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Development of a Digital Body Weight Scale Prototype with IoT-Based BMI Calculation and Real-Time Weight Tracking

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ABSTRACT

Obesity is a growing health concern in Indonesia, with its prevalence steadily increasing and contributing to a variety of non-communicable diseases such as diabetes and heart disease. One effective way to monitor and manage body weight is by regularly calculating the Body Mass Index (BMI). This study aims to develop a digital weighing scale prototype based on the Internet of Things (IoT), equipped with BMI calculation and real-time weight tracking features. The prototype utilizes load cell sensors, HX711, ESP8266, and an OLED display for measuring weight, which is then transmitted to a Flutter-based application (MyWeightApp) connected to Firebase for data storage and graphical visualization. The research adopts the waterfall model for system development, encompassing requirements analysis, planning, modeling, construction, and system handover. Hardware testing demonstrates an accuracy rate of 0.78% error, well below the 5% tolerance threshold. Software testing using black-box testing confirms that the application successfully tracks weight, calculates BMI, and provides effective weight progress graphs. The results of this study indicate that the IoT-based digital weighing scale prototype developed can serve as a practical solution for obesity prevention and health monitoring in Indonesia.

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1. INTRODUCTION

Advancements in technology in the healthcare sector, particularly in monitoring body weight and obesity, have become a significant concern in Indonesia. According to the 2023 Indonesia Health Survey, the prevalence of overweight individuals has reached 14.4%, while obesity has increased to 23.4%, reflecting a substantial rise compared to five years ago. This growing rate of obesity poses a risk of triggering various non-communicable diseases, such as heart disease and diabetes. As highlighted in a journal, obesity is a major contributor to non-communicable diseases, including heart disease, diabetes, high blood pressure, and high cholesterol [1]. According to data from the Health Department of Serang City, the obesity rate was 13.2% from January to May 2024, compared to 14.8% in 2023.

The causes of obesity and overweight are often related to an imbalance between energy intake and expenditure. According to research, this imbalance can lead to the accumulation of body fat, which can alter physical appearance and increase the risk of various diseases [2]. Therefore, it is important for individuals to regularly monitor their weight and calculate their BMI as a preventive measure and for controlling obesity. BMI is a commonly used method to categorize body fat based on weight and height [3]. One solution that can be implemented to regularly monitor weight is by utilizing technological advancements, such as the IoT, which enables real-time weight monitoring. According to Saraswati's research, the use of information technology in health monitoring has increasingly been introduced as a solution to facilitate direct health monitoring [4]. Using load cell sensors connected to an IoT-based application, users can monitor weight changes in real-time and view measurement history. This technology can support diet and weight loss programs by providing accurate data that is easily accessible through smartphones.

Various studies related to the design of IoT-based digital scales have been conducted using different approaches. Yonanthan Tri Handiko (2022) designed a digital scale using a load cell sensor, NodeMCU v3 ESP8266, LCD, and HX711. The weight data is displayed on the LCD and automatically recorded in a web-based database with an accuracy rate of 99.94% [5]. Erlangga Firdaus (2022) developed an IoT-based height and weight measurement tool using a load cell and ultrasonic sensor, leveraging the Blynk platform for monitoring.

This device is capable of categorizing body weight with an error margin of less than 1% [6]. Dirman Nurlette (2018) designed a height and weight measurement device based on Arduino, utilizing the HY-SRF04 ultrasonic sensor and a load cell, with a failure rate of only 0.1% [7]. Alberto Prendy (2023) focused his measurement system on infants, using the ESP32, load cell sensor, and ultrasonic sensor, with the load cell sensor error rate ranging from 0.0005% to 0.016% [8]. Study conducted by Eko Arianto (2024) utilized IoT as a communication system to store and display data in a database [9]. These studies demonstrate the significant potential of IoT-based digital weighing devices to enhance the accuracy and efficiency of weight measurements, as well as the storage and real-time monitoring of data.

Therefore, the author proposes the development of a prototype digital scale with BMI calculation and IoT-based tracking, which can serve as a practical solution to combat obesity in Indonesia and raise public awareness about the importance of regular weight monitoring. As highlighted by [4], Consistent weight monitoring and BMI calculation can help prevent obesity and raise awareness about the importance of maintaining a healthy weight.

