Research Article

Internet of Things Based Remote Body Temperature Monitoring in Public Transportation

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Abstract

Monitoring body temperature in society has become an essential requirement under pandemic conditions. This study aims to monitor individuals' body temperatures and report those exceeding the limit to facilitate early detection of the pandemic. In areas such as public transportation, remote measurement of individuals' wrist temperatures has been implemented, and this data is associated with personalized transportation cards. Due to the effects of factors such as age, gender, activity level, environmental conditions, and biological clock on temperature, it has been proposed that variable threshold values should be established instead of a fixed limit temperature. The prototype developed for this purpose collects temperature data via the ThingSpeak platform and provides an infrastructure for training artificial intelligence to make personal limit temperature predictions.

Keywords: *Pandemic Detection, Real-Time Temperature Monitoring, Contactless Temperature Measurement, Public Transport Health Monitoring, Internet of Things (IoT), Personalized Temperature Threshold, Smart Transportation, ThingSpeak .*

1. Introduction

In pandemic conditions, monitoring body temperature in the community has become an essential requirement. This study aims to monitor individuals' body temperatures and report those exceeding the limit to the relevant authorities, thereby facilitating early detection of the pandemic. Studies in the literature related to remote body temperature measurement and data transmission over the internet have been reviewed, and a suitable technique has been selected for measuring and transmitting temperature data [1], [2].

For this purpose, a circuit has been designed that provides a suitable infrastructure for remote temperature data measurement and transmission [3]. The collected data can be integrated with a personalized transportation card or any radio frequency identification card and transferred to desired systems [4]. The goal of this system could be to monitor individuals at risk of high temperatures in specific areas, such as public transportation, by measuring wrist temperature, taking precautions, or generating statistical data [5].

In some studies, wrist temperature measurements have been found to be more stable than contactless forehead measurements under different conditions, and they have been evaluated as having suitable fever screening capabilities in indoor patients. This suggests that wrist temperature could be a practical alternative for COVID-19 screening. The cutoff value for detecting tympanic temperature of 37.3 °C was set at 36.2 °C for wrist temperature, showing a sensitivity of 86.4% and specificity of 67.0% [5]. Considering that it can be easily integrated into existing card reading systems already used in public transport, the proposed system also utilizes wrist temperature measurement.

Additionally, due to factors such as age, gender, activity level, environmental factors, and biological clock affecting wrist temperatures, it has been established that temperature thresholds should vary rather than rely on a single limit temperature value [6]. To accurately determine these thresholds, an infrastructure is provided for training artificial intelligence with temperature data collected on the ThingSpeak platform, enabling the prediction of limit temperatures [7]. The developed prototype combines remote temperature monitoring and card reading systems to collect and report temperature data [8].

2. Materials and Methods

In the literature, studies related to remote body temperature measurement and data transmission over the Internet have been examined. A low-cost, suitable technique that can be used in large areas has been selected for measuring and transmitting temperature data [1], [2]. A circuit has been designed for remote measurement and transmission of data, and MATLAB code has been written to list and display in real-time the card IDs that exceed the specified temperature limit on the ThingSpeak platform. The ThingSpeak platform plays an important role in the process of recording and analyzing data, and its low-cost structure increases its applicability, especially in large areas [9][10]. With the proposed system, temperature data can be sent to any system for preventive measures or statistical purposes during pandemic processes.

In this study, 270 wrist measurements were taken from a known healthy subject between December 4 and December 10. Only 4 of these measurements exceeded 32 degrees. Since the limit temperature was set at 32 degrees, those exceeding this threshold were simultaneously plotted on a graph in ThingSpeak, with the exceeded values highlighted in red and listed, thus validating the limit temperature of 32 degrees. Figure 1 shows a photo of the proposed hardware.

