



## EXPERT SYSTEM FOR FETAL HEART RATE MEASURING DEVICES: LITERATURE REVIEW

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### ABSTRACT

With the current development of science and technology, many fetal heart rate detection devices have been designed and have become superior in the field of technology. The aim of the literature study is to find out which expert systems have been developed to detect fetal heartbeats. This research method is a literature study, with a search using Evidence Based Practice (EBP) from the Google Scholar data base. There are 10 articles based on searching results using the PICO technique for the last 5 years from 2019-2023. After conducting an article search, 10 research articles were selected that met the inclusion criteria. The results of the analysis found that there are several expert systems that have been developed to detect fetal heartbeats, including: Android-based, Bluetooth low energy, LabVIEW, Telefetalcare system, Blind Source Separation, smartwatch, Demster-Shafer, Phantom, Arduino Uno, and ATmega8 microcontroller. It was concluded that the health sector system had developed a lot.

Keywords: expert system; fetal heart rate; measuring device

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### INTRODUCTION

Fetal heart rate (FHR) is a vital sign of the fetus, normal FHR results change as the pregnancy progresses, FHR fluctuations are also normal (Gameraddin et al., 2015). At the beginning of pregnancy, the FHR fluctuates constantly but during the third trimester it becomes more stable. The normal FHR range can be expected to lie between 120 and 160 bpm (Herhaleness, 2018). DJJ has a sound that beats faster than an adult human's pulse, and has a rhythm that tends to be regular. On the other hand, in abnormal conditions it can change to be faster or slower and can be accompanied by rhythm irregularities. DJJ monitoring is mandatory for pregnant women and women giving birth. This is done to assess whether or not there is a pulse irregularity, if a large difference is found, it means there is a rhythm abnormality and will determine the next analysis related to the medical decision making that will be carried out (Endjun & Affandi, 2013).

DJJ determines the welfare of the fetus in the womb. The components that can be used as measurements to determine the condition of the fetus are fetal movement, movement of the fetal chest cavity, fetal tone, FHR, and the amount of amniotic fluid (Faradisa et al., 2017) which are carried out to detect early the presence or absence of risk factors for prenatal death (hypoxia/asphyxia, growth disorders, congenital defects, and infections) (Anggraini et al., 2020; Chabibah & Laela, 2017).

Maternal Mortality Rate and Infant Mortality Rate are indicators of a country's health status. The SDG's target in 2030 for MMR is 70/100,000 KH and IMR 12/1000 KH. The 2024 RPJMN target for MMR is 183/100,000 KH and IMR 12/1000 KH. To date, the MMR in Indonesia has still reached 305/100,000 KH, while the MMR in Central Java in 2021 is 199/100,000 KH and the MMR in Semarang Regency in 2021 is 151/100,000 KH with a total of 20 maternal deaths. The biggest causes of maternal death are bleeding, preeclampsia and covid. According to data from the Ministry of Health, the Infant Mortality Rate (IMR) in Indonesia in 2020 was 16.85 per 1,000 live births, Central Java Province was 12.77 per 1,000 live births (Badan Pusat Statistik, 2023). And according to data from the Semarang District Health Service in 2021, it was 8.99/1000 KH with 109 cases. The biggest cause of death occurs in neonates with the 3 highest causes being asphyxia, LBW and congenital abnormalities (Dinas Kesehatan Provinsi Jawa Tengah, 2022).

In this case, the government continues to strive to reduce MMR and IMR by developing science and technology as well as the skills of health workers in health services during pregnancy and childbirth in monitoring the welfare of the mother and fetus including: FHR can be done using Fetal Doppler (Abadi, 2023), (Smith et al., 2021), laenec (Seah et al., 2023), or Cardiotocography (CTG) (Irawan et al., 2021; Tengah, 2019). With the current development of science and technology, many DJJ detection tools have been designed and have become superior in the field of health technology. It is hoped that the use of technology in the health sector by adding the DJJ monitoring feature will become an alternative for monitoring the well-being of the fetus and mother, especially DJJ, safely and both for the mother and health workers (Kurnianingsih et al., 2016). An expert system is a computer-based system that uses knowledge, facts and reasoning techniques to solve problems that usually can only be solved by an expert in a particular field. Expert systems provide added value to technology to help in dealing with an increasingly sophisticated information era (Yuvidarmayunata, 2018). The aim of this literature study is to determine the development of expert systems in measuring fetal heart rate.

