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Modified Doppler Healthy Pregnancy Monitoring (MODEM-KES) to speed up examinations of pregnant women

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ABSTRACT

Monitoring fetal health is a major factor in ensuring a healthy pregnancy and safe delivery. However, in Indonesia, especially in remote areas, limited access to quality health services, lack of sophisticated medical equipment, and difficulty reaching health facilities are serious challenges that contribute to high maternal and infant mortality rates. This study developed MODEM-KES (Modified Doppler Healthy Pregnancy Monitoring) which aims to evaluate the effectiveness of MODEM-KES in supporting health workers, especially midwives in remote areas, in conducting pregnancy monitoring more practically, accurately, and quickly. This tool integrates three important indicators: gestational age estimation, fetal weight estimation, and fetal heart rate, using Doppler sensors and fundus uteri height (FUH) measurements combined with digital methods. The research method involved testing the MODEM-KES prototype against standard tools, such as metline for FUH measurement and Doppler for FHR, with five measurements on each respondent with a gestational age of 26-40 weeks. Results showed that the difference in results between MODEM-KES and standardized tools was relatively small: FUH had a difference of 0-3 cm with an error rate of 0%-10.75%, FHR had a difference of -4/min to 4/min with an error rate of -3.0%-3.1%, and estimated fetal weight had a difference of 0-465 grams with an error rate of 0%-18.8%. Although the accuracy rate varies, MODEM-KES still shows potential as an alternative pregnancy monitoring tool that is practical and easy to use.

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1. INTRODUCTION

The recognition of Pregnancy monitoring is necessary to reduce the risk of mortality and morbidity in the fetus and neonate, as well as in the mother [1]. These risks can be prevented through regular monitoring of pregnancy development so that pregnancy complications can be treated early [2]. Through quality maternal and newborn health services, it is hoped that maternal and infant mortality rates can be reduced [3]. Based on the latest data from the 2022 Indonesian Nutrition Status Survey (SSGI), Indonesia's maternal mortality rate is 189 per 100,000 live births, while the infant mortality rate is 16.8 per 1,000 live births. This figure is still far from the Sustainable Development Goals (SDGs) target of reducing maternal mortality to less than 70 per 100,000 live births and IMR to below 12 per 1,000 live births by 2030 [4], [5]. This condition shows the need for strategic and comprehensive efforts, because to achieve the target of reducing MMR to 183 per 100,000 KH by 2024, a reduction in maternal mortality rates of 5.5% per year is needed [6], [7]. Based on data from the 2018 IDHS, the perinatal mortality rate in Indonesia is 26 deaths per 1,000 births [8]. This condition is classified as high in ASEAN. Performance data from the NTB Health Office in 2021 explains that the Neonatal Mortality Rate remains the same, namely 19/1000 births [9]. IUFD caused the cause of death in the perinatal group at 29.5% and LBW at 11.2% [10], [11]. Some of the main factors contributing to the high MMR and IMR include obstetric complications (preeclampsia, postpartum hemorrhage, infection), malnutrition of pregnant women, delays in accessing health services, and limited health workers and facilities, especially in remote areas [12]. A study by Raina et al. [13] found that the limitations of effective pregnancy monitoring mean that many complications are not detected early, increasing the risk of maternal and infant mortality [14].

Monitoring fetal well-being is important during pregnancy, it is useful to be able to see the development of the fetus [15], [16]. Most of these problems are related to pregnancy conditions, especially in monitoring fetal welfare, one of which is birth weight, which is the most

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important parameter in determining neonate survival [17]. Based on these problems, the main strategy to improve access and coverage of quality maternal and newborn health services was designed through the creation of fetal monitoring technology during pregnancy. Currently available pregnancy monitoring methods, such as ultrasonography (USG) and fetal Doppler, although accurate, have significant limitations. Ultrasound requires trained operators, considerable cost, as well as adequate infrastructure, which is often not available in remote areas [18]. Manual methods such as fundus uteri height (FUH) measurement using a metline also have limitations in accuracy and rely heavily on the experience of medical personnel [19]. Previous studies have shown that lack of access to pregnancy monitoring technology contributes to delayed diagnosis of complications, such as fetal distress and impaired fetal growth, which increases the risk of preterm birth and low birth weight (LBW). However, until now, there have not been many innovations in pregnancy monitoring tools that are portable, affordable, and can be used by health workers with minimal training [20], [21]. Therefore, this research created the MODEM_KES Innovation tool (Modification of Healthy Pregnancy Monitoring). It is a digital-based innovation tool created for early screening, pregnancy monitoring and fetal well-being with assessment indicators based on 3 points, namely 1. Estimated gestational age, 2. Estimated fetal weight. and 3. Fetal heart rate. The purpose of making this tool is to develop and evaluate MODEM-KES, an innovative digital-based tool to monitor fetal health more accurately, practically, and affordably so that it can help midwives and health workers in remote areas in conducting early detection of pregnancy complications, so that treatment can be done more quickly and effectively [22].

