices for pregnant women. The $p$-value is an index to measure the difference between the control group and the experimental group. When the $p$-value is less than 0.05, it indicates that there is a significant difference between the two groups. While the $p$-value is less than 0.01, it indicates that the difference between the two groups is extremely significant.

#### 5.2.1. The influence of age of pregnant women

People of various ages have different levels of acceptance. Young people have a higher degree of acceptance and understanding of new things. As a topical subject in the medical device industry that has developed rapidly in recent years, wearable IoT devices are gradually garnering attention and acceptance from people. In table, it can be seen that the p-values are all greater than 0.05, i.e. pregnant women of different ages show consistency in their willingness to use wearable IoT devices (see Table 1).

We performed a chi-square analysis to correlate the age of pregnant women with the importance of factors in their choice of wearable devices. There was a significant difference between the age of pregnant women and their scores on "function" (*p* value is $0.019<0.05$). Thus, the younger the age, the higher the score on the importance of "function".

### *5.2.2. The influence of regional distribution*

We summarised the regions where pregnant women who participated in the questionnaire survey are based on China's current city rankings. First-tier cities refer to metropolises that play an important role in the country's economy and politics, with higher economic status, greater influence, and popularity. Second-tier cities are second to first-tier cities, while third-tier cities and lower-tier cities are weaker in the aforementioned aspects. The *p*-value of the chi-square test is 0.038. Therefore, there is a significant difference between the regional distribution of pregnant women and their scores on the comfort level of wearable IoT devices. Pregnant women participating in the questionnaire in first-tier cities have higher scores for "comfort".

### *5.2.3. The influence of annual household income*

The number of samples with an annual family income of CNY 50,000–80,000 and less than 50,000 are small. Therefore, we combined these as income less than CNY 80,000. There was a significant difference between the annual household income of pregnant women and the willingness to occasionally use wearable IoT devices (*p* value is $0.008<0.05$). Pregnant women with an annual income of more than 500,000 and those with an annual income of less than 80,000 are far less willing to use them. The *p*-value of the annual family income of pregnant women and the pregnant women's willingness to wear devices like smart watches and bracelets is 0.001, which means they are significantly related. The lower the annual household income, the less willing they are to use devices such as smart watches and bracelets (see Table 2).

The *p*-value is 0.018, indicating that the annual household income of pregnant women and their willingness to accept wearable devices to provide out-of-hospital remote monitoring and intelligent diagnosis functions are significantly related. According to Table, groups with high annual household income are more willing to accept remote monitoring and intelligent diagnosis functions outside the hospital, especially groups with an annual income of CNY 120,000–500,000. The *p*-value of the annual household income of the pregnant women and their willingness to accept personal smart advice provided by wearable devices based on the monitoring results and make the corresponding behavioural changes (such as diet, sleep and physical fitness) is $0.001<0.05$. In other words, there is a significant difference between the groups. The lower the annual income group, the less the willingness to accept these suggestions and make behavioural changes. Moreover, the acceptance of the group with CNY 500,000 annual income is not as high as the group with an annual income of CNY 120,000–500,000.

### *5.2.4. The influence of the educational background*

There are few samples in the 315 samples with middle school education or below and high school or vocational high school education, which total 5 and 10, respectively. We merge these two categories into high school or below vocational high school education for analysis. The *p*-value between the educational background of pregnant women and their willingness to use wearable devices to detect maternal and foetal status during pregnancy is 0.018, i.e. there is a significant correlation between them. We also see that pregnant women with higher educational backgrounds are more willing to use these devices (see Table 3).

There is also a significant correlation between pregnant women's educational background and their attitudes towards wearable devices providing out-of-hospital remote monitoring and intelligent diagnosis functions. The *p*-value is 0.004, and the proportion of pregnant women with a high school or secondary vocational technical school education or below with a positive willingness to use these devices were lower, and the proportion of those who showed they were unclear was higher. The educational background of pregnant women is related to their scores for wearable IoT devices. The p-values between the educational background and their scores for "function", "appearance", and "comfort" are 0.005, 0.013, and 0.002, respectively. The higher the educational background of pregnant women, the higher are the scores for the importance of "function' and "comfort", and lower are the scores for the importance of "appearance".