2. RESEARCH METHODS

2.1 Research Flow

This research employs the waterfall model approach. According to Nasution (2012), as cited in Rusmawan's book, the waterfall model is a systematic and sequential information system development method. Each phase in this model is executed in a step-by-step and continuous manner, ensuring that each stage is completed before moving on to the next phase [10]. The stages are divided into five phases: requirements analysis, planning, modeling, construction, and system handover [11] as shown in Figure 1.

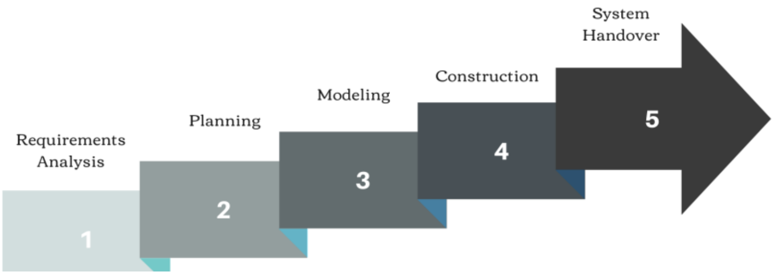

Figure 1. The research flow of the waterfall model

The waterfall model is divided into five stages: (1) Requirements Analysis: This stage involves data collection through interviews with officers from the Serang City Health Office to identify the system's needs and the components that will be used. (2) Planning: In this phase, hardware components are selected, data visualization methods are planned, and workflow designs are created. Testing of each component is also conducted during this stage. (3) Modelling: This stage focuses on creating a visual design of the system to be developed. (4) Construction: In this phase, the system is built according to the design created in the previous stage. (5) System Handover: This final stage ensures the system functions properly and meets all the specified requirements.

2.2 Research Design

The research design ensures that the research process is structured and well-directed. The workflow is divided into phases for hardware and software design and testing, as illustrated in the flowchart in Figure 2. The workflow is divided into two main phases: hardware design and software design, with each phase including specific testing procedures.

2.2.1 Hardware Design and Testing

The hardware design phase involves assembling components such as the load cell sensor, HX711, ESP8266, and OLED display. The load cell sensor is connected to the HX711 to amplify and convert the analog signal into a digital signal [12][13]. The digital signal is then sent to the ESP8266, which displays the output on the OLED. The circuit diagram in Figure 3 outlines the connections of these components.

