Telemedicine System for Real-Time Vital Sign Monitoring Through the Internet of Things

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Abstract. The IoT-based Telemedicine System for Medical Checkups offers a comprehensive medical examination designed to assess overall health, identify risk factors, and detect potential health disorders that could develop into diseases. This research aims to develop a prototype Medical Checkup Station using the NodeMCU ESP8266, capable of performing health assessments across several key parameters. These include measuring the patient's height, weight, heart rate, and body temperature. The system calculates Body Mass Index (BMI) from the height and weight data, classifies heart health based on heart rate, and assesses body temperature to provide a relevant classification. All measurement results and classifications are displayed on a smartphone equipped with the Medical Checkup Station application. This Medical Checkup Station demonstrates a 99.9% accuracy rate in each measurement compared to conventional instruments. The system's response to the raw data inputs for each parameter is precise, indicating that the sensors provide high-quality readings and that the classification process is accurate. This tool is expected to make medical checkups more flexible, effective, and efficient, thereby helping to reduce the daily workload of medical staff.

Keywords: Body Mass Index, IoT, Medical Checkup, Telemedicine System

1 Introduction

Health is essential for everyone. The importance of health has been particularly highlighted during the recent pandemic, which has led to increased public awareness and education on the topic. The pandemic also strained the capacity of hospitals to provide healthcare services, with many facilities facing overcapacity issues. As a result, general patients with mild complaints, such as those seeking routine physical medical checkups, have not been prioritized. This has particularly affected individuals needing medical checkups for job applications in Indonesia. A medical checkup is a comprehensive health examination designed to assess overall health, identify risk factors, and detect potential health issues that could develop into diseases. Although medical checkups can involve many parameters (Makarim, 2021), those required for job applications typically focus on a physical examination. This process generally

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includes assessing Body Mass Index (BMI) through height and weight measurements, checking blood pressure, evaluating vision (including tests for visual acuity and color blindness), hearing assessments, and several other procedures depending on the hospital (Nasution, 2019). To support patients who require only a routine medical checkup, a tool is needed that can independently assess the patient's health across the necessary parameters. Such a medical checkup tool would make the process more flexible, effective, and efficient, reducing the daily workload of medical staff. With this tool, medical professionals would only need to supervise the patient during the examination, rather than perform every check manually. While there has been extensive research on physical medical checkups, most studies focus on a single parameter. For example, several studies concentrate on measuring height and weight to calculate BMI. Research such as that by Abrianto (2018), Fitriani et al. (2017), and Fajaryati et al. (2018) focuses on calculating BMI for toddlers and children, aiming to assess their nutritional status. Additionally, many BMI-related studies use Arduino as the microcontroller platform (Afdali et al., 2018; Kusriyanto & Saputra, 2016; Nurlette & Wijaya, 2018; Loniza et al., 2021; Shokhibul Kahfi et al., 2015). Among these, only Shokhibul Kahfi et al. (2015) utilize the Atmega 8535 microcontroller. However, a limitation of using Arduino as the microcontroller is its lack of flexibility and inability to be accessed remotely. Consequently, in all the BMI-related studies mentioned, the output is only viewable on an LCD display. Another area of research focuses on the heart rate parameter, where the output is measured in Beats Per Minute (BPM). Similar to BMI-related studies, all heart rate research referenced here uses Arduino as the microcontroller platform. However, unlike BMI studies, heart rate research yields more varied outputs. For instance, Arthana (2017) integrated a GSM module to send BPM readings via SMS, allowing results to be viewed on a cellphone. The limitation of this approach is that the SIM card in the GSM module must always have credit to send the data. Muhajirin and Ashari (2018) used USB serial communication to display the output on a Personal Computer (PC), and they included an examination database on the PC for easier access to the patient's heart health history. However, this system's use is restricted to a single PC, posing a risk of data loss if the PC fails. In other studies, such as those by Fachrul Rozie and Ferry Hadary (2016) and Yudhana et al. (2019), a Bluetooth module was added, enabling the output to be viewed on a smartphone app. This makes the process more flexible, as any smartphone with the app installed and connected via Bluetooth can access the data.

