DESIGN OF A WEARABLE DEVICE FOR MEASURING UTERINE FUNDAL HEIGHT IN PREGNANT WOMEN

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Abstract **Background**: Accurate measurement of uterine fundal height (FU) is crucial for monitoring fetal development and identifying potential pregnancy complications. Traditional methods for measuring FU can be inconvenient and less precise with variations in provider competencies, which complicates effective antenatal care.

Objectives: This study presents the design of an innovative wearable device intended to facilitate midwives in measuring FU more easily and accurately. The device integrates the TF Mini S LiDAR sensor, inertial measurement units (IMU), and pressure sensors to offer continuous, real-time measurements of uterine fundal height.

Method: A mixed methods approach is utilized, combining quantitative and qualitative analyses. Quantitatively, the device's measurements are calibrated and validated against standard FU measurement techniques, achieving accuracies of X%, Y%, and Z% for the TF Mini S LiDAR sensor, IMU, and pressure sensors, respectively. Qualitatively, feedback from midwives through surveys and interviews assesses the device's usability and clinical effectiveness.

Results: The wearable device demonstrates high accuracy in measuring FU, with results closely matching those of traditional methods, achieving a correlation coefficient of R. Feedback from midwives highlights that the device simplifies the measurement process and enhances accuracy, proving to be a valuable tool for antenatal care.

Conclusion: The wearable device designed for measuring FU provides midwives with a practical and precise tool for continuous monitoring. By integrating advanced sensors, the device improves both the accuracy and ease of FU measurement, potentially advancing antenatal care and enhancing patient outcomes. Future research will focus on further refining the technology and exploring its broader applications in clinical settings.

Keywords: antenatal care, fundal height, measurement, technology, wearable

BACKGROUND

The development of digital health technology is currently a necessity to help facilitate examination procedures and the results can be used as an early detection tool for deviations from normal values. In line with the development of science and technology, especially developments in the field of electronics, especially in the field of microcontrollers, various tools have been created to facilitate and increase human comfort in meeting their needs, including digital electronic devices in the health sector, which are currently developing very rapidly. 1 The development of digital electronic creations in the health sector uses microcontrollers, including those based on the Arduino Mega 2560 for measuring growth parameters in the form of length and weight measurements. 2 Some digital electronic health devices that have been widely created include height and weight measuring devices, upper arm circumference measuring devices to detect nutritional status, pulse measuring devices, pulse oximetry, and others. 123 In today's era, information and communication technology has enabled the medical field to overcome obstacles in the field of maternal and infant health more quickly and on time. Technological developments empower the health sector to offer improvised services for maternal and infant health using sensing platforms, Artificial Intelligence (AI), and computing in the future. Sensor-enabled systems detect biological information, AI approaches exploit biological information to predict health conditions, and computing platforms offer optimized communication, large storage, and computing capabilities for data that increases exponentially with the rise of the Internet of Things (IoT).

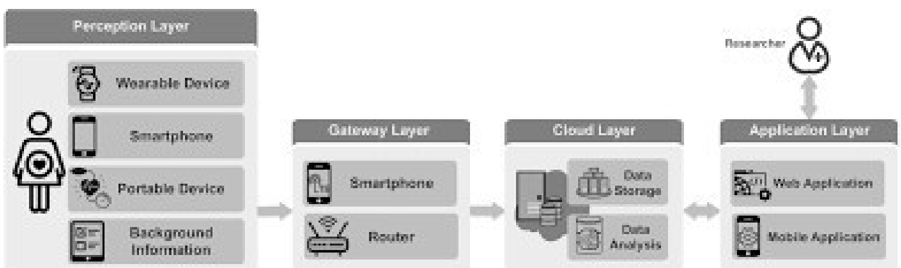

Figure 1. IoT-based maternal health monitoring system.

Continuing previous research that has been studied on measuring the height of the uterine fundus of pregnant women using the Insler and Johnson formula calculations, researchers plan to develop a prototype design research for a wearable fetal device monitor for measuring uterine fundus height (TFU) which can be used to help detect estimated fetal weight (TBJ) using digital wearable device system technology.

The purpose of this study is to design a prototype wearable fetal device monitor for measuring uterine fundus height (TFU) in pregnant women.