## **METHOD**

This study is a comprehensive summary in the form of a literature review regarding the development of expert systems in measuring Fetal Heart Rate. The protocol and evaluation of the literature review will use the PRISMA checklist to select studies found that are tailored to the objectives of the literature review. The methods used in this study are literature/systematic review, experiment, Quasi Experimental and qualitative phenomenological design of expert system development in measuring Fetal Heart Rate. The aim of this study is to collect and analyze articles related to the development of expert systems in measuring fetal heart rate. The literature search was carried out from January to February 2024. The data in this literature review uses secondary data obtained from the results of research by previous researchers from 2019 to 2023. The data collection method is using the ScienceDirect, PubMed, and Google Scholar data databases in last 5 years. Data that meets the requirements and relevant reviews is 10.

Searching for journals or articles in this literature review uses keywords (AND, OR, NOT) which are used to specify and expand the search, so that it will make it easier to determine which article or journal to use. Quality assessment in this research uses guidelines for analyzing reporting among those selected, namely Critical Appraisal Skills Program Tools (CASP). The keyword used is the development of an expert system in measuring fetal heart rate. The strategy used to search for articles using PICOS, which consists of Population/problem is part of the problem being analyzed, namely health services,

Intervention is a particular action or management of a problem, namely the development of an expert system in measuring Fetal Heart Rate, Comparators are other comparable interventions or management namely none, Outcomes are the results obtained from previous research studies, namely showing the development of an expert system in measuring Fetal Heart Rate, and Study design is the research design used in the research, namely literature/systematic review, experiment, Quasi Experimental, and qualitative phenomenological design.

**RESULTS**

There were 10 articles that met the inclusion criteria and study topic:

Table 1.  
Data on article characteristics collected (n= 10)

No	Title and Author	Setting (Place and Year)	Research design	Expert system	Result
1	A fetal ECG monitoring system based on the android smartphone. Li Yuan, Yanchao Yuan, Zhuhuang Zhou, Yanping Bai and Shuicai Wu(Yuan et al., 2019)	China, 2019	Quasy Eksperi-ment	Android smartphone based DJJ monitoring	Monitoring FHR with an Android smartphone is suitable as a non-invasive fetal ECG monitoring tool
2	Evaluation of Digital Compressed Sensing for Real-Time Wireless ECG System with Bluetooth low Energy. Yishan Wang, Sammy Doleschel, Ralf Wunderlich, Stefan Heinen(Wang et al., 2016)	Jerman, 2016	Pre Eksperimen	Monitoring DJJ with Wireless ECG System with Bluetooth low Energy	Bluetooth Low Energy (BLE) wearable and wireless ECG system in smartphones with its compact characteristics and long working time, this system provides a viable solution for conducting DJJ examinations.
3	Non-invasive fetal monitoring: A maternal surface ECG electrode placement-based novel approach for optimization of adaptive filter control parameters using the LMS and RLS algorithms. Radek Martinek, Radana Kahankova, Homer Nazeran, Jaromir Konecn, Janusz Jezewsk, Petr Janku, Petr Bilik, et al(Martinek et al., 2017)	Republik Ceko, 2017	Pre Eksperimen	Uses signals provided by the latest version of the LabVIEW Based Multi-Channel Non-Invasive Maternal-Fetal Abdominal Electrocardiogram Signal Generator	The experimental results confirm the theoretical assumption that the optimal setting of this adaptive filter depends on the position of the ECG electrodes on the mother's body, and can achieve much better results than without using optimization
4	Monitoring fetal heart rate during pregnancy: Contributions from advanced signal processing and wearable technology. Maria G. Signorini, Andrea Fanelli, and Giovanni Magenes(Signorini et al., 2014)	Italia, 2014	Pre Eksperimen	Monitoring DJJ with Tele Fetal Care system technology	Calculation of FHR with signals is significant in helping to describe the pathological mechanisms of the cardiovascular and nervous systems