This background underlies the urgency and relevance of creating innovative tools that midwives are spearhead who play an important role in providing basic maternal and child health services, These services are still a top priority in efforts to reduce maternal and infant mortality in Indonesia [23]. Midwives in carrying out their functional role professionally in providing quality midwifery services require tools that support their work to monitor the development of pregnancy easily, practically and accurately, so that complications that may occur during pregnancy can be anticipated early [24]. Through the creation of a digital-based innovation product "MODEM-KES", it is hoped that it can help village midwives, especially in providing Maternal and Child Health (MCH) services in remote areas, so that the development of their pregnancies can be easily monitored, especially considering the geographical conditions, especially in NTB and the low ability of the community to get professional midwifery services is an obstacle in monitoring the welfare of the fetus and mother comprehensively. The importance of monitoring pregnancy to reduce maternal and fetal mortality rates cannot be overstated. In Indonesia, challenges such as limited access to quality healthcare, geographical barriers, and resource constraints have exacerbated these risks. Innovative solutions like the MODEM-KES device aim to address these gaps by offering a practical, digital-based tool for midwives, particularly in remote areas. Pregnancy complications often arise undetected, contributing to adverse outcomes. Accurate and timely monitoring can mitigate these risks, allowing early interventions. Traditional methods like ultrasound, while effective, are often inaccessible due to high costs and the need for specialized personnel. The MODEM-KES device integrates essential parameters such as gestational age, fetal weight, and heart rate, providing a comprehensive approach to fetal health assessment without reliance on complex or expensive tools. This study emphasizes the need for affordable and portable solutions that empower midwives to deliver quality care in underserved regions. By leveraging technology, the MODEM-KES device bridges the gap in maternal and child health services, aligning with global efforts to reduce maternal and infant mortality rates. The integration of user-friendly features and precise measurement capabilities ensures its relevance and effectiveness in diverse settings, making it a transformative tool in the field of midwifery and public health.

2. MATERIALS AND METHOD

A. Dataset

This study used a quasi-experimental design with a comparative approach, aiming to evaluate the accuracy and effectiveness of MODEM-KES in pregnancy monitoring compared to conventional methods. Testing was carried out by comparing the measurement results of the MODEM-KES tool against standard tools, such as metline for Fundus Uteri Height (FUH) and fetal Doppler for Fetal Heart Rate (FHR) [25]. The study sample was selected using purposive sampling method, with inclusion criteria such as pregnant women with gestational age 26-40 weeks who underwent antenatal check-ups at primary health facilities, No history of severe pregnancy disorders, such as severe preeclampsia, uncontrolled gestational diabetes, or significant fetal congenital abnormalities, and Willing to participate in the study, by providing written consent (informed consent) [26]. Exclusion criteria included pregnant women with acute obstetric complications requiring immediate intervention as well as conditions that prevented measurement of key parameters. The total sample used in this study was 50 pregnant women, selected from several health facilities in areas with limited access to health services. Data were collected through a series of measurements using MODEM-KES and standardized tools. Each participant was examined five times with both methods to ensure consistency of results. This study has received ethical approval from the Health Research Ethics Committee of the Poltekkes Kemenkes Mataram (Number: DP.04.03/F.XI.VIII.14/469/2024). All participants were given complete information about the objectives, procedures, and risks and benefits of the study before giving written consent. Participant data was kept

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confidential, and the research was conducted based on the Nuremberg Code and the Declaration of Hensinki to ensure the safety and rights of research participants.

B. Data Collection

In this study, the data collection process was carried out with certain procedures to ensure accurate results. Fig. 1 shows the data collection carried out by the midwife.

