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Temperature Data Acquisition System for Showcase Refrigerator Based on ESP32 and Online Remote Display

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In this paper, we discuss the utilization of ESP32 as an IoT device applied to a data acquisition system for monitoring temperature conditions within a showcase refrigerator. Within the showcase refrigerator, one section has its temperature conditions measured and recorded using a thermocouple sensor. The interface is facilitated by the MAX6675 module, with ESP32 serving as the processing unit. The temperature data is sent to Google Drive in the form of a Google Spreadsheet, enabling online access. Data visualization is conveniently accessible via a web app built using Google Apps. ESP32 connects to the internet via smartphone Wi-Fi. To validate the accuracy of temperature measurements, the results obtained from four thermocouple sensors were compared with readings from a precision glass thermometer. The second sensor exhibited the smallest error, whereas the other three sensors displayed increasing error rates when the temperature difference exceeded room temperature, with each thermocouple having an error of about 1.06, 0.58, 1.02, and 1.49 °C. The reliability of the internet connection, facilitated by the smartphone, primarily hinges on the physical distance between ESP32 and the smartphone. It is less dependent on the smartphone's workload from other applications. At a distance of 12 m, the data loss percentage was recorded at 3%.

1. Introduction

Advancements in science and technology continually drive the development of measurement devices and equipment. This progress significantly contributes to enhancing our comprehension of the world around us and facilitates advancements across various scientific and technological domains. The emergence of IoT[(1)] devices and associated equipment has notably simplified and made measurement and monitoring more cost-effective and accessible to a broader audience. This, in turn, has ushered in a wave of innovation and broader applications across multiple

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sectors, hastening the development of data-driven technologies. IoT is a new paradigm that has changed the traditional way of living into a high-tech lifestyle, as discussed by Kumar *et al.*,[2] who explained and clarified IoT and its applicability to the real world. The development of IoT cannot be separated from the use of computers. Chataut *et al.*[3] provided an overview of the emergence of IoT devices, delved into their prevalent applications, and explored future prospects within this promising field of computer science.

The current state of the significant advantages of IoT devices, including the Arduino, Raspberry pi,[4] and ESP32[5] types, each having several variations and technologies,[6] can be attributed to measurement systems, including the ability to collect and analyze real-time data and improve accuracy and measurement precision, and they are not affected by human error, predictive maintenance, or maintenance costs. The advantages of IoT, which proposes an interconnection between physical devices and networks,[7] captured the interest of many people. It is considered that in 2022, 14.3 billion IoT devices were connected to the network, and it is expected to grow this year.[8] On the other hand, the disadvantages of IoT technology[9] are associated with existing measurement systems, including security risks, data overload, reliability issues, and compatibility. IoT technology in measurement systems can be improved in terms of standardization, processing, data analysis, security, reliability, and power management.

IoT devices are fundamentally changing the way we measure by providing real-time access to necessary data, enabling deeper analysis and smarter decisions based on that data. IoT has emerged as a solution to this challenge by connecting physical objects using electronics, sensors, software, and communication networks. IoT devices are used in a wide range of applications, including home automation, industrial monitoring and control, environmental monitoring, agriculture and farming, wearables and health monitoring, smart energy management, and data logging and analytics.[8]

IoT is the idea that it is not only computers that can connect to the internet, but also everyday objects. Doing so brings new functionality, says Felix Wortmann, the scientific director of the Bosch IoT Lab at the University of St. Gallen in Switzerland, who studies IoT and its impact on business. He said, "add Wi-Fi and motion sensors to a light bulb, and you have a remote alarm system, add Wi-Fi to a stereo system, you can control music from your phone".[10]

One popular example is an ESP32 IoT device that is applied to a weather station tool, which also functions to measure gas concentrations in air. Several weather parameters that are measured are wind speed, wind direction, air humidity, ambient air temperature, air pressure, rainfall, and UV index. An IoT-based real-time telemetry device using ESP32 can read data from sensors and process them at the same time. The data obtained are used to analyze air quality and surrounding weather conditions, processed, and uploaded to a server. The client device will receive the data set, which is then stored and displayed on a monitor.[11]