No	Title and Author	Setting (Place and Year)	Research design	Expert system	Result
5	Design of a Portable Maternal Electrocardiogram Based on Blind Source Separation for Monitoring. Ahmad Asrori, Mohammad Kamalul Wafi, Ikrarda Tegar Pambudi, Hasan, Ola Dwi Sandra(Ahmad Asrori et al., 2013)	Surabaya, 2013	Pre Eksperimen	Design of a Portable Maternal Electrocardiogram Based on Blind Source Separation	The device can monitor the heart condition of the mother and fetus and can be used independently without the help of a doctor
6	Measuring Fetal Heart Rate in Mothers by Inducing Labor Through the Use of a Smartwatch. Vina Dhian Titisari, Melyana Nurul Widyawayi, dan Kurnianingsih(Titisari et al., 2021)	Semarang, 2021	Quasy Eksperimen	Smartwatch with DJJ measuring feature	Measuring Fetal Heart Rate in Mothers by Inducing Labor Through the Use of a Smartwatch
7	Application of an Expert System to Identify Pregnancy Problems Using the Dempster-Shafer Method. Ashari (Ashari, 2015)	Makassar, 2015	This data was obtained through: Library research, field research and interviews	Using Dempster-Shafer based on responsive web	The research results show that the system can work well according to its objectives. An expert system for identifying pregnancy cases through a web application can provide a diagnosis so that it can help pregnant women
8	Development of Phantom Antenatal Care as an Educational Media to Improve Pregnancy Examination Skills. Anisa Fadilah, Happy Dwi Aprilina, Tutut Setiawati (Fadilah et al., 2022)	Purwokerto, 2022	Research and Development (R&D)	Development of Phantom Antenatal Care	The development of phantom antenatal care has been created which can function for measuring uterine fundal height, Leopold physical examination and auscultation of fetal heartbeat.
9	Laennec Bluetooth for Fetal Heart Rate Checking. Eko Nugroho, Wijayanti, Noradina Rahmawati. (Nugroho et al., 2023)	Surakarta, 2023	Research and Development (R&D)	Design and Build Laennec Bluetooth Based on Arduino Uno	The test results show that the Laennec Bluetooth error percentage is 0.31%. The furthest distance that can be reached by Bluetooth is 14 meters so this value is still within the tolerance limit that the device is suitable for use.
10	Fetal Doppler Simulator. Hanifah Rahmi Fajrin, Sari Maharani, Aidatul Fitriyah, (Fajrin et al., 2021)	Yogyakarta, 2021	Planning hardware, software design.	Microcontroller ATmega8	The BPM Simulator Tool for Fetal Doppler can function well because it has an error value below the tolerance of $\pm 5$ for BPM on fetal doppler.

## **DISCUSSION**

Based on the results that have been discussed regarding the development of expert systems for measuring fetal heart rate, the researchers summarize them in several sub-sections that are more structured based on the results and technology used, namely as follows:

### **Phantom Antenatal Care as an Educational Media**

(Fadilah et al., 2022) developed Phantom Antenatal Care, a tool designed to improve prenatal screening skills. This tool allows measurement of uterine fundal height, Leopold's physical examination, and auscultation of the fetal heart rate. With technological components: Phantom Antenatal Care is equipped with speakers, connector cables, push buttons, mini DF player, memory card, LCD display, plugs, and 5 volt voltage source adapter, and product revision validation tests and small trials have been carried out and it is concluded that The development of Phantom Antenatal Care can be used as an educational medium that functions to measure uterine fundus height, Leopold's physical examination and accumulation of fetal heart rate.

### **Smartphone-Based Fetal ECG Monitoring System**

(Yuan et al., 2019) developed features and designed a low-power portable fetal ECG system that collects ECG signals from the mother's abdomen in real-time and sends them to a smartphone via Bluetooth. Which uses FastICA technology and algorithms and sample entropy for real-time analysis and extraction of fetal ECG signals. Android smartphone-based fetal ECG monitoring system, as a non-invasive fetal ECG monitoring tool. this study designed a low-power portable fetal ECG collector, which collects ECG signals from the mother's abdomen in real-time. ECG data is sent to the client's smartphone via Bluetooth. Smartphone application software is developed based on the Android system. The application integrates a fast fixed point algorithm for independent component analysis (FastICA) and a sample entropy algorithm, for real-time extraction of fetal ECG signals from maternal abdominal ECG signals. The fetal heart rate is calculated using the extracted fetal ECG signal. The experimental results show that the FastICA algorithm can extract the fetal ECG clearly, and the sample entropy can precisely determine the channel location of the fetal ECG. The proposed fetal ECG monitoring system is feasible for non-invasive and real-time fetal ECG monitoring.

