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Article

Pre-Study on the Development of Internet of Things-Based Prototype Data Logger for Measuring Heat Sufficiency Number

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Abstract. This study aimed to develop an IoT-based data logger prototype to improve data acquisition and monitoring during the sterilization process. Achieving an adequate heat sufficiency value, commonly known as the F0 value, was crucial for effective sterilization, and a thermocouple sensor was typically employed for temperature recording. The research involved designing, constructing, and testing the prototype with a focus on enhancing durability and functionality. Key improvements included adding waterproof sealants to prevent leakage, integrating connectors for enhanced connectivity, and coating the sensor's connector end to ensure long-term performance. Performance evaluation compared the improved IoT data logger with a conventional data logger in terms of heat penetration measurement. Results showed that the IoT prototype recorded heat penetration data with comparable accuracy to the conventional system, confirming its reliability for practical application. The bias for the difference was less than 10%. This innovation demonstrated the potential for improved monitoring in sterilization processes, contributing to enhanced process control and product safety.

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1. Introduction

Food processing often involves a heating process to ensure product safety and extend shelf life. This process is typically conducted using a steam-pressure retort when canned packaging is employed. However, for packaging types such as pouch retorts, glass containers, or other materials that cannot withstand high pressure, an over-pressure retort is utilized to prevent deformation. The primary objective of this heating process is to eliminate microorganisms that cause both aerobic and anaerobic spoilage, thereby ensuring food safety. Additionally, the retort heating method plays a crucial role in preserving the sensory and nutritional quality of the product, particularly when temperature and duration are optimized to minimize the degradation of color, flavor, and heat-sensitive nutrients [1]. Despite its importance, achieving effective heat distribution in the sterilization process remains a challenge, particularly in ensuring that all parts of the product reach the desired sterilization temperature. To address this, two key temperature points are typically monitored: the interior temperature of the retort and the core temperature of the product.

Thermocouples or data loggers are commonly employed for these measurements to verify optimal heat distribution. The retort temperature measurement is performed by positioning the thermocouple above the water level at the bottom of the retort to accurately capture the coldest environment inside the retort. For core temperature measurement, thermocouples are inserted inside the product package before the sealing process to track heat penetration during sterilization. This ensures that every section of the product achieves sufficient heating to eliminate pathogenic microorganisms and extend shelf life [2]. A crucial factor in the sterilization process is the heat sufficiency number, commonly referred to as the F0 value.

The F0 value denotes the time (in minutes) required to achieve sufficient thermal lethality to reduce pathogenic microorganisms to a safe level at a reference temperature of 121.1°C. This concept is closely related to the thermal death time (TDT), which quantifies the duration needed to destroy a specified microbial population under controlled conditions. By maintaining proper F0 values, processors can achieve effective microbial inactivation without compromising product quality [3]. Conventional methods for calculating the F0 value rely on thermocouples or data loggers with docking systems. These devices record temperature data from the beginning of the heating process through the cooling phase. However, this approach has limitations in terms of accessibility and data retrieval. To address these issues, the development of an Internet of Things (IoT)-based data logger has emerged as an innovative solution.

Recent studies have demonstrated the potential of IoT-based monitoring tools in enhancing food sterilization processes, improving temperature tracking precision, and ensuring product safety [4-5]. IoT technology enables devices to transmit and receive data over a network, allowing remote access and real-time monitoring without human intervention. This advancement enhances the efficiency of temperature monitoring during sterilization, enabling faster calculation of the F0 value and improved control over the heating process [6]. However, until now there has been no prototype design of an IoT data logger that is fully adapted for measuring heat penetration in flexible packaging that meets BPOM standards. Given the potential benefits of IoT-based data loggers in food processing, this study aims to investigate the development and application of a prototype IoT-based data logger for real-time temperature monitoring during sterilization. This research seeks to provide valuable insights into the effectiveness of this technology in improving the precision and efficiency of F0 value calculation, ultimately contributing to safer and higher-quality food products.

2. Experimental Section

2.1.Tools and Materials

Tools and materials used in this research is IoT-based data logger, conventional data logger (Omega OM-CP-HITEMP140), retort (Indah Jaya Teknik), autoclave (GEA YX18 LDJ), adapter, device, router, corn starch, distilled water, retort pouch packaging, sealer.

2.2. Prototype Design

The prototype design was developed in stages based on real conditions encountered during the sterilization testing process. Initially, the prototype was designed and immediately tested to evaluate its functionality in actual situations. When issues or shortcomings in the tool's performance were identified, a thorough evaluation was conducted, followed by a series of modifications to the prototype design.