### *5.2.5. The influence of whether it is the first pregnancy*

The *p*-value is 0.04, which means that there is a correlation between whether this is the first pregnancy of respondents and their willingness to use wearable loT devices to detect the status of the mother and the foetus during pregnancy. In addition, women pregnant with their first child showed stronger willingness. The *p*-value of the chi-square test between whether this is the first pregnancy of respondents and the score for the importance of choosing wearable devices is 0.005, which means that there is a strong correlation between them. Respondents who were pregnant for the first time gave higher scores for the importance of "function". Further, they have no correlation in the score for the importance of "appearance", "comfort", "price", and "safety". The *p*-value of whether this is the first pregnancy of respondents and the duration for which pregnant women are willing to use wearable IoT devices are 0.560 and 0.394, respectively, meaning that they have no correlation.

### *5.2.6. The influence of pregnancy risk categories*

Some pregnant women in the survey sample did not know their pregnancy risk categories, therefore, the results of the correlation analysis for them were meaningless. We filtered out pregnant women who did not know their pregnancy risk categories. However, because the survey samples are rated as red risk, i.e. there are only three high-risk pregnant women, it may bias the experimental results.

The *p*-value of the different pregnancy risk categories of pregnant women and their willingness to share the monitoring data with obstetricians is 0.000, that is, there is a strong correlation between them. Moreover, pregnant women with high risk are less willing to share monitoring data with obstetricians. The *p*-value of the different pregnancy risk categories of pregnant women and their willingness to accept the smart advice provided by wearable devices based on the monitoring results and make corresponding behavioural changes (such as diet, sleep, and physical fitness) is 0.000, implying that they have a strong correlation, and pregnant women with high risk are less willing to accept personal intelligent suggestions and make corresponding behavioural changes.

The p-values of the different pregnancy categories of pregnant women and the duration for which they are willing to use wearable IoT devices such as bracelets and watches daily is 0.045 (such as clothes with hidden electrodes or sensors, abdominal belt, and) is 0.005, therefore, there is a significant correlation between them, and pregnant women with low-risk or general risk categories are willing to use it for a shorter time per day.

**Table 1**
Influence of age on pregnant women's knowledge and usage of wearable IoT devices (* means $p < 0.05$ and ** means $p < 0.01$).

| Question number | Name | Age distribution | | | | Total | $\chi^2$ | $p$ |
|---|---|---|---|---|---|---|---|---|
| | | 20–25 | 26–30 | 31–35 | 35–50 | | | |
| 19 | 1.0 | 1(2.50) | 1(0.61) | 0(0.00) | 0(0.00) | 2(0.63) | 24.281 | 0.019* |
| | 2.0 | 1(2.50) | 1(0.61) | 0(0.00) | 0(0.00) | 2(0.63) | | |
| | 3.0 | 3(7.50) | 8(4.88) | 3(3.06) | 0(0.00) | 14(4.44) | | |
| | 4.0 | 6(15.00) | 39(23.78) | 42(42.86) | 7(53.85) | 94(29.84) | | |
| | 5.0 | 29(72.50) | 115(70.12) | 53(54.08) | 6(46.15) | 203(64.44) | | |
| Total | | 40 | 164 | 98 | 13 | 315 | | |

**Table 2**
Correlation of pregnant women's annual family income and the duration for which they are willing to use wearable devices (* means $p < 0.05$ and ** means $p < 0.01$).

| Question number | Name | Educational background (%) | | | | | Total | $\chi^2$ | $p$ |
|---|---|---|---|---|---|---|---|---|---|
| | | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | | | |
| 20 | 1.0 | 4(26.67) | 24(19.83) | 28(23.53) | 20(42.55) | 4(30.77) | 80(25.40) | 21.403 | 0.045* |
| | 2.0 | 9(60.00) | 45(37.19) | 53(44.54) | 17(36.17) | 8(61.54) | 132(41.90) | | |
| | 3.0 | 2(13.33) | 42(34.71) | 29(24.37) | 8(17.02) | 1(7.69) | 82(26.03) | | |
| | 4.0 | 0(0.00) | 10(8.26) | 9(7.56) | 2(4.26) | 0(0.00) | 21(6.67) | | |
| Total | | 15 | 121 | 119 | 47 | 13 | 315 | | |
| 21 | 1.0 | 7(46.67) | 51(42.15) | 45(37.82) | 30(63.83) | 7(53.85) | 140(44.44) | 18.850 | 0.092 |
| | 2.0 | 3(20.00) | 41(33.88) | 51(42.86) | 12(25.53) | 4(30.77) | 111(35.24) | | |
| | 3.0 | 5(33.33) | 22(18.18) | 21(17.65) | 4(8.51) | 2(15.38) | 54(17.14) | | |
| | 4.0 | 0(0.00) | 7(5.79) | 2(1.68) | 1(2.13) | 0(0.00) | 10(3.17) | | |
| Total | | 15 | 121 | 119 | 47 | 13 | 315 | | |