### **Evaluation Research on ECG Systems with Wireless and BLE**

(Wang et al., 2016) and (Martinek et al., 2017) evaluated and developed a wireless ECG system with Bluetooth Low Energy (BLE), applying Digital Compressed Sensing (CS) techniques for energy efficiency. Results and Optimization of the developed system demonstrated increased battery life and effectiveness in detecting fetal ECG signals. (Wang et al., 2016) conducted research on the evaluation of a digital compressed sensing real-time wireless ECG system with Bluetooth low energy, by designing and developing a DJJ monitoring tool with a Wireless ECG System with Bluetooth low energy and the research results showed that the Bluetooth Low ECG system Energy (BLE) wearable and wireless on smartphones with compact characteristics and long working time, this system provides a viable solution for carrying out DJJ examinations.

The wearable, wireless ECG system is designed with Bluetooth Low Energy (BLE). Can be used to detect 3-lead ECG signals and is completely wireless. Digital Compressed Sensing (CS) is applied to improve the energy efficiency of wireless ECG sensors. Different sparsification bases, different compression ratios (CR) and several reconstruction algorithms are simulated, the reconstruction is carried out by an Android application on the smartphone

to display the signal. Power efficiency is measured and compared with a system without CS. The optimal satisfaction basis constructed by 3-level decomposed db4 wavelet coefficients, 1-bit Bernoulli random matrix and the most suitable reconstruction algorithm are selected through simulation and applied to the sensor nodes and Applications. Sensor node battery life is extended from 55 hours to 67 hours. The presented wireless ECG system with CS can significantly extend battery life by up to 22%. With the characteristics of compact and long service life.(Martinek et al., 2017), conducted research by developing an FHR examination using LabVIEW-based ECG signals, to confirm the theoretical assumption that the optimal setting of the adaptive filter depends on the position of the ECG electrodes on the mother's body, and can achieve much better results than without using optimization.

This study applies and verifies a new method for optimization of control parameters (such as step size  $\mu$  and filter order  $N$ ) of LMS and RLS adaptive filters used for noninvasive fetal monitoring. The optimization algorithm is driven by considering the position of the ECG electrodes on the surface of the mother's body to improve the performance of the adaptive filter. The main criterion for selecting optimal parameters is the Signal-to-Noise Ratio (SNR). The researchers conducted experiments using signals provided by the latest version of the LabVIEW-based Multi-Channel Non-Invasive Maternal-Fetal Abdominal Electrocardiogram Signal Generator, which provides flexibility and the ability to model the primary distribution of maternal/fetal ECGs in the human body. This new algorithm makes it possible to find the optimal settings of the adaptive filter based on the placement of the maternal surface ECG electrodes. These improvements may in turn result in more accurate detection of fetal hypoxia. This approach may offer potential for use in clinical practice to establish standard electrode placement recommendations and find optimal adaptive filter settings for extracting high-quality fetal ECG signals.

### **Development of DJJ Measurement Technology Based on Smartwatches, Expert Systems and Blind Source Separation**

(Titisari et al., 2021) developed a Smartwatch for DJJ Measurement, a smartwatch equipped with sensors and a coding system for real-time DJJ measurements. (Ashari, 2015) developed an Expert System with the Dempster-Shafer Method, to separate maternal and fetal ECG signals, enabling independent use of the tool without the need for a doctor. (Ahmad Asrori et al., 2013) developed the design of a portable maternal electrocardiogram device based on Blind Source Separation. (Titisari et al., 2021) carried out smartwatch-based DJJ measurements, which are part of a wearable device that refers to the computing capabilities embedded in the device. Smartwatches offer users the ability to interact in the digital world, one of which is the ability to monitor and display data related to the user's health. Smartwatches are watch-like devices that are generally equipped with a powerful processor, memory subsystem, and various important sensors (Park et al., 2019; Siradj, 2016). The smartwatch developed in this research uses a sensor in the form of a microphone to capture DJJ signals, DJJ signal coding is made using NE5532, then DJJ data is processed using a microcontroller equipped with Wifi and Bluetooth which can be used for wireless data transmission processes. so it can appear on the smartwatch screen.