Fig. 1. Data Collection Conducted by Midwives.

Data collection was conducted with respondents with a gestational age of 26-40 weeks, data was taken 5 times. Fetal Heart Rate (FHR) and Fetal Heart Sound (FHS) were recorded for approximately 1 minute. The Doppler transducer is placed on the fetus back because it is closest to the heart so that the fetal heart can be heard clearly and heart rate can be detected correctly. The Digital Metline is also included in the focus to measure the distance between the symphysis bone and uterine fundal height in cm with the aim of predicting the age and weight of the fetus.

To ensure repeatability and consistency, data from each respondent were collected five times under standardized conditions. This iterative approach helped to identify and mitigate potential errors or anomalies in the measurements. The focus was not only on obtaining accurate readings but also on training the midwives to ensure consistent placement of the transducer and measurement devices across all respondents. Additionally, rigorous ethical protocols were followed. All participants provided informed consent, and the study was conducted in compliance with ethical guidelines for human research. The collected data were anonymized to maintain confidentiality and were stored securely to prevent unauthorized access.

C. Data Processing

The data processing workflow utilized advanced digital signal processing techniques to ensure high precision in measurement outputs. The transducer has an Oscillator that emits a frequency of 2-3MHz, the signal is transmitted to the stomach and reflects the signal and is captured by the receiver on the transducer [27]. This signal underwent amplification through a preamplifier circuit, followed by filtering with a digital band-pass filter operating within a 2-3 Hz range. This filter was specifically designed to eliminate noise and enhance the clarity of the heart signal. The output signal from the filter is processed on the microcontroller to display the Beat per minute of the fetal/baby's heartbeat. To enhance the accuracy of BPM calculation, the Root Mean Square (RMS) method can be employed to process the filtered signal [28]. RMS provided a robust measure of the signal's energy, aiding in the accurate detection of peak intervals necessary for calculating the Fetal Heart Rate (FHR). The formula for RMS Eq (1) [28]:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=0}^{N} x_i^2} \quad (1)$$

where, represents the signal samples, and N is the total number of samples within a specific time window. Once the RMS value is computed, the periodicity of the signal peaks can be derived to calculate BPM.

For the metline section, this time the researcher used a rotary encoder which was converted by the microcontroller into centimeters, the metline functions for Measurement of the Fundus Uteri Height (FUH) and abdominal circumference can be used to estimate gestational age and fetal weight [20], [29]. FUH is measured from the midpoint of the upper border of the sympisis pubis to the highest point on the fundus uteri using a centimeter scale measuring device [19]. The abdominal circumference of the pregnant woman is measured parallel to the umbilicus. FUH has a strong relationship with fetal weight and reflects fetal growth and size [30]. To interpret the fetal weight, the Johnson Toshach formula can be used based on the FUH measurement results [31].

After measuring FUH, IFW (Interpreted Fetal Weight) can be calculated using the following Johnson Toshach formula Eq (2) and Eq (3) [31]:
If the fetal head has not entered the upper door of the pelvis (PAP)

$$IFW\ (gram) = (FUH - 12) \times 155 \quad (2)$$

If the fetal head has entered the upper door of the pelvis (PAP)

$$IFW\ (gram) = (FUH - 11) \times 155 \quad (3)$$

In addition, the examination also includes measuring the fetal heart rate to assess its frequency in one minute. This examination is categorized based on its state, namely regular or irregular, as well as normal or abnormal when the punctum is at its maximum. A normal fetal heart rate ranges from 120-160 beats per minute.

D. Design Research

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Fetal Doppler is a medical device used to monitor fetal heartbeat. Modem-kes is designed to be combined with metline where it makes it easier for midwives to examine the baby's fetus. The block diagram is presented in Fig. 2.