**Table 3**
Correlation between educational background and willingness to use devices to detect maternal and foetal health status (* means $p < 0.05$ and ** means $p < 0.01$).

| Question number | Name | Educational background (%) | | | Total | $\chi^2$ | $p$ |
|---|---|---|---|---|---|---|---|
| | | 1.0 | 2.0 | 3.0 | | | |
| 17 | 1.0 | 7(46.67) | 213(80.38) | 29(82.86) | 249(79.05) | 15.436 | 0.004** |
| | 2.0 | 5(33.33) | 36(13.58) | 1(2.86) | 42(13.33) | | |
| | 3.0 | 3(20.00) | 16(6.04) | 5(14.29) | 24(7.62) | | |
| Total | | 15 | 265 | 35 | 315 | | |
| 18 | 1.0 | 3(20.00) | 73(27.55) | 11(31.43) | 87(27.62) | 17.710 | 0.024* |
| | 2.0 | 8(53.33) | 177(66.79) | 20(57.14) | 205(65.08) | | |
| | 3.0 | 1(6.67) | 9(3.40) | 2(5.71) | 12(3.81) | | |
| | 4.0 | 0(0.00) | 1(0.38) | 0(0.00) | 1(0.32) | | |
| | 5.0 | 3(20.00) | 5(1.89) | 2(5.71) | 10(3.17) | | |
| Total | | 15 | 265 | 35 | 315 | | |

## 6. Challenges and opportunities

### 6.1. Challenges

For the IoT smart platform, it is usually recognised that the data accuracy of the physiological parameters of pregnant women detected by wearable devices is the biggest problem. However, other issues in aspect of devices management cannot be neglected as well.

#### 6.1.1. Combination of management of wearable devices and existing medical model

Currently, the primal problem of the devices management is that people are not able to build and expand a new management model by combining the electronic medical records and wearable devices for pregnant women. From the perspective of hospitals, they expect to enquire and invoke records that presented in different organisation forms. From the perspective of maternal and child healthcare, it is expected to construct different subsystem for maternal and child healthcare management platform.

Besides, wearable devices for pregnant women must combine with existing medical model, for the reason that it is tough to inspire the pregnant women and doctors to continuously participate in this model if it only provides simple data collecting function. Only by applying to mainstream clinical process, making it possible to provide organic component of medical service model, giving clinically meaningful information feedback and relatively solutions to pregnant women through using artificial intelligence algorithm to process and analysis or further in-depth interpretation by obstetric medical personnel, can the application and practice of intelligent platform based on wearable devices gain sustainable development and widely acceptance.

#### 6.1.2. Large in size and complex configuration and operation

The existing wearable devices is far from miniature, lightweight, beautiful and delicate. Whether the mainstream Philips foetal heart rate recorder or the Doppler foetal heart rate procured by other manufactures, the wearability and portability need to be improved. What is more, these equipment need maternity experts or medical staffs to guide or help to wear, while the devices which have advantages of being light, easy to install and configure, easeful to wear are the ones that pregnant women truly demand.

#### 6.1.3. Limited battery life

The battery life has always been a pain point to wearable devices designed for women. To pregnant women, some factors affect the usage of wearable devices, for example, long-term continuous biological information collection and monitoring consumes lots of power, the capacity of battery is limited and the cruising ability is poor. While the current battery density cannot be improved by other technical means, so the main solution is to save power consumption of sensors and processors through technologies like power management. Simultaneously, certain new battery technologies like wireless charging and fast but safe technology are gradually applied to wearable devices.

#### 6.1.4. Poor data collection accuracy

In the medical healthcare area where have more applications of wearable devices, the biggest issue of the self-monitoring for pregnant women is that some unforeseen factors like excising, emotion, pills, sleep state, even the impacts that brought by weather and etc. are unavoidable, and they may cause data perturbation. Besides, there is still a lack of professional pathological analysis. Using wearable devices to realise the data collection is only the first step to learn the health status judgement, due to the lack of cloud professional pathology diagnosis and personalised treatment plan, it is difficult to supervise the pregnant women to attach importance to the data and then change their life habits and regulations. For the wearable devices used for medical monitoring, the relevant national agencies have not yet given specific regulations and supervision, leading to a lack of standardisation of data monitored by wearable devices. Furthermore, hospitals lacks a sense of identity with these data for the reason that these data has no corresponding regulatory constrains, resulting that these data totally has no use value.