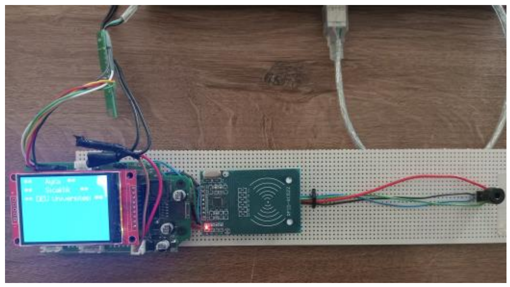


Figure 1: Photo of the Proposed Hardware

2.1. IoT-Based Remote Body Temperature Monitoring System Design

The hardware and software requirements are provided in Table 1.

Table 1: Hardware and Software Requirements

Hardware	**Function**
Espressif ESP32 - WROOM - 32	Reads data from the sensor, sends output, and connects to the network for data transfer to the IoT cloud database.
MLX90614 Contactless Infrared Temperature Sensor	Detects body temperature without contact.
RFID-RC522	Retrieves the user's personal information.
TFT LCD	Displays body temperature and user information; emits a red light if the temperature exceeds 32°C.
Software	**Function**
Arduino IDE	Used for writing and compiling code for the Espressif ESP32-WROOM-32.
ThingSpeak	Receives data from the temperature sensor and RFID-RC522, displaying individuals exceeding 32°C.

The hardware circuit diagram is shown in Figure 2.

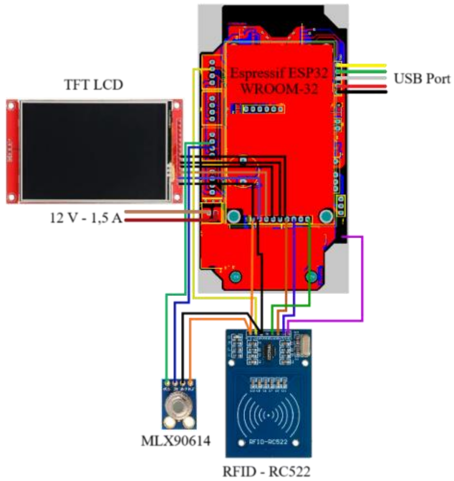


Figure 2: Hardware Circuit Diagram

The hardware requirements of the system are as follows: The Espressif ESP32-WROOM-32 module has been selected for reading data from the sensor, sending output, and connecting to the network to transfer data to the IoT cloud database (ThingSpeak). The MLX90614 contactless infrared temperature sensor is used to detect body temperature without contact. Infrared sensors have been chosen as the temperature sensor because they provide non-contact measurement, respond quickly, and deliver accurate results [3], [4]. The RFID-RC522 card reader is used to obtain user information. The TFT LCD screen displays user information and body temperature. If the detected body temperature is below 32°C, the screen emits blue light; if it exceeds 32°C, it emits red light and displays a warning message. The system is connected to a computer via a USB port.
Figure 3 provides a flowchart to explain the working principle of the hardware and its connection to ThingSpeak.