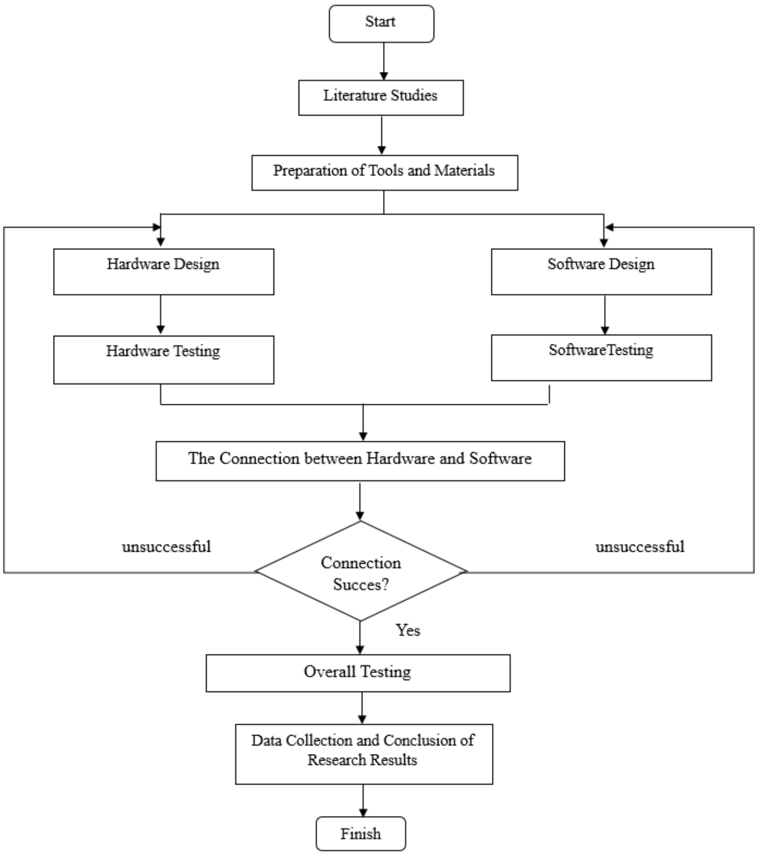

Figure 2. Results design workflow

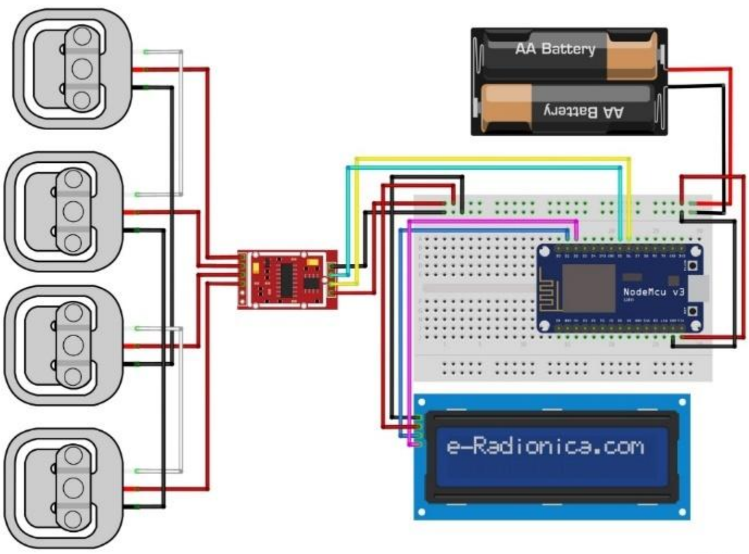

Figure 3. Weighing system circuit

To ensure the accuracy of the received data, testing is conducted to validate the load cell sensor readings by comparing the system's measurement results with a standard weighing scale. This is done to determine the margin of error and ensure that the system's measurement results fall within a tolerance limit of 5% [1].

2.2.2 Design and Testing Software

The software design focused on the development of the MyWeightApp smartphone application. The app was developed using Visual Studio Code with the Flutter framework, and Firebase was used for database storage. The app provides real-time weight tracking and BMI calculation for users, helping them to monitor their weight effectively.

The application testing process carried out using a black-box testing method that focuses on functional testing of the application [14]. Application validation is conducted to ensure that the BMI and weight tracking results displayed by the application are consistent and relevant for different categories of users. This aims to ensure application can provide precise results, independent of the user's demographic variations.

3. RESULTS AND DISCUSSION

3.1 Research Results

After completing the entire series of tool development, testing was carried out through three stages: hardware testing, software testing, and overall system testing. Hardware testing is done to determine the error value of the scales made, while software testing evaluates the performance of the application. Finally, overall system testing ensures the integration and smooth operation of the system.

3.1.1 Hardware Testing Results

Hardware testing was conducted to validate the accuracy of the scale with a load range of 0-200 kg on 10 test subjects (5 men and 5 women), aged between 19 and 22 years old, with body weights varying from 35 kg to 90 kg. The test involved comparing readings from the IoT-based digital scale with those available in the market as a reference.

Table 1. Error value testing

Name	Digital Scale Reading (Kg)	Verified Scale Reading (Kg)	Error (%)
S1	64,8	64,7	0,15
S2	58,6	58,7	0,17
S3	35,5	36	1,39
S4	49.1	48.8	0,61
S5	43.9	43.8	0,23
S6	55,9	56	0,18
S7	52.8	53.4	1,30
S8	85,2	85	0,23
S9	47,7	47	1,49
S10	68,9	69,8	1,29
Average (%)			0.78%

Based on the test results, Table 1 shows an average error rate of 0.78%. This error is well below the standard margin of error of 5% [1], indicating that the system operates with acceptable accuracy for practical use. Factors such as foot positioning on the scale, placement of the scale on a hard and flat surface, and environmental conditions (temperature and humidity) were controlled to reduce external influences. The findings of this study demonstrate a lower error value, suggesting an improvement in the accuracy of the developed scales. Therefore, it can be concluded that the scale offers a good level of accuracy for body weight measurement. The examples of measurement results can be shown in Figure 4.