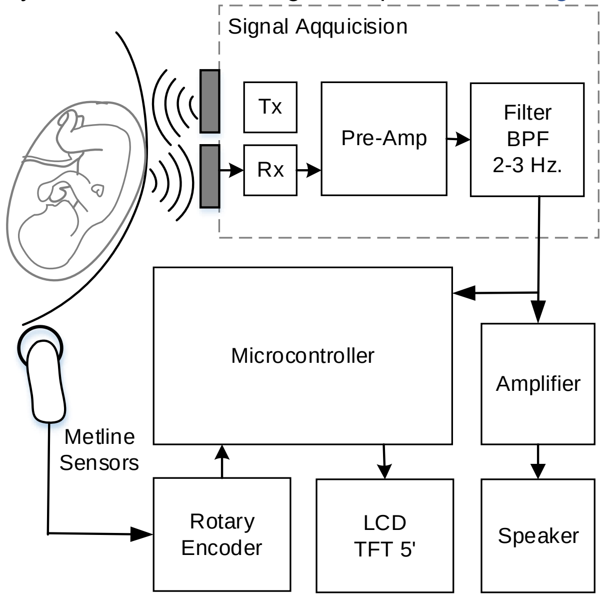

Fig. 2. Block Diagram MODEM-KES

Fig. 2 is the block diagram of a fetal Doppler device. This device operates based on the Doppler effect, which is the change in frequency of a wave due to a moving wave source. In the signal acquisition block, ultrasonic waves with a frequency of approximately 2-3 MHz are transmitted by the TX towards the fetus. These waves are then reflected back by the beating fetal heart valves. The signal received by the RX is amplified by a pre-amplifier and filtered by a 2-3 Hz band-pass filter to remove noise. The clean signal is subsequently processed by a microcontroller to detect the signal peaks representing each heartbeat. The microcontroller then calculates the fetal heart rate based on the interval between the peaks. Additionally, a rotary encoder is employed to measure the Fundus Uteri Height (FUH). The Doppler shift in the reflected ultrasound waves is directly proportional to the velocity of the fetal heart valves, enabling the accurate measurement of the fetal heart rate. The LCD TFT display presents the Fundus Uteri Height (FUH) in centimeters, Fetal Heart Rate (FHR) in beats per minute (BPM), Fetal Weight Prediction (FWP) in grams, and the calculated results of the predicted gestational age in weeks. The FWP is an estimated value calculated based on various factors, including FUH, FHR, and gestational age. The device incorporates safety measures to minimize potential risks associated with ultrasound exposure, such as limiting the duration of the examination. The design emphasizes practicality and adaptability to the needs of users in both clinical and non-clinical environments. Continuous feedback from field tests was incorporated into the design process to ensure the device met real-world operational demands. This iterative approach not only improved device usability but also enhanced its diagnostic accuracy, making MODEM-KES a versatile tool for midwifery practices in remote settings.

E. Materials Design

It is ergonomically designed to support practical and effective fetal health checks. With its compact form and integrated features, it makes it easy for users, especially medical personnel, to measure fetal heart rate. Its mechanical design combines modern technology with user comfort, so it can be used in various clinical and non-clinical environments.