(Ashari, 2015) applies an expert system to pregnancy using the Dempster-Shafer method. This research includes system design (UML diagram design, database design and interface design) and Dempster-shafer analysis. System design begins with designing a knowledge base. Knowledge base design uses production rules to present recommendations, directions, or knowledge strategies. Production rules are written in the form of if-then statements. The if-then rule connects (antecedent) with the resulting consequences. In designing this expert

system knowledge base, the premise is that the symptoms found in pregnancy are the type of pregnancy, so the form of the statement is (if-then). The premise part of a rule in a production rule can have more than one proposition, meaning that in this expert system one rule can have more than one symptom. In the Demster-Shafer method, an expert is needed to determine a belief value, then with this belief value there will be a reasonable value to find out the possible value using the Demster-Shafer method. The system testing process consists of inputting data on symptoms experienced by the patient. The design of an expert system in identifying pregnancy problems is carried out using the demspter shafer method based on rules according to the expertise of experts by measuring the strength of evidence in supporting a set of propositions and is carried out by a computer system as a tool. results of designing system diagrams or flow, database design and expert system interfaces.

(Ahmad Asrori et al., 2013) designed a portable maternal electrocardiogram device based on Blind Source Separation, which can monitor the condition of the mother's and fetus' hearts and can be used independently without the help of a doctor. The aim is to separate mixed signals where there is a lot of noise that occurs when carrying out FHR examinations on pregnant women. There are several mixed signal separation techniques that can be used to purify the heart signals of pregnant women, one of the most frequently used is filtering. This design does not use filtering techniques, because filtering can remove some parts of the signal, making the diagnosis process difficult. The signal separation technique used is Blind Source Separation (BSS). The BSS algorithm works by using input signals from readings from several sensors arranged in an array, which is a group of sensors connected into one unit to receive and transmit physical signals. In this case the sensor used is a disposable electrode.

These electrodes will capture signals originating from the mother (maternal heart), fetus (fetal heart), and noise from various sources. The BSS algorithm will then separate the three by referring to the difference in propagation of each signal to each electrode. Apart from being able to completely separate maternal and fetal ECG signals, the Portable Maternal Electrocardiogram is also designed to be used by anyone and anywhere. So the tool must be made as simple as possible without reducing its main function as a signal separator. The electrodes used for the sensor circuit are disposable. The electrical signal from the electrode reading is then processed on the ECG instrument so that it can be read by the BSS separator program. ECG instruments are designed with a power supply from a battery that can be recharged if it runs out. Meanwhile, the separation program was created in Visual Basic 6.0 software and produces output in the form of maternal and infant ECG signals.

From the design results obtained, several things can be concluded, including: the tool has been able to separate the mother's ECG signal from the fetus's ECG signal, where the mother's signal frequency is smaller than the fetus' signal frequency, the position of the electrode arrangement device which is parallel to the pregnant woman's stomach produces a higher ECG signal amplitude. very small, can monitor the condition of the mother's heart and the fetus' heart, and can be used independently by anyone without having to be accompanied by a doctor.

### **Fetal Doppler Simulator and Latest Innovations**

(Nugroho et al., 2023) developed Recent Research with Arduino, this research explores the use of Bluetooth Laennec based on Arduino Uno for DJJ measurements which can be accessed up to a distance of 14 meters. (Fajrin et al., 2021) developed a fetal doppler simulator with an ATmega8 microcontroller, allowing adjustment of BPM values. (Nugroho et al., 2023) conducted research checking DJJ using Bluetooth Laennec based on Arduino

Uno, the furthest distance that can be reached by Bluetooth is 14 meters so this value is still within the tolerance limits of a device suitable for use. Laennec's Bluetooth design based on Arduino Uno displays the number of fetal heartbeats (DJJ) in real time and continuously in Beats per Minute (BPM) on an LCD screen installed on the device and can also be displayed on an Android smartphone via an application that is installed on it which is connected via Bluetooth. The monitoring system is designed to monitor and measure DJJ automatically. DJJ measurements use the MAX4466 Sensor and Arduino Uno as data processors. Bluetooth Laennec testing is carried out by comparing the measurement results with the original Laennec which is made from aluminum by comparing the error values. Based on the results of tests on samples carried out with Bluetooth Laennec and measurements carried out directly by Laennec, an average error percentage of 0.31% was obtained. The Bluetooth range on the Bluetooth Laennec is a maximum of 14 meters because at the time of the inspection it was in a closed room blocked by walls.

(Fajrin et al., 2021) conducted research on a fetal doppler simulator using the ATmega8 microcontroller, which aims to create a BPM simulator for fetal doppler with the addition of BPM options from 60 to 240 in multiples of 30 by using a solenoid instead of a tap heart and other supporting electronic circuits. In measurements, BPM 60 has an error value of 0.027%, BPM 90 has an error value of 0.034%, BPM 120 has an error value of 3.3%, BPM 150 has an error value of 0.031%, BPM 180 has an error value of 0.031%, BPM 210 has an error value of 0.019%, and the smallest error value is 0% at the BPM 240 measurement point. The BPM Simulator tool for Fetal Doppler can function well because it has an error value below the tolerance of  $\pm 5$  for BPM on Fetal Doppler. The hardware design of this tool uses several circuit modules including the ATmega8 microcontroller circuit, while the software used is CV AVR programming software for data processing on the tool. The microcontroller circuit is used as the brain to control device activity. The microcontroller circuit uses ATmega8 which is equipped with an internal ADC, making the converter system easier. In the microcontroller circuit there is also a downloader port which functions to enter the required program. In this circuit there is a 100nF capacitor connected to the VCC port and ground, there is a 100nF capacitor connected to the reset button and connected in series with a 4k7 resistor which goes to PORTC/reset. PORTB6 and PORTB7 are connected to a 22pF capacitor connected to a 16 MHz crystal.

This series of LCDs uses an output display in the form of a 2x16 LCD, where later the ADC (Analog To Digital Converter) value that is read in the form of a set BPM value will be displayed on the LCD screen. To turn on the LCD a +5V voltage supply is required on the VDD pin, ground on the VSS pin. To adjust the LCD brightness, use a resistor with a small value or a large value with an LED indicator. This driver circuit is used to activate the solenoid component using the ATmega 8 microcontroller. When the minis circuit has received voltage, the driver circuit will automatically receive voltage via port d, port d functions as input or output. The function of DDRD = 0xFF is that when the driver receives voltage, the solenoid component is not active because there is no command and the input is located at PORTD = 0x00 which will activate the solenoid when there is a command from PORTD.3. The solenoid can be active because it gets voltage from the TIP 120 Transistor or NPN type Transistor where the transistor functions as a switch that can flow current so that it can activate the solenoid if it gets a voltage of more than 5v and the solenoid will activate or move when given a command from the program.

### **Development of Telefetalcare system technology**

(Signorini et al., 2014) developed the Telefetalcare system technology for measuring FHR, with the results of calculating FHR with significant signals in helping to explain pathological mechanisms of the cardiovascular and nervous systems. This study focuses on monitoring procedures applied to fetal heart rate variability (FHRV) signals, collected during pregnancy, to assess fetal well-being. The use of linear time and frequency techniques and the calculation of nonlinear indices can contribute to increasing the diagnostic power and reliability of fetal monitoring. This study shows how advanced signal processing approaches can contribute to the development of new diagnostic and classification indices. Its utility was evaluated by comparing two selected populations: normal fetuses and fetuses with intrauterine growth restriction (IUGR). The results show that calculating various FHRV signal indices, both linear and nonlinear, provides useful indications for delineating the pathophysiological mechanisms involved in the cardiovascular and nervous systems controlling the fetal heart. As a further contribution, this study briefly describes how the introduction of a wearable system for fetal ECG recording may provide a new technological solution that improves the quality and utility of prenatal monitoring.

### **CONCLUSION**

Based on the results of the literature review, there are 10 articles about the development of an expert system for measuring fetal heart rate. It is hoped that this literature study will provide information and consideration for health workers, especially midwives, nurses and doctors, in providing health services by developing technology in the health sector to increase patient comfort.

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