This study aims to develop a prototype of a IoT-based Medical Checkup Station, a booth-based tool that can perform health checks across several physical medical checkup parameters. The device can measure height, weight, heart rate, and body temperature. Height and weight measurements provide three data points: raw height in centimeters, weight in kilograms, and a BMI classification (underweight, normal, or overweight). Heart rate measurements yield two data points: raw BPM and a heart health classification (low, normal, or high heart rate). The final parameter, body temperature, is measured in °C, with a classification indicating whether the temperature is low, normal, or high.

2 Methodology

The development of this tool begins with a review of previous research on the required inspection parameters, including the health classifications derived from these parameters, aligned with national and international standards. The design process then proceeds through several stages: hardware and software design, development of a mobile application for Android, testing, and iterative improvements.

2.1 Hardware Design

This section details the schematic design of the tool's circuit, including the components used, the pin connections between them, and the prototype of the device. The tool is built around the NodeMCU ESP8266 microcontroller, utilizing an HC-SR04 ultrasonic sensor for height measurement, a Load Cell with an HX711 module for weight measurement, an AK-90 heart rate sensor (commonly known as a pulse sensor) for heart rate monitoring, and a DS18B20 sensor for body temperature measurement. The prototype of the device is shown in Figure 1. Meanwhile, Figure 2 illustrates the complete circuit of the Medical Checkup Station, depicting the connections between each sensor and the NodeMCU ESP8266.

Figure 1. Prototype of the IoT-based medical checkup station

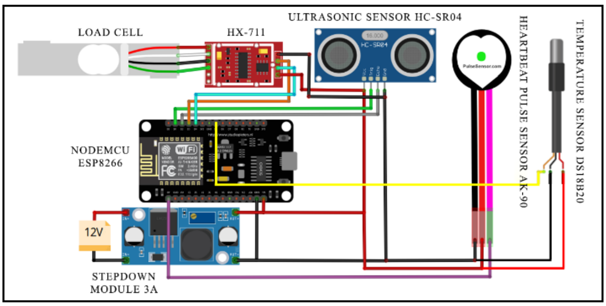

Figure 2. Wiring diagram of the IoT-based medical checkup station

2.2 Software Design

This stage outlines the overall programming workflow for the tool, which is implemented on the NodeMCU ESP8266 using the Arduino IDE software. The operation sequence of the tool is illustrated in the flowchart and block diagram provided below.

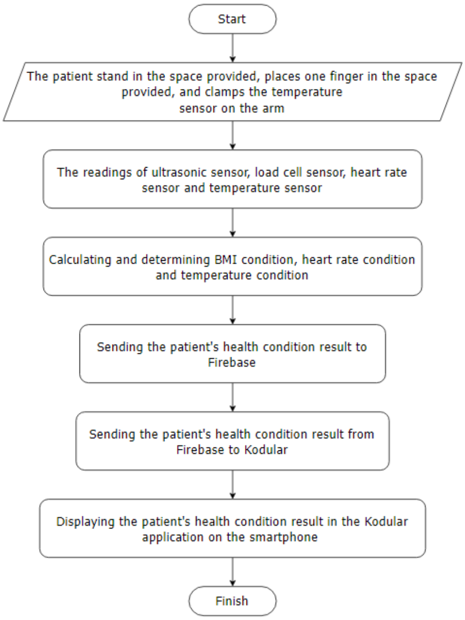

Figure 3. Flowchart of the IoT-based medical checkup station

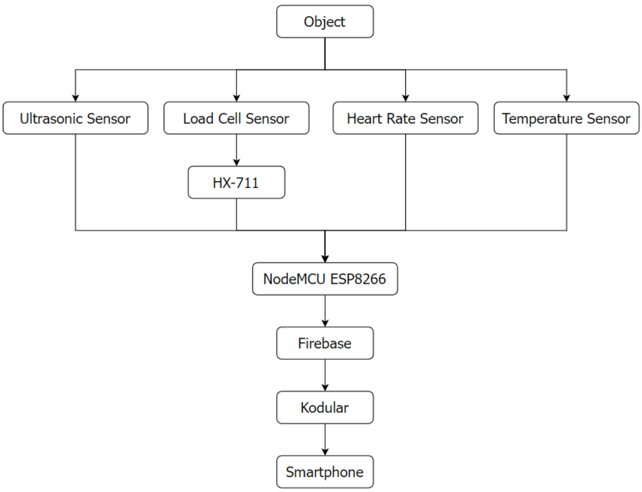

Figure 4. Block diagram of the IoT-based medical checkup station

Based on Figures 3 and 4, when the Medical Checkup Station is activated, the patient stands in the designated area, places one finger in the provided slot, and attaches the temperature sensor to their arm. The four sensors will automatically read and assess the patient's health according to their specific functions. The program processes the raw data from these readings to generate health classifications for each parameter: height and weight data are used to calculate BMI, heart rate data (BPM) determines heart condition, and temperature data is classified based on normal human body temperature ranges. These results are then sent to Firebase and subsequently displayed in the Kodular application on the smartphone.

2.3 Android-Based Mobile Application Design

In this stage, the mobile application will be developed using Firebase and Kodular. Firebase, a service provided by Google, simplifies backend development for applications. In this setup, Firebase acts as a communication bridge between the NodeMCU ESP8266 and the application. As illustrated in Figure 5, Firebase retrieves sensor data and temporarily stores it in its database. The application then reads this data from Firebase and displays it to the user.

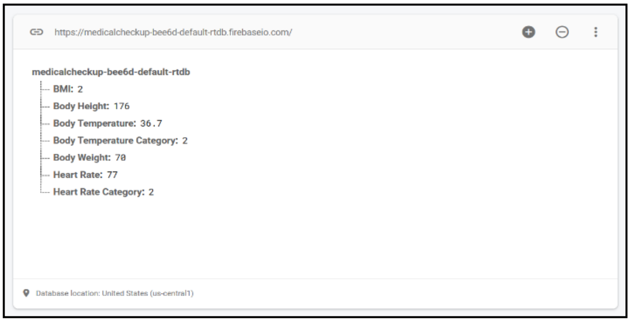

Figure 5. Realtime database on Firebase

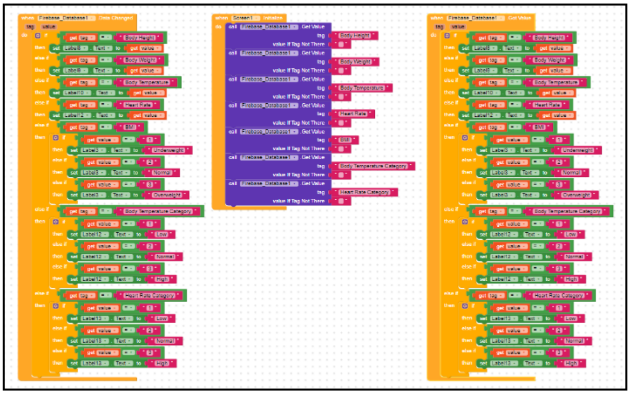

Figure 6. Program block on Kodular

Kodular is a platform for creating Android applications that use block-based programming, similar to MIT App Inventor, as shown in Figure 6. The application designed with Kodular for this device is intended to display the results of the sensor readings and their corresponding health classifications. This design ensures that patients can easily understand their health status, indicating whether they are in good health or if there are concerns based on the parameters being examined.

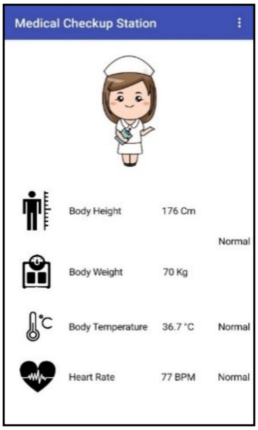

Figure 7. Medical checkup Android application

Using this application is straightforward. Medical officers simply need to install and open the app on their smartphones. Once the application is connected to the device via the internet, it will automatically display the measurement results as soon as a patient is present in the booth. As shown in Figure 7, the data displayed includes raw readings from each sensor and their corresponding health classifications, which are shown on the far right.

3 Result and Discussion

3.1 Sensor Accuracy Testing

This test involves sampling patient data multiple times from each sensor on the Medical Checkup Station. The results are then compared with those obtained using conventional measuring instruments. Tables 1 through 4 present the measurement results for each sensor on the Medical Checkup Station. Measurements were taken from 5 patients with 4 trials each. Table 1 compares height measurements from the Medical Checkup Station with those from a manual meter. Table 2 compares body weight measurements from the Medical Checkup Station with conventional scales. Table 3 compares heart rate measurements from the Medical Checkup Station with those from an oximeter. Finally, Table 4 compares body temperature measurements from the Medical Checkup Station with those from a thermometer.

Table 1. Body height measurement results by medical check-up station device

No.	Name	Age (year)	Medical checkup station (cm)				Meter (cm)	Average (cm)	Accuracy (%)
			Trial 1	Trial 2	Trial 3	Trial 4			
1.	Patient 1	21	164	163	164	164	164	163.75	99.85
2.	Patient 2	22	175	176	176	176	176	175.75	99.86
3.	Patient 3	22	167	167	167	166	167	166.75	99.85
4.	Patient 4	48	156	156	156	155	156	155.75	99.84
5.	Patient 5	26	157	156	157	157	157	156.75	99.84

Table 2. Body weight measurement results by medical check-up station device

No.	Name	Age (year)	Medical checkup station (kg)				Scale (kg)	Average (kg)	Accuracy (%)
			Trial 1	Trial 2	Trial 3	Trial 4			
1.	Patient 1	21	55	54.8	55	55	55	54.95	99.91
2.	Patient 2	22	70	69.8	70	70	70	69.95	99.93
3.	Patient 3	22	75	75	75	74.8	75	74.95	99.93
4.	Patient 4	48	55	55	55	54.8	55	54.95	99.91
5.	Patient 5	26	47	46	47	47.8	47	46.95	99.89

Table 3. Heart rate measurement results by medical check-up station device

No.	Name	Age (year)	Medical checkup station (BPM)				Oximeter (BPM)	Average (BPM)	Accuracy (%)
			Trial 1	Trial 2	Trial 3	Trial 4			
1.	Patient 1	21	77	78	77	77	77	77.25	99.93
2.	Patient 2	22	78	79	79	79	79	78.75	99.93
3.	Patient 3	22	86	86	85	86	86	85.75	99.93
4.	Patient 4	48	73	73	73	72	73	72.75	99.93
5.	Patient 5	26	105	104	105	105	105	10.75	99.89

Table 4. Body temperature measurement results by medical check-up station device

No.	Name	Age (year)	Medical checkup station (°C)				Thermometer (°C)	Average (°C)	Accuracy (%)
			Trial 1	Trial 2	Trial 3	Trial 4			
1.	Patient 1	21	36.4	36.5	36.5	36.5	36.5	36.475	99.93
2.	Patient 2	22	36.7	36.7	36.7	36.6	36.7	36.675	99.93
3.	Patient 3	22	36.6	36.6	36.5	36.6	36.6	36.575	99.93
4.	Patient 4	48	36.5	36.4	36.5	36.5	36.5	36.475	99.93
5.	Patient 5	26	36.4	36.4	36.3	36.4	36.4	36.375	99.89

From these tables, it is evident that the Medical Checkup Station exhibits a very high accuracy rate of 99.9%. This indicates that the quality of the readings from each sensor is excellent and closely aligns with the measurements obtained from the conventional instruments used for comparison.

3.2 Classification Results

In addition to displaying raw measurement data, the application also provides health classifications for each parameter to assist medical officers and patients in interpreting the results. These classifications include Body Mass Index (BMI), body temperature, and heart rate. BMI classification helps assess health based on height and weight measurements, and is based on the national BMI standards outlined in (*P2PTM Kemenkes RI*, 2018a) and (*P2PTM Kemenkes RI*, 2018b), summarized in Table 5. These classifications make it easier for both medical officers and patients to understand and diagnose the results from the examination data.

Table 5. National BMI classification

Classification		BMI
Underweight	Heavy	<17.0
	Light	17.0 – 18.4
Normal		18.5 – 25.0
		25.1 – 27.0
Overweight	Light	>27.0
	Heavy	<17.0

Additionally, body temperature classification is performed to categorize the temperature readings based on the results of the body temperature measurements. This classification follows the standards set by the World Health Organization (WHO) as outlined in (Makarim, 2021), and is summarized with 3 categories namely: infant (36.3 – 37.7°C), children (36.1 – 37.7°C), and adults (36.5 – 37.5°C).

Table 6. NIH heart rate standard

Age	Normal heart rate (BPM)
<1 month	70 – 190
1 – 11 month	80 – 160
1 – 2 years	80 – 130
3 – 4 years	80 – 120
5 – 6 years	75 – 115
7 – 9 years	70 – 110
>10 years	60 – 100

Finally, heart rate classification is used to assess heart function, diagnose conditions, and identify any abnormalities based on heart rate measurements. This classification follows the standards set by the National Institutes of Health (NIH) as detailed in (Kompas.com, 2021) and is summarized in Table 6. The results of the BMI classification, body temperature classification, and heart rate classification from the Medical Checkup Station are presented in Tables 7 and 8.

Table 7. National BMI classification

No.	Name	Age (year)	Height (cm)	Weight (kg)	BMI condition
1.	Patient 1	21	164	55	Normal
2.	Patient 2	22	176	70	Normal
3.	Patient 3	22	167	75	Overweight
4.	Patient 4	48	156	55	Normal
5.	Patient 5	26	157	47	Normal

Table 8. Conditioning of body temperature and heart rate

No.	Name	Age (year)	Temperature (°C)	Temperature condition	Heart rate (BPM)	Heart condition
1.	Patient 1	21	36.5	Normal	77	Normal
2.	Patient 2	22	36.7	Normal	79	Normal
3.	Patient 3	22	36.6	Normal	86	Normal
4.	Patient 4	48	36.5	Normal	73	Normal
5.	Patient 5	26	36.4	Normal	105	High

Tables 7 and 8 reveal that two patients had abnormalities in one of their conditioning parameters. Specifically, Patient 3 was classified as overweight, while Patient5 had an elevated heart rate. These findings can assist medical officers in diagnosing existing or potential health issues. Additionally, the results indicate that the Medical Checkup Station effectively assesses and classifies patient health parameters, demonstrating its capability to accurately evaluate and report on various health conditions.

4 Conclusion

After conducting tests and collecting data four times, with each session lasting four minutes per patient, it can be concluded that the Medical Checkup Station achieves an accuracy rate of 99.9% for each measurement compared to conventional instruments. The classifications derived from the raw data are accurate, with two patients identified as having abnormalities in one of their parameters. This indicates that the sensor readings are highly reliable and that the system's classification capabilities are effective. The tool is expected to enhance the flexibility, effectiveness, and efficiency of medical checkups, ultimately helping to reduce the workload of medical staff in their daily patient care.

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