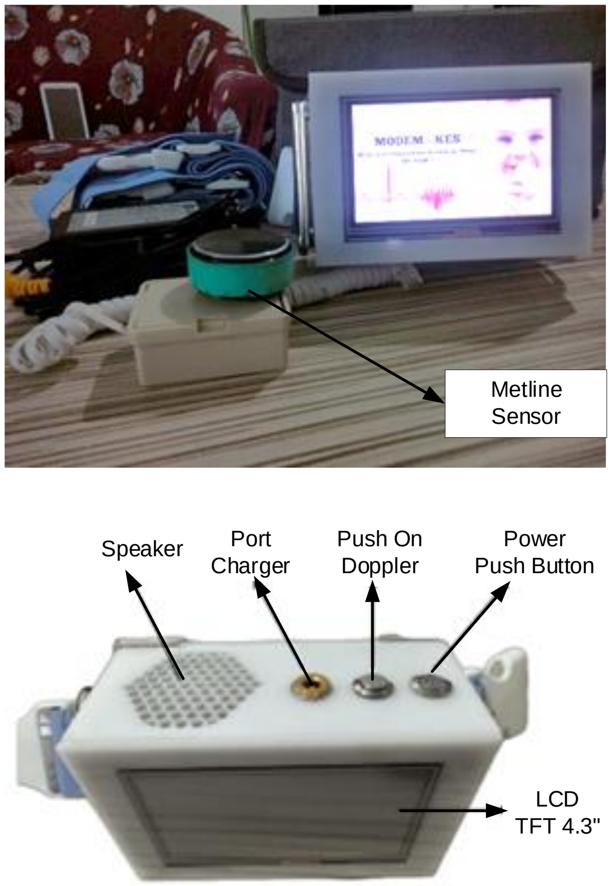

Fig. 3. Mechanical Design MODEM-KES

In the tool design Fig. 3 it has a 4.3-inch LCD screen on the front to visually display measurement data. On the top side, there is a speaker to play the sound of the fetal heartbeat directly. There is also a charger port for charging, ensuring that the device can be used repeatedly. Two main buttons are located at the top of the device: the Doppler On/Off button to enable or disable the Doppler function, and the Power On/Off button to turn on or off the device as a whole. This compact and portable design makes it easy for users, such as medical personnel, to operate the device efficiently when performing pregnancy checks.

The mechanical design of the MODEM-KES device was developed with an emphasis on user ergonomics and operational efficiency. The compact and lightweight form

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factor ensures portability, making it ideal for use in remote or resource-limited settings. Key features of the device include a 4.3-inch LCD screen for displaying real-time measurement data, a built-in speaker for auditory feedback of fetal heart sounds, and a rechargeable battery to support extended field use.

Durability was a critical consideration in the design process. The device was constructed using high-quality, medical-grade materials that are resistant to wear and tear. The layout of the controls was optimized for intuitive use, with clearly labeled buttons for activating the Doppler function and powering the device on or off. The integration of a rotary encoder for measuring fundal height and abdominal circumference further enhanced the device's utility, providing accurate and reliable measurements. The mechanical assembly underwent rigorous testing to ensure compliance with safety and performance standards. Stress tests, drop tests, and usability evaluations were conducted to validate the device's resilience and functionality in various environmental conditions.

3. RESULTS

A. Accuracy

The importance of the accuracy of the data displayed by the tool created, the researcher calibrated the prototype in the test and calibration laboratory and obtained the results in Table 1. The data in Table 1 shows that the MODEM-KES results are quite close to the standard tool. The largest discrepancy occurs in the estimation of fetal weight (FWP) with an error of up to 18.8%, which may be due to maternal anthropometric factors that have not been taken into account in the measurement method. However, FUH and FHR have a higher level of accuracy, with an error below 10%. This comparison is in line with the research of Mossayebnezhad et al. (2021) which shows that FUH-based fetal weight prediction has limited accuracy because this method does not consider other factors such as amniotic fluid or fetal position. In addition, the study by Doulaveris et al. (2020) emphasized that the variability of FUH measurement results can be reduced with the use of digital technology, as done in MODEM-KES.

Table 1. Calibration Result of Modul Prototype.

Setting on Standart (BPM)	Measurements on Tools (BPM)	Measurement Uncertainty (BPM)	Tolerance (%)
30	[redacted]		±5%
60			
90	87.84	±0.79	
120	121.29	±2.23	
150	152.18	±6.59	
180	172.24	±0.79	
210	167.01	±0.79	

Our module has been calibrated by the West Nusa Tenggara Provincial Testing and Calibration Laboratory. The test compared measurement results on various beats per minute (BPM) standards. With the results obtained, namely at the BPM 90 standard, the tool shows results of 87.84 BPM with measurement uncertainty ±0.79. At a standard BPM of 120, the measurement results reached 121.29 with an uncertainty of ±2.23. When the BPM standard is 150, the measurement result is 152.18 with an uncertainty value of ±6.59. At standard BPM 180, the device shows a result of 172.24 with an uncertainty of ±0.79, while at standard BPM 210, the measurement result is 167.01 with an uncertainty of ±0.79. According to the West Nusa Tenggara Provincial Testing and Calibration Laboratory, it can be concluded that the tool is fit for use / passed calibration. This is because the uncertainty value obtained from the measurement is still below the normal limit, where the normal limit or tolerance of uncertainty is ±5%.

B. Performance

Measurements were made with respondents with gestational age between 26 and 40 weeks, the data in Table 2 is the result of an average of 5 data collections. Then the researcher compared it with tools on the market, namely metline to measure Fundus Uteri Height (FUH), and Doppler to calculate Fetal Heart Rate (FHR), and the Fetal Weight Prediction (FWP) formula. In the first respondent with a gestational age of 35 weeks, the measurement results with the MODEM-KES method showed a FUH value of 34cm, FHR 127/min, and FWP 3410 grams. The difference in results to measurements by the Metline method is 2cm for FUH, the Doppler method is 1/min for FHR, and by formula is 310 grams with an error rate of 5.9%, 0.8%, and 9.1% respectively. The second respondent with a gestational age of 36 weeks obtained results with the MODEM-KES method is FUH 33cm, FHR 132/min, and FWP 3255 grams.

