# Home Healthcare Technologies and Services: Heart-Rate Fetus Monitoring System Using an MCU ESP8266 Node

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***Abstract*—In this paper, a preliminary implementation of a system monitoring the fetus's heart rate (FHR) has been designed and implemented as a mobile wearable measuring system with remote sensing specifically developed on Node MCU ESP8266 (ESP). In particular, the proposed system uses sensors for heart rate, humidity, temperature, and a transceiver module. The transceiver module is capable of efficient data transmission to a remote server station using an IEEE 802.11 b/g/n protocol—based on the wireless network. A major benefit is that the patient's data is monitored at distance using an IoT device. Hence, it complies with the health safety distance measures required due to various situations, including that of the COVID-19 pandemic. The proposed implementation has been proven to be efficient in terms of hardware simplicity and cost-effectiveness and is accompanied by preliminary accurate measurements of the FHR.**

***Keywords—Telemedicine, Home Healthcare Technologies and Services, Photoplethysmography, Fetus, Pregnancy, Heart-rate, ESP 8266, Raspberry, fetal ECG, IoT, COVID-19, Electrocardiograph, Pulse Oximetry***

## I. Introduction

In the last decade, the Internet of Health Things (IoHT), such as smart body sensor network systems, has been incorporated greatly. The previous implementation was accomplished at various healthcare facilities and included medical monitoring (IoMT), remote health monitoring and tracking. Moreover, IoHT technology provided the ability of sending health alerts to personal doctors and harvest data for analysis issues via the Internet [1].

Such services were destined for helpless patients to be privileged in response time and accuracy while maintaining a low overall cost to diagnose heart disease in the fetus. A critical fact is the provision of health services to pregnant women. An indicative case is the fetal heart rate (FHR) measurement, considered one of the most significant approaches to monitoring the cardiac status of fetal human beings [2]. In the past years, various applications were proposed for obtaining FHR measurements, e.g., please see [3-9] and references therein.

More recently, various situations such as Covid-19, the economic crisis, and the energy crisis have harmed people's standard of living at a global level. Travelling is limited while serious health problems have emerged due to the decreased disposal of needed goods. By using new technologies in telecommunications, health, and technology, it is possible to confront such difficult situations.

In this paper a development platform is proposed which provides the user-patient and the personal physician the capability of real-time monitoring the cardiac state of the fetus as well as that of the pregnant woman. The cost of this device is cheap (about 10 dollars) compared to a similar measurement device in a clinic environment (hospital) without the possibility of remote monitoring [10, 11].

The proposed system has been designed and implemented as a mobile and wearable measuring device with remote sensing by including pulse-oximeter sensors and a low-cost development board based on Internet of Things (IoT) technology. The main goal is to detect the fetus's pulse by employing a photoplethysmography (PPG) sensor for measurement acquisition. Light-based technology is used to detect the blood flow rate as controlled by the heart pump.

To demonstrate the system's validity, measurements have been conducted against a gold standard at random times, revealing an occurring error is lower than 1%.

The rest of the paper is organized as follows: Section II discusses related published works. Section III offers measurements of the FHR, while section IV describes data harvesting. The integrated system's description is found in section V. The various specifications of the Thingspeak application, the development board, the sensors, and the shields are presented in VI. Advantages are presented in section VII while restrictions are discussed shortly in section VIII. Finally, conclusions are given in section IX.

## II. Related Published Works and Motivation

In this section, a brief technical literature review is presented relevant to the research area of techniques, wearable devices, and the trends of the technology directly related to health issues and monitoring [12]. In the bibliography, techniques for heart rate detection (HRD) have been proposed in fetal monitoring. Examples in [2, 13] are relevant to a rule-based phonocardiographic (PCG) method for long-term FHR. In [3], real-time signal processing techniques for FHR measurements have been proposed. In [14], is presented a vector machine for intrapartum FHR classification. In [15], robust fetal heartbeat detection techniques via r-peak interval

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distribution have been addressed. The latest research papers (in the year 2022) as [9, 16] are relevant to a heart rate system using a wearable development board that can detect real-time pulses monitored by a personal doctor 24h a day. The fetus's data can further be monitored by using a smart or/and satellite phone, or even any well-known internet browser connected to the specific network. Thus there is complying with the health safety distance measures required due to various situations, including the COVID-19 pandemic, based on a cloud platform that can collect data from the wearable device of a pregnant woman.

