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Development of a Portable Ultrasonic Digital Anthropometry System with Automated CIAF Classification

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ABSTRACT
Child malnutrition, particularly stunting, remains a critical public health issue with long-term effects on growth and cognitive development. In many community health settings, conventional anthropometric measurement tools used in community health services often present challenges, including human measurement error, non-standard data recording, and a lack of real-time diagnostic output. This study aims to develop and validate a portable ultrasonic sensor-based digital anthropometric system capable of automatically detecting the Composite Index of Anthropometric Failure (CIAF) in real-time. The novelty of this research lies in integrating non-contact ultrasonic height measurement with automated CIAF classification based on WHO 2006 growth standards, cloud-connected data storage, and a user-friendly interface designed for community health workers. This Research and Development study involved system design, laboratory calibration, field validation, and user acceptability testing. A total of 80 toddlers and 30 users (midwives, nutritionists, and Posyandu cadres) participated across regions with low and high stunting prevalence. Measurement accuracy was compared to gold-standard anthropometry, while usability was assessed through a Likert-scale evaluation. Laboratory tests indicated measurement error ranging from 0.0 to 0.2 cm, indicating high sensor precision. Field tests showed a mean difference of ≤1 cm with no statistically significant difference (p>0.05) compared to standard measurement. User evaluation reported high satisfaction, particularly in ease of use (92%), accuracy (90%), and program support benefit (94%). The developed portable ultrasonic digital anthropometry system provides accurate, fast, and standardized CIAF-based malnutrition detection, supporting more efficient child growth monitoring programs. The tool demonstrates strong potential for integration into community-based nutrition surveillance and national health information systems.

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I. Introduction

Malnutrition in children, including stunting, wasting, and underweight, remains a major global public health problem that severely impacts physical growth, cognitive development, and long-term quality of life. According to the United Nations International Children's Emergency Fund (UNICEF) (2023), approximately 148.1 million children, or 22.3% of those under five years old, suffer from stunting worldwide[1]. In Indonesia, the prevalence of stunting reached 21.5% based on the 2023 Indonesia Health Survey[2]. These figures underscore the urgency of strengthening early detection systems for growth failure

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and improving the quality of routine anthropometric measurements in community health services.

Anthropometric assessment using conventional tools such as stadiometers and infantometers is the cornerstone of child growth monitoring programs. However, these methods are prone to several limitations, including dependence on the measurer's skill, reading errors, and disconnection from health information systems[3], [4]. Small inaccuracies in length or height measurements may lead to misclassification of nutritional status, delayed identification of growth failure, and reduced effectiveness of nutrition surveillance programs. These challenges are particularly evident in community-based settings, where measurements are often conducted by health cadres with varying levels of training and experience.

Recent advances in digital and sensor-based measurement technologies have opened new opportunities for improving anthropometric assessment. Ultrasonic sensor technology, in particular, has been widely applied in biomedical and body measurement research due to its non-contact nature, speed, and precision[5]–[8]. Previous studies have demonstrated the feasibility of using digital or sensor-based systems to measure children's anthropometry [9], applied a machine learning approach to determine stunting[10], and adopted in various fields due to its speed and measurement accuracy[6]–[8], [11]. Previous studies have developed digital or sensor-based systems to measure children's anthropometry[9], apply a machine learning approach to determine stunting[10], or introduced portable anthropometric kits such as body-length mats[12]. Nevertheless, most of the studies focus primarily on the measurement of body length or height, and do not integrate an automated nutritional status classification system.

The application of ultrasonic sensor technology for automated nutritional status classification, especially for calculating the Composite Index of Anthropometric Failure (CIAF), remains limited. Existing approaches typically require separate software or manual interpretation to convert anthropometric measurements into Z-scores and nutritional status categories. As a result, health workers must perform additional steps to determine nutritional status, which increases the risk of classification errors and delays intervention. Furthermore, most digital anthropometry systems have not yet incorporated composite indicators such as CIAF, which are recommended to capture overlapping forms of growth failure more comprehensively than single indices alone[3]

This research addresses the gap by developing an ultrasonic sensor-based digital anthropometry system that integrates real-time, length/height measurement with automated Z-score computation and CIAF classification within a single portable device. Unlike previous systems that separate measurement and classification processes, the proposed system combines anthropometric measurement, nutritional status computation, data storage, printing, and cloud-based reporting in one workflow suitable for primary healthcare and Posyandu settings. A Person-Centered Design (HCD) approach was applied during the design and development phase by involving potential users (midwives, nutritionists, and Posyandu cadres) in iterative interface design, workflow refinement, and usability feedback. Previous research has shown that the participation of healthcare workers in the development of new technologies can increase acceptance and confidence in the technology, as well as reduce user anxiety toward it[13].

Anthropometric Z-scores in this system are calculated based on the WHO 2006 Child Growth Standards, and nutritional status classification follows the Indonesian Ministry of Health Regulation No. 2 of 2020, which adapts WHO thresholds into national reporting categories and is applied in CIAF-based classification. This integration allows the system to generate standardized nutritional status outputs compatible with national reporting requirements.

The key contributions of this research are: (1) development of a portable, ultrasonic sensor-based system that integrates height/length measurement with automated CIAF calculation using WHO 2006 standards; (2) provision of real-time anthropometric measurements and nutritional status classification, enabling immediate identification of growth failure; (3) integration of multi-platform data storage and reporting, allowing measurement results to be printed directly, saved to local memory, or uploaded to cloud hosting for remote monitoring and linkage with national child health information systems;(4) application of a user-centered design approach that ensures the device is practical, easy to operate, and acceptable for use by community-level health workers (midwives, nutritionists, and Posyandu cadres), specifically in both low-resource and high-prevalence regions.

This research supports timely, evidence-based decision-making and nutritional interventions, aligning with Indonesia's vision for a golden generation by 2045 and the Sustainable Development Goals (SDGs) to eradicate hunger, as well as health transformation specific to the third pillar: health resilience system transformation. This paper is organized as follows: Section II presents the research methodology, including system design, laboratory calibration, field testing, and user evaluation procedures. Section III describes the development of the ultrasonic sensor-based digital anthropometry system, including hardware configuration, software algorithms, and data integration features. Section IV reports the results of laboratory accuracy testing, field performance validation, and user acceptability assessment. Section V provides the discussion, comparing the findings with previous studies, highlighting strengths, limitations, and implications for practice, and Section VI concludes the study and offers recommendations for future research and implementation.

II. Material and method

A. Dataset

1. Study design.

This study employed a Research and Development approach in three main phases: (1) design and

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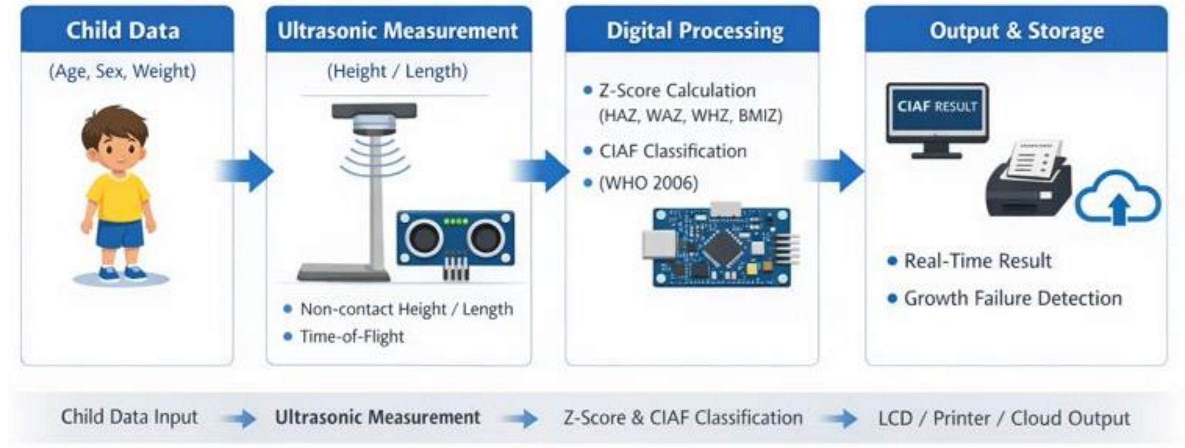

Fig. 1. System block diagram for automated CIAF detection

development, measurement testing, (2) system analysis and evaluation, (3) A Person-Centered Design approach was integrated during the development phase through iterative consultation with healthcare workers to refine interface layout, data entry workflow, and measurement procedures (Fig. 1).

2. Setting and time.

Field testing was conducted in health services in Indonesia, in areas with low stunting prevalence (Posyandu Yogyakarta) and high prevalence (Central Java and South Kalimantan). The selection of locations tested the system's performance under various environmental conditions. The research lasted 8 months (January-August 2024) and included the design and development of equipment, laboratory tests, and field tests.

3. Research materials and instruments. The research materials included: 1) Ultrasonic Sensor: JSN-SR04T, waterproof and capable of detecting distances with 1 mm accuracy, 2) HMI LCD: 4.3-inch colour type TJC4827X543-011RS-Y for data storage and processing, 3) Arduino Nano: for data processing, 4) SD Card Module: for external data storage, 5) ESP32: Bluetooth printer driver, 6) ESP8266: Web hosting for cloud data storage, 7) Web Hosting Application: for storing measurement data on the cloud, allowing access from different locations. Although the ultrasonic sensor had a nominal resolution of 1 mm, overall system accuracy depends on calibration, mechanical stability, and signal processing algorithms. Therefore, laboratory and field validation were conducted to determine real-world anthropometric accuracy. The Arduino Nano functions as the main processor responsible for sensor signal processing and nutritional status computation, whereas the HMI LCD serves as the human–machine interface for data entry and command control. Gold-standard instruments used for comparison were a calibrated infantometer (Seca® 417) for recumbent length and a stadiometer (Seca® 213) for standing height. The ultrasonic sensor operated on the principle of emitting high-frequency sound waves and measuring the time interval (time-of-flight) until the reflected echo was received. This interval was then converted into distance using the formula:

$$\text{Distance} = (\text{Speed of Sound x Time}) / 2. \quad (1)$$

This technology enabled precise and rapid measurement of body length/height. For anthropometric status, Z-scores were calculated for height-for-age (stunting), weight-for-height (wasting), and weight-for-age (underweight) based on WHO growth standards. The Composite Index of Anthropometric Failure (CIAF) was derived by categorizing children into mutually exclusive groups of anthropometric failure and classifying those with any form of failure as CIAF cases. The instruments included a questionnaire designed to evaluate anthropometry, focusing on ease of use, accuracy, quality, support/benefit for growth monitoring, and overall satisfaction. The evaluation used a Likert scale ranging from 1 to 5, where 1 represents a very low score, and 5 represents a very high score.

B. Data Collection

Height or length was measured using the ultrasonic sensor, while body weight was entered manually. Data were stored locally and optionally transmitted to cloud storage. User acceptability was assessed using a Likert-scale questionnaire evaluating ease of use, accuracy, quality, perceived benefit, and overall satisfaction. The research sample was used during the field-testing stage to assess the accuracy of the measurement results in real-time. The sample was divided into two groups: one for the accuracy test of the tool for toddlers under 24 months (measured in a recumbent position) and another for toddlers aged 24 months and older (measured in a standing position). In the low stunting prevalence area (Yogyakarta), the sample consisted of 20 toddlers under 24 months and 20 toddlers aged 24 months and older. In areas with high stunting prevalence (Central Java and South Kalimantan), each region contributed 10 toddlers under 24 months and 10 toddlers aged 24 months and older. Therefore, the total sample for recumbent position measurements was 40 toddlers under 24 months, while the total sample for standing measurements was 40 toddlers aged 24 months and older. This sample size was determined as a pragmatic validation for prototype testing

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rather than for population-level inference. The literature indicates that pilot and feasibility studies of new instruments commonly employ small samples (approximately 10-40 participants)[14]. To assess operability and preliminary performance, validation studies of digital or non-contact anthropometric devices frequently use sample sizes of approximately 30-45 subjects for agreement and accuracy evaluation[14]. On this basis, the present sample size was considered sufficient to evaluate measurement accuracy and system performance under field conditions. The inclusion criteria were children being present at the Posyandu and having no physical conditions that would interfere with anthropometric measurements. The exclusion criteria were fussy babies who could not undergo anthropometric measurements and mothers or legal guardians who did not consent to participate in the study. Meanwhile, the digital anthropometric evaluation sample included 10 potential users from each of the low and high-prevalence areas, totalling 30 people. These users included Posyandu cadres, midwives, nutritionists, health

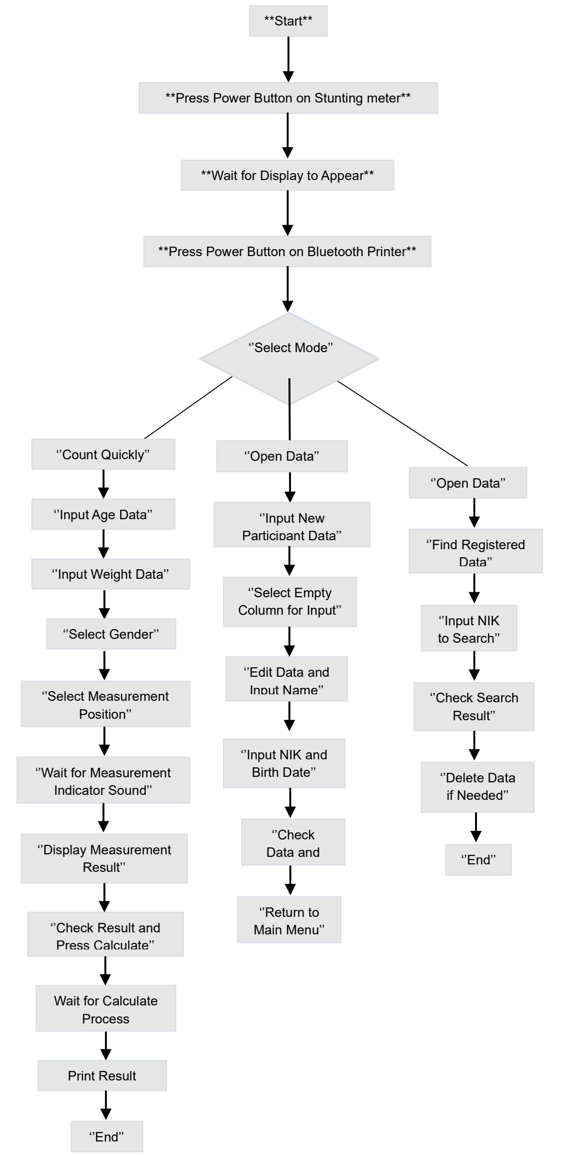

Fig. 2. How to use digital anthropometry

promotion workers, doctors, and family assistance teams. The inclusion criteria were having experience with conventional anthropometry, including the use of an infantometer and stadiometer, and being willing to participate as respondents.

C. Data Processing

Height/length data were converted using the time-of-flight principle. Z-scores (HAZ, WAZ, WHZ, and BMIZ) were computed based on the WHO 2006 Child Growth Standards[15]. Nutritional status classification followed the Indonesian Ministry of Health Regulation No. 2 of 2020[16], which was adapted from WHO thresholds into national reporting categories. CIAF was derived by classifying children into mutually exclusive anthropometric failure groups. Accuracy was assessed using paired t-tests comparing digital anthropometry with gold-standard tools.

III. Result

This section presents the results of the system development process, including the prototype architecture and system block diagram, programming implementation, and performance evaluation through laboratory and field testing.

A. Prototype development and system block diagram

Prototype development included the system block diagram, prototype design, programming, and instructions for using digital anthropometry. The ultrasonic sensor-based anthropometric system was successfully designed and developed, with a block diagram that illustrates the system's components and data flow (Fig.1.). The system uses a JSN-SR04T ultrasonic sensor to measure height, with the data transmitted to the Arduino Nano, which serves as the data traffic controller and displays the information via the HMI LCD. In addition to functioning as an input-output interface, the HMI LCD serves as the main data processing center. The primary functions of the HMI LCD in this system include storing the child's identity data, sending commands to the Arduino Nano to calculate the CIAF value, directing the ESP32 module to print data using a Bluetooth thermal printer, and storing basic information such as age, gender, weight, and height in the EEPROM I2C AT24C256 for easier access. It also instructs the SD Card module to store measurement data externally for later processing when an internet connection is unavailable and directs the ESP8266 to upload the data to the web host so that the measurement results can be accessed remotely. The nutritional status results are compared with the WHO anthropometric standards of 2006 and the Regulation of the Minister of Health Regulation No. 2 of 2020 to ensure the accuracy and relevance of the data obtained.

B. Prototype design

The tool's mechanical components included the main cover, HMI LCD touchscreen, switch button, water level indicator, sensor, Arduino Nano, control box, ESP 32, M4 insert nut, base cover, box cover for the ESP 32 control, JP M4X20MM voltage, B HK D118 10000 mAh battery, and JF M4X20MM voltage. The dimensions of the tool are 190 mm x 99 mm x 40 mm.

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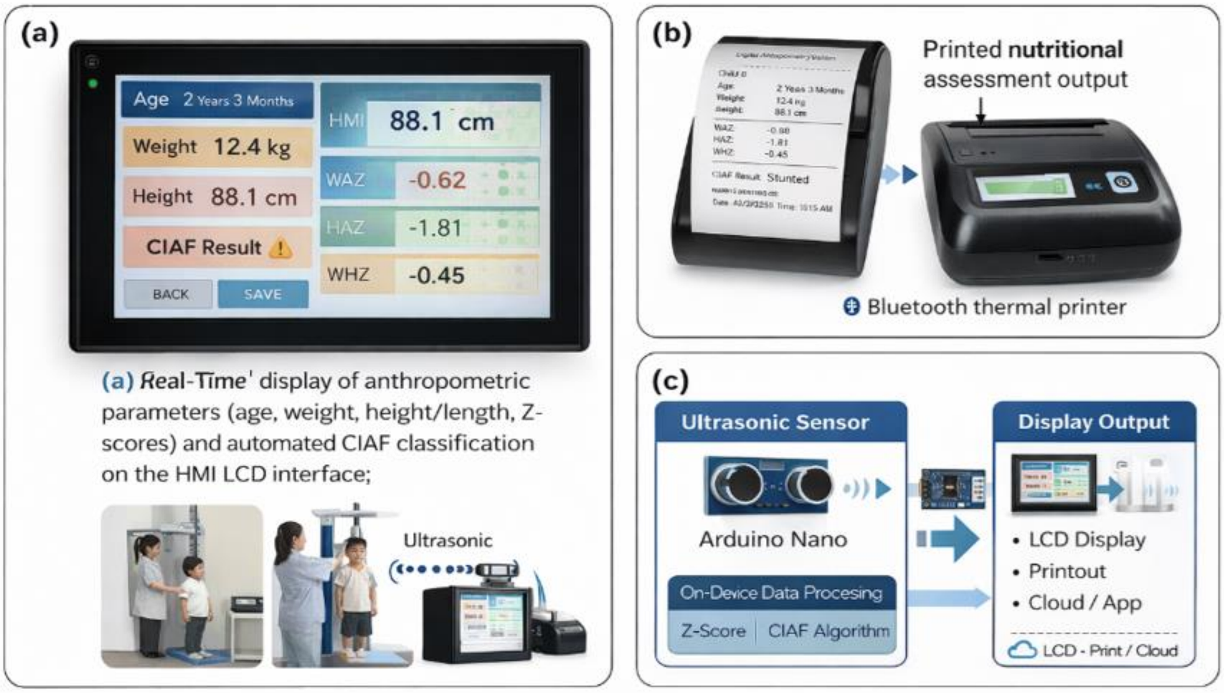

Fig. 3. Output and operational workflow of the ultrasonic-based digital anthropometry system: (a) real-time display of anthropometric parameters, including age, weight, height/length, Z-scores (HAZ, WAZ, WHZ, BMIZ), and automated CIAF classification on the HMI LCD interface, (b) printed nutritional assessment result generated via Bluetooth thermal printer, (c) ultrasonic height/length measurement and embedded data processing workflow integrating sensor acquisition, Arduino Nano processing, Z-score computation based on WHO 2006 standards, CIAF classification, and multi-platform output (LCD, printout, and cloud storage).

1. Programming

The data generated by the sensor is transmitted to the Arduino Nano, which functions as the main processor, manages data flow to storage components such as EEPROM, SD Card, and web hosting. The primary interface in this system is the HMI LCD, which is used to enter the child's identity data, including name, unique child number, date of birth, gender, weight, and height. When the height measurement is taken automatically using the ultrasonic sensor, the Arduino Nano processes the collected data to calculate the nutritional status, including values for LAZ/HAZ, WAZ, WLZ/WHZ, and BMIZ, and displays the child's growth status. The results of the CIAF calculation are displayed on the HMI LCD and can be stored in various storage media. If internet access is available, the data is sent to the web hosting via ESP8266, enabling real-time access from other locations. The stored data includes complete information, such as the unit number of the device, the serial number, the child's identity, and measurement parameters (weight, height, and CIAF score). For printing purposes, the ESP32 controls the Bluetooth thermal printer, allowing the measurement results to be printed directly. The results can be downloaded in several formats: printed directly with a thermal printer, stored in the cloud, or saved on an SD Card if internet access is unavailable. Data stored on the web hosting can be downloaded in Excel format for advanced analysis, such as creating child growth charts or assisting in decision-making for stunting prevention programs.

2. Instructions for using digital anthropometry

Table 1. Laboratory testing result

Method	Setting (cm)	Gold standard (cm)	Outcome measurement (cm)				Delta (cm)
			1	2	3	Average	
Recumbent	30	30	29.9	29.9	29.9	29.9	0.1
	60	60	60.1	60.1	60.1	60.1	0.1
	90	90	90.2	90.2	90.2	90.2	0.2
	120	120	119.8	119.8	119.8	119.8	0.2
Standing	30	30	30	30	30	30	0
	60	60	60.2	60.2	60.2	60.2	0.2
	90	90	90.1	90.1	90.1	90.1	0.1
	120	120	120.1	120.1	120.1	120.1	0.1

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Table 2. Field testing results

Variable	Outcome		Delta (cm)	p-value
	Digital Anthropometry (cm)	Gold standard (cm)		
Recumbent (n=40 children)	79.56	78.91	-0.65	0.791
Standing (n=40 children)	107.01	107.78	0.77	0.87

Fig. 2. provides detailed guidelines for the use of a digital anthropometric tool based on ultrasonic sensors. This device utilizes ultrasonic sensors to automatically measure a child's height, with the data processed by an Arduino Nano to calculate nutritional status, including the CIAF score. The measurement results are displayed directly on an HMI LCD screen and stored in a storage medium such as an SD card, uploaded to the cloud via ESP8266, or printed using a Bluetooth thermal printer. The system is designed to be user-friendly for Posyandu cadres and healthcare workers, requiring no intensive training. The output of the measurements includes the toddler's age, gender, weight, and height or length, which are digitally generated, as well as the LAZ, WAZ, WLZ, and BMIZ scores processed using the 2006 WHO anthropometric standards. Additionally, this tool provided information on the toddler's nutritional status based on the Indonesian Ministry of Health Regulation Number 2 of 2020. As shown in Fig. 3(a), the LCD shows the child's anthropometric parameters and CIAF classification in real time, the printed output is presented in Fig. 3(b), while the ultrasonic-based measurement workflow is illustrated in Fig. 3(c).

C. Testing

Based on laboratory testing, digital anthropometry showed good accuracy in measuring recumbent and standing object heights of 30 cm, 60 cm, 90 cm, and 120 cm, although there is still a difference of 0-0.2 cm in the measurement results. However, this difference can be minimized by calibrating the device using a water pass. The detailed laboratory testing results are shown in Table 1. The results of the field-scale test indicated that the difference between the digital anthropometry measurements and the gold standard was less than 1 cm, and there was no statistically significant difference, as detailed in Table 2. In addition to testing the accuracy of digital anthropometry in laboratory and field settings, we also conducted assessments to gather feedback from potential users. Overall, the tool received positive feedback from potential users in terms of ease of use, quality, benefit ratings, and general satisfaction, as detailed in Figure 4.

Overall, this ultrasonic sensor-based digital anthropometry provides an innovative solution for measuring the nutritional status of toddlers. The system demonstrates a high level of accuracy, improves efficiency in monitoring toddler growth, and enables faster, data-driven dietary interventions. The implementation of this technology in healthcare has significant potential to support the reduction of malnutrition prevalence and greatly aids in rapid decision-making. This invention has been patented with certificate No. IDS000008910, dated September 11th, 2024, and No. IDS000001192 dated August 25th, 2025.

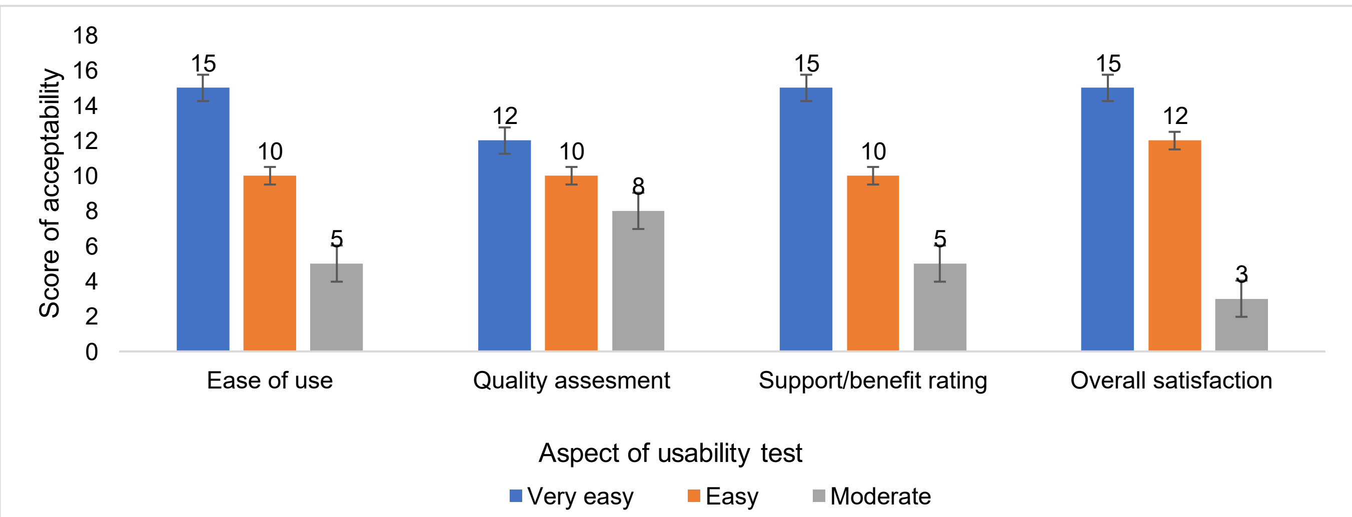

Fig. 4. Acceptability test by potential users

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IV. Discussion

This study demonstrates the feasibility of an ultrasonic-based digital anthropometry system for real-time CIAF classification. The laboratory test showed a very small measurement error (0.0–0.2 cm), compared to the gold standard. Practically, this level of precision is adequate for routine child growth monitoring. The field test results showed no statistically significant difference compared with the standard method. Such a small measurement discrepancy is unlikely to lead to changes in nutritional status classification in most cases; therefore, the risk of misclassification can be minimized. Furthermore, the digital measurements demonstrated good agreement with standard anthropometric tools. These findings suggest that the ultrasonic sensor–based system can be used as an alternative method for anthropometric assessment in primary healthcare settings without compromising measurement validity.

This is in line with narrative and systematic studies that state that digital and non-contact anthropometric technologies have high potential in improving the precision and consistency of measurements compared with manual methods[3], [4], [17], [18]. The results of previous research in various studies also show that digital and non-contact anthropometric technologies have better accuracy and reproducibility than manual methods, both through three-dimensional body scans, multisensor systems, optical scanning, and non-contact radar[9], [19], [20]. However, most of those studies still focus on measuring height or height without automatically integrating the classification of nutritional status. Machine learning-based approaches to stunting prediction generally use survey data or manual inputs so that they do not produce nutritional status outputs directly at the time of measurement, while portable devices such as body length measuring mats still require manual interpretation by health workers[12], [21]–[23]. In contrast to these studies, the system developed in this study integrates ultrasonic sensor-based anthropometric measurements with Z-score calculations as well as automatic Composite Index of Anthropometric Failure (CIAF) classification in one portable device, allowing for a more comprehensive early identification of growth failures.

In addition, the level of accuracy obtained shows that this system is able to minimize the variation between gauges, which has been a major weakness of conventional anthropometry. Manual measurement errors are often influenced by the officer's skills, the child's position, and the error of the tool's scale[4], [18]. By automating the process of measuring length/height, these ultrasonic sensor-based systems have the potential to reduce the contribution of *human error* and improve the standardization of measurement results, as also reported in studies on digital anthropometry based on optical scanning[19], [20], non-contact radar[24], and ultrasonic sensors[7], [9].

The results of this study are in line with the findings of Rodríguez et al., who showed that digital anthropometric technology has better reproducibility than manual methods[4]. In addition, the study of Umiatin et al. proved that a non-contact multisensor system can be used for early detection of stunting, although it has not yet been integrated with automatic nutritional status outputs[9]. Machine learning-based approaches to stunting prediction have also been developed, but generally use survey data or manual inputs, rather than real-time anthropometric measurements[10], [22], [25]. Portable devices such as *length mats* still require manual interpretation by healthcare workers, so the potential for classification variations and intervention delays remains high[12]. Furthermore, although composite indicators such as CIAF or ECIAF are increasingly recommended for capturing overlapping forms of growth failure, their integration into automated digital anthropometry systems remains limited[17], [26], [27]. Therefore, the application of ultrasonic technology for real-time anthropometric measurement combined with automated CIAF classification, as proposed in this study, represents an important novelty in the development of digital anthropometry.

The main contribution of this research lies in the integration of ultrasonic sensor-based anthropometric measurements with Z-score calculations (HAZ, WAZ, WHZ, BMIZ) and CIAF classifications[28], [29] in one portable device. Composite indicators such as CIAF are recommended because they can capture overlapping growth failure conditions (e.g., stunting accompanied by wasting or underweight) that are often not identified when using a single indicator[17], [18], [30]. By embedding the CIAF algorithm directly into the system, the device enables a more comprehensive early identification of growth failures at the service point without the need for additional software or manual calculations by healthcare workers. This approach reinforces the function of the tool not only as a measurement instrument, but also as a clinical decision support system based on anthropometric data[31], [32]. From a system design perspective, the architecture developed combines a microcontroller as a sensor signal processor with an HMI interface as a medium for user interaction and data management. This system allows anthropometric data processing, local storage, result printing, and cloud upload in a single integrated workflow. This integration is relevant for the context of primary services because it can speed up measurement times, reduce reliance on manual recording, and improve standardization of measurement results. This is in line with the concept of digital anthropometry, which emphasizes the efficiency, accuracy, and interoperability of data[17], [18], [33], [34]. The results of user acceptance tests showed a high level of satisfaction with the ease of use, perception of accuracy, and practical benefits of the tool. These findings can be explained through the application of a human-centered design (HCD) approach at the system design and development stage. In this study, health workers (midwives, nutritionists, and Posyandu cadres) were actively involved in improving the interface, measurement

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workflow, and output format. This approach is in line with previous research that the involvement of healthcare workers in technology development increases acceptance, decreases resistance to new technologies, and increases the chances of sustainable adoption[13], [35], [36]. In addition, recent studies show that the application of HCD in the development of digital health technology significantly increases usability and acceptability because the system was designed according to the needs and work context of the end user [37]. Another study also confirms that the involvement of health workers from the design stage to the system trial contributes to increasing the perception of ease of use and readiness to integrate technology into primary service practices[38]. Furthermore, a recent systematic review identified that ease of use and perceived benefits are key determinants of digital technology adoption by healthcare workers, which can be optimized through a user-based participatory design approach[39].

In the context of public health policy, the system is in line with the health system transformation agenda and the strengthening of digital-based nutrition surveillance[19], [20], as well as global recommendations on the use of digital health interventions to strengthen health systems and support evidence-based decision-making[40]. The system's ability to store data locally, print results directly, and upload data to *the cloud* allows for flexibility of use both in areas with limited internet access and in areas with better digital infrastructure. This integration has the potential to strengthen nutrition surveillance systems by providing faster, more standardized, and more easily analyzed anthropometric data to support evidence-based decision-making[40]. Research shows that delayed detection of nutritional problems can have a serious impact on children's growth and development, so a monitoring system that can produce data quickly and accurately is needed[41]. Therefore, the availability of efficient and precise anthropometric measuring instruments is very important, especially in areas with a high prevalence of stunting. In addition, the digitization of anthropometric measurements has been shown to improve the completeness and quality of maternal and child health data and to support electronic recording systems in primary services[17], [42], [43].

In the context of public health policy, this system is in line with the agenda of transforming the health system and strengthening digital-based nutrition surveillance[44][40]. The system's ability to store data locally, print results directly, and upload data to *the cloud* allows for flexibility of use in both areas with limited internet and areas with better digital infrastructure. This integration has the potential to strengthen nutrition surveillance systems by providing faster, more standardized, and more readily analyzed anthropometric data for evidence-based decision-making.

However, this study has some limitations. First, the developed system has not integrated automatic weight measurement, so it still requires manual input, which has the potential to be an additional source of error in weight-based indicators. Second, field tests were conducted in three provinces so that the generalization of results to regions with more diverse social and geographical characteristics is still limited. Third, this study has not evaluated the aspects of device durability, maintenance needs, and performance stability in long-term use in the field, and forth the assessment has not been associated with an analysis of the impact on the quality of anthropometric data or nutrition program outputs directly.

The implication of these findings is that ultrasonic sensor-based digital anthropometry with automatic CIAF classification has the strong potential to be a key supporting tool in child growth monitoring in primary services. Further development should prioritize multisensor integration, broader validation across diverse populations, and interoperability with national health information systems. This system can enhance primary healthcare practice and digital nutrition surveillance by serving as a point-of-care decision support tool for early detection of growth failure.

V. Conclusion

This research has successfully developed and validated an ultrasonic sensor-based digital anthropometry system that measures children's length/height while automatically classifies CIAF. The system is designed to support child growth monitoring in primary health care. The laboratory test showed a measurement error of 0.0–0.2 cm, while the field test showed a difference of less than 1 cm compared to the standard tool, with $p > 0.05$. The system is able to produce CIAF-based nutritional status output in real-time, thereby increasing the accuracy and speed of early detection of growth disorders. Further research needs to focus on full multisensor integration, including automated weight measurement, as well as validation in a wider and more diverse population. In addition, the system needs to be integrated with the national health information system and developed with predictive analytics as part of an early warning system for child nutrition.

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Ethical Consideration
This research has received ethical approval from MHREC FKKMK UGM Yogyakarta No: KE/FK/0671/EC/2023 on 27 April 2023. All respondents signed an informed consent before the study was conducted.

Conflict Of Interest
We declare that there is no conflict of interest.

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References

[1] UNICEF, World Health Organization, and The World Bank, *Joint Malnutrition Estimates: Levels and Trends 2023 Edition*, New York/Geneva/Washington DC: UNICEF/WHO/World Bank, 2023. [Online].

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Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i1.299

Available: https://data.unicef.org/resources/jme-report-2023/ (accessed Nov. 9, 2023).

[2] Badan Kebijakan Pembangunan Kesehatan, *Survey Kesehatan Indonesia (SKI) 2023*, Jakarta: Kementerian Kesehatan RI, 2023, pp. 1–68.

[3] T. Siswati, M. Primiaji Rialihanto, and B. A. Paramashanti, "Non-contact measurement using ultrasonic technology for human anthropometric: A narrative review," *J. Sci. Res. Rep.*, vol. 29, no. 7, pp. 1–7, 2023, doi: 10.9734/JSRR/2023/v29i71754.

[4] L. R. Rodríguez, M. S. SanSegundo, R. F. Cascales, N. G. D'Urso, A. Z.-Martí, and J. A. Hurtado-Sánchez, "Comparison of body scanner and manual anthropometric measurements of body shape: A systematic review," *Int. J. Environ. Res. Public Health*, vol. 18, no. 1, 2021, doi: 10.3390/ijerph180100xx.

[5] G. D. Ceniccola et al., "Current technologies in body composition assessment: Advantages and disadvantages," *Nutrition*, vol. 62, pp. 25–31, 2019, doi: 10.1016/j.nut.2018.11.028.

[6] R. S. Thiebaud, T. Abe, J. P. Loenneke, E. Fujita, and T. Akamine, "Body fat percentage assessment by ultrasound subcutaneous fat thickness measurements in middle-aged and older adults," *Clin. Nutr.*, vol. 38, no. 6, pp. 2659–2667, 2019, doi: 10.1016/j.clnu.2018.11.017.

[7] J. C. Pineau and M. Bouslah, "Prediction of body fat in male athletes from ultrasound and anthropometric measurements versus DXA," *J. Sports Med. Phys. Fitness*, vol. 60, no. 2, pp. 251–256, 2020, doi: 10.23736/S0022-4707.19.09985-7.

[8] L. J. Jilantikiri, S. A. Yahaya, T. M. Ajibola, S. Oluwajoba, and C. A. Obioha, "Development of a digital body mass index (BMI) measuring device for low-resource settings," *J. Low-Resource Technol.*, vol. 4, no. 2, pp. 44–57, 2023.

[9] U. Umiatin, W. Indrasari, T. Taryudi, and A. F. Dendi, "Development of a multisensor-based non-contact anthropometric system for early stunting detection," *J. Sens. Actuator Netw.*, vol. 11, no. 4, 2022, doi: 10.3390/jsan11040069.

[10] Y. I. A. A. Ningrum, "Early detection of stunting based on feature engineering and machine learning algorithm approach," *IJEEMI*, vol. 6, no. 3, pp. 147–155, 2024.

[11] J. O. Totosy de Zepetnek et al., "Test–retest reliability and validity of body composition methods in adults," *Clin. Physiol. Funct. Imaging*, vol. 41, no. 5, pp. 417–425, 2021, doi: 10.1111/cpf.12716.

[12] M. Wigati, A. N. Nurlita, I. M. A. Gunawan, N. Y. Hendarta, M. Hasanbasri, and S. Helmyati, "Anthropometric kit development for stunted early detection among children under-two years old: Providing a portable body length measurer," *Open Access Maced. J. Med. Sci.*, vol. 10, no. E, pp. 852–859, 2022, doi: 10.3889/oamjms.2022.8952.

[13] W. Huo, X. Yuan, X. Li, W. Luo, J. Xie, and B. Shi, "Increasing acceptance of medical AI: The role of medical staff participation in AI development," *Int. J. Med. Inform.*, vol. 175, art. no. 105073, 2023, doi: 10.1016/j.ijmedinf.2023.105073.

[14] M. A. Hertzog, "Considerations in determining sample size for pilot studies," *Res. Nurs. Health*, vol. 31, no. 2, pp. 180–191, 2008, doi: 10.1002/nur.20247.

[15] World Health Organization, *WHO Child Growth Standards*, Geneva: WHO, 2006. [Online]. Available: https://www.who.int/tools/child-growth-standards

[16] Kementerian Kesehatan Republik Indonesia, *Peraturan Menteri Kesehatan Republik Indonesia Nomor 2 Tahun 2020 tentang Standar Antropometri Anak*, Jakarta: Kemenkes RI, 2020. [Online]. Available: http://hukor.kemkes.go.id/uploads/produk_hukum/PMK_No__2_Th_2020_ttg_Standar_Antropometri_Anak.pdf

[17] E. Mocini et al., "Digital anthropometry: A systematic review on precision, reliability and accuracy of most popular existing technologies," *Nutrients*, vol. 15, no. 2, art. no. 302, 2023, doi: 10.3390/nu15020302.

[18] S. B. Heymsfield, B. Bourgeois, B. K. Ng, M. J. Sommer, X. Li, and J. A. Shepherd, "Digital anthropometry: A critical review," *Eur. J. Clin. Nutr.*, vol. 72, no. 5, pp. 680–687, 2018, doi: 10.1038/s41430-018-0145-7.

[19] G. M. Tinsley, M. L. Moore, J. R. Dellinger, B. T. Adamson, and M. L. Benavides, "Digital anthropometry via three-dimensional optical scanning: Evaluation of four commercially available systems," *Eur. J. Clin. Nutr.*, vol. 74, no. 7, pp. 1054–1064, 2020, doi: 10.1038/s41430-019-0526-6.

[20] B. Smith, C. McCarthy, M. E. Dechenaud, M. C. Wong, J. A. Shepherd, and S. B. Heymsfield, "Anthropometric evaluation of a 3D scanning mobile application," *Obesity*, vol. 30, no. 6, pp. 1181–1188, 2022, doi: 10.1002/oby.23434.

[21] J. Kim et al., "Preclinical trial of noncontact anthropometric measurement using IR-UWB radar," *Sci. Rep.*, vol. 12, no. 1, art. no. 12209, 2022, doi: 10.1038/s41598-022-12209-1.

[22] H. Shen, H. Zhao, and Y. Jiang, "Machine learning algorithms for predicting stunting among under-five children in Papua New Guinea," *Children*, vol. 10, no. 10, art. no. 1638, 2023, doi: 10.3390/children10101638.

[23] M. K. Ayele, G. A. Baye, S. H. Yesuf, A. A. Engda, and E. T. Mitiku, "Predicting stunting status among under-five children in Ethiopia using ensemble machine learning algorithms," *Sci. Rep.*, vol. 15, no. 1, art. no. 27907, 2025, doi: 10.1038/s41598-025-03206-1.

[24] G. Dumlu Bilgin et al., "Deciphering the concurrent phenomenon of childhood malnutrition using the extended composite index of anthropometric failure (ECIAF): Facts from the BESLEN project," *Public Health Nutr.*, vol. 28, no. 1, art. no. e9, 2024, doi: 10.1017/S1368980024002520.

[25] M. Briguglio et al., "Anthropometric measurements from a 3D photogrammetry-based digital avatar: A non-experimental cross-sectional study to assess reliability and agreement," *Appl. Sci.*, vol. 15, no. 10, art. no. 5738, 2025, doi: 10.3390/app15105738.

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Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i1.299

[26] WHO Multicentre Growth Reference Study Group, *WHO Child Growth Standards: Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age: Methods and Development*, Geneva: World Health Organization, 2006.
[27] M. de Onis, A. W. Onyango, E. Borghi, A. Siyam, and J. Siekmann, "Development of a WHO growth reference for school-aged children and adolescents," *Bull. World Health Organ.*, vol. 85, no. 9, pp. 660–667, 2007, doi: 10.2471/BLT.07.043497.
[28] D. Chan, M. C. Chua, M. Hadimaja, S. Mukherjee, J. Wong, and F. Yap, "Artificial intelligence-driven anthropometric assessment for young children: Evaluating the accuracy and practicality of a digital image-based length and weight prediction tool," *BMJ Health Care Inform.*, 2025, doi: 10.1136/bmjhci-2025-101540.
[29] E. J. Topol, "High-performance medicine: The convergence of human and artificial intelligence," *Nat. Med.*, vol. 25, no. 1, pp. 44–56, 2019, doi: 10.1038/s41591-018-0300-7.
[30] T. Schmitz et al., "Effectiveness of an electronic clinical decision support system in improving the management of childhood illness in primary care in rural Nigeria: An observational study," *BMJ Open*, vol. 12, no. 2, art. no. e055315, 2022, doi: 10.1136/bmjopen-2021-055315.
[31] J. Haskew, M. Ro, S. S. Turner, Y. Kim, S. S. S. Moon, and A. S. Chan, "Implementation of a cloud-based electronic medical record for maternal and child health in rural Kenya," *Int. J. Med. Inform.*, vol. 84, no. 5, pp. 349–354, 2015, doi: 10.1016/j.ijmedinf.2015.01.005.
[32] World Health Organization, "Digital health," 2024. [Online]. Available: https://www.who.int/health-topics/digital-health
[33] M. McLaughlin, L. Metiboba, A. Giwa, O. F. Ojo, and N. Ravi, "Adherence to integrated management of childhood illness (IMCI) guidelines by community health workers in Kano State, Nigeria through use of a clinical decision support (CDS) platform," *BMC Health Serv. Res.*, vol. 24, art. no. 11245, 2024, doi: 10.1186/s12913-024-11245-z.
[34] T. Siswati, B. A. Paramashanti, L. Waris, N. Setiyawati, and A. Wijanarka, "Acceptability of a stuntingmeter digital ultrasonic: A mixed methods approach," *Malays. J. Med. Health Sci.*, vol. 20, suppl. 9, pp. 209–215, 2024, doi: 10.47836/mjmhs20.s9.34.
[35] K. D. Tzimourta, "Human-centered design and development in digital health: Approaches, challenges, and emerging trends," *Cureus*, vol. 17, no. 6, art. no. e85897, 2025, doi: 10.7759/cureus.85897.
[36] P. R. Pognon, F. Boima, and Z. A. Mekonnen, "Health workers' acceptance and satisfaction on the usability of digital health goods in Kono District, Sierra Leone," *BMC Health Serv. Res.*, vol. 25, art. no. 267, 2025.
[37] N. Alotaibi, C. B. Wilson, and M. Traynor, "Enhancing digital readiness and capability in healthcare: A systematic review of interventions, barriers, and facilitators," *BMC Health Serv. Res.*, vol. 25, art. no. 500, 2025, doi: 10.1186/s12913-025-12663-3.
[38] World Health Organization, *WHO Guideline: Recommendations on Digital Interventions for Health System Strengthening*, Geneva: WHO, 2019.
[39] D. A. Prihanggara and L. S. Handini, "The effectiveness of integrated growth monitoring and nutritional surveillance for early detection and prevention of malnutrition in early childhood: A literature review," *J. Divers. Med. Res.*, vol. 2, no. 3, pp. 91–96, 2025, doi: 10.33005/jdiversemedres.v2i3.105.
[40] J. d. A. Silva et al., "Digital health and primary health care quality: A survey case study," *Int. J. Environ. Res. Public Health*, vol. 22, no. 7, art. no. 1015, 2025, doi: 10.3390/ijerph22071015.
[41] S. Carsley, C. S. Birken, P. Parkin, E. Pullenayegum, and K. Tu, "Completeness and accuracy of anthropometric measurements in electronic medical records for children attending primary care," *J. Innov. Health Inform.*, vol. 25, no. 1, p. 963, 2018, doi: 10.14236/jhi.v25i1.963
[42] World Health Organization, "Digital health," 2021. [Online]. Available: https://www.who.int/health-topics/digital-health (accessed Dec. 30, 2024).

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