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Developing a Digital Anthropometry Device Using IoT-Based Sensors for Monitoring Small Babies

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Abstract:

Background: Accurate anthropometric measurements are essential for monitoring the growth and health of small babies, particularly those born with low birth weight (LBW) or prematurely.

Objectives: This study aims to develop a digital anthropometry device integrated with Internet of Things (IoT) technology to support early detection, real-time monitoring, and data reporting in primary healthcare settings.

Method: In this study, a Research and Development (R&D) design based on the Borg and Gall model, involving stages of needs assessment, device design, prototyping, expert validation, and limited field testing, was used. The device incorporates a load cell, ultrasonic sensors (JSN-SR04T), and an ESP32 microcontroller connected to cloud platforms (Firebase/ThingsBoard). Usability and feasibility were evaluated through mixed methods involving healthcare workers and parents.

Results: The outcome of this protocol is a functional, validated, and user-friendly IoT-based digital baby scale capable of accurately measuring weight and length. The device is expected to enhance data accuracy, support growth monitoring at the community level, and integrate with existing public health reporting systems.

Discussion: This innovation will address long-standing challenges in neonatal growth monitoring by offering a scalable, real-time, accurate measurement and supporting data-driven interventions at the community level. The device's design aligns with current digital transformation efforts in public health, although further testing is needed to assess its long-term implementation and cost-effectiveness.

Conclusion: The study presents a novel IoT-based anthropometry device that improves measurement accuracy, usability, and data integration in the care of small babies. It holds promise for strengthening primary health services and malnutrition prevention strategies.

Keywords: Digital anthropometry, IoT, Baby scale, Small babies, Primary healthcare, Device development.

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1. INTRODUCTION

The health of small babies, comprising both low birth weight (LBW) infants (birth weight of less than 2500 grams) and those born prematurely (gestational age less than 37 weeks), continues to pose a significant global health challenge, particularly in low- and middle-income countries [1] [2]. In 2020, out of 135 million live births globally, 23.4 million (1 in 5) were small for gestational age (SGA), and 13.4 million (1 in 10) were preterm. A total of 35.3 million (26.2%) were classified as small, vulnerable newborns (SVNs), born preterm, SGA, or both, comprising 99.5% of the world's 20 million LBW cases. Nearly two-thirds (63%) of term SGA babies were in southern Asia [3]. In Indonesia, the LBW prevalence was 6.1% in 2023 [4].

These newborns face heightened risks of neonatal mortality [3], delayed physical and cognitive development [5], [6], obesity [7], and long-term non-communicable diseases [7], [8]. In Indonesia, the persistently high prevalence of small babies, as reported in national health surveys [4], underscores the urgent need for improved strategies in early detection, continuous monitoring, and comprehensive postnatal care.

Addressing this issue requires a multisectoral approach involving maternal nutrition, antenatal care quality, and equitable access to skilled birth attendants. Strengthening community-based health services and integrating data-driven interventions are also essential to reduce the burden of low birth weight and improve newborn outcomes [2], [9]– [12].

Accurate and timely anthropometric measurements are essential for the effective management and follow-up of children, including LBW and small babies [13], [14]. Key parameters, such as weight, length, and head circumference, are vital indicators of nutritional status and developmental progress [15]. However, manual measurement techniques, which are still widely used in frontline health services, especially in under-resourced settings, present significant limitations. These include human error, inconsistent methodology, and poorly calibrated tools factors that reduce measurement reliability and compromise the quality of infant health interventions [16]– [18].

Although digital health technologies have expanded in recent years, a major gap remains in the availability of anthropometric tools specifically designed for small babies and suitable for decentralized healthcare settings. Existing digital devices are often intended for newborns with normal birth weight [19] or the adult population [20], [21], lacking both precision and the integration of Internet of Things (IoT) features needed for real-time data transmission and centralized health monitoring. Moreover, limited research has addressed how such devices can be adapted for use in community contexts, considering factors like usability, connectivity, and interoperability.

Many existing digital anthropometry devices, as reported in previous research [22]– [24], primarily target newborns with normal birth weight and require either stable electricity or manual data recording, which may limit their use in low-resource or mobile health settings. Additionally, most commercially available tools lack integration with real-time digital health reporting platforms. They are not designed for seamless interoperability with national systems, such as e-PPGBM or SatuSehat. This presents a critical limitation in community-based healthcare systems that rely heavily on frontline workers with minimal training in digital tools. By contrast, the device proposed in this study is specifically tailored for SVNs. It is equipped with modular IoT features, cloud storage compatibility, ergonomic baby-friendly designs, and off-grid functionality. These features address real-world constraints, including limited infrastructure, time constraints during Posyandu visits, and the urgent need for valid data to inform stunting prevention strategies.