Figure 4. Measurement results with verified scales

Figure 5. Measurement results with IoT scales

3.1.2 Software Testing Results

Black-box testing has been conducted on the MyWeightApp application, focusing on its core functionalities: monitoring weight, calculating BMI, and recording weight change trends. The testing employed a black-box testing approach that emphasizes the application's functionality [15]. The results indicate that the app effectively monitors weight, calculates BMI, and tracks weight changes. The average response time for sending data from the ESP8266 to Firebase is 2 seconds. The application has been successfully integrated with digital scales and can display real-time weight data. Based on the test results presented in Table 2, it can be concluded that the MyWeightApp application is fully functional and ready to be used with the scales to monitor weight, calculate BMI, and track weight change trends.

Table 2. Black-box testing results

Tested Features	Testing Scenario	Input	Expected Results	Actual Results	Status
Login Page	The user fills in the Email and Password correctly	Email and Password	The user successfully logs in and is redirected to the main page.	Retrieved	Success
Registration Page	The user fills in all fields	Username, name, email, password, height, date of birth, gender	The user is successfully registered, and directed to the login screen.	Retrieved	Success
Main Page	The app retrieves sensor data and calculates BMI based on the latest sensor data	GET request to Firebase server	Display the latest sensor data and calculate BMI displayed on the main page.	Retrieved	Success
Calculator Page	The user selects gender and enters height and weight.	Gender, Weight, and Height	BMI is calculated and results are displayed	Retrieved	Success
Graphic Page	The application retrieves sensor data and the overall history of scale usage.	GET request to Firebase server	Sensor data will be converted into graphical form and display the date of use of the scales.	Retrieved	Success
Profile Page	The application retrieves user data from the Firebase database.	GET request to Firebase server	User data results are displayed on the profile page.	Retrieved	Success

The test results show that the system can record and synchronize the user's weight data in the MyWeightApp application in real-time. The main page, shown in Figure 6, accurately displays weight, height, age, the measured BMI calculation result, and an explanation of the BMI category.

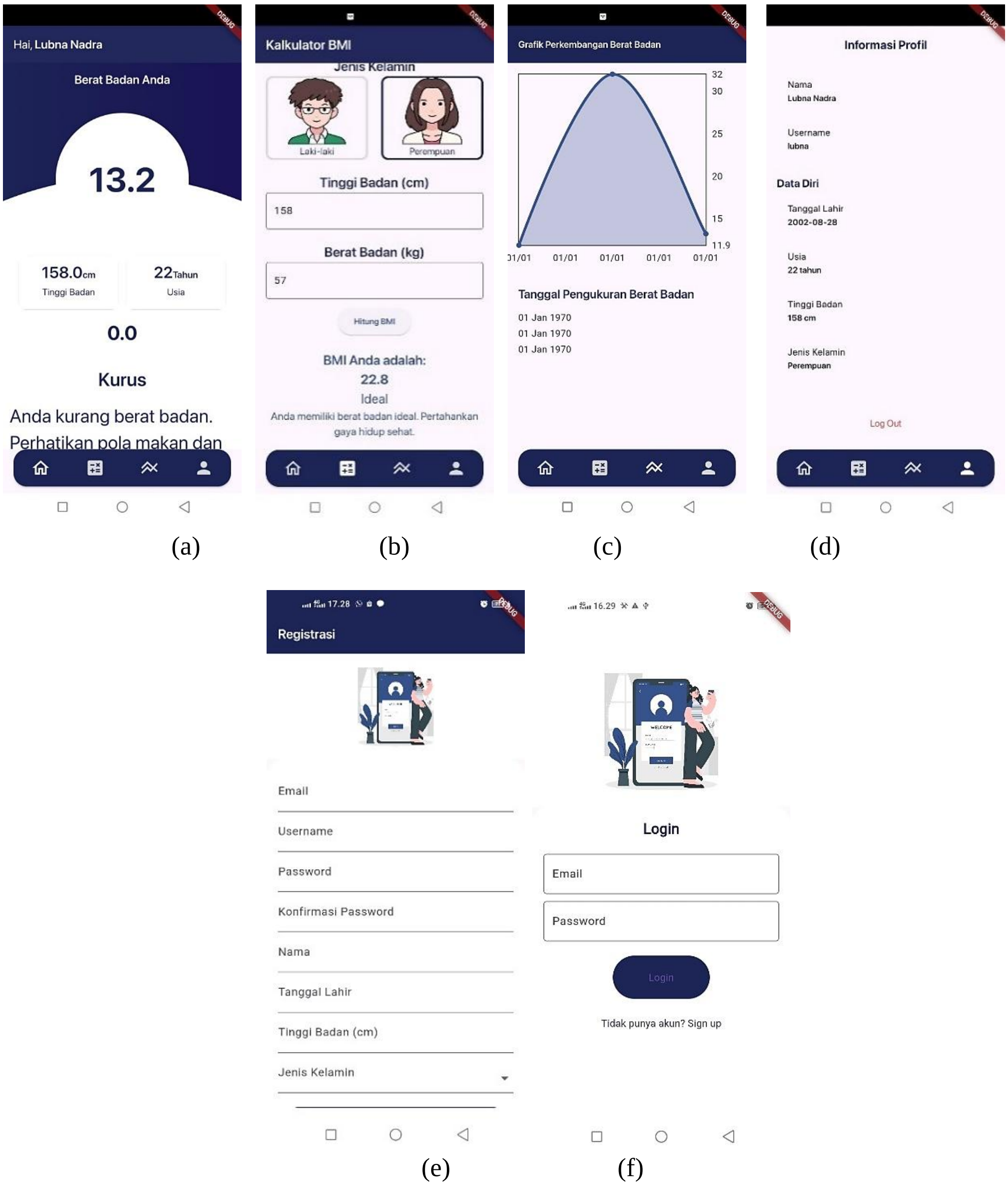

Figure 6. Application testing results page

3.1.3 Overall Testing Results

Functionality testing of the MyWeightApp application was conducted on 25 research subjects, divided into five groups based on BMI categories: underweight, normal, overweight, obese, and class I obesity. The test lasted for two days and used a digital scale powered by ESP8266, which was integrated with the MyWeightApp app via a Wi-Fi connection. The main objective of the test was to assess the accuracy and reliability of weight data transmission from the ESP8266 device to the MyWeightApp app. In addition, the test evaluated whether the app displays data in real time and confirmed the functionality of key features, including automatic BMI calculation, BMI categorization, and data visualization through graphs. The test results are summarized in Table 3 and Figure 7.

Table 3. Testing results of scales and connected applications

Sample	Testing Time	Measurement Result (kg)	Data Displayed in the Application (kg)	BMI	BMI Category	Data Synchronization
A1	31 October 2024	40,8	40,8	14,1	Slim	Synchronized
A2	31 October 2024	48,6	48,6	17,2	Slim	Synchronized
A3	31 October 2024	41	41	15,8	Slim	Synchronized
A4	31 October 2024	53	53	17,7	Slim	Synchronized
A5	31 October 2024	45,9	45,9	16,8	Slim	Synchronized
A6	31 October 2024	66.5	66.5	22.6	Ideal	Synchronized
A7	31 October 2024	57,1	57,1	21,5	Ideal	Synchronized
A8	31 October 2024	51,6	51,6	20,2	Ideal	Synchronized
A9	31 October 2024	55,9	55,9	22,1	Ideal	Synchronized
A10	31 October 2024	55,5	55,5	20,4	Ideal	Synchronized
A11	1 November 2024	73,4	73,4	24,8	Overweight	Synchronized
A12	1 November 2024	64,7	64,7	23,8	Overweight	Synchronized
A13	31 October 2024	65,6	65,6	23	Overweight	Synchronized
A14	1 November 2024	59.6	59.6	24.2	Overweight	Synchronized
A15	1 November 2024	60,8	60,8	24,7	Overweight	Synchronized
A16	31 October 2024	68	68	25,6	Class I Obesity	Synchronized
A17	1 November 2024	72,6	72,6	26,7	Class I Obesity	Synchronized
A18	1 November 2024	65,4	65,4	29,5	Class I Obesity	Synchronized
A19	1 November 2024	88,7	88,7	27,4	Class I Obesity	Synchronized
A20	1 November 2024	76,6	76,6	25,9	Class I Obesity	Synchronized
A21	31 October 2024	92,1	92,1	30,1	Class II Obesity	Synchronized
A22	31 October 2024	103,5	103,5	33,8	Class II Obesity	Synchronized
A23	1 November 2024	90,2	90,2	31,6	Class II Obesity	Synchronized
A24	1 November 2024	110,2	110,2	34,8	Class II Obesity	Synchronized
A25	1 November 2024	90,7	90,7	33,3	Class II Obesity	Synchronized

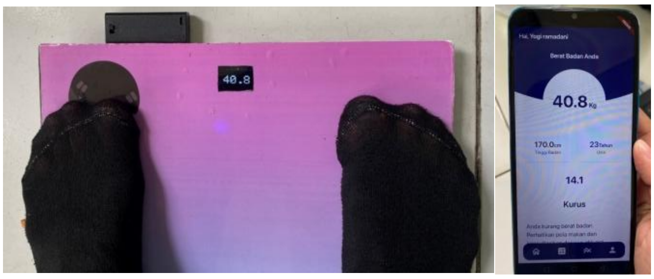

Figure 7. Scales testing results with MyWeightApp

3.2 Discussion

The error measurements summarized in Table 1, taken from 10 test subjects, reveal an error rate of 0.78%. This discrepancy comes from the operation of the load cell sensor, which converts mechanical force into an electrical signal. When a load is applied, the sensor element deforms slightly, changing its resistance. Since this resistance change is very small, a Wheatstone bridge circuit is required to detect it with precision. However, the sensitivity of the sensor is not immune to external influences. Factors such as temperature fluctuations, uneven mounting surfaces, and electromagnetic interference can destabilize the readings, making accuracy a challenge.

3.2.1 Results Analysis and Error Factor

Based on the test results in Table 1, it is found that the error rate tends to be higher for body weight below 50 kg. This can be caused by more significant mechanical distortion in the loadcell sensor when measuring weights below 50 kg. In addition, the placement of the user's feet with the surface of the scales can affect the readings due to uneven load distribution. The tests were conducted in less controlled environmental conditions but had relatively low electromagnetic fields. However, external factors such as temperature, humidity, and air pressure were not specifically monitored. These factors can contribute to significant measurement variations, especially in sensors that are highly sensitive to environmental changes.

In addition to environmental factors, the connectivity and integration of electronic components also play a role in the accuracy of the system. The quality of the cable connection is one of the critical aspects that affect the stability of the sensor signal. Electrical contact variations in the cable connections can cause data fluctuations that impact the accuracy of the measurements. Therefore, in further development, the use of higher quality cables and a better connection security system can be a solution to improve system stability. As a corrective measure, some methods that can be applied include the use of data filtering algorithms to reduce noise from sensor readings, as well as the implementation of an environmental compensation system that can adjust measurement results to external variables. With these strategies, it is expected that the measurement error rate can be minimized so that the system can produce more accurate and reliable data.

3.2.2 Utilization of Historical data for Weight Trend Analysis

The test results show that the system can record and synchronize the user's weight data in the MyWeightApp application in real-time. The main page, shown in Figure 6a, accurately displays weight, height, age, the measured BMI calculation result, and an explanation of the BMI category. In addition, as seen in Figure 6b, the app enables manual BMI calculation by allowing users to enter their gender, height, and weight. Figure 6c illustrates the app's ability to display a weight progress chart along with the corresponding measurement date. Furthermore, Figure 6d shows that the app effectively presents user profile information, including name, username, date of birth, age, and gender. The registration page, depicted in Figure 6e, provides fields for entering email, username, password, password confirmation, name, date of birth, height, and gender. Finally, the login page, as shown in Figure 6f, allows users to log in using their email and password. These results confirm that the app performs all the required processes accurately and is aligned with the intended design specifications.