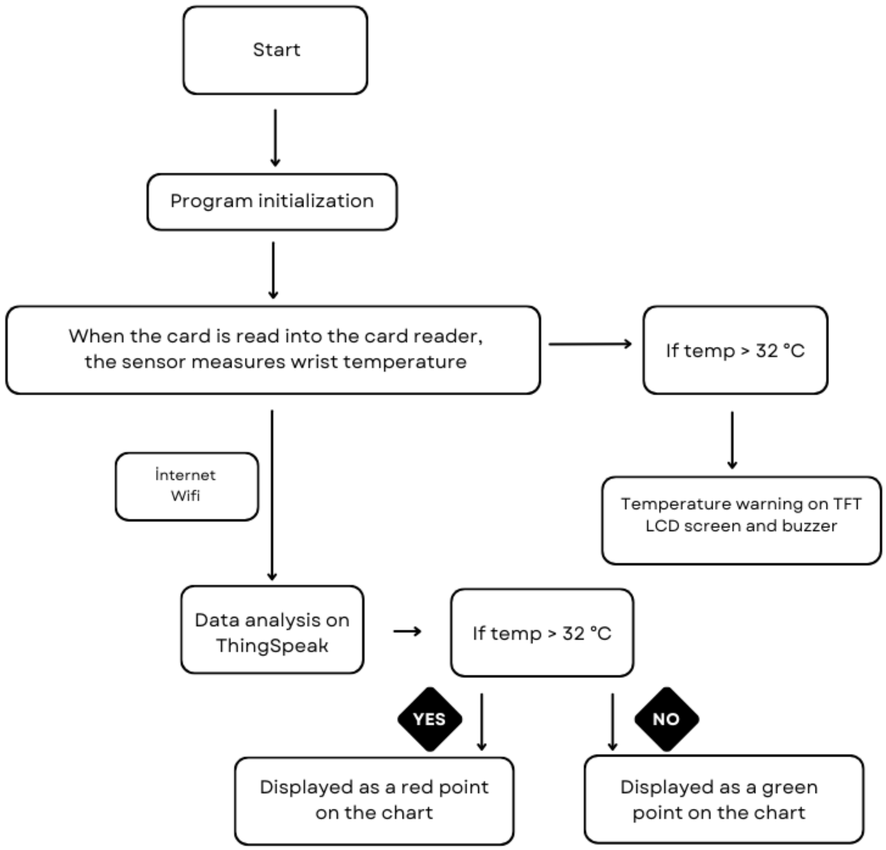


Figure 3: Flowchart Related to the Operation of the Hardware

2.2. Cloud Database Software Design

The ThingSpeak platform has been used to collect and analyze data from Internet of Things (IoT) devices. Compared to alternatives like Google Sheets, ThingSpeak was preferred for its integrated MATLAB code executor, which provides broader data analysis and modeling capabilities. The platform establishes a secure connection with device hardware via an API key and processes data in real-time.

2.2.1. ThingSpeak Working Principle and Visualization

Visualization of Temperature Data: ThingSpeak visualizes the collected temperature data with graphs. The lowest measured temperature is 24.69 °C, while the highest temperature is 32.35 °C The content of the recorded data has been examined, with 32°C selected as the threshold temperature. In particular, wrist temperatures between 30°C and 35°C have been focused on.

Data Below the Limit: Shown in green on the graphs.
Data Above the Limit: Measurements exceeding 32°C are marked with red dots. This process has been demonstrated in Figure 4, visualizing temperatures above the threshold of 32°C. This threshold value is used to emphasize that there may be risky situations above a certain temperature level.

2.2.2. Data Analysis and Regression Methods:

In the data analysis, two regression methods have been used to model the linear and more complex variations of temperature data:
Linear Regression
Polynomial Regression (Degree 2)
Figure 5 was created to compare the predictions of these two regression models. While linear regression attempts to model a linear relationship of temperature changes over time, polynomial regression models the more complex (curvilinear) structure of temperature changes over time.
Since temperature thresholds may not remain constant throughout the day, using a single threshold value (e.g., 32°C) may not be meaningful in every case. Considering that temperature variations throughout the day may have different threshold values in different contexts, it is necessary to analyze temperature data with various models. Therefore, the comparison of linear and polynomial regression predictions in Figure 5 has been preferred as a more suitable approach to understand this variability. Both regression models provide a more accurate modeling of how temperatures change over time, facilitating the adaptation of threshold values to different contexts.

Accuracy of Model Predictions

The accuracy of temperature predictions is evaluated in Table 4 using the Root Mean Square Error (RMSE) metric for the regression models used. RMSE is calculated as the square root of the average of the squares of the differences between the predicted temperatures and the actual measurements.

2.2.3. Limitations of the Free Version of ThingSpeak

The free version of ThingSpeak can send data every 15 seconds and allows a total of 3 million messages [11]. Additionally, it supports only 4 channels and 1 active channel. A paid version is required for more channels or faster updates. These limitations affect the software's capacity, adding waiting time to the data collection process. In the Arduino

IDE code, a waiting period has been implemented considering this limitation, displaying a "Please wait" message after reading the data, and once the time is up, a "You can scan the card now" warning appears.