2.3. F0 Measurement Procedure

This study was conducted to develop a prototype of an IoT-based data logger tool used to measure heat sufficiency numbers. In this study, an IoT-based data logger prototype was tested in the product sterilization process using a retort device. The IoT-based data logger is installed on the retort device by inserting the data logger cable through a temperature vessel coated with thick rubber to maintain vacuum conditions. The data logger temperature sensor is set to be placed at three points of the retort: the bottom, middle, and top layers covering the retort's coldest points. The heat sufficiency value is calculated based on the recorded temperature data per minute obtained during the sterilization process, as expressed by the following formula [7].

$$F0 = \int_{o}^{t} LR\ Dt$$

2.4. Validation and Comparison Test

The data were obtained from three replications and statistically analyzed. The data loggers were connected to an application that could be monitored in real-time. As a further development, conventional data loggers were used to compare the temperature of the IoT data loggers while measuring the heat sufficiency number utilizing an autoclave. Heat Sufficiency Number Measurement Procedure

1. Prepare a dummy sample containing a 10% corn starch solution by dissolving 10 g of corn starch in 90 mL of distilled water and sealing the solution in retort pouch packaging using a sealer.
2. Insert the data logger sensor into the dummy sample through a pre-sealed opening, ensuring proper sealing to maintain vacuum conditions inside the pouch.
3. Place the sample containing the data logger sensor inside the autoclave.
4. Set the autoclave temperature to 121°C and process for 3 minutes.
5. Monitor the temperature profile using both IoT-based and conventional data loggers connected to the system.
6. Record the temperature data collected throughout the process and calculate the heat sufficiency number using the recorded temperature profile data.

The heat sufficiency number is calculated based on the accumulated lethality (F-value) during the sterilization process. The F-value calculation considers the time-temperature profile data recorded by the data logger to ensure optimal heat penetration and product safety.

3. Results and Discussion

3.1. Specification and Heat Distribution Test of IoT-based Prototype Data Logger

The data logger is a series of tools that record and store data automatically [8]. IoT-based data logger is a temperature recording device capable of transmitting temperature data in real-time to the application by utilizing an internet connection. In this study, an IoT-based data logger prototype was developed designed to record temperature while measuring the heat sufficiency number. The developed prototype can be seen in Figure 1.

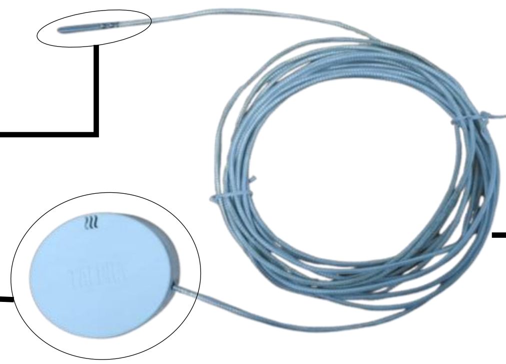


Figure 1. IoT-based data logger prototype

The IoT-based data logger prototype consists of three main components: a Printed Circuit Board (PCB), temperature sensor, and connecting cable. PCB is the main component where various electronic devices are installed [9] and acts as a signal transmitter to transmit temperature data in real-time. The temperature sensor is placed at the end of the connecting cable, which is an intermediary between the sensor and the signal transmitter to ensure temperature data can be transmitted accurately and efficiently. The specifications of the IoT-based prototype data logger can be seen in Table 1.

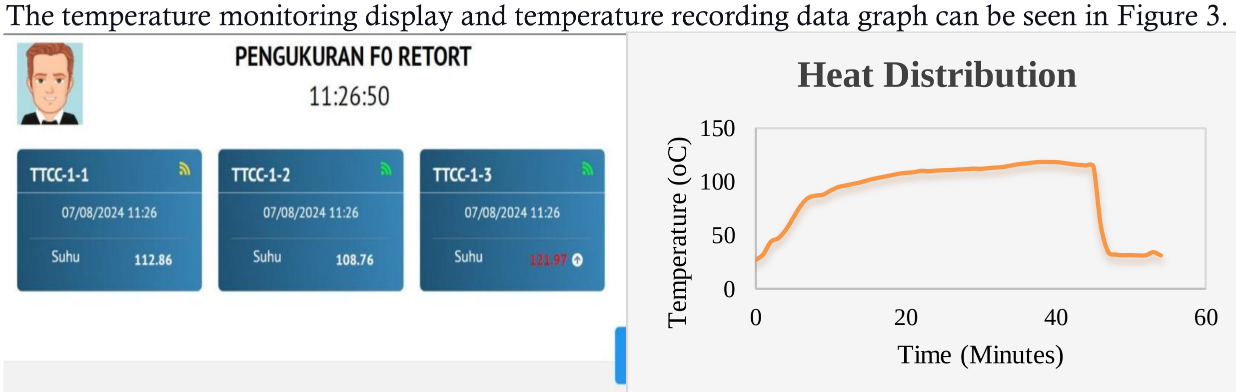
Table 1. IoT-based prototype data logger specifications