To address this gap, this study protocol outlines the development of an innovative digital anthropometry device embedded with IoT-based sensors for monitoring small babies. The device integrates microcontroller systems and smart sensors to support precise, consistent, and efficient measurement in community settings. This research fills a critical need by providing an evidence-based, context-sensitive, and scalable solution aligned with both national maternal-child health goals and global initiatives to reduce infant morbidity and mortality through technology-enabled care.

2. MATERIALS AND METHODS

2.1. Study Design

This protocol follows a Research and Development (R&D) approach based on the Borg and Gall model, focusing on early-stage product innovation. The study consists of the following phases: (1) preliminary research and needs assessment, (2) product design and prototyping, (3) expert validation, and (4) limited field testing at selected community health centers (Puskesmas).

2.2. Study Location and Participants

The research was conducted in collaboration with Posyandu, Puskesmas, and hospitals in Yogyakarta, Indonesia. Participants were 15 healthcare professionals (midwives, doctors, nurses, and community health workers), 3 experts, including subject matter experts in pediatrics, biomedical engineering, and digital health, as well as parents of small babies (defined as low birth weight and/or preterm infants) receiving care at the selected health centers (30 participants). The sample size in this study was determined based on the consideration of the minimum need for functional validation of the tool in the early-stage studies (pilot R&D), as well as referring to similar studies [25].

The inclusion criteria were: a) Healthcare professionals (midwives, nurses, doctors, and community health workers) working at Posyandu, Puskesmas, or hospitals participating in the study in Yogyakarta; b) Parents (mother or father) of small babies (defined as low birth weight <2500 grams and/or preterm <37 weeks) who receive care at the selected health facilities and are willing to participate in the device testing, c) Experts in pediatrics, biomedical engineering, or digital health who are available to provide input during the validation process, d) Participants who provide written informed consent and agree to participate throughout the study following the research protocol, e) Parents aged 18 years or older, with the ability to communicate effectively in Bahasa Indonesia. The exclusion criteria were: a) Healthcare professionals or parents who are on extended leave or not actively working during the data collection period, b) Parents of babies with complex medical conditions (severe congenital anomalies or genetic syndromes or others) that may affect anthropometric measurements, c) Participants who refuse or withdraw consent at any point during the study, d) Babies who are currently under intensive care (NICU) during the field trial phase, e) Participants with communication or cognitive impairments that hinder the interview, validation, or data collection process. The statistical analysis used included Pearson correlation tests, Bland-Altman plots to test the suitability of digital measurement results compared to manual methods, and SUS descriptive analysis to evaluate user experience.

2.3. Material of Prototype Design

The prototype of the digital anthropometry device included embedded microcontrollers and sensors for weight and length measurements. The primary instrument developed in this study is a digital anthropometric device specifically designed for infants with low birth weight (LBW) or born prematurely. The device integrates hardware and software components supported by Internet of Things (IoT) infrastructure to ensure real-time, accurate, and user-friendly anthropometric data collection. The tool is developed in a modular design and includes three major components, which are as follows:

2.3.1. Hardware Components

The hardware prototype consists of the following elements:

a) Load Cell Sensor (capacity 5–10 kg): Installed to measure infant weight with precision up to ±50 grams. The sensor is calibrated against a standard digital baby scale to ensure measurement accuracy.

b) Ultrasonic Sensor (JSN-SR04T): Used to measure the length of the baby's body (lying length). Two sensors are placed at each end of the measuring board to automatically detect the head-to-toe distance when the baby is placed on the board.

c) Microcontroller Unit (ESP32): Serves as a processing center for collecting, converting, and transmitting sensor data. It is chosen for its integrated Wi-Fi and Bluetooth capabilities, which facilitate cloud data transmission.

d) TFT LCD Display (4.3”): Displays weight and length measurement results in real-time for healthcare worker feedback and review.

e) Rechargeable Battery Pack (7.4V/2200mAh): Allows portable use in Posyandu or rural field settings, supporting off-grid measurement.

f) Baby Protective Tray and Measuring Pad: Designed with medical-grade materials that are easy to sanitize to ensure safety, hygiene, and comfort for babies during measurements.

2.3.2. IoT Software Systems and Dashboards

The software system includes firmware embedded in microcontrollers and a web-based IoT platform that can be accessed by healthcare workers and program administrators. This system includes:

a) Firmware Algorithm: Converts raw sensor data into standard anthropometric output (grams and centimeters), adjusted to sensor deviations and environmental noise.

b) Cloud-Based Storage (Firebase or ThingsBoard): Automatically stores baby measurement data, is linked with a unique subject ID, and is accessible for longitudinal growth tracking.

c) User Authentication Module: Ensures data privacy and limited access to healthcare personnel through secure login credentials.

d) Data Visualization: Displays individual child growth charts and enables export to national reporting systems.

2.3.3. Device Development and IoT Integration

The device was developed using microcontroller-based systems embedded with precision sensors. The IoT component utilized wireless data transmission modules, allowing real-time uploads to a cloud-based platform. This platform included features for remote monitoring, automated alerts for abnormal values, and data visualization dashboards for health workers and pediatricians.

2.4. Instruments of Validation and Usability Test

The validation was carried out by following a Delphi technique [26], involving iterative feedback from interdisciplinary experts to ensure compliance with safety, accuracy, and ergonomic standards. Usability testing was conducted using the System Usability Scale (SUS) [27] [28], along with real-time observations of health workers performing measurements on infants. The digital device’s outputs were statistically compared with manual measurements to assess accuracy, time efficiency, and inter-rater reliability. The instruments used in this study consist of:

a) Validation checklists designed for expert review, focusing on technical feasibility, accuracy, and usability.

b) System Usability Scale (SUS) questionnaire for healthcare workers, to evaluate user experience and satisfaction during the field test.

c) Observation sheets to assess device handling, time efficiency, and inter-user consistency during measurements.

d) Standard anthropometry tools (infant scales, length boards).

e) Accuracy tests, including Maternal and Child Health Handbook for small babies, calibration of age, weight, and length, z-scores of WAZ, HAZ, and HAZ, as well as accuracy test by a certified institution, namely BPAFK of the Ministry of Health of the Republic of Indonesia.

2.5. Ethical Considerations

This research has been approved by the IRB of MHREC UGM Yogyakarta, Indonesia, No. KE/FK/1939/EC/2024 dated December 31st, 2024. Participants were informed of their rights, and written consent was obtained before any data collection. Data privacy and confidentiality were maintained throughout the study, following national and international ethical standards.

3. EXPECTED RESULTS

The expected outcome is a validated, user-friendly, and scalable digital anthropometry device with integrated IoT features, suitable for use in decentralized healthcare systems. The device will contribute to improved monitoring and early intervention for small babies in community health settings.

4. DISCUSSION

The development of a digital anthropometric device integrated with IoT technology specifically targets critical gaps in neonatal growth monitoring, especially for low birth weight (LBW) and preterm infants. Traditional measurement tools often suffer from inconsistencies due to operator dependency, limited accuracy, and the absence of seamless integration with digital health systems [17], [18], [20], [29], [30]. These limitations hinder early detection and timely intervention in cases of growth faltering, especially in remote or underserved areas. By focusing on high-risk neonatal populations, this research contributes to a broader effort to improve maternal and child health outcomes through digital innovation.

The tool aims to strengthen routine monitoring at the grassroots level and promote more effective surveillance practices. In the context of Indonesia or other similar countries, disparities in the capacity of health cadres, limited human resources, low motivation among volunteers, and the absence of reliable anthropometric tools remain persistent challenges [31]– [35]. This innovation offers a practical and scalable solution. By enabling accurate, automated, and real-time data collection integrated with national health information systems, the tool addresses long-standing issues of data inaccuracy, delayed reporting, fragmented health service delivery, and supporting nutrition surveillance. It empowers frontline workers with user-friendly technology, reduces their workload, enhances data-driven decision-making, and ultimately supports more equitable and efficient growth monitoring and stunting prevention efforts across diverse and often under-resourced community health settings.

This innovation combines ergonomic, child-safe hardware with smart technologies such as load cell and ultrasonic sensors for accurate measurement of infant weight and length, integrated via an ESP32 microcontroller that enables real-time data transmission through Wi-Fi or Bluetooth. The system automatically uploads measurements to an IoT-based dashboard, significantly reducing human error, improving workflow efficiency, and facilitating prompt responses to growth deviations. Its interoperability with national health platforms like e-PPGBM and SatuSehat enhances surveillance accuracy and accelerates follow-up actions for at-risk infants, aligning with Indonesia's digital transformation strategy in stunting reduction [36], [37]. Furthermore, its potential integration into Posyandu and Puskesmas workflows, supported by automated data archiving and longitudinal monitoring features, demonstrates both its scalability and practical value in strengthening community-based child health services.