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Table 2. MODEM-KES measurement results of 5 pregnant women.

Gestational Age (weeks)	Average Result with Modem-Kes			Average Result With Metline	Average Result Doppler	Average Result By Formula	Error (%)		
	FUH (Cm)	FHR (Bpm)	FWP (Grams)	FUH (Cm)	FHR (Bpm)	FWP (Grams)	FUH (Cm)	FHR (Bpm)	FWP (Grams)
26	24	128	1860	24	124	1860	0,00	3,13	0,00
30	28	144	2480	25	148	2015	10,71	2,78	18,75
35	34	127	3410	32	126	3100	5,88	0,79	9,09
36	33	132	3255	30	136	2790	9,09	3,03	14,29
40	38	136	4030	36	132	3720	5,26	2,94	7,69

The differences in measurements with the metline method for FUH 3 cm, the doppler method for FHR -4/min, and by formula for FWP 465 grams, and the error rates are 9.1%, -3.0%, and 14.3%, respectively. The third respondent with a gestational age of 26 weeks, the measurement results with MODEM-KES were FUH 24 cm, FHR 128/min, and FWP 1860 grams. The difference between these results and measurements by the metline method is 0 cm for FUH, 4/min for FHR with the doppler method, and 0 grams for FWP in the formula method. These results have an error rate of 0.0% for FUH, 3.1% for FHR, and 0.0% for FWP. In the fourth respondent with a gestational age of 30 weeks, the measurement results obtained by the MODEM-KES method are FUH worth 28 cm, FHR 144/min, and FWP of 2480 grams. The difference between these results and the measurement with the metline method is 3 cm for FUH, -4/min for FHR, and 365 grams for FWP with an error rate of 10.75, -2.8%, and 18.8% respectively. In the fifth respondent with a gestational age of 40 weeks, the measurement results obtained in the MODEM-KES method were 38 cm for FUH, 136/min for FHR, and 4030 grams for FWP. The differences to the measurement results with the metline method are FUH 2 cm, FHR 4/min, and FWP 310 grams. These results have an error rate of 5.3%, 2.9%, and 7.7%, respectively.

4. DISCUSSION

A comparison of the results between MODEM-KES and traditional methods showed an acceptable level of accuracy. However, the error margins found in some measurements, particularly in fetal weight prediction, indicate the need for improvement of the algorithms used. The addition of artificial intelligence (AI)-based predictive features may be a solution to address this challenge.

As a digital-based tool, MODEM-KES provides real-time data that can be accessed directly by healthcare workers, thereby reducing the risk of manual errors and enabling faster clinical decisions. In a global context, this tool contributes to the achievement of Sustainable Development Goal (SDG) targets, especially in the aspect of maternal and child health. However, further evaluation is needed to understand how the tool adapts to challenges in the field, such as the quality of health worker training and local infrastructure support.

The use of MODEM-KES in this study showed significant efficiency in providing better antenatal care, especially in remote areas. Compared to traditional tools such as metline and doppler that require manual calculations or certain technical skills, MODEM-KES presents a more practical and intuitive technology. This supports the results of previous studies showing that technology-based innovations can effectively address the challenges of limited health resources.

This study successfully demonstrated that MODEM-KES, a digital-based pregnancy monitoring device, improves the accuracy and efficiency of antenatal care (ANC). By integrating three important parameters-estimation of gestational age, fetal weight, and fetal heart rate-it provides a comprehensive and easy method to assess fetal health. Calibration results confirmed the reliability of the tool, with deviations consistently within acceptable tolerance limits (<5%). Although there is still variation in error rates, these results are in line with previous studies showing that digital technology-based tools can improve the accuracy of pregnancy monitoring over manual methods. In addition, research by Mossayebnezhad et al. indicated that FUH-based fetal weight measurement still has accuracy limitations, especially if not performed by experienced medical personnel [19]. MODEM-KES offers a solution by integrating digital sensors that are more consistent than manual methods. In the context of fetal heart rate monitoring, a study by Knupp et al. (2020) found that the use of a portable Doppler can improve early detection of

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fetal distress. However, available tools are still expensive and difficult to access in remote areas [22]. MODEM-KES, with its lower cost and portable design, provides a more inclusive alternative for health workers in resource-constrained regions.

This study has several limitations. First, the sample size is relatively small, which may affect the generalizability of the results. Expanding this study to include a more diverse population with different geographical and cultural contexts may yield more comprehensive insights. Second, the performance of the tool was evaluated in a controlled environment, which may not fully represent its effectiveness in field conditions with potential challenges such as device maintenance and operator variability. The results of this study have important implications in clinical practice and maternal and child health policy. MODEM-KES can be used by midwives in remote areas to conduct early screening of fetal health, allowing early detection of pregnancy complications without the need for conventional ultrasound or Doppler devices. At a lower cost, this tool has the potential to increase the coverage of antenatal care (ANC) services and help achieve the SDGs target of reducing maternal and infant mortality in Indonesia. In addition, the results of this study support the integration of technology in primary health care. The Ministry of Health can consider using MODEM-KES as part of a technology-based pregnancy monitoring program in Puskesmas and Posyandu, especially in areas with limited medical infrastructure. Overall, this study shows that MODEM-KES is an innovation that can improve the accuracy, accessibility, and efficiency of pregnancy monitoring, especially in areas with limited health facilities. The results of this study reinforce previous findings that suggest the need for digital-based technologies to address gaps in maternal and fetal health services. With further implementation and continuous technological development, MODEM-KES can be a tool that contributes to improving the quality of antenatal care and reducing maternal and infant mortality in Indonesia. The results of this study show that MODEM-KES has a high degree of accuracy in measuring FUH, FHR, and estimated fetal weight, with relatively small differences in results compared to conventional methods. FUH measurement with MODEM-KES has an error rate between 0%-10.75%, FHR between -3.0% to 3.1%, and estimated fetal weight between 0%-18.8%. Previous studies have emphasized the challenges of pregnancy monitoring in low-resource settings, including limited access to ultrasound technology and trained personnel [18], [21]. Innovations such as MODEM-KES align with previous efforts to address these issues using cost-effective technologies [22].

5. CONCLUSION

This study aims to develop a classifier by classifying 7 gestures that are robust against variations of forearm orientation. This study has evaluated MODEM-KES as a digital-based pregnancy monitoring tool and shown that it has high accuracy in measuring Fundus Uteri Height (FUH), Fetal Heart Rate (FHR), and fetal weight estimation. Compared to conventional methods, MODEM-KES has an error rate that is still within standard tolerance limits (<5% for FHR and FUH, although there is still a variation of up to 18.8% for fetal weight estimation). These findings confirm that digital sensor-based technology can improve the accuracy of pregnancy monitoring, especially in areas with limited access to advanced health services.

In terms of practice and policy implications, MODEM-KES has the potential to optimize antenatal care (ANC) services by providing a solution that is more affordable, portable, and easy for health workers in the field. Implementation of this tool can accelerate the early detection of pregnancy complications, allowing for more timely medical intervention. For health policy, the results of this study can serve as a basis for the government and health institutions to consider the integration of MODEM-KES in community-based pregnancy monitoring systems, such as Puskesmas and Posyandu.

However, this study has several limitations, including a limited sample size, potential variations in health workers' skills in using the tool, as well as a lack of evaluation of maternal anthropometric factors that may affect measurement accuracy. Therefore, further research is needed to address these limitations and develop more sophisticated and accurate tools.

As a recommendation for future research, the development of artificial intelligence (AI)-based algorithms can be integrated to improve the accuracy of fetal weight estimation. In addition, further studies with a wider and more diverse population will help to ensure the external validity of the results. Long-term evaluation is also needed to understand the impact of MODEM-KES on pregnancy outcomes and early medical intervention rates.

In conclusion, MODEM-KES is a promising innovation in maternal and fetal health monitoring, especially in areas with limited access to health services. With wider application, this tool can be a real contribution to efforts to reduce maternal and infant mortality, support the achievement of Sustainable Development Goals (SDGs), and pave the way for the use of technology in improving maternal and neonatal health services in Indonesia.

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