2.3. Data Collection Conditions and Minimization of Variables

Body temperature is a dynamic variable that can be influenced by many environmental and personal factors. Therefore, the goal has been to minimize variables to enhance the accuracy and reliability of the experimental data. These limitations were achieved by keeping and controlling certain variables constant. This approach aims to improve the validity of the experimental results. Below, the factors considered during the data collection process and how these factors were controlled are summarized in Table 2 for simplification.

Table 2: Data Collection Conditions and Control of Variables

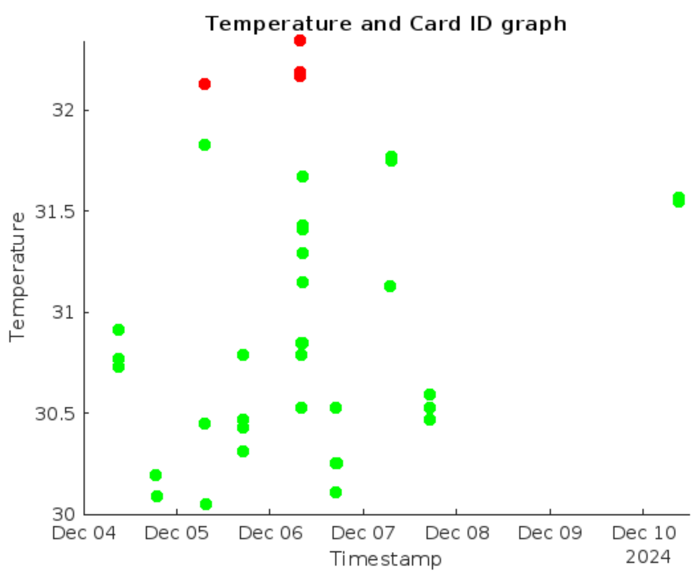
Variable	Details
Personal Information	Person: Card ID 53f99634, Gender: Female, Age: 35, Height: 168 cm, Weight: 58 kg, Not in menstrual cycle, Measurements taken in the same clothes.
Eating Habits	December 4: Person not having breakfast ("Not having breakfast person"), December 5-6-7: Early breakfast person ("Early breakfast person"), December 8-9: Measurements taken without regard to eating habits.
Food Type and Portion Control	Retrieves the user's personal information. December 4: Lunch "Food Type 1", December 5-6-7: Breakfast "Food Type 1", Lunch "Food Type 2", Dinner "Food Type 3", December 8-9: Measurements taken without regard to food type.
Ambient Temperature	December 4: 18.5°C - 19.6°C, December 5: 19.1°C - 20.0°C, December 6: 19.2°C - 20.0°C, December 7: 19.1°C - 19.8°C, December 8: 19.4°C - 19.6°C, December 9: 19.6°C - 19.9°C
Physical Activity	December 4-7: Physical activities at the same times, duration, and pace (normal-paced walking), December 8-9: Physical activity not considered.

2.4. Legal Opinions

In Türkiye, Article 5 of the Law No. 6698 on the Protection of Personal Data outlines the conditions for processing personal data, while Article 6 specifies the conditions for processing sensitive personal data, including health data. According to Article 6, sensitive personal data cannot be processed without the explicit consent of the individual. However, personal data other than health and sexual life can be processed in cases prescribed by law. Health and sexual life-related personal data, on the other hand, may only be processed without the explicit consent of the individual by individuals or authorized institutions bound by confidentiality obligations, in situations such as protecting public health, preventive medicine, medical diagnosis, treatment, and the management of healthcare services [12].

In this context, it should be noted that there may be differences in personal data protection among countries. For example, in Türkiye, during the COVID-19 pandemic, access to health data was provided, and this data was processed in accordance with the aforementioned legal framework. Additionally, the General Data Protection Regulation (GDPR) is implemented in the European Union to protect personal data. The GDPR establishes strict rules for the protection of individuals' personal data and includes specific regulations regarding the processing of health data [13].