One of the most recent research outcomes concerns the monitoring and recording of fetal heart rate by using an ECG [16]. Our research study focuses on data acquisition using ECG sensors, and the data transfer with the use of Bluetooth. The results show that the proposed system records the AECG in different postures. The average Sensitivity (Se), positive predictive accuracy (PPV), accuracy (ACC), and mean (F1) scores are 99.62%, 97.90%, 97.40%, and 98.66%, respectively. A considerable part of the related research has focused on developing wearable devices for clinical purposes and especially for pregnancy [1, 17-22].

Such applications related to wearable "intelligent" devices are expected to significantly enhance patients' quality of life because they promote a healthier lifestyle and physical exercise in which the birth quality of a given population can be significantly improved [22-24]. E.g., pregnancy can be benefited from in-time alarming of unwanted conditions or even from not scheduled appointments with the physician [16]. The use of novel, sophisticated materials, and reduced-size electronics contributed to the evolution of miniaturized body-worn sensors [1, 9, 10, 25, 26]. These kinds of technologies are useful for examining weight management, gestational diabetes mellitus, asthma, correcting body position, and they can significantly improve self-monitoring.

Wearable devices with mobile technologies during pregnancy can benefit their users. It is vital for the fetus's life, the early detection of the peripartum cardiomyopathy (PPCM) [27]. Specifically, PPCM is a potentially life-threatening pregnancy-associated myocardial disease, associated with heart failure (HF) and left ventricular (LV) systolic dysfunction, occurring about the end or after childbirth. It must be emphasized that some women with low left ventricular ejection fraction accepting the use of wearable devices, such as cardioverter/defibrillator life vests, exhibited events of ventricular fibrillation with successful therapy, relying on early detection. The most important of all effects to be emphasized is an outcome of PPCM being the psychological impact due to medical treatment. An imminent result could also be avoiding the appearance of psychological disorders [28]. Monitoring the fetus throughout pregnancy is vital to avoid life-threatening situations, such as fetal hypoxia and asphyxia [18].

A usual measuring technique of the fetus's conditions is cardiotocography, which employs a clinical procedure of Doppler ultrasounds. Unfortunately, this technique is very complex and requires dedicated acting personnel. For that reason, alternative monitoring schemes have been presented, such as wearable devices based on the acquisition of an abdominal electrocardiogram (ECG). An in-home examination through a screening process is possible without the need for hospitalization [18]. Another relevant research addresses the BWSN prototyping of a body area network consisting of transducers, to jointly monitor blood flow and FHR, employing Doppler ultrasound [29].

Another research, by Boatin et al., [30] showed that the majority of both clinicians and pregnant women were fond of mobile measuring technology (about 95% and 65%, respectively). In the same research, a system configuration used wireless technology (Wi-Fi) based on a transceiver for transmitting and receiving data relevant to ultrasound measurements. The successful fetal monitoring did not exceed 88%. The establishment of Wi-Fi communication was very challenging, because of the high demand for accurate synchronization between the mobile device and the Internet. Borges et al. [25] proposed comfortable belts and wearable sensors for fetal movement monitoring in low-risk pregnancies. They could detect in real-time various fetal movements using IEEE 802.5.4 protocol-based communication while the cost of such devices is large enough along with their complexity. The latest works mention the detection of fluctuations, which are a crucial step in the process of isolating heart rate oscillation signals and noise.

