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Design and Construction of an IoT-based Body Mass Index (BMI) Measuring Tool Using an Android Application

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ABSTRACT

Body Mass Index (BMI) is a measure of a person's fitness level monitoring obtained from a comparison between weight and height using a separate measuring instrument and requires the energy of other people in the measurement process, namely using a manual meter and scales. Therefore, a height and weight measuring instrument is needed that is integrated into a BMI measuring instrument to determine body health which is categorized into 5, namely, very thin, thin, normal, fat, and obese. The purpose of making this final project is to design the tool, find out the function test, and find out the performance test of the tool. The research stage consists of needs analysis, design, manufacture, and testing of the measuring instrument. The results of this study are that an IoT-based BMI measuring instrument using an android application was successfully created. The results of the function test show that each component is in good condition. While the results of the tool performance test are the same as the application showing that height measurements by ultrasonic sensors and weight measurements by load cell sensors from measurements of 15 people have a good error rate with an average of below 5%, namely 0.64% and 1.50% respectively against manual measurements using standard measuring instruments.

Indeks Massa Tubuh (IMT) merupakan ukuran pemantauan tingkat kebugaran seseorang yang didapatkan dari perbandingan antara berat dan tinggi badan menggunakan alat ukur terpisah dan memerlukan tenaga orang lain dalam proses pengukurannya yaitu menggunakan meter manual dan timbangan. Oleh karena itu diperlukannya alat pengukur tinggi dan berat yang terintegrasi menjadi alat pengukur IMT untuk mengetahui kesehatan tubuh yang dikategorikan menjadi 5 yaitu, sangat kurus, kurus, normal, gemuk, dan obesitas. Tujuan pembuatan proyek akhir ini adalah membuat rancang bangun alat, mengetahui uji fungsi, dan mengetahui uji kinerja alat. Tahap penelitian terdiri dari analisis kebutuhan, perancangan, pembuatan, dan pengujian alat ukur. Hasil dari penelitian ini adalah alat pengukur IMT berbasis IoT menggunakan aplikasi android berhasil dibuat. Hasil uji fungsi menunjukkan bahwa setiap komponen dalam kondisi baik. Sedangkan hasil uji kinerja alat sama dengan aplikasi menunjukkan bahwa pengukuran tinggi oleh sensor ultrasonik dan pengukuran berat oleh sensor load cell dari pengukuran 15 orang memiliki tingkat error yang baik dengan rata-rata di bawah 5% masing-masing yaitu 0,64% dan 1,50% terhadap pengukuran manual menggunakan alat ukur standar.

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1. Introduction

Measurement is a field of science that involves the process of collecting data or information objectively. One of the pieces of information obtained in the measurement process is in the form of meters (m) for distance and kilograms (Kg) for mass. Every individual needs to meet the need for monitoring their health in the challenge of managing fitness. Therefore, measurements are taken of the comparison of height and weight to determine the BMI value. BMI is a measure used to monitor a person's fitness status which is obtained from the comparison of weight and height [1].

The tools that are often used to measure a person's height and weight are manual meters and scales. The measurement process is carried out with separate measuring instruments and requires other human labor in the measurement process. Because the measurement data is carried out manually and has not been integrated between tools, the process takes a long time to find out the BMI value. This method is not yet effective and efficient because it has not utilized technology that can combine the two measuring instruments. The use of technological assistance that makes it easier for humans, one of which is innovating tools for measuring height and weight into measuring tools for height, weight, and BMI that can work automatically [2].

In previous research conducted by Hidayat and Fajrianti in 2020 created a BMI measuring tool (categories underweight, ideal, overweight, fat, and very fat) using Arduino R3 and the measurement results were displayed on a Bluetooth-based android and GoogleSheet. Research by Fadil and Thamrin in 2020 created a BMI measuring tool (categories thin, ideal, fat, obesity for men and women) using Arduino UNO R3 with measurement results displayed on a 20x4 LCD, computer, and GoogleSheet. Research by Krisnadi and Ridwanto in 2021 created a BMI measuring tool (categories thin, normal, fat, and obesity) using ESP8266 with measurement results displayed on a 16x2 LCD and android. Meanwhile, research by Putra *et al*. in 2023 created a BMI measuring tool (categories thin and severe, normal, and obese and mild and severe) using ESP8266 with measurement results displayed on a 16x2 LCD and GoogleSheet.

Based on references to previous studies, there has not been a BMI measuring tool created with the categorization of very thin, thin, normal, fat, and obesity according to Balanced Nutrition Guidelines, in monitoring body health according to the current BMI categorization in Indonesia. In addition, there has also not been an application created that can store the results of measuring height, weight, BMI, and BMI categories that can be monitored periodically.

Here, we use the NodeMCU ESP8266 microcontroller to process data from the HC-SR04 ultrasonic sensor as a distance meter and a load cell sensor along with the HX711 amplifier module as a mass meter. The measurement results are displayed on a 20x4 LCD and an Android application. In the Android application, monitoring can be carried out in real time or periodically on the storage of measurement results. The measurement results displayed are height, weight, BMI value, and BMI category (very thin, thin, normal, fat, and obese) which are indicated by the LED lights. Red LED (very thin and obese), yellow LED (thin and fat), and green LED (normal). The tool will be designed in such a way by combining several components along with the development of IoT-based applications. Application development is designed using Firebase and the application is made using Thunkable which is a web application creation platform. With this tool, it is hoped that the process of measuring a person's height and weight and body mass index will be more effective and efficient and obtain accurate results.

2. Methods

2.1 Measurements

Measuring instruments are tools used to carry out the process of checking the size of an object. The use of measuring instruments in each measurement is determined by various functions, measurement limits and the accuracy of the measuring instrument. For example, to measure the length of an object that is estimated to have a length of 50 meters, the measuring instrument used is a meter with a minimum measurement limit equal to the length of the object being measured. Measurements using the measuring instrument must be carried out carefully to obtain accurate values [3]. The practical value in the design and development of a system needs to go through an operation process and testing of usability. The measurements required in the design of the BMI measuring instrument are measurements with standard length and standard mass. In the design of the BMI measuring instrument, the type of measurement carried out is direct linear measurement. The direct linear measurement method is a measurement using a measuring instrument whose measurement results can be read directly on a measuring scale that has been calibrated on the standard measuring instrument. The direct measuring instruments used in BMI measurements are meters to measure height and scales to measure weight [4].

2.2 Body Mass Index

Body Mass Index (BMI) is a measure of a person's fitness level monitoring obtained from the comparison between body weight and height. BMI is one indicator of whether a person has a weight that is appropriate for their height or not [5]. A person's health risk can increase significantly if the BMI value is outside the normal limit. Body mass measurement is basic information related to a person's body condition, which is used for medical diagnosis and activities that involve physical activity. Therefore, it is important to know the body mass index in order to determine the level of health [8].

The calculation of the BMI value is body weight in kilograms (Kg) divided by the square of the height in meters (m^2). The use of this formula can only be applied to someone aged 18 to 70 years, with a normal back structure, not an athlete or bodybuilder, and not a pregnant or breastfeeding mother [6]. According to Indonesian Ministry of Health, BMI can be calculated using the Eq. (1).

$$\text{BMI } (\text{Kg}/\text{ m}^2) = \frac{weight\ (Kg)}{height^2\ (m^2)} \tag{1}$$

Each person's BMI values and categories are different by not measuring body fat directly and also not taking into account age, gender, ethnicity, or muscle mass in adults. However, BMI uses a standard weight status that can help doctors track weight status across populations and identify potential problems in individuals [5]. The threshold for measuring BMI values is modified based on clinical experience and research results in several developing countries. The following is the current BMI categorization in Indonesia.

Table 1. Category of BMI

Category	BMI
Very thin	<17,0
Thin	17,0 - <18,5
Normal	18,5 – 25,0
Overweight	>25,0 – 27,0
Obese	>27,0

People who are included in the category of very thin and thin or or severely underweight need attention to increase their weight. Weight gain is done by providing sufficient nutrition in the body accompanied by exercise activities. A person must apply a healthy lifestyle in order to achieve a BMI level in the normal or ideal category. While someone with a BMI value in the overweight to obese category needs to be careful not to experience continuous weight gain. Therefore, it is advisable to immediately lose weight within the normal range [1].

2.3 Monitoring System

Monitoring is a process of collecting data and monitoring to determine the condition of an object. The measurement results monitored in the final project created are height, weight, BMI, and BMI category. Monitoring measurement results is one of the important things to do because it is to monitor body health in the challenge of managing fitness. In the Final Project created, the monitoring

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carried out is the measurement results by providing a report on the measurement results of an object in real time which can be monitored on the LCD screen or application and periodically on the application storage. Storage in the application is integrated with storage on Firebase, so if the storage of measurement results in the application is deleted, it will automatically be deleted on Firebase.

2.4 Internet of Things

Technology in the world today is developing rapidly with various innovations applied in everyday human life, for example smart homes, smart cars, automation machines, and so on. This is related to the important role of the internet as a medium for connecting devices through wireless data transmission. Advanced technology that can connect devices wirelessly is IoT. IoT is an advanced technology that aims to expand the benefits of internet connectivity by connecting all devices online. With an internet connection, connected devices can be accessed and operated with a remote-control system that makes it easy for users to control at quite distant locations via mobile devices. The advantages of IoT technology that provide ease and speed of sharing information can be a problem if the data is not protected. However, this is difficult to overcome because of the different varieties and production. Basically, the IoT architectural structure consists of three layers, namely the perception layer in the form of sensors, the network layer in the form of Wi-Fi and Firebase cloud computing, and the application layer in the form of creating applications using the Thunkable web application.

3. Designs

The process of designing the BMI measuring device consists of several stages consisting of needs analysis, design, manufacture, and testing. The following is a flow diagram of the tool manufacturing process.

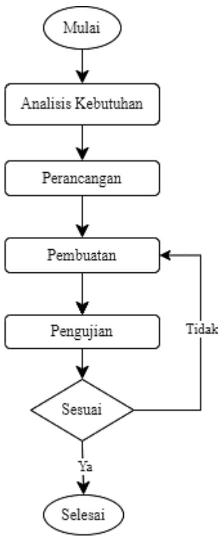

Fig. 1. Research flow diagram

Needs analysis is a stage that is a stage of analysis regarding the urgency of making a design for a BMI measuring device. This needs analysis stage is by conducting field observations and also literature studies. Field observations were conducted at one of the health centers in Semarang using a height measuring instrument using a manual meter and a mass measuring instrument using a scale which was carried out using a separate measuring instrument. While the literature study was conducted to find solutions to these problems based on various literature. The literature obtained was in the form of articles obtained from various journals.

3.1 Flowchart

The following is a flow diagram of the IoT-based BMI measuring system using an Android

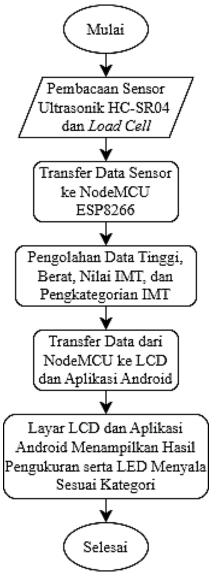

Fig. 2. Flowchart

Fig. 2 above is a system flow diagram of the IoT-based BMI measuring device design using an android application. The HC-SR04 ultrasonic sensor and load cell sensor perform the process of reading the height and weight of a person taking the measurement. The readings from the very small load cell sensor are converted using the HX711 module. Data from the readings of the two sensors will be transferred to the NodeMCU via cable, so that the data is stored in the NodeMCU ESP8266 program. The height and weight data of a person that is entered will be processed into height, weight, BMI and BMI category values. The processed data is sent to the LCD on the installed device hardware and to the programmed android application. The data is then displayed on the LCD screen and application in the form of height, weight, BMI and BMI category data. Delivery to the application may be delayed due to the complexity of the internet network and communication protocols used as well as the overhead of the process on the Firebase server. The categorization of BMI values is also displayed in the form of LED lights. The android application is programmed with a measurement result storage feature so that users can monitor the measurement results periodically

3.2 Hardware Setup

The hardware manufacturing process consists of two parts, namely electrical design and mechanical design. Electrical design includes the creation of electrical wiring diagrams, while mechanical design includes the creation of physical designs of tools and mechanical components of the tools to be made. The following are the results of hardware design.

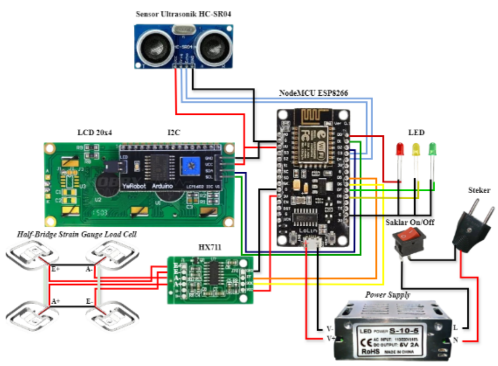

Fig. 3. Wiring Diagram of electronics components

Fig. 3 above is a wiring diagram of the IMT measuring instrument to be made. In the circuit there are several components used including the HC-SR04 ultrasonic sensor, 4 50kg load cell sensors

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installed in parallel, the HX711 module, NodeMCU ESP8266, 20x4 LCD, and I2C to facilitate the LDC connection to the microcontroller.

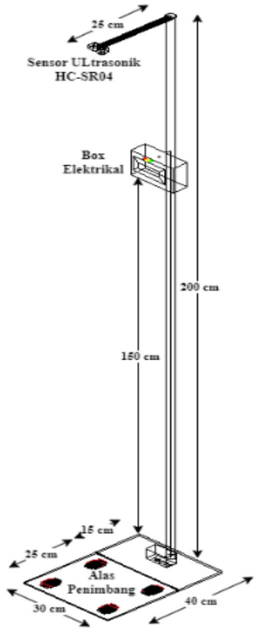
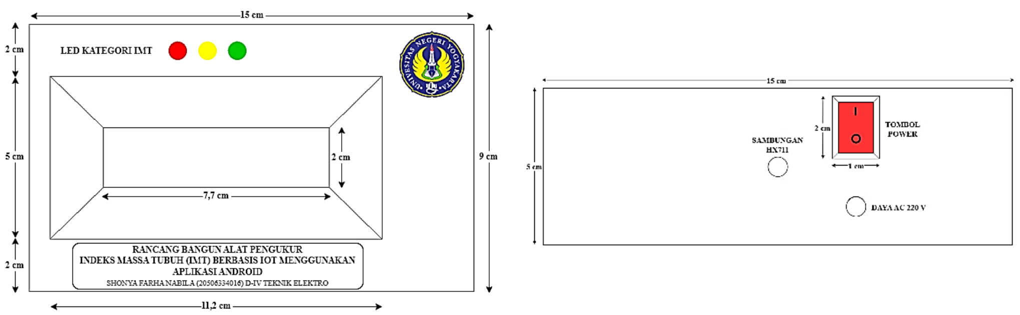


Fig. 4. Hardware design

Fig. 4 is the frame of the IMT measuring device with the height or distance of the HC-SR04 ultrasonic sensor with a weighing surface of 200 cm. While the distance or height of the LCD screen is 150 cm from the surface of the weighing platform. The size of the weighing board is 40x30cm.



Front Bottom

Fig. 5. Box design

Fig. 5 is a bottom view of the electrical box which contains a switch to turn the device on and off as well as a cable connection hole to the HX711 module and a plug connection cable to connect to a 220V AC power source.

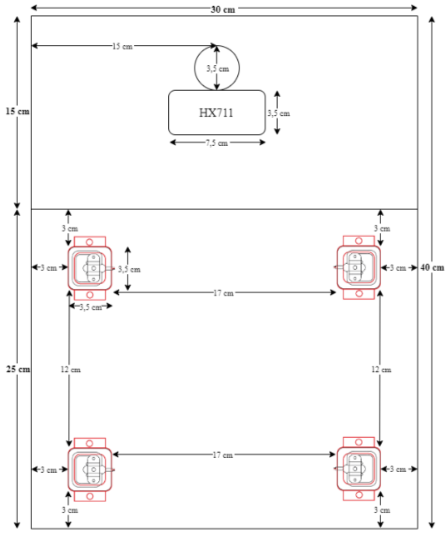


Fig. 6. Design of measurement device

Fig. 6 is a display of the placement of the load cell and HX711 module on the weighing base. Placing the load cell sensor on the board is important to ensure the accuracy and stability of the weight measurement. Some things to consider in placing the load cell include the central position according to the point where the load is most often applied so that the load distribution is even, the surface where the load cell is placed is flat and hard, and ensuring that the cable from the load cell is not pinched when the load is applied.

3.3 Software

This stage is carried out to find out the process of creating software design for an IoT-based BMI measuring system using an Android application. This software design is carried out in three stages, namely the stage of creating a program or coding in the Arduino IDE application, creating a Firebase link, and creating an application on the Thunkable web platform.

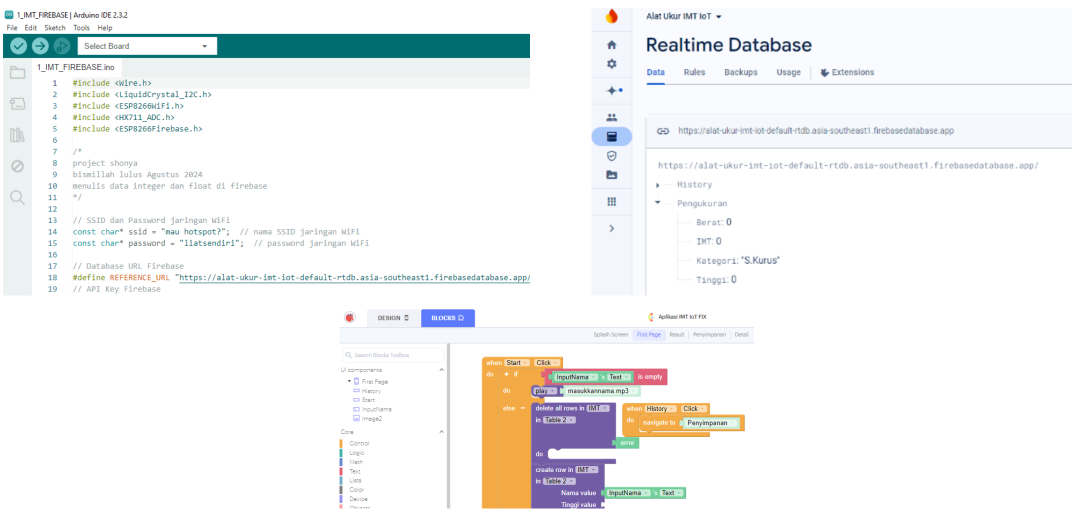


Fig. 7. Arduino IDE and Firebase

4. Results and Discussion

4.1 Hardware Analysis

The results of making the IMT measuring system hardware consist of making electrical and mechanical systems. The electrical system consisting of several components is made in a PCB so

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that the components used are neater and safer. After that, the electrical components are put into the box that has been made. The following is a picture of the tool that has been made.

Fig. 8. BMI measurement device

Figure 8 above is the design result of the BMI measuring tool that has been made. Based on the box image, the design consists of an LCD which is used to display data and also a power button which functions to turn on the device. Meanwhile, the component in the form of the HC-SR04 ultrasonic sensor is above and the load cell sensor is below the weighing base.

4.2 Software Analysis

The creation of this system software consists of creating a program on the NodeMCU ESP8266 microcontroller which is created using the Arduino IDE software. The NodeMCU ESP8266 microcontroller functions to control each component used. In addition, this microcontroller has a Wi-Fi feature that can be used to send sensor reading data to the IOT platform. The following are the results of creating a program on the NodeMCU ESP8266.

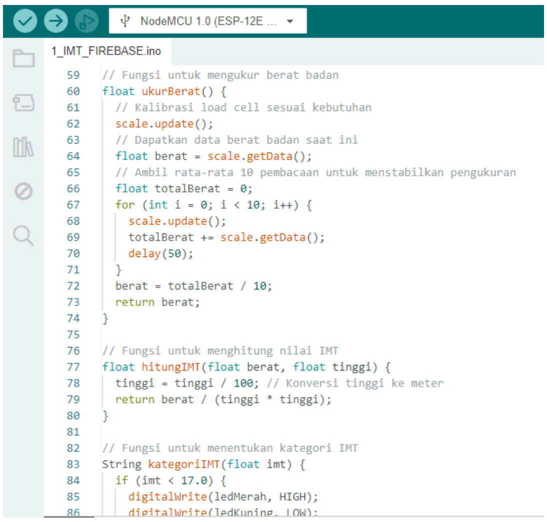

Fig. 9. Source code on Arduino IDE

After writing a program on Arduino IDE, the next step is to create a Firebase link. Creating a link in the form of an API KEY link and Database URL. The API Key and database URL that have been created are listed in the Arduino IDE programming and in the Thunkable Firebase setting menu. In the Firebase settings, you can also set the name of the application to be created and upload the application icon to be used.

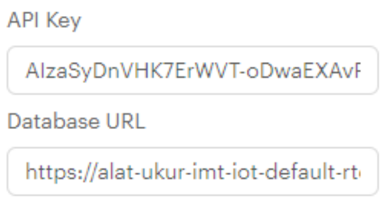

Fig. 10. Link Firebase

Next is the creation of the design and logic blocks of the application program adjusted to the desired design. The creation of the program in the application is done using the Thunkable web application. Thunkable is connected to Firebase which can send data from the NodeMCU ESP8266 microcontroller in real time. Connecting Firebase to Thunkable is done by setting the API Key address and Database URL in the Firebase Setting Thunkable.

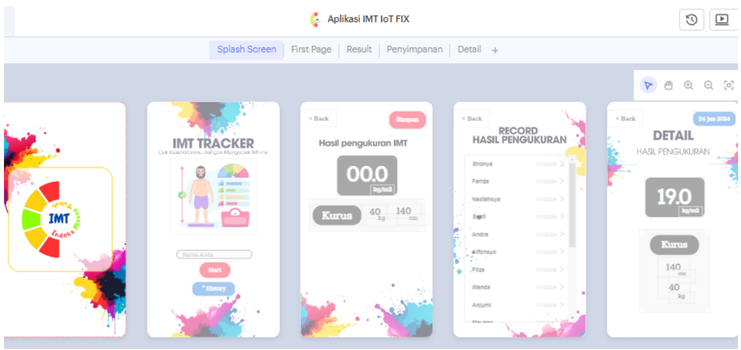

Fig. 11. Application design

4.3 Testing and Analysis

Manual measurement testing is carried out to determine the measurement values measured using a meter and scales. The results of the height and weight measurements will later be used to calculate the BMI value using equation (1), so that it can be categorized as very thin, thin, normal, fat, and obese. The following are the results of the height and weight measurement tests and the calculation of the BMI value that has been carried out.

Table 2. Manual Measurement

Persons	Height (cm)	Weight (kg)	Measurement Value IMT (kg/m^2)	Category
Person 1	160,4	41,4	16,09	Very thin
Person 2	155,1	59	24,53	Normal
Person 3	152,7	52,1	22,34	Normal
Person 4	162,8	45,7	17,24	Thin
Person 5	164,2	63,4	23,51	Normal
Person 6	168,5	64	22,54	Normal
Person 7	167,9	61,8	21,92	Normal
Person 8	142,3	34,6	17,09	Thin
Person 9	158,4	37,6	14,99	Very thins

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Persons	Height (cm)	Weight (kg)	Measurement Value IMT (kg/m^2)	Category
Person 10	157,7	81	32,57	Obese
Person 11	165,2	66,9	24,51	Normal
Person 12	157,2	47,2	19,10	Normal
Person 13	179,6	72,8	22,57	Normal
Person 14	165,5	61,8	22,56	Normal
Person 15	143,1	60,1	29,35	Obese

Table 2 is the result of manual measurements of 15 people using a standard meter to measure height and a manufacturer's scale to measure weight. The calculation is carried out using equation (1), obtained from the BMI value results of 2 people with a very thin BMI category, 2 thin people, 9 normal people, and 2 obese people. These manual measurements will later be compared with measurements on the tool or application to determine the level of error and the level of success of the tool. Furthermore, measurement testing on the tool was carried out to determine the results of the measurement values using the BMI measuring tool that had been made. The tests carried out were height measurements using an ultrasonic sensor and weight using a load cell sensor, as well as BMI value calculations and their categorization. The results of the measurements will be displayed on a 20x4 LCD screen that displays 4 data, namely height, weight, BMI, and category. The following are the results of height and weight measurement tests and BMI value calculations on the tool that have been carried out.

Table 3. Measurement using tools result

Persons	Height (cm)	Weight (kg)	BMI (kg/m^2)	Category	LED indicator
Person 1	161.9	41.5	15.83	Very thin	Red
Person 2	156.31	59.24	24.25	Normal	Green
Person 3	153.95	52.72	22.24	Normal	Green
Person 4	163.44	45.9	17.18	Thin	Yellow
Person 5	164.71	61.85	22.80	Normal	Green
Person 6	169.38	62.86	21.91	Normal	Green
Person 7	169.11	60.24	21.06	Normal	Green
Person 8	143.36	35.43	17.24	Thin	Yellow
Person 9	159.89	38.53	15.07	Very thin	Red
Person 10	158.52	82.72	32.92	Obese	Red
Person 11	166.25	66.16	23.94	Normal	Green
Person 12	158.63	48.39	19.23	Normal	Green
Person 13	179.93	71.95	22.22	Normal	Green
Person 14	166.77	61.24	22.02	Normal	Green
Person 15	143.68	59.67	28.90	Obese	Red

The test results carried out on the device can be monitored on the LCD screen, while the measurement results can be monitored and saved in the application. The measurement results displayed on the LCD screen and the Android application are the same, namely displaying 4 data, namely height, weight, BMI, and category. The BMI results obtained are the same as the results of manual measurements, namely there are 2 people with a very thin BMI category, 2 thin people, 9 normal people, and 2 obese people. The measurements of this tool will later be compared with manual measurements using standard measuring instruments such as meters and scales.

Furthermore, the measurement test on the tool is carried out simultaneously with the measurements on the application because it is integrated in one program. This test is carried out to compare the display of measurement results between the LCD screen and the application whether it is appropriate or not. The measurement data received by the application via Firebase from the NodeMCU ESP8266 microcontroller is 2-4 seconds slower than the display of measurement data on the LCD. This is due to the complexity of the internet network and communication protocols used as well as the overhead of the process on the Firebase server. However, the display of measurement results on the application screen will remain the same as the display of measurement results on the LCD. The following are some examples of synchronization results between monitoring using tools and applications.

Fig. 12. Results on Apps

Fig. 12 is an example of synchronization of BMI test results in the very thin category between monitoring on the LCD screen and the application. The results of height, weight, BMI, and BMI category on the LCD screen match the application screen. The LED light on the device that is lit is red, while the background of the results on the application screen is also red. This indicates that the monitoring synchronization between the LCD screen and the application is in the appropriate condition. After getting the results of measuring a person's height which is measured manually using a meter and measured using a measuring device that has been made, the next step is to compare the measurement results to determine the level of error and success. The following are the results of a comparison of height measurements between manual measurements using tools or monitoring via applications that have been carried out.

Table 4. Height measurements

Persons	Manual (cm)	BMI Device (cm)	Error (cm)	Percentage Error (%)	Accuracy (%)
Person 1	160.4	161.9	1.5	0.94	99.06
Person 2	155.1	156.31	1.21	0.78	99.22
Person 3	152.7	153.95	1.25	0.82	99.18
Person 4	162.8	163.44	0.64	0.39	99.61
Person 5	164.2	164.71	0.51	0.31	99.69
Person 6	168.5	169.38	0.88	0.52	99.48
Person 7	167.9	169.11	1.21	0.72	99.28
Person 8	142.3	143.36	1.06	0.74	99.26
Person 9	158.4	159.89	1.49	0.94	99.06
Person 10	157.7	158.52	0.82	0.52	99.48
Person 11	165.2	166.25	1.05	0.64	99.36
Person 12	157.2	158.63	1.43	0.91	99.09
Person 13	179.6	179.93	0.33	0.18	99.82
Person 14	165.5	166.77	1.27	0.77	99.23
Person 15	143.1	143.68	0.58	0.41	99.59
Average			1.02	0.64	99.36

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Table 4 is the result of a comparison of the height measurement test of a person who has been measured between manual measurements and measurements using a tool or application monitoring. Based on this comparison, the average results of the measurements of 15 people were obtained, the success rate of the tool based on the reading of the HC-SR04 ultrasonic sensor was 99.36% and the error rate was 0.64%. This shows that the accuracy value of the HC-SR04 ultrasonic sensor in detecting distance is in good condition because the success rate of the tool is high, and the error is less than 1%. The largest error value is 0.94% in the measurements of Person 1 and 9. While the smallest error value is 0.18% in the measurement of Person 13. After getting the results of a person's weight measurement measured manually using a scale and measured using a measuring tool that has been made, the next step is to compare the measurement results to determine the level of error and success. The following are the results of a comparison of body weight measurements between manual measurements using a tool or monitoring via an application that has been done.

Table 5. Weight measurements

Persons	Manual (kg)	BMI Device (kg)	Error (kg)	Percentage Error (%)	Accuracy (%)
Person 1	41.4	41.5	0.1	0.24	99.76
Person 2	59	59.24	0.24	0.41	99.59
Person 3	52.1	53.72	1.62	3.11	96.89
Person 4	45.7	45.9	0.2	0.44	99.56
Person 5	40.1	40.43	0.33	0.82	99.18
Person 6	43.9	45.18	1.28	2.92	97.08
Person 7	39.8	40.25	0.45	1.13	98.87
Person 8	62.5	61.92	0.58	0.93	99.07
Person 9	60.1	61.77	1.67	2.78	97.22
Person 10	50.2	49.78	0.42	0.84	99.16
Person 11	74.2	74.92	0.72	0.97	99.03
Person 12	61.8	62.55	0.75	1.21	98.79
Person 13	61.3	62.23	0.93	1.52	98.48
Person 14	64	62.86	1.14	1.78	98.22
Person 15	63.4	61.85	1.55	2.44	97.56
	Mean		0.96	1.50	98.50

Table 5 is the result of a comparison of the weight measurement test of a person who has been measured between manual measurements and measurements using tools or application monitoring. Based on this comparison, the average results of the measurements of 15 people were obtained, the success rate of the tool based on the reading of the load cell sensor by the HX711 module was 98.50% and the error rate was 1.50%. This shows that the accuracy value of the load cell sensor by the HX711 module in detecting mass is in good condition because the success rate of the tool is high, and the error is less than 5% according to the tolerance limit of the load cell in general. The largest error value is 3.11% in the measurement of Person 3. While the smallest error value is 0.24% in the measurement of Person 1.

5. Conclusion

The design of an IoT-based BMI measuring device is used to measure height, weight, and BMI. This measuring device is made using NodeMCU ESP8266 which processes height measurement data by the HC-SR04 ultrasonic sensor and weight measurement by the load cell sensor with the help of the HX711 module to convert very small values from load cell readings. Both data variables are then processed into BMI values and can then be classified into 5 categories (very thin, thin, normal, fat, and obese) which are marked with LED lights as indicators. In addition to being monitored in real time on the LCD, measurement results can be monitored periodically using the Android application that has been created. Measurement data is stored by Firebase or the application. Functional testing of the IoT-based BMI measuring system using the Android application that has been carried out shows that each component used can function and work properly. The functional testing stages are carried out by providing a program to the component or checking the pin using a multimeter. This test is also carried out by comparing the test results with component specifications.

Performance testing of IoT-based BMI measuring devices using an android application was carried out to determine the level of error and success. The results of height and weight readings by the BMI measuring device were compared with standard measuring devices such as meters and scales. The average comparison value or error of ultrasonic sensor readings by 15 measuring persons was 0.64%, while the sensor success rate was 99.36%. The average comparison value or error of load cell sensor readings by the HX711 module against 15 measuring persons was 1.50%, while the sensor success rate was 98.50%. Based on the results of the height and weight reading test by both sensors, it shows that the device is in good condition because the comparison value is below 5%.

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