#### 6.1.5. Personal privacy issues

The more data that wearable devices can record, the more personal privacy can be caught, and the information security risk is higher. In other words, if the pregnant women use these wearable devices for a quite long time, all information about them will be invisible, including their health conditions and life preferences, which may be leaked at any time and used illegally by other person.

### 6.2. Opportunities

Wearable devices designed for pregnant women and emerging In-home health monitoring mode may bring tremendous revolution to the future medical model. Various of wearable devices combined with relative health management system can naturally and conveniently record the physiological parameters of the pregnant women in real time, which boarder the space of pregnant women health management and medical research. The future development of wearable devices for pregnant women can be summarised as the main directions listed below.

#### 6.2.1. Wearable materials

Wearable devices for pregnant women need to be worn directly on pregnant women, for instance, they need to cover a highly flexible skin surface. To pregnant women, the comfortableness, portability, durability and flexibility are really important. Fibre based materials are ideal. At the same time, the development of new conductors and semiconductor materials has provided new impetus for the design of foetal ECG, such as conductive high molecular polymers, nanoparticles metals and metal oxides, and carbon-based nano-materials. These materials has good electrical conductivity and good mechanical properties as well. The conductive fabric is soft, light and easy to stretch and deform, making it ideal for pregnant women.

#### 6.2.2. Automatic analysis and dynamic detection through big data and artificial intelligence

At present, all kinds of wearable devices for pregnant women are mainly applied to realise the real-time monitoring of changes in physiological health index of pregnant women. But in fact, the majority only play a shallow health management function, which is still so far from the true meaning of diagnosis and medical care concept. In order to offer better estimated performance and preciser decision support to In-home health monitoring for pregnant women, we need to integrate different ways of monitoring and devices, introduce automatic analysis system. By doing these, we can raise the reliability and veracity of the maternal and child monitoring. Hence, wearable devices that help analyse and diagnose for pregnant women is the key of the further development. It aims to realise real-time dynamic analysis and data visualisation, further the pregnant women will rely more on In-home monitoring devices, which cuts down the readmission rates for pregnant women.

#### 6.2.3. Wireless data transmission

Wearable devices can collect massive physiological data from pregnant women. At the same time, pregnant women have great demands of comfortableness and portability, which accelerates the miniaturisation of the wearable devices. Therefore, the data collected by the terminal of wearable devices need to be uploaded to the Internet cloud platform to calculate and the results need to be transmitted to the terminal so that it can give feedback to pregnant women. The efficient and safe wireless transmission technology is the guarantee of this application model. Nowadays, the wireless communication technologies which are widely used includes WI-FI, BlueTooth, ZigBee, infrared ray etc. And the BlueTooth and ZigBee are more usually used as the data transmission mode for wearable devices for pregnant women, for the reason that they have the advantages of low-power consumption and low-cost.

#### 6.2.4. Lower the cost

The products need to productisation and marketisation, so that here we need to pay more attention to consider how to cast down the cost. The computing resources of wearable and embedded devices will be limited for the limited cost. How to maximise the limited existing resources and further exploit its full potential is a big challenge. Pointed to the maximum utilisation of the limited resources, we put forward some solutions that includes a power battery management scheme, minimising deep neural networks for artificial intelligence and the fusion of acquired data.

## 7. Conclusion and future work

Thanks to its multidisciplinary approach, IoT has been phenomenal in revolutionising many aspects of traditional healthcare paradigms. At the same time, traditional healthcare systems can no longer satisfy the needs of a continuously growing and developing society. The world today needs to face the inherent need of assisted-living environments for the population of pregnant women. This paper has proposed a state-of-the-art, and a novel IoT paradigm for smart maternal healthcare services using wearable devices and its key technologies, and also investigates its applications and monitoring and management modes in home for obstetrics departments in hospitals.

For future work, we will study lessons learned that how the underlying system can be transferred to other scenarios and in other hospitals. This is very useful and helpful that if other organisations hope to use some mature solutions with low cost and risks. Another future direction is a comparison between the proposed systems in the paper and other similar systems. The comparison could consider the application areas, the underlying implementation techniques of the systems, and the usage and reliability analysis of the systems.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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