Utilizing IoT technology in refrigeration systems and refrigerators enhances operational efficiency, reliability, and safety. This application not only leads to cost savings but also mitigates the risk of damage or spoilage of stored goods. By implementing IoT, refrigeration systems can gain a comprehensive understanding of their performance by collecting substantial real-time data.[12] Additionally, this approach paves the way for data-driven smart heating, ventilation, and air conditioning (HVAC) operations.[13]

The existing need in both industrial and commercial sectors for enhanced precision in monitoring, quicker problem resolution, energy conservation, and improved maintenance scheduling requires the integration of measurement and data acquisition systems.[14] These integrated systems, when coupled with IoT devices, enable the implementation of advanced data analysis technologies such as machine learning and predictive analytics, ultimately enhancing overall industry efficiency and productivity. This approach is particularly well suited when applied to a showcase[15] refrigerator, which serves as an industrial product utilized in commercial operations.

In this study, a data acquisition (DAQ) system, which involves connecting sensors to ESP32 as the IoT device for collecting data from a showcase refrigerator, was developed. The collected data were then transmitted via a Wi-Fi internet network from a smartphone to Google Drive, serving as the data storage center.

2. Research Methods

The research methodology employed in this study consists of the following stages.
1. Design
2. Preparation of components
3. System installation
4. Programming
5. Test and analysis of the working system

The hardware design consists of ESP32 as a microcontroller, four MAX6675 and thermocouple K-type sensors to read temperature data, and a liquid crystal display (LCD) to display data from these sensors, as shown in Fig. 1.

In designing the software, it is essential to configure ESP32 for data acquisition, enabling it to transmit the data collected from sensors. Starting with the ESP32 microcontroller, which is programmed using the Arduino IDE application to manage the temperature data from a sensor, the data is processed for readability. Then, it is displayed on the LCD and simultaneously transmitted to Google Spreadsheets, as illustrated in Fig. 2.

The system design is depicted in Fig. 3. In this setup, the sensors are positioned within the showcase refrigerator to monitor temperature. The sensors are connected to the ESP32-based

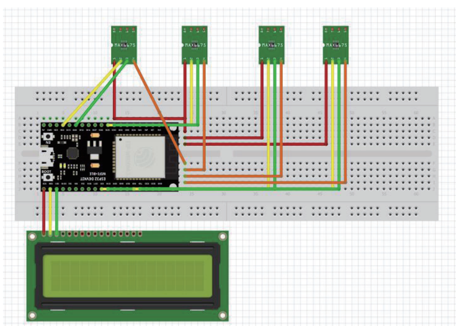

Fig. 1. (Color online) DAQ system hardware design.

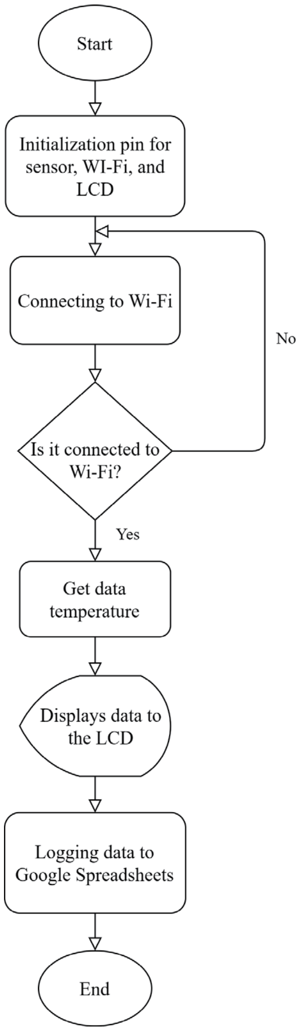

Fig. 2. Flowchart of software design.

Fig. 3. (Color online) System setup design.

DAQ system, which establishes a connection to Wi-Fi from a smartphone, enabling the transmission of sensor data to Google Spreadsheets.