Parameters	Temperature operating range : -200~220°C Temperature accuracy (-80~0) : ±1°C Temperature other: ±2°C
Ecosystem	IoT (Internet of Things)
Interface	Web platform (Diawan.io) and android application (Autentik)
Interval data storage	1 min (default)
Interfal backup data	±8 hour
Interval data transmission	±5 sec
Early warning system	Whatsapp messenger
Casing	ABS
Dimension	60,99x17,1 mm
Net weight	±50 g
Shipping weight	±302 g
Mounting	Desk and Wall
Antenna	Internal
Power	USB Type C 5VDC/3 A
Network	IEEE802.H b/g Wifi
Report	Pdf, Xls, CSV
Cable lenght	5 meter

In calculating the heat penetration value, two temperature parameters are measured, one of which is the measurement of heat distribution in the retort tool [2]. This study uses a data logger with an IoT system to measure heat distribution and is installed on the retort tool. The installation process is carried out by adjusting the flow of cables connecting the data logger to the power source and ensuring the correct installation position on the retort tool to record the temperature during sterilization accurately [4]. The data logger temperature sensor is placed at three points: the bottom layer, middle layer, and top layer of the retort. This placement is expected to record the coldest temperature of the sterilized product [10]. The laying and sterilization conditions using the prototype can be seen in Figure 2.

Figure 2. Temperature sensor placement of the IoT data logger prototype

The measurement of the heat sufficiency rate using the IoT data logger prototype is directly connected to an application called "Authentic" installed on a laptop or cellphone device. The temperature recorded by the data logger will be sent immediately and can be monitored in real time through monitoring in the application. As soon as the sterilization process is complete, the recorded data can be immediately downloaded in Excel format to further calculate the heat sufficiency number. The temperature monitoring display and temperature recording data graph can be seen in Figure 3.



(a) **(b)**

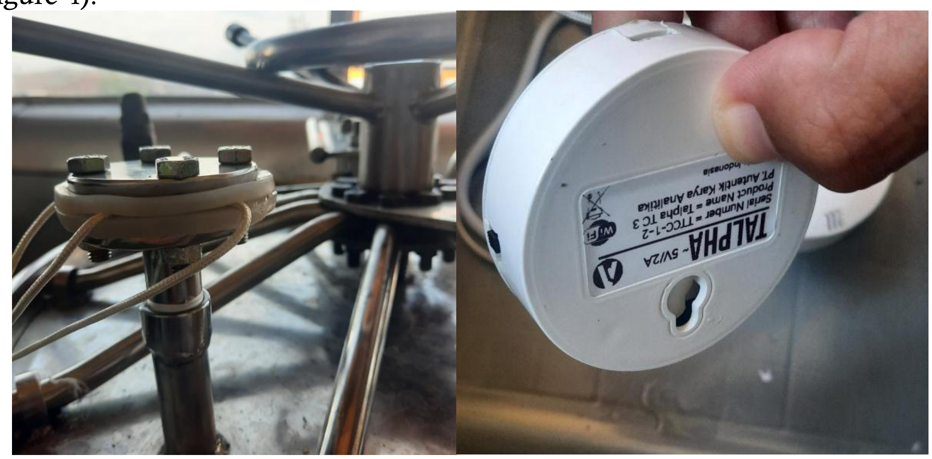
Figure 3. (a) Real time temperature monitoring, (b) heat distribution temperature data during the sterilization process

Based on the testing of the IoT-based data logger prototype in the process of measuring the heat sufficiency number with a sample in the form of rendang, the recording results are obtained during the sterilization process with the temperature before sterilization is 27 °C and the highest temperature of sterilization is 121°C. The prototype can record the heat distribution temperature in the retort tool properly and efficiently. The smooth transmission of temperature recording data in the monitoring application is influenced by the signal connection and noise (interference) around the device. If the transmission strength is significantly higher than the noise level, the device can operate optimally by ignoring the interference that occurs. However, if the received signal has an intensity comparable to the environmental noise, the device will have difficulty in distinguishing the communication signal from the interference. This condition has the potential to hamper the effectiveness of wireless communication and cause the data transmission process to not run optimally [11-12].

Weak signals connection can cause delays in data transfer on the monitoring screen. The time and temperature displayed on the monitoring screen experience a delay of about 1 to 2 minutes so that it is not fully in real time. This can be overcome by using a router or mobile Wifi connected to the IoT data logger, so that the signal connection is stable and the data transfer process can run smoothly.

3.2. Tool Problems and Improvements

During the heat distribution measurement process, there was a problem with the data logger being developed, namely a leak in the connecting cable. This is thought to be caused by the high pressure in the retort, which allows water to enter through the temperature sensor on the data logger installed in the retort (Figure 4).