In ensuring practical applicability, the research emphasizes a user-centered design process [38]– [41]. Midwives, nurses, and health cadres participated in evaluating the tool's usability, contributing to a culturally relevant and context-specific product. The use of the Design and Development Research (DDR) methodology allowed iterative testing and refinement, improving the tool's functionality and user-friendliness [42]. Technical trials in both clinical and field settings revealed that the device operates within acceptable error margins, comparable to conventional instruments. This confirms not only the validity of the technology but also its acceptability and feasibility in real-world applications across diverse healthcare contexts, as stated by Rogers [43].

Despite these promising outcomes, challenges remain for full-scale implementation. Network connectivity issues in rural areas, device calibration maintenance, and the digital literacy of frontline health workers must be addressed to ensure long-term success. Moreover, standardized training modules are needed to support consistent and competent use of the tool at the community level. Future research should include large-scale pilot testing, cost-benefit analysis, and integration with predictive analytics to further enhance the impact of the program [44]. Ensuring robust data privacy and interoperability standards will also be essential as the device becomes more widely adopted. Addressing these factors will enhance sustainability and facilitate institutionalization within Indonesia's primary healthcare system [45].

In conclusion, this study contributes valuable insights into the design and deployment of IoT-based anthropometric devices tailored for neonatal health surveillance. The innovation demonstrates strong potential to improve data quality, service efficiency, and evidence-based decision-making within community and primary care settings. Its integration with national platforms ensures strategic alignment with health system transformation goals. While refinements are necessary, the device presents a scalable and sustainable solution for stunting prevention in high-risk infant populations. Ultimately, the study reinforces the critical role of digital health technologies in addressing persistent public health challenges in Indonesia and similar low- and middle-income countries. Some of the limitations of this study include the limitations of internet connectivity in rural areas, the possibility of bias from small sample sizes that are not yet representative of the entire demographic context of Indonesia, as well as the need for ongoing technical training for frontline health workers in operating the equipment.

CONCLUSION

This study introduces a novel, sensor-integrated digital anthropometry device enhanced with IoT technology, specifically designed to improve the accuracy and efficiency of growth monitoring in small and vulnerable newborns within primary healthcare settings. Combining ultrasonic and load cell sensors, an ESP32 microcontroller, and real-time cloud connectivity enables automated, precise, and timely data capture that can seamlessly integrate with national health information systems, such as e-PPGBM. Its ergonomic, portable, and user-centered design makes it universally applicable for community-level use, particularly in Posyandu and rural settings. With strong potential to transform stunting prevention strategies through data-driven early detection and intervention, this innovation offers a scalable, sustainable solution that aligns with Indonesia's digital health transformation and holds promise for adoption in other low- and middle-income countries facing similar public health challenges. In addition to providing concrete solutions for monitoring the growth of small babies, this tool also opens up opportunities for further integration with digital health systems, such as AI, for predictive stunting risk detection. This development also provides the basis for further research in the context of user-centered device design and the strengthening of data-driven health systems in developing countries.

LIST OF ABBREVIATIONS

LBW	=	Low Birth Weight
IoT	=	Internet of Things
ESP32	=	Embedded Systems Platform 32-bit Microcontroller
SUS	=	System Usability Scale
SVN	=	Small and Vulnerable Newborn
LCD	=	Liquid Crystal Display
R&D	=	Research and Development
NICU	=	Neonatal Intensive Care Unit
POSYANDU	=	Pos Pelayanan Terpadu (Integrated Service Post)
Puskesmas	=	Pusat Kesehatan Masyarakat (Community Health Center)
e-PPGBM	=	Elektronik-Pencatatan dan Pelaporan Gizi Berbasis Masyarakat
STROBE	=	Strengthening the Reporting of Observational Studies in Epidemiology
UGM	=	Universitas Gadjah Mada
IRB	=	Institutional Review Board
TFT	=	Thin-Film Transistor
DDR	=	Design and Development Research
SUS Score	=	A scoring system used to evaluate the usability of a system or device
BPFK	=	Balai Pengamanan Fasilitas Kesehatan

AUTHORS' CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: M.P.R.: Study conception and design; F.A.: Conceptualization; I.I.: Methodology; T.S.: Draft manuscript;. All authors reviewed the results and approved the final version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This research has been approved by the IRB of MHREC UGM Yogyakarta, Indonesia, No. KE/FK/1939/EC/2024 dated December 31st, 2024.

HUMAN AND ANIMAL RIGHTS

No animals were used in this research. All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or research committee and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

Written informed consent for publication was obtained from all participants involved in this study, including parents of small babies and healthcare professionals, in accordance with ethical standards.

AVAILABILITY OF DATA AND MATERIALS

All data generated or analyzed during this study are included in this published article.

STANDARDS OF REPORTING

STROBE guidelines were followed.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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