The data collected from the sensor are compared with readings from a precision glass thermometer. This comparison is followed by the calculation of the error as a step in verifying the accuracy of the temperature measurement. The experiment was conducted by measuring the temperature of water within the showcase refrigerator for 2 h, during which time, data were collected at 10 s intervals.

A data logging test is conducted by comparing the amount of data transmitted to the micro-SD card with that sent to Google Spreadsheets. This test was conducted over a period of 2 h, with data collection occurring at 10 s intervals. The test took place during daytime, utilizing the tethered connectivity of a personal smartphone.

3. Results and Discussion

The DAQ system hardware that was designed and implemented is shown in Fig. 4, and contains the components that have been installed in the project box. This system was tested in a showcase refrigerator, as shown in Fig. 5, where a smartphone is used as an internet connection provider for the ESP32-based DAQ system.

The experimental results are graphically represented in Fig. 6, which illustrates that the temperature readings from the sensors are consistently higher than those from the glass thermometer. The names of the four sensors of MAX6675 are Temp 1, Temp 2, Temp 3, and Temp 4. Temp 4 shows the largest difference in measurement value, whereas Temp 2 shows the smallest difference, with respective values of 1.49 and 0.58 °C. Temperature readings are obtained while the showcase refrigerator operates for approximately 2 h. The glass thermometer is capable of measuring temperatures as low as −1 °C, whereas the thermocouple with the MAX6675 module can only measure temperatures as low as 0.5 °C. This can be caused by different reading accuracies.

Fig. 4. (Color online) DAQ system box.

Fig. 5. (Color online) Measurement system setup.

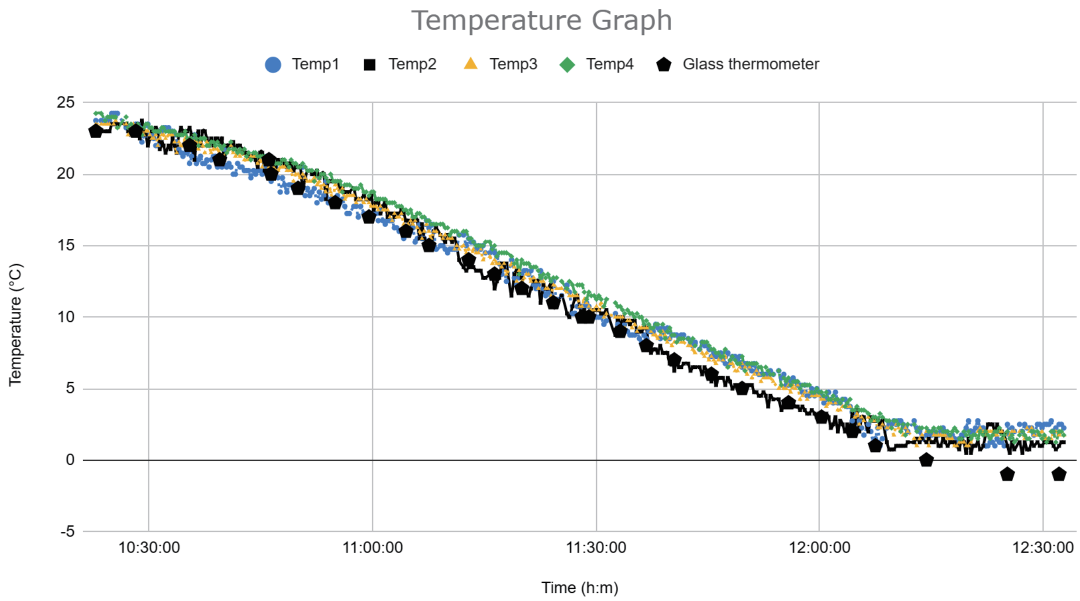

Fig. 6. (Color online) Temperature comparison graph between sensors and glass thermometer.

Data on temperature differences between each sensor and the glass thermometer are shown in Table 1.

To perform the data logging test within the showcase refrigerator, the sensors and glass thermometer were positioned inside a container filled with approximately 600 mL of water in the showcase refrigerator cabin, as depicted in Fig. 7.

Figure 8 shows the decrease in temperature as the test progresses. Initially, the temperature was logged at 24 °C and gradually decreased to approximately 0 °C over time. The rate of temperature reduction is higher when the gap between the cabin temperature and the ambient temperature is minimal, and the temperature tends to stabilize at approximately 0 °C, which is the typical setting for the showcase refrigerator temperature.

Aside from comparing the measurement outcomes between the sensors and the glass thermometer, a comparison was made regarding the amount of data logged onto the micro-SD card and that transmitted to Google Spreadsheets. The data stored in the micro-SD card amounted to 413 data, whereas the data on Google Spreadsheets comprised 400 data, resulting in a data loss rate of 3%. Data loss was experienced at approximately 11:30 based on data in Fig. 8, primarily due to a change in distance between ESP32 and the smartphone that acts as an internet connectivity provider, from its previous 2 m proximity to 12 m. This change led to an unstable connection and subsequently resulted in data loss within Google Spreadsheets.

The data stored in Google Spreadsheets can be displayed on a webpage, as shown in Fig. 9. The webpage displays the data graph and table for each sensor used. The temperature readings from sensors are also displayed on the LCD, as shown in Fig. 10.

Table 1
Sensor error values.

Difference (with glass thermometer)	Temp 1 (°C)	Temp 2 (°C)	Temp 3 (°C)	Temp 4 (°C)
Maximum	2.75	1.75	2.75	2.50
Minimum	0.00	0.00	0.25	0.50
Average	1.06	0.58	1.02	1.49

Fig. 7. (Color online) Sensor placement inside showcase refrigerator cabin.

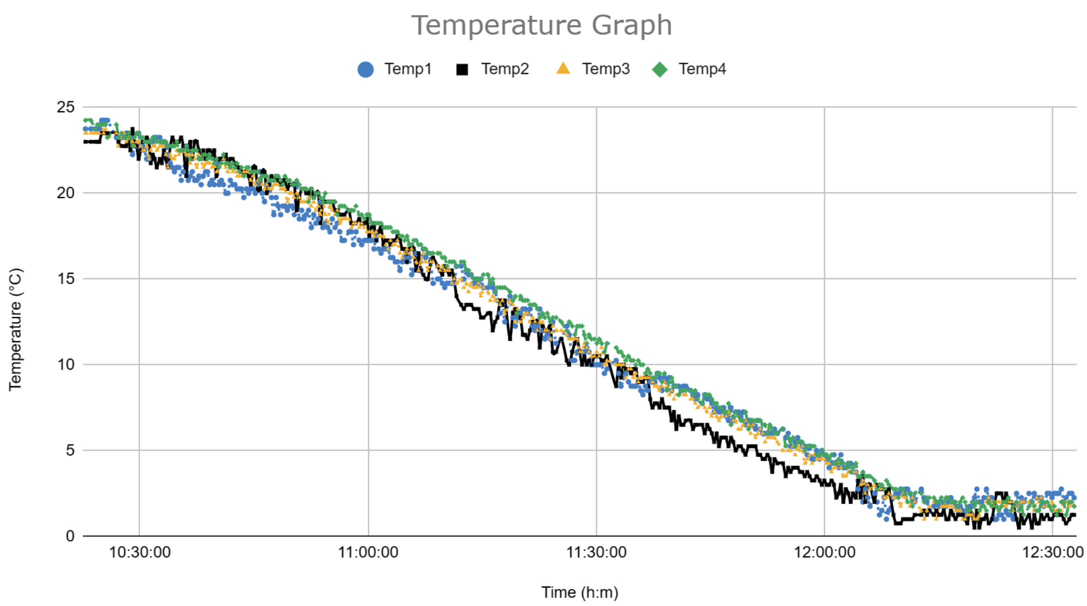

Fig. 8. (Color online) Graph of water temperature in cabin against time.