In [31], the proposed model depends on the scheme of wave analysis for filtering out the background noise of the heartbeat during athlete exercise and isolates the R-wave heartbeat signal from the background noise. At the conference of Computing in Cardiology (2022), in [32] a developed algorithm presented energy-saving and cost-effective characteristics, namely Lullaby, and was developed to extract the fetal heart rate information from a pregnant mother's abdominal electrocardiography (ECG) signal. The algorithm was validated using the Physionet 2013 Challenge Dataset and can determine the fetal peaks with an average score of 81% despite the limited computational resources available, making remote reporting of the fetal HR possible using this configuration. Additionally, evaluation on real hardware shows that the proposed algorithm is suitable for devices having a minimum RAM of 64 Kb, which can be implemented on low-cost MCUs while it is designed to be energy-saving for longer-time and continuous monitoring.

## III. MEASUREMENTS OF FHR

The system is designed for pregnancy when the fetus is in utero-period. The system monitors whether the fetus's heart rate ranges in the normal range from 110 to 160 beats per minute (bpm) [2, 3]. Specifically, the system design comprises four layers (Fig. 1). The first layer involves the various sensors with their inputs for acquiring several physiological data. The second layer includes the development board along with various potential auxiliary boards for better signal processing. Then, the data are led to the third layer which includes all the internet services such as iCloud and online applications. The data can also be acquired from this layer as complementary to those originating from sensors. Afterward, various data and results are directed to the fourth layer (i.e. healthcare staffing agency and health information technology - IT - services). These services can utilize the data for being fed to machine learning processes thus artificial intelligence entities to find the best solution for the patient (e.g. the proper doctor and healthcare strategy). Finally, the fifth layer is relevant to information merging and the information displayed on various devices such as mobile phones, tablets, etc. Nevertheless, an important feature is that the final information can be directed back to the first layer, providing in this way a feedback loop (iterative procedure) for further enhancing the digital signal processing procedures.

It should also be emphasized that the system is responsible for recognizing the heartbeat of the fetus in the period shortly before delivery, as well as detecting in real-time the temperature, heartbeat, and hydration of the pregnant woman. The duration of the prenatal period is 38 weeks (fetal weeks) measured from the day of conception. However, since the day of conception is generally unknown due to reasons such as menstrual irregularities, the utero-period duration is conventionally estimated at 40 weeks-time (gestational weeks), measured from the first day of the last period of the pregnant woman [2, 3]. During pregnancy, FHR is increased up to about 170 bpm until the 10th week and then is decreased to about 130 bpm. Lower values of FHR than normal ones usually imply a condition known as bradycardia, whereas higher values of FHR are known as tachycardia. Heart rate is measured with the use of a pulse oximeter in children, adolescents, and adults. The process of pulse measurement is simple. Heart rate is measured by placing the sensor above the patient's body area of arterial pulse [17]. FHR measurement is also easy because the pregnant woman can place the sensor effortlessly on the area of her abdomen, precisely indicated by her physician. The required signals are measured with the patient lying back on the bed or a stretcher. The system's acquired pulses are refreshed and visualized between periods of 30 sec, using the thingspeak.com platform. Specifically, the utilized algorithm can update the displayed pulses at a 30-sec time window, i.e., by acquiring the number of pulses every 30-sec. The application calculates the heart rate by using a pulse-oximeter sensor [33]. For comparison purposes, the so-called fetal electrocardiogram signal is used as an alternative diagnostic tool for FHR measurements [34-36].

## IV. Data Harvesting, Processing and Information

The Data harvesting takes place with the activation of the board while the sensor collects data in numerical values. The acquired data from PPG are found between the numerical scale of 0 to 1023 units. As shown in Fig. 2, the implemented algorithm is constituted of four (4) interior loops. The first (outer) loop receives values classified into two groups. These are the group (A), consisting of values greater than 550 units, and group (B), consisting of values less than 550 units. In the case of the value being greater than the limit of 550 units, then the acquired heart rate value is larger than 108 bpm. If this value equals 1023 units, then the corresponding true value reaches 200 bpm. This range depends on the fetus's age (weeks) and can be altered accordingly [9]. If the measured value is less than 550 units, the process repeats itself until a pulse is detected, otherwise, the algorithm proceeds to the next level. An auxiliary variable y which corresponds to the time in seconds, increases by one unit every 1-sec measurements, till it reaches 60 sec, i.e., when $k = 20$ and $y = 60$. The next loop examines whether there is the following condition: $x < 50$ units. When x equals 50 units, then 1 second time is reached. Specifically, after acquiring a cycle of 10 measurements (i.e., when $j = 10$), the algorithm reverts to the "False" path to calculate the mean value of the aforementioned 10 loops. By completing each round of 10 loops, this condition creates a 20ms software delay. Therefore, to reach 1 second time, 50 sets of 10 loops (if $x < 50$) are needed. In this way, 1-second measurements are acquired with each loop iteration, adding the previously obtained measurement to the next one. The mean value of these measurements is found by dividing

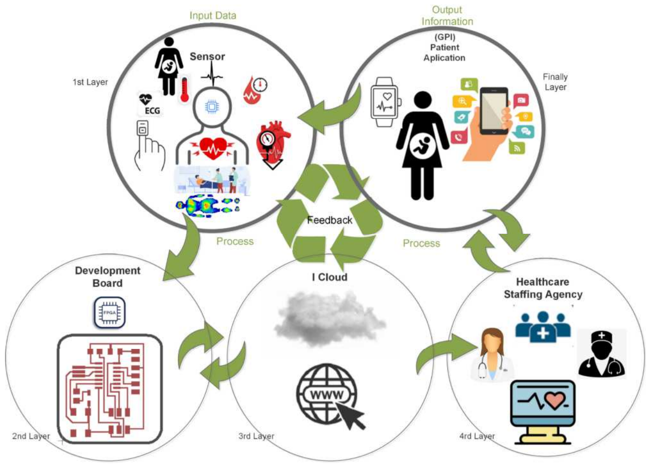


Fig. 1. Integrated system configuration

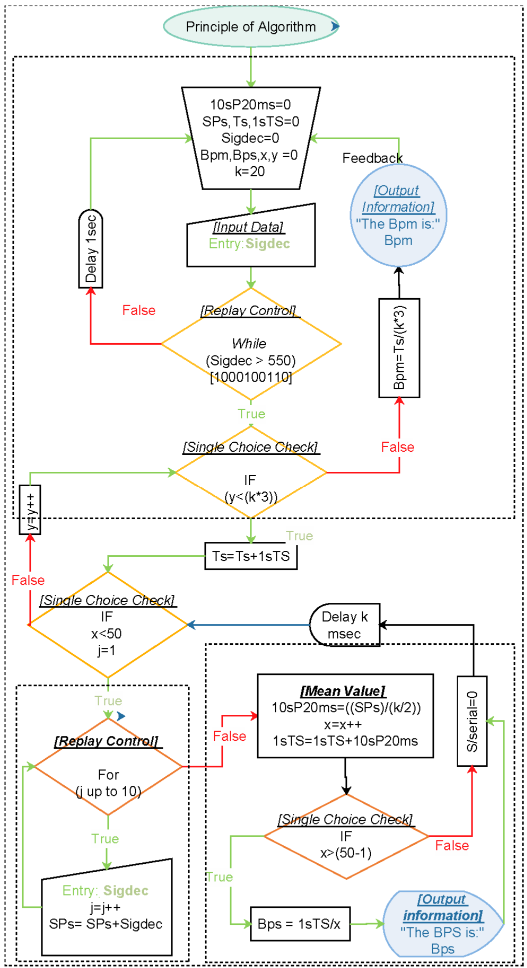


Fig. 2. Data flow control.