The application can serve as a personalized health monitoring system that detects weight gain or loss trends and suggests appropriate actions. The app can be recommended to encourage lifestyle modifications such as dietary changes or increased physical activity. Similarly, for those experiencing rapid weight loss, the app can suggest nutritional adjustments or consultations with healthcare professionals. Beyond individual tracking, historical weight data collected in Firebase holds significant potential for public health management. The ability to store and analyze users' weight history allows for deeper insights into long-term weight trends, which can be leveraged at both individual and community levels. By examining patterns of weight fluctuations over time, the system can identify individuals at risk of obesity or weight-related health conditions and provide tailored recommendations.

From a public health perspective, aggregated historical data from various users can be analyzed to identify broader weight trends within specific demographics or geographic areas. Users can report weight trend measurement results to health agencies that can be used to design targeted intervention programs for obesity prevention, particularly in areas with high obesity prevalence. If the data indicates an increasing trend in obesity rates within a community, policymakers can initiate public awareness campaigns, promote healthier eating habits, and encourage physical activity to address the issue. Moreover, early warning systems can be developed using machine learning algorithms to predict future weight trends based on historical data. Such a system could enable preventive health measures by notifying individuals and healthcare providers about potential risks, reducing the likelihood of obesity-related diseases such as diabetes, hypertension, and cardiovascular disorders. Furthermore, cloud-based integration with wearable health devices and telemedicine platforms could extend the utility of historical weight data beyond individual users. By incorporating AI-driven insights, the system could offer more precise and proactive health recommendations, further solidifying its role in comprehensive weight management and obesity prevention strategies.

The utilization of historical weight data in this study demonstrates the potential for large-scale health monitoring and intervention, making it a valuable tool not only for individuals but also for public health authorities and medical professionals. Future research could explore the integration of machine learning models for predictive analysis, enabling more accurate and personalized weight management solutions.

3.2.3 Research Comparison

Table 4. Research comparison table

The Research	Loadcell Sensor Accuracy	Database Storage Type	Feature
Yonanthan Tri Handoko (2022)	0,06%	Web-Based	No real-time Synchronization
Erlangga Firdaus (2022)	<1%	Local Storage	Does not Support Firebase Database
Dirman Nurlette (2018)	0,1%	Manual	Manual Calibration

Based on Table 4, the system in this study has advantages in real-time data synchronization using Firebase and has additional features such as storage and recording of weight history. The utilization of IoT technology for weight-based health monitoring offers advantages in terms of real-time data integration, cloud storage, and more comprehensive data analysis. The system developed in this research possesses several similar technologies. The main advantage of this system is its real-time data synchronization with Firebase, allowing users to access and monitor their weight on a smartphone without the need for manual data entry. In previous research, data was only stored locally. This prototype features automatic BMI calculation that directly categorizes users' weight, enabling them to understand their body condition without manual calculations. This system provides a visualization of weight trend graphs not implemented in prior research.

4. CONCLUSION

This study successfully developed a digital body weight scale prototype based on the IoT using a load cell sensor, HX711, OLED I2C, and ESP8266. The device is capable of measuring body weight with an accuracy rate of 99.22% and has been tested on 10 subjects aged between 19 and 22 years. It is designed to connect with the MyWeight app, developed using the Flutter framework with Firebase as its database. The app features functionality to monitor body weight, record weight history, and calculate BMI both automatically and manually. The system's ability to store and analyze historical weight data opens new possibilities for public health management. Future developments could explore the integration of machine learning algorithms to predict weight trends and provide early health warnings. Additionally, expanding the system for use in health institutions and national wellness programs could enhance large-scale obesity prevention and intervention efforts. This study highlights the potential of IoT-based weight monitoring as a critical tool for both personal and public health applications Application testing was conducted using black-box testing, which showed that all features of the app functioned properly. The system integrates the scale and the app in real time, using the ESP8266 to send body weight data to Firebase and then to the app. The system was tested on 25 individuals, with 5 people representing each weight category. The test results showed that the app successfully transmitted data consistently provided the Wi-Fi connection remained stable. Future developments could include adding features such as weight measurement reminder notifications and incorporating Machine Learning and Fuzzy Logic technologies to analyze weight trends and classify bodyweight categories.

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