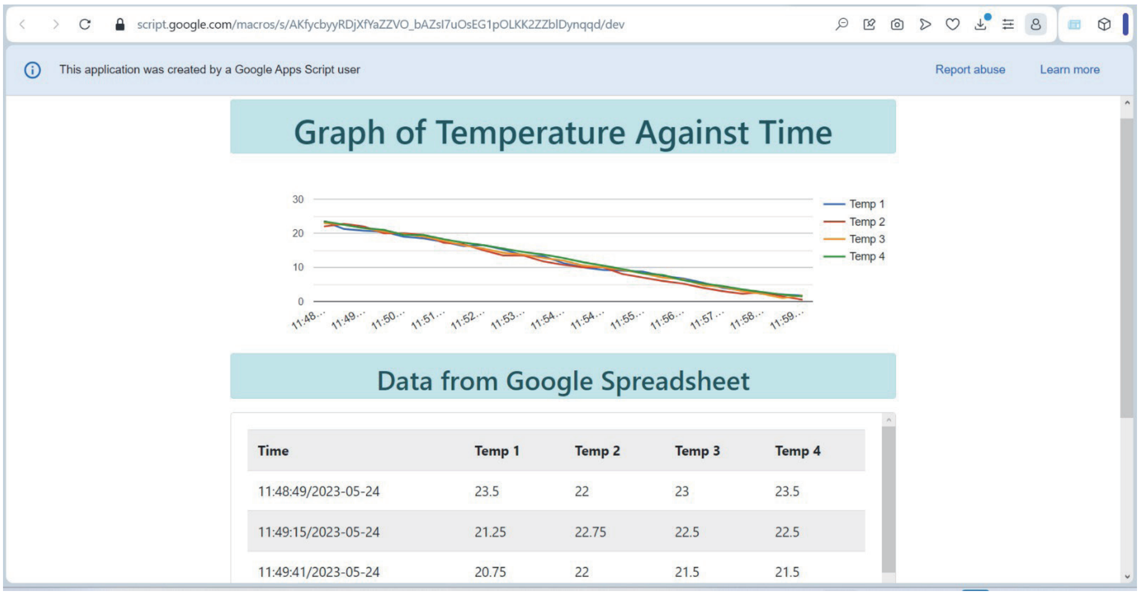

Fig. 9. (Color online) Display of data table and graph on webpage.

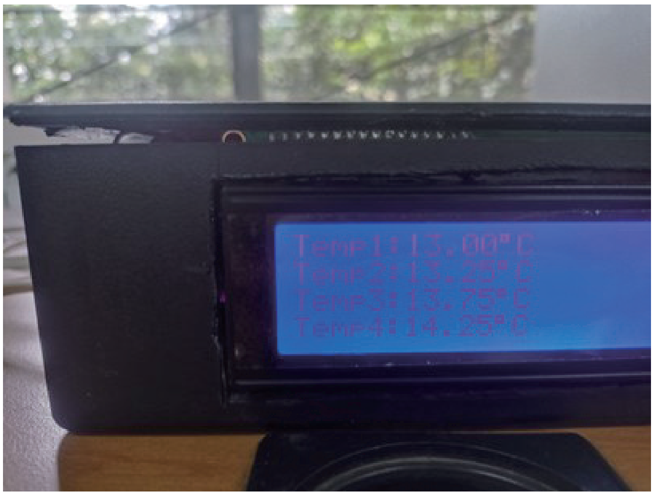

Fig. 10. (Color online) Display of temperature readings on LCD.

4. Conclusions

On the basis of the analytical results of the DAQ system in this study, the following can be concluded.

1. The DAQ system designed using ESP32 successfully displays data on the LCD and transmits it to Google Spreadsheets.
2. The average error values for the four thermocouple sensors with the MAX6675 module when compared with the glass thermometer for each sensor are 1.06, 0.58, 1.02, and 1.49 °C.

3. The data transmitted from ESP32 to Google Spreadsheets were compared with those stored on the micro-SD card, and a data loss rate of 3% was found. This is mainly due to the distance between the smartphone and ESP32, which is 12 m, compared with how busy the smartphone is with other applications.

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