the sum of 1-second measurements by the number of iterations. While being in the condition of $x < 50$, the measurements can be forwarded for further processing, storage, and monitoring. In addition, the variable 1-second total sample (1sTS) is added to its previous value. Every time that the y is increased, the sum is accumulated in the variable "Ts". This procedure repeats itself 60 times, in the condition of "$y < 60$" is sustained. When this condition is false, flow control will proceed to the next stage. There, the total sum of the data is divided by the number of 60 repetitions, so that the

Bpm (Beat per minute) is evaluated, and sent to the cloud platform for the process of Bpm [37]. All variables will then be zeroed and a new 60-second life cycle begins, by adding a 1-sec delay for proper system reset. Finally, relevant to the achieved signal-to-noise ratio, the system configuration can automatically display the best-validated values of pulses following the threshold of 550 units. This threshold has the practical use of a tight bound for correctly digitizing the pulse values under real conditions.

## V. INTEGRATED SYSTEM DESCRIPTION

The primary system function is the recognition of the heart rates of the pregnant woman and the fetus by employing heart rate sensors (Fig. 1). Also, additional sensors such as those of temperature, perspiration, blood pressure, heart rate, and body pressure measurement system are used for real-time recording and observing while they are attached to the pregnant woman's body. The sensors interface and communicate through Wi-Fi or wired with the development board (mainly in wire operational mode).

The hardware development board connects to a small battery power supply. Shields attached to the development board are responsible for transmitting the processed data acquired from the sensors toward the router communication gateway wired or wirelessly (Wi-Fi). The router gateway enables ports to forward the data to a specific link address. Data are stored locally, or sent through the shield for further processing to a predefined web platform or the Thingspeak application, by using the IEEE 802.11 b/g/n protocol. Note that the Thingspeak.com platform is accessible by all commercial 3G-4G-5G mobile devices. It is possible to directly access the patient's data at any requested time and this can be done by the personal physician or even the patient. Then, the personal physician can evaluate the clinical condition and accordingly deliver a proper prescription to the patient. Feedback is also possible between the patient and the system to improve the quality of pregnancy as well as the safety of the fetus. So, multiple similar systems can be deployed simultaneously to a network and can harvest a large amount of data.

In turn, the purpose of the research was to create a system that can redistribute and reevaluate the data based on a feedback architecture. Moreover, the previous procedure provokes a feeling of security in the pregnant woman that the fetus is alive and healthy, avoiding unpleasant clinical conditions.

## VI. THINGSPEAK APPLICATION, DEVELOPMENT BOARD, SENSORS AND SHIELDS

The ThingSpeak.com website is eligible for research purposes providing up to one year free of charge. This application is capable of monitoring, storing, and comparing large data. This data can be obtained from a customized hardware project. A graphical user interface (GUI), a gauge, a matrix table, a numeric display, and a lamp for monitoring purposes are available.

Fig. 3 shows the interfaces with an example of measurement from our project whereas the fetal heartbeat is represented as a circular indicator. There is also a numbered area depicting the same measurement. The virtual instrument ranges from 85 to 200 bpm with areas of different colors for easily monitoring the subject's status. In addition to the previous, a quick virtual representation regarding a specific


Fig. 3. Example of fetus heartbeat equal to 106 bpm.

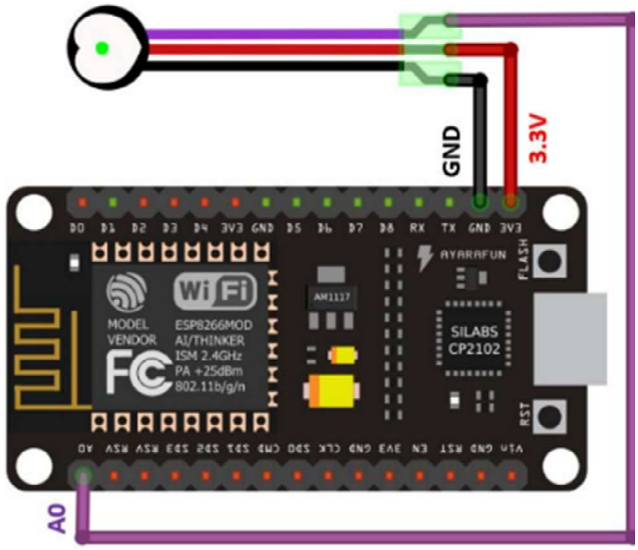


Fig. 4. Schematic diagram with important pin assignments, Node MCU ESP 8266.

FHR measurement is available through the display of a lamp. If the measured value (for a fetus's age of more than 12 weeks) is over 110 bpm, the application displays a green lamp, otherwise, it displays a red lamp as an alarm that the fetus is at risk.

Fig. 4 depicts a schematic diagram of the development board. The development board includes a microcontroller and a sensor, with upgrade capabilities for further enhancing or just providing a new function [9, 25, 26]. The development board costs less money than those found in [9, 16, 38] and also exhibits a low power consumption. The microcontroller Unit (MCU) software enables the debugger, defines the signal port, initializes the name of the local service set identifier, and pings the server connection. The sensor serves as a detector circuit connected to the development board. This board is the sink of all signals. The sensor, which can be placed on a pregnant belly, sends to the sink (board) the needed signals for processing. The development board can store locally the sensor data or even send them to a web platform using a shield. Our development board includes the shield onboard. The shield transmits, receives, or harvests data. In this work, the used commercial shield can send and receive data through Wi-Fi. E.g. in [9, 38], an additional module shield is used for transmitting data that provokes more power consumption.

In Table 1, a comparison is made between the specifications of development boards such as Arduino UNO [29], ESP8266 Node MCU [30], and ESP8266-12E module

[39]. The development board ESP8266 Node MCU was used in our research. The suggested development board has a Tensilica L106 32-bit processor and the maximum operating frequency is 160 MHz and ranges from 24 MHz to 52 MHz, against the Arduino which has an ATmega328P or AT-Mega 16U2/8 MHz or 16MHz processor respectively. The Arduino board has a previous report in a previous research paper [9]. The ESP8266-12E module has a Crystal oscillator exhibiting a frequency of 40MHz. The Power Consumption in working mode for the aforementioned development boards is 42mA, 15mA, and 80mA respectively without any additional attached shield or components. The deep sleep mode on the same development boards is 10mA 20uA and 10uA respectively. The working voltage on Arduino, ESP8266, and ESP8266-12E is around 2.7-5.5V or 7-12V (as it depends on the power VCC slot), 2.5-3.6V, and 3-3.6V respectively. The power consumption for Arduino is 0.29Watts, at ESP8266 Node MCU is 0.045Watts and at ESP8266-12E module is 26.4Watts. It must be noted the Arduino Board and ESP 8266-12E module must connect to each other and they work together. This implies that all consumptions must be added and this leads to an increase in energy consumption.

TABLE I. POWER CONSUMPTION OF DEVELOPMENT BOARDS.

| **Platform** | **Differences between development boards** | | | |
|---|---|---|---|---|
| | ***CPU / Freq Speed*** | ***Current (mA)*** | ***Voltage (V)*** | ***Power Consumption (W)*** |
| Arduino UNO [40] | ATmega328, ATMega 16U2 / 8 MHz or 16 MHz | 42 | 2.7-5.5 or 7-12 | 0.29 |
| ESP8266 Node MCU [41] | Tensilica L106 32-bit processor Max 160 MHz / crystal frequency ranges from 24 MHz to 52 MHz | 15 | 2.5-3.6 | 0.045 |
| ESP8266-12E module [42] | Crystal oscillator frequency of 40MHz | 80 | 3-3.6 | 26.4 |
| ***Platform*** | ***Sleep Mode (uA)*** | ***Specifications*** | | |
| Arduino UNO [40] | 10 | NO Wi-Fi onboard, 32 KB Flash, 2KB SRAM, 20 GPIO pins, 1 KB EEPROM | | |
| ESP8266 Node MCU [41] | 20 | Wi-Fi onboard (3DBi, 1×1 MIMO, 2×1 MIMO), SRAM < 50kB, 16 MB memory capacity, 17 GPIO pins, Cloud Server | | |
| ESP8266-12E module [42] | 10 | Wi-Fi onboard (3DBi, 1×1 MIMO, 2×1 MIMO), SRAM < 50kB, 16 MB memory capacity, 17 GPIO pins, LAN Server | | |

## VII. BENEFITS

This research proposal introduces a scheme for the implementation of a healthcare monitoring environment for many problems that could occur during pregnancy and can be efficiently addressed with the provided knowledge. Reduced fetus oxygenation can vary the heart rate causing bradycardia and thus fetal's heart rate fluctuations. Moreover, several conditions, known as maternal thyroid dysfunction, maternal infection, chorioamnionitis, etc., can lead to fetal heart alterations. Consequently, the proposed system may exhibit beneficial effects on fetal well-being. Also, the proposed FHR monitoring can be easily used by pregnant women during difficult conditions such as COVID-19 quarantines. In more detail, its specifications include, a) detection and alerting about needed intervention, b) detection of underreporting physiological metrics that could be crucially relevant to fetus and mother health, and c) the field of telemedicine and online monitoring will be heavily upgraded by using state-of-the-art technologies (e.g. 5G). Consequently, the advantages of the application are many and important:

- As far as the cost of this system, it is low and thus is reliable. E.g. a gold standard (well-known cardiograph) cost about 1500 euros while our project provides still efficient health monitoring at a production cost as low as 15 euros.
- The proposed system can be easily implemented, operated, and at the same time portable, and comfortable while being operated in remote or even inaccessible areas due to weather conditions.
- Pregnant women can use the portable system even by using remote sensing. Moreover, using a wireless network and an application, a remote system can obtain, process, and present data in real-time. The proposed system can sustain more features like blood pressure, glucose level, and the detection of the psychological state. These kinds of conditions may include maternal respiratory sinus arrhythmia [15], fetal acidosis detection [14], and risk of oxygen deprivation during childbirth [43].
- Capability of 24 h-tracking and large backup with the possible outcome of avoiding the birth of a dead fetus.
- On-time appointment with the doctor because the condition of the fetus/pregnant woman is already known [44] thus there is the capability of examining and diagnosing several patients at the same time.
- Live monitoring by specialists toward dealing with demanding cases such as low or high heartbeats where a fetus is thought to be in danger and thus avoiding premature birth.

## VIII. RESEARCH RESTRICTIONS AND FUTURE GOALS

The current research study is in the prototyping stage, but it exhibits adequate results when comparing the proposed system board to a gold standard. Nevertheless, restrictions apply. The system needs to be widely tested when all the sensors (with a preference for low-cost solutions) will be implemented while ensuring that no significant errors could emerge during extensive testing. Likewise, an upgraded intelligent system (with decreased size, weight, and power consumption) based on experiences of the pregnant women and thus on machine learning (ML) / artificial intelligence (AI) [45, 46] to be able to predict future conditions during childbirth or pregnancy. The subsequent development of future research is to make the system capable of intervening in maternal health remotely, using smart algorithms based on ML and AI schemes.

## IX. CONCLUSIONS

In this paper, we presented a cheap, portable, and home-based PPG monitoring application system based on an ESP8266 node that can be applied to the health monitoring of pregnant women and at the same time serves as an IoT platform. The fetal health monitoring system contributes in terms of medical resources and physicians' time. The system is suitable for pregnant women and has certain application prospects and adequate upgrade capabilities. In the future, the data collection of more participants will be carried out to verify the practicability of the wearable fetal monitoring system in a 24-h or long-term monitoring system.

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