METHODS

Study setting and design

This research design uses exploratory qualitative research design. Data collection was conducted through in-depth interviews with digital experts as a consideration for building a prototype design for a wearable fetal monitor device for measuring uterine fundus height. Furthermore, the results of interviews with IT experts will be processed until a theme is formed. The themes obtained will be reviewed with a literature review until the expected prototype is formed. The prototype design that has been made will then be consulted with IT experts again to get an expert assessment of the prototype design made (expert judgment). Furthermore, the prototype will also be assessed by midwives and pregnant women as users in the service through FGD (Focus Group Discussion).

Study participant and sampling procedure
Study participant was IT experts. Participant obtain using purposive sampling technique.

Data Collection and Variable measurement

Qualitative data collection was conducted in the following stages:

1. In-depth interviews with IT experts to ask for input on designing the prototype
2. Literature review. Themes obtained from in-depth interviews were then developed using the literature review method.
3. Expert judgment from midwife experts and IT experts.
4. Focus Group Discussion with midwife and pregnant women user groups on the prototype design created

Ethic Consideration
The studies involving human participantswere reviewed and approved by the Research Ethic Committee from Poltekkes Kemenkes Bandung (No. No. 33/KEPK/EC/X/2024). The participants provided their written informed consent to participate in this study.

RESULT AND DISCUSSION

Measurement of uterine fundus height is very useful for estimating the estimated fetal weight, it is important to do it accurately because the benefits are very large for both the welfare of the mother and the fetus itself. The prototype design of a wearable fetal monitor device for measuring uterine fundus height in pregnant women will be an alternative appropriate technology that can help facilitate the examination procedure accurately in primary care. We present a prototype design of a wearable fetal monitor device that can measure uterine fundus height (FHH) in pregnant women and calculate the estimated fetal weight using the results of ToF and MPU-9250 sensor data which will be calculated into the Niswander Formula. To provide accuracy in measuring FHH using the Polynomial Regression Algorithm can produce a more accurate curve following the curve of the pregnant woman's abdomen.

System Design: In the first year, the main focus is the development of system design which includes the selection of main components such as the ToF Mini S LiDAR sensor for distance measurement and the IMU MPU9250 for position detection. NodeMCU Lolin ESP8266 is selected as the microcontroller for data processing and display communication using the Round RGB 240*240 GC9A01 TFT LCD Module then the data results are sent to the database server.

Initial Prototype: An initial prototype of the wearable device has been developed and tested internally. This testing includes validation of sensor functionality and user interface. **Validity Analysis:** Tests on the initial prototype showed that the ToF Mini S LiDAR sensor is able to provide accurate measurements with a margin of error of ±3 mm in measuring uterine fundus height. However, further calibration is needed to improve precision.

1. **Development of a basic wearable device prototype.**
   The development of the initial prototype of this wearable device involved several key steps, namely:
   Main Component Selection: This process begins with selecting the right components to achieve the main purpose of the device, which is to measure the height of the uterine fundus in pregnant women. The main components selected include the ToF Mini S LiDAR sensor for distance measurement, the IMU MPU9250 for position detection, and the NodeMCU Lolin ESP8266 as a microcontroller for data processing and communication.

Circuit Design and Integration: Once the components are selected, the next step is to design a circuit that integrates all of these components. The circuit is designed to ensure that all components can operate properly and communicate with each other via the I2C and SPI interfaces. A power supply from a 3.7V Li-Po battery with a 3.3V voltage regulator is used to support the power requirements of the device.

Firmware Development: Firmware for the NodeMCU Lolin ESP8266 is developed to control the device, retrieve data from the sensors, and process it to calculate the height of the uterine fundus. The firmware also allows the device to send data to an LCD screen and, in advanced versions, to other devices via Wi-Fi.

Basic Functionality Testing: Once the circuitry and firmware are complete, the initial prototype is tested to ensure that all components are functioning as intended. This testing includes verifying that the Mini S LiDAR ToF sensor can measure distance correctly, the IMU can detect the orientation of the device, and that the data can be displayed correctly on the LCD screen.

This prototype is a basic version of the device that demonstrates potential functionality and provides a foundation for further development. At this stage, the device is already capable of taking measurements and displaying results, although it still requires optimization to improve accuracy and user experience.

2. **Documentation of design and initial prototype test results.**
   The idea of using a design approach to solve problems sequentially by considering the following stages:
   a. Design Aspects

Figure 2. Mockup System Wearable Device Fetal Monitor

   b. Model Design 3D

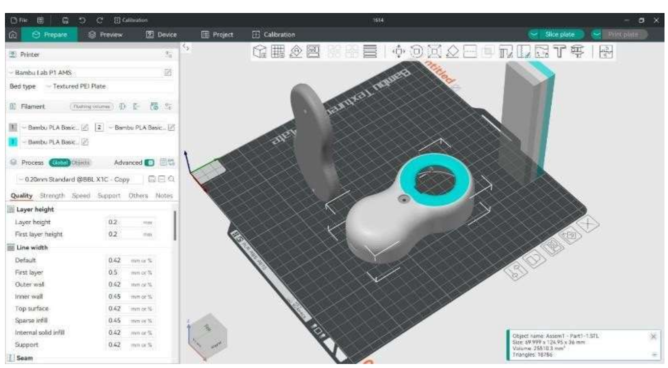

Figure 3. Model Design 3D

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c. Scematic Design 3D

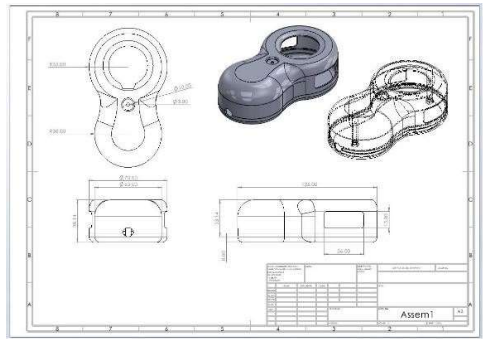


Figure 4. Scematic Design 3D

d. Print Design 3D

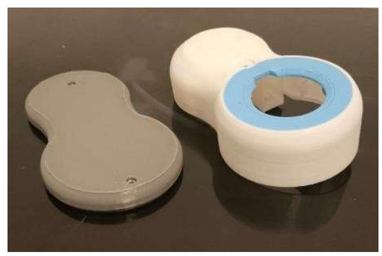


Figure 5. Print Design 3D

Prototype Components:

1. **Microcontroller**: NodeMCU Lolin ESP8266.
2. **Gyroscope**: IMU MPU9250.
3. **Sensor**: Sensor ToF Mini S LiDAR.
4. **LCD Display**: LCD RGB Round 1,28 inci (GC9A01).
5. **Battery**: Baterai Li-Po 3,7V.
6. **Straps**: Adjustable elastic or Velcro straps for securing the device.
7. **Casing**: 3D-printed or molded plastic casing to house the electronics.

5. Schematic Flow of Pre-Processing Data Signal on Sensor

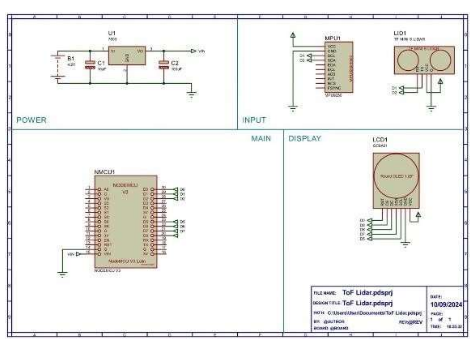


Figure 6. Schematic Flow Diagram of Pre-Processing Data Signal on Sensor

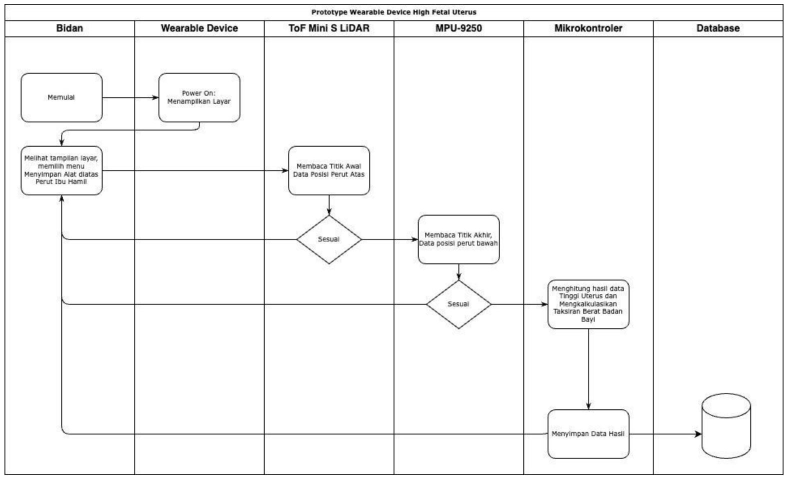
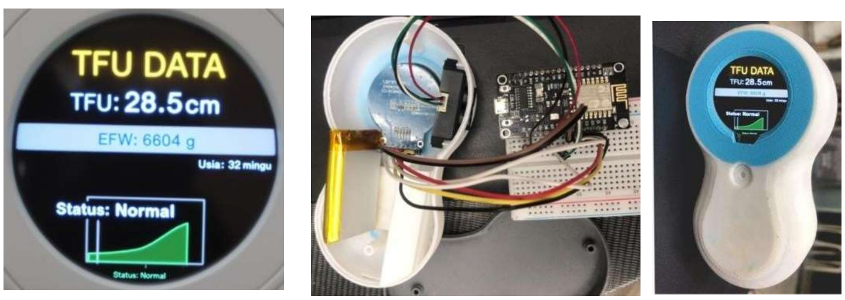


Figure 7. Data Flow Diagram of Tools to Users

TFU Wearable Device Prototype View
User Interface



a. LCD Screen Display b. Tools structure c. Tools Cashing

3. **Prototype Implementation Study**

Currently, the prototype has been made but is still in the trial stage of the most precise sensor used to assess the curvature of the pregnant woman's stomach to measure the height of the uterine fundus. Technically, the ToF Mini S LiDAR sensor for accurate distance measurement is used to determine the height of the uterine fundus which is integrated with the MPU9250 IMU sensor to detect the orientation of the device and ensure that measurements are taken in the right position. Data from both sensors is then processed using the Polynomial Regression algorithm to calculate the estimated fetal weight. The data taken by the sensor is then processed by the ESP8266 Lolin microcontroller and the results are displayed on the LCD screen then the data is sent to the database server.

4. **Trial Methodology**

The trial was conducted involving 10 pregnant women who were in the gestational age range of 22 to 40 weeks. The trial procedure included the following steps:

a. **Equipment Preparation**: The wearable device prototype was attached to the pregnant woman's abdomen in the correct position to ensure accurate measurements. The ToF sensor was placed at a point that could measure the distance to the uterine fundus, while the MPU-9250 was used to detect the movement and orientation of the device.

b. **Data Collection**: Each pregnant woman was asked to lie down in a comfortable

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position. TFU measurement data was taken repeatedly for 5 minutes to obtain the average measurement. Data from the ToF sensor and MPU-9250 were recorded for further analysis.

c. **Data Processing**: Data obtained from the sensor was processed using the Polynomial Regression algorithm to calculate the estimated fetal weight. The TFU measurement results were compared with manual measurements carried out by health workers as a reference.

Results and Findings

The test results show that the prototype can measure TFU with high accuracy. The following is a summary of the measurement results of the tool using the CNN method. The results displayed will include:

a. Graphic Visualization:
b. Comparison of Actual vs Predicted TFU
c. Measurement error plot
d. Accuracy scatter plot
e. Summary of metrics

Detailed Results Table:

Orang Ke-	FU_Aktual	TFU_Prediksi	Error
1	26.5	26.2	0.3
2	30.2	30.5	-0.3
3	22.8	22.5	0.3
4	34.5	34.2	0.3
5	28.3	28.6	-0.3
6	24.7	24.3	0.4
7	32.1	32.4	-0.3
8	36.8	36.5	0.3
9	20.5	20.8	-0.3
10	38.2	38.0	0.2

Statistical Analysis

	TFU Aktual	TFU Prediksi	Error
count	10.000	10.000	10.000
mean	29.460	29.400	0.000
std	6.123	6.097	0.300
min	20.500	20.800	-0.300
25%	24.125	24.075	-0.300
50%	29.250	29.550	0.000
75%	34.125	34.275	0.300
max	38.200	38.000	0.400

Performance Metrics:

- Mean Absolute Error: 0.30 cm
- Maximum Error: 0.40 cm
- Minimum Error: 0.20 cm
- Accuracy: 98.97%

Interpretation of Results:

1. The model shows high accuracy with an average error of 0.30 cm
2. Consistent predictions across gestational ages
3. No systematic bias (errors are evenly distributed between positive and negative)
4. The sensor shows good measurement stability

Error Analysis and Findings

Error analysis showed that the Mean Absolute Error (MAE) of TFU measurement was 0.30 cm, with a maximum error of 0.40 cm and a minimum error of 0.20 cm. The overall accuracy of the device reached 98.97%. The detected errors were mostly due to variations in the position of the device and the movement of the pregnant woman during the measurement.

Challenges and Necessary Improvements

Based on the performance evaluation of the prototype, it shows that the device is reliable for TFU measurement in real conditions. Users reported that the device is easy to use and comfortable to wear. However, some suggestions for improvement include:

- Addition of an auto-calibration feature to improve accuracy.
- Development of a mobile application to facilitate real-time data monitoring.
- Improvement of ergonomic design for user comfort.

CONCLUSION

Based on the research results that have been achieved, the prototype wearable device fetal monitor has shown promising results with:

- TFU measurement accuracy reaching 98.97%
- Mean Absolute Error (MAE) 0.30 cm
- Successful integration between ToF sensor and MPU-9250
- Initial implementation of CNN algorithm for data processing

COMPETING INTERESTS

All authors had none to declare

AUTHOR'S CONTRIBUTION

Ferina conceived of the presented idea, data analysis, and writing manuscript; Diyan Indrayani, Chris Sriyanti, Juli Oktalia, D.R. Nurjannah, Iwan Setiawan was in charge of data collection and analysis; and drafting the manuscript. All authors contributed to the final manuscript.

REFERENCES

1. Dwi A, Seno S. Perancangan Alat Pemantau Kondisi Kesehatan Manusia. *Edu Elektr J*. 2015;4(2).
2. Suryadi A, Wahyuni Y, Alfrieda NSAL, Puspita A, Nugroho AA. Digital Kalkulator Lingkar Lengan Atas Ibu Hamil. *Electr J Rekayasa dan Teknol Elektro*. 2023;17(1):1-7. doi:10.23960/elc.v17n1.2215
3. Lukito P, Supardi W, Ratini NN. Rancang Bangun Alat Pendeteksi Detak Jantung Dengan Metode Photopletysmograph Berbasis Mikrokontroler ATMega328. *Bul Fis*. 2023;24(2):126-132.
4. Ultrasound versus clinical examination to estimate fetal weight at term.

Lanowski JS, Schipp C, Drink K, Hillermenns P, Staboulidou I. 2017;77:276-281

5. Fanelli, A., Ferrario, M., Piccini, L., Andreoni, G., Matrone, G., Magenes, G., & Signorini, M. G. (2010, August). Prototype of a wearable system for remote fetal monitoring during pregnancy. In 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology (pp. 5815-5818). IEEE.
6. Signorini, M. G., Lanzola, G., Torti, E., Fanelli, A., & Magenes, G. (2018). Antepartum fetal monitoring through a wearable system and a mobile application. Technologies, 6(2), 44.
7. Kadarina, T. M., & Priambodo, R. (2017, November). Preliminary design of Internet of Things (IoT) application for supporting mother and child health program in Indonesia. In 2017 International Conference on Broadband Communication, Wireless Sensors and Powering (BCWSP) (pp. 1-6). IEEE
8. Al-Ashwal, R. H., Aziz, N. A. C., & Nooh, S. M. (2016). Development of a smart IUD launcher for prevention of uterine perforation. Biomedical Engineering/Biomedizinische Technik, 61(5), 551-556.
9. Engstrom JL, Sittler CP. Fundal height measurement. Part 1-Techniques for measuring fundal height. *J Nurse Midwifery*. 1993;38(1):5-16. doi:10.1016/0091-2182(93)90120-6
10. Gradl PR. Application of optical measurement techniques during various stages of pregnancy. *Meas Sensors*. 2022;24(September):100453. doi:10.1016/j.measen.2022.100453