3. Results



Output from last evaluation

```
Over-limit points:
        Timestamps          Temperature       CardID
   ____________________     ___________    ____________

   05-Dec-2024 07:00:06        32.13       {'53f99634'}
   06-Dec-2024 07:34:01        32.17       {'53f99634'}
   06-Dec-2024 07:34:31        32.35       {'53f99634'}
   06-Dec-2024 07:35:09        32.19       {'53f99634'}
```

Figure 4: Detection of Measurements Exceeding the 32°C Limit Temperature After December 4

In Figure 4, the values identified as being above the fixed threshold of 32 degrees from measurements taken after December 4, along with their card IDs and measurement times, are listed on ThingSpeak.

In Figure 5, the actual measurement values for different days are shown as round dots, linear regression predictions are represented by a solid line, and polynomial regression predictions are indicated by a dashed line.

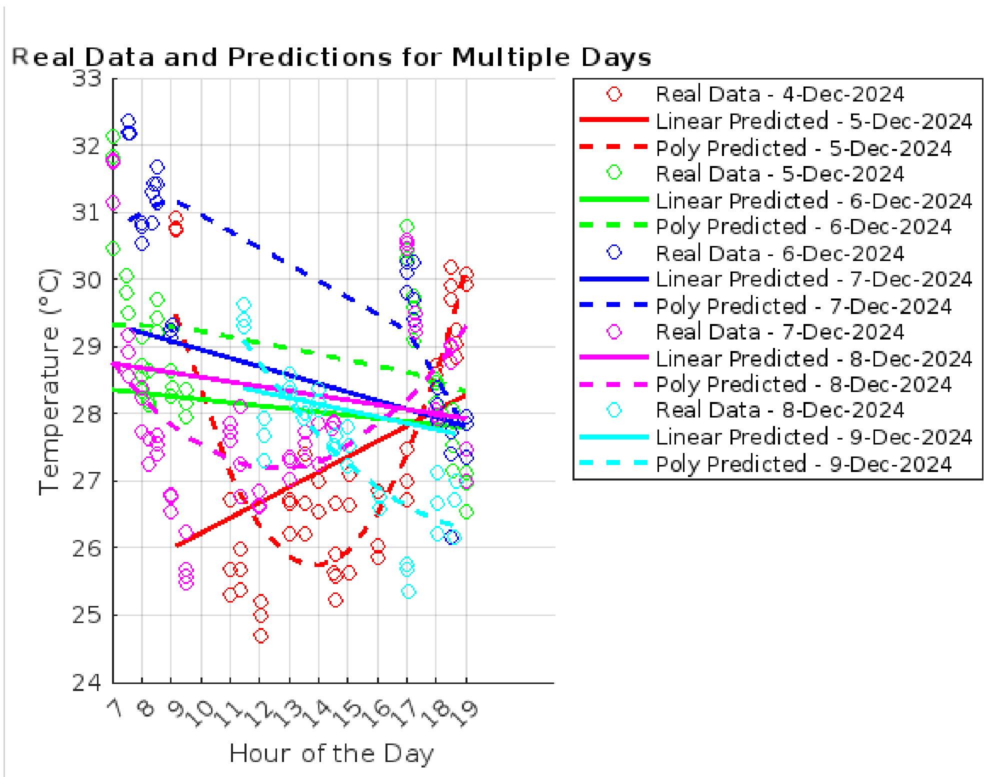


Figure 5: Prediction Graphs of Linear and Polynomial Models Between December 4 and December 9

The comparison of RMSE calculations for Linear Regression and Polynomial Regression methods is presented in Table 3 .

Table 3: Comparison of RMSE Calculations for Both Regression Methods

Date	Linear Regression (RMSE)	Polynomial Regression (RMSE)
December 5, 2024	1.6565	0.86661
December 6, 2024	1.4723	1.1824
December 7, 2024	1.7298	0.96819
December 8, 2024	1.4817	1.2022
December 9, 2024	1.0304	0.54649

December 5, 2024: The difference between Linear Regression (RMSE = 1.6565) and Polynomial Regression (RMSE = 0.86661) indicates that the polynomial model performs significantly better than the linear model. However, since this is the first day's data, it can be said that the model has not yet been adequately trained.

December 6, 2024: The RMSE for linear regression is 1.4723, while for polynomial regression it is 1.1824. Both models show improvement. The polynomial regression demonstrates better performance compared to the previous day, indicating that as the amount of data increases, the models start to make more accurate predictions.

December 7, 2024: Between Linear Regression (RMSE = 1.7298) and Polynomial Regression (RMSE = 0.96819), the polynomial regression again shows much better performance. However, since the RMSE value for linear regression has increased, it suggests that the model needs more training with additional data, which may improve its accuracy.

December 8, 2024: Again, Polynomial Regression (RMSE = 1.2022) outperforms Linear Regression (RMSE = 1.4817). In this case, an improvement in model accuracy is observed, but the improvement is more limited compared to previous days. This indicates that the days used have provided sufficient training data, but the predictive power of the model could increase with more data.

December 9, 2024: The RMSE value for polynomial regression (0.54649) is much lower than that of linear regression (1.0304), indicating that polynomial regression provides the most accurate prediction.

4. Discussion and Conclusion

In this study, the effectiveness of a system developed to monitor body temperatures and detect abnormal temperatures during the pandemic was evaluated. The main objective of the system is to detect and report individuals who exceed a certain temperature threshold through remote temperature measurement. Temperature data were collected and analyzed using the ThingSpeak platform. In the initial method with a fixed temperature limit, the automatic detection and graphing of temperatures above 32°C were achieved. In the second part, where regression analyses were compared, predictions based on regression methods were made with temperature data, and the error rates of these predictions were compared. It can be said that the regression methods used still have a statistical basis and a low proportion of artificial intelligence. Models that produce better RMSE values for AI-supported predictions should continue to be tested.

Data Analysis Results**:** In the analyses conducted, temperature data were modeled using linear and polynomial regression methods. The polynomial regression model provided lower RMSE values compared to the linear model, resulting in more accurate predictions. However, the improvements observed in all modeling processes indicate that accuracy may further improve as the amount of data used increases.

Future and Improvement of the System: The accuracy of the system will improve as it is tested with more data and different personal information. Although temperatures exceeding 32°C have been set as a critical threshold for now, these thresholds can be dynamically adjusted by considering environmental factors and personal characteristics. In the future, personalized temperature thresholds can be established to more precisely define the temperature limits for each individual. The free version of ThingSpeak offers limited data collection capabilities. The paid version may be preferred for model training with larger datasets. Although MATLAB codes that can be used in ThingSpeak were implemented, it was observed that some necessary MATLAB codes for AI training could not be run in this system (e.g., fitlm, fitrsvm, fitctree, trainNetwork, pca, crossval,..) [14]. The desktop MATLAB application may provide better model training.

To improve the accuracy of temperature measurements, hardware enhancements can be made. Thermal cameras can support wrist temperature measurements, and sensors that measure ambient temperature can be added.

Legal and Ethical Aspects: The collection of personal health information by the system poses significant responsibilities regarding personal data security. Therefore, it should be noted that the feasibility of the system must be evaluated within the framework of health data laws. The processing of such data can only be done with the individual's explicit consent or in specific health-related situations (e.g., public health protection, medical diagnosis, and treatment). These data may be processed by individuals who are bound by confidentiality obligations for purposes such as planning and managing health services.

Wrist temperature measurement may be an accurate indicator of body temperature, and specific threshold values should be adjusted with personalized data [15]. Monitoring wrist temperature has been identified in previous studies as an effective method for ensuring accurate temperature measurement [16], [17]. Future studies could use artificial intelligence and machine learning algorithms to enhance the system's accuracy, enabling more accurate predictions [18].

This system allows for the rapid identification of individuals at high temperature risk in areas such as public transportation during emergency health situations like pandemics. Systems developed with artificial intelligence and IoT technologies could be a significant step towards a safer public transportation environment and more effective public health management.

5. Acknowledge

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