(a) **(b)**

Figure 4. (a) Water leak through the cable, (b) leakage on the prototype data logger

Leakage that propagates to the PCB's causes the prototype to be unable to record or transfer data to the application. Leaks on PCB's can compromise device performance. While digital circuits can still function even when exposed to liquids, leaks can cause corrosion that shortens the life of the device [13]. To overcome this problem, further development was carried out by adding a waterproof sealant to the prototype frame and adding a seal at the end of the temperature sensor to prevent the process of water propagation during the sterilization process. The IoT-based data logger that has been coated with sealant and seal can be seen in Figure 5.

(a) (b)

Figure 5. (a) Prototype that has been coated with sealant and (b) seal on sensor

Data loggers that have been modified with additional waterproof sealants coated through the PCB and seals on sensors are used as a substitute for the previous version in measuring heat distribution. In testing the prototype that has been coated with sealant proved to be able to prevent water from entering the protoype. Sealants play a critical role in enhancing the performance of coated surfaces by improving adhesion between the coating and the substrate. Sealed surfaces generally exhibit superior performance compared to unsealed ones, particularly in terms of corrosion resistance under specific environmental conditions. Additionally, sealants can be formulated to impart non-adhesive surface characteristics, depending on the functional requirements of the application [14]. The modified heat distribution prototype can be seen in Figure 6.

Figure 6. IoT data logger prototype for heat distribution

However, after these improvements, a new problem arise, namely that some products were damaged or the packaging was broken during the sterilization process. This damage was not caused by the prototype but was influenced by the pressure in the retort which exceeded 1 Psi. Pressure that is too high can squeeze existing products so that products that are in the sterilization process break or can caused waffling defect [15] (Figure 7). This can be prevented by always controlling the pressure on the retort during the sterilization process and can be prevented by introducing overpressure air during the cooling phase, which helps preserve the integrity of the packaging and prevents the container from becoming deformed [16].

Figure 7. Product damage due to high pressure

According to the Badan Pengawasan Obat dan Makanan (BPOM) regulation No. 27 of 2021 [17] concerning Requirements for Hermetically Packed Low-Acid Processed Food and Validation Protocol for Heat Process sufficiency of Commercial Sterile Food Sterilized After Packaging [18], the measurement of the heat sufficiency number in food products must be carried out by measuring the temperature of the product in the package which is referred to as heat penetration. Based on this, the development of an IoT-based data logger prototype requires a different prototype design to be able to meet existing regulations. The development of the IoT-based data logger prototype is carried out by adding a temperature sensor connector that connects the temperature sensor inside the package with the temperature press component outside the sterilizer. The development and testing of the modified IoT prototype can be seen in the following description.

3.3. Specifications and Heat Penetration Test IoT-based Prototype Data Logger

The development of the IoT data logger prototype is aimed at improving the data logger that meets the standards as well as improving the shortcomings in the previous design which is designed to measure the temperature of the product in the package and is resistant to pressure. IoT-based prototype development can be seen in Figure 8.

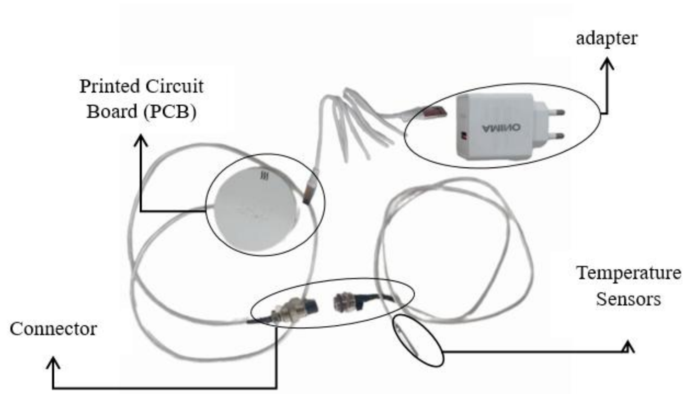


Figure 8. Development of IoT-based data logger prototype

The difference in the data logger design lies in the presence of a connector that can connect the temperature sensor inside the package with the signal capture PCB placed outside the sterilizer. The use of the modified IoT data logger can be seen in Figure 9.

Figure 9. Layout modification of IoT-based prototype data logger

The development of the IoT-based data logger prototype was carried out by testing the function of the connector on the product. The test was conducted on a dummy containing corn starch solution with a concentration of 10% packaged using a retort pouch. The connector is installed on the retort pouch packaging that has been previously punched with a size according to the diameter of the connector tip. The end of the connector equipped with the temperature sensor was placed inside the package so that it could be in direct contact with the product, while the part of the connