



Innovation Article

Fetal movement monitoring system using a flexi sensor

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A B S T R A C T

Background: Fetal movement monitoring is an essential indicator of fetal well-being and a critical factor in reducing perinatal morbidity and mortality. Current monitoring methods rely on maternal perception or periodic clinical assessment, which are subjective and may delay detection of complications. Real-time, sensor-based, and IoT-enabled monitoring systems remain limited.

Purpose: This study aimed to develop and evaluate a simple, IoT-based fetal movement monitoring device using a flex sensor.

Methods: A research and development (R&D) approach with the waterfall model was applied. This approach consisted of requirements analysis, system design, implementation, system testing, and maintenance. The prototype was tested on third-trimester pregnant women, including non-pregnant participants, for specificity testing.

Results: The device detected between 14 and 33 fetal movements per hour during one-hour monitoring sessions in pregnant participants. No movements were detected in non-pregnant participants, confirming device specificity.

Conclusion: An IoT-based fetal movement monitoring device using a flex sensor was successfully developed and demonstrated acceptable accuracy and specificity. This innovation offers a practical and cost-effective tool to support healthcare providers and pregnant women in early detection of potential pregnancy complications, with a possible impact on reducing perinatal morbidity and mortality.

INTRODUCTION

Fetal movement is a well-recognized clinical marker of fetal health and well-being. A reduction in fetal activity, particularly in the third trimester, is strongly associated with adverse perinatal outcomes. Studies report that approximately 25% of pregnancies with reduced fetal movement result in poor birth outcomes, while 55–63% of intrauterine fetal deaths are preceded by maternal perception of decreased movement.^{1,2} This decline is often linked to reduced placental perfusion and subsequent fetal distress.

Globally, pregnancy and childbirth remain high-risk periods for maternal and neonatal survival. According to UNICEF, an estimated 2.8 million maternal and neonatal deaths occur each year, equivalent to one death every 11 seconds.³ Most of these deaths are preventable through timely detection and intervention. In line with the Sustainable Development Goals (SDGs), the global target 2030 is to reduce neonatal mortality to below 12 per 1,000

live births and maternal mortality to less than 70 per 100,000 live births.⁴ In Indonesia, despite progress, maternal mortality remains a challenge, with Surakarta City reporting 30.72 maternal deaths per 100,000 live births in 2023, and 20% of pregnancies experiencing obstetric complications.⁵ These statistics highlight the urgent need for practical, accessible, and affordable maternal-fetal monitoring solutions.

Recent Internet of Things (IoT) advances have enabled real-time physiological monitoring through interconnected devices. Several prototypes and patents have been proposed for maternal-fetal health surveillance. For example, patent IDS000003773 (filed April 2021) describes a device that monitors maternal vital signs and fetal heart rate but lacks specificity in measuring fetal movement per unit time.⁶ Similarly, patent IDS000007108 (filed December 2023) presents a portable fetal monitoring system using photoplethysmography (PPG) and electrocardiography (ECG) sensors; however, its reliance on multiple sensors limits practicality and does not focus on movement-specific monitoring.⁷

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These limitations indicate a research gap in developing a simple, cost-effective, and movement-specific fetal monitoring device. The present study introduces an IoT-enabled fetal movement monitoring system using a single flexi sensor to address this. This design reduces hardware complexity, enhances usability, and enables real-time fetal movement detection. Beyond clinical benefits, such a system may also empower pregnant women in self-monitoring and support early intervention in cases of abnormal fetal activity.

This study aims to design, develop, and evaluate an IoT-based fetal movement monitoring device utilizing a Flexi sensor for third-trimester pregnancies. The device is expected to provide a practical, movement-specific monitoring tool that supports clinical decision-making and maternal engagement in fetal health surveillance.

METHOD

This study employed a Research and Development (R&D) approach using the Waterfall model, which consists of five stages: requirements analysis, system design, implementation, system testing, and maintenance.

Stage 1 Requirements Analysis

A literature review and field observation were conducted to identify current challenges in fetal monitoring. Existing tools, such as Doppler devices, are typically limited to use by health professionals in clinical settings, highlighting the need for a more accessible, user-friendly, and cost-effective device for fetal movement monitoring.

Stage 2 System Design

The system was designed to detect fetal movements using a flex sensor embedded in a wearable abdominal belt. Sensor signals were processed by a microcontroller (ESP32), displayed on an OLED screen, and transmitted to a cloud server via Wi-Fi for remote access. The device was powered by a rechargeable lithium-ion battery with integrated power management. Figure 1 presents a block diagram of the system architecture.

Stage 3 Implementation

The design was realized into a functional prototype integrating hardware and software components. The system was calibrated to detect abdominal wall movements associated with fetal activity and store data in a cloud-based platform for further analysis.

Stage 4 System Testing and Clinical Evaluation

System functionality was first verified through laboratory testing. Subsequently, a pilot clinical evaluation was conducted in Surakarta, Indonesia, in July 2024. The study population included third-trimester pregnant women (>28 weeks of gestation). Inclusion criteria were pregnant women willing to participate, while exclusion criteria were refusal to participate. Purposive sampling was applied. Ethical approval was obtained from the Research Ethics Committee of PKU Muhammadiyah Surakarta Institute of

Science and Health Technology (Approval No. 026A/LPPM/ITS.PKU/II/2024). All participants provided informed consent before enrollment.

Stage 5 Maintenance

To ensure device reliability, maintenance tests were conducted to assess stability, battery performance, and sensor durability under repeated use.

RESULTS

Requirements Analysis

The analysis confirmed the need for a simple and accessible fetal monitoring tool that could be used not only by healthcare professionals but also by pregnant women for self-monitoring. A literature review and field observations revealed limitations of existing tools, which are restricted to clinical use. This established the basis for developing an IoT-enabled fetal movement monitoring system.

System Design

The system was designed with a flex sensor integrated into a wearable abdominal belt. Data acquisition was performed by an ESP32 microcontroller, with results displayed on an OLED screen and transmitted wirelessly to a cloud database for storage and further analysis (Figure 1–2). The system architecture consisted of two devices: (i) a detection unit worn by the mother, and (ii) a receiver unit connected to cloud storage and an alarm system.

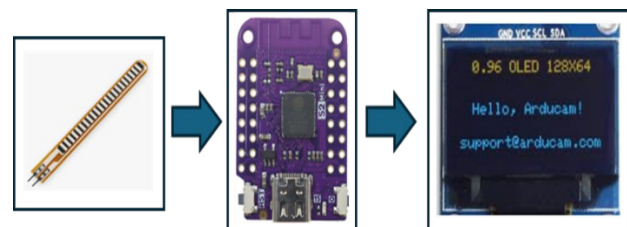


Figure 1: Sensor fleksi, controller, display



Figure 2: Fetal movement monitor

Implementation

The prototype was successfully realized by integrating hardware (flex sensor, ESP32, OLED display, Li-Ion battery) and software components. The device was calibrated to detect fetal movement and transmit real-time data.

System Testing

After designing the device, enter the Device Operating Procedure stage. The operating procedure includes the steps to turn on the device, use it, and stop it (Figure 3).

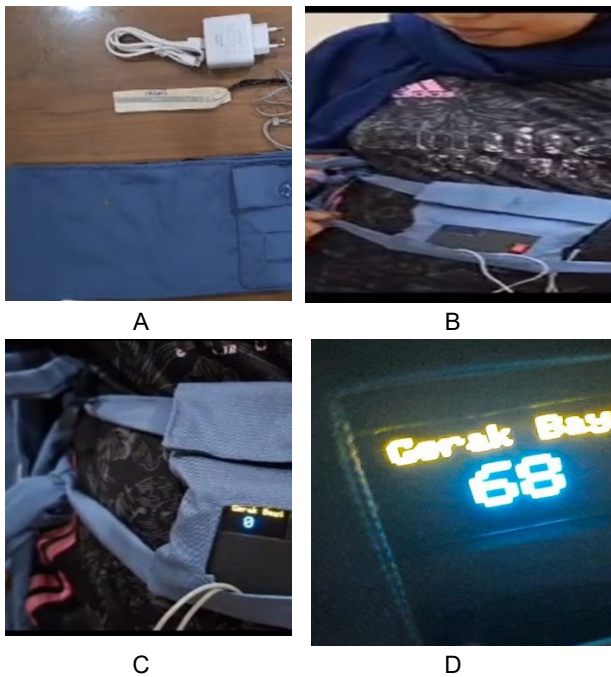


Figure 3. A: Device; B: Process of installing equipment on the abdomen of a pregnant woman; C: The device is installed on a pregnant woman; D: Interpretation Device

Device evaluation was carried out in four phases (Table 1).

Table 1. Summary of Device Testing Phases

Phase	Participants	Duration	Sensor Type	Main Findings	Limitations	Follow-up Action
I	Pregnant woman (3rd trimester)	~5 h (night)	Muscle sensor	Detected fetal + maternal movement	False positives; discomfort	Lowered sensitivity; redesigned casing
II	Pregnant woman (3rd trimester)	~4 h (night)	Muscle sensor	Still detected maternal movement	Same issue as Phase I	Replaced with a flex sensor
III	Pregnant woman (3rd trimester)	Several h	Flex sensor	Successfully detected fetal movement	Minor discomfort	Further packaging redesign
IV	Non-pregnant woman	2 h	Flex sensor	No movement detected	None	Confirmed specificity

Operational Testing

Quantitative testing with the flex sensor was conducted on four pregnant respondents (Table 2).

Table 2. Fetal Movement Detected by Flex Sensor (1-hour monitoring)

Respondent	Device ID	Time Range	Number of Movements
1	1	09:44:45–10:44:27	21
2	1	09:57:59–10:44:27	33
3	2	17:50:57–18:43:46	13
4	2	14:14:23–15:14:53	14

The device detected between 14 and 33 fetal movements per hour (mean $XX \pm SD$), consistent with expected fetal activity during the third trimester. No movements were recorded in non-pregnant participants, confirming device specificity.

Maintenance

Routine maintenance included battery charging, storage in a dry environment, and cleaning after use to ensure device durability.

DISCUSSION

This study resulted in an IoT-based fetal movement detection tool using flex sensors. The device enables real-time monitoring and cloud-based storage of fetal movement data. Fetal movement has long been recognized as an essential indicator of fetal health. Previous studies reported that approximately 25% of pregnancies with decreased fetal movement in the third trimester result in poor perinatal outcomes.¹ Maternal perception of reduced fetal movement is a valuable signal to seek immediate medical care to prevent complications.¹⁹⁻²¹ In addition, fetal movement reflects the functional integrity of the musculoskeletal and central nervous systems, as a normal fetus is capable of active movement with alternating periods of activity and rest.¹¹

The monitoring system developed in this research operates by collecting sensor data, applying a recognition algorithm, and transmitting information via Bluetooth and IoT networks. The system architecture allows real-time data transfer to the cloud for processing and interpretation.^{8,9} The integration of IoT technology has been increasingly adopted in medical applications, enabling interconnection between sensors, devices, and healthcare professionals to improve the quality of care.¹⁰

Evidence also shows that fetal movements can be reliably detected using fetal magnetocardiography (FMCG), which provides insights into fetal autonomic function.^{17,18} However, FMCG and other advanced modalities remain limited to specialized facilities. In contrast, maternal perception of fetal activity remains essential, but is subjective and influenced by personal habits and knowledge.¹³⁻¹⁶ Objective alternatives have included electromagnetic devices, electro-pressure sensors, piezoelectric sensors, impedance monitors, and ultrasonic Doppler-based tools.^{12,22,25} While Doppler ultrasound is widely used in clinical practice, long-term and home-based monitoring remains limited.²⁴ This highlights the clinical need for reliable and accessible home-based fetal movement monitoring systems.

The flex-sensor-based device tested in this study detected between 14 and 33 movements per hour in third-trimester pregnancies, consistent with expected physiological ranges. No false signals were detected in non-pregnant participants, confirming device specificity. Nonetheless, several limitations were observed: the current prototype could only be used in supine or resting positions, the maximum monitoring duration was less than 10 hours, and the 20 cm sensor length limited abdominal coverage. Future work should focus on packaging improvements, multi-sensor arrays, and enhanced flexibility using conductive yarns to improve durability and signal quality.

CONCLUSIONS AND RECOMMENDATION

This study developed and evaluated an IoT-based fetal movement monitoring device using a flex sensor. The prototype demonstrated the ability to detect fetal movements with acceptable accuracy and specificity, offering a simple, cost-effective, and user-friendly tool for both healthcare providers and pregnant women. The device has the potential to support early detection of pregnancy complications and contribute to reducing perinatal morbidity and mortality. Integration of this technology into antenatal care may enhance clinical decision-making and empower mothers in self-monitoring. Future work should focus on optimizing device design, validating performance in larger clinical trials, and establishing regulatory standards to ensure safety, reliability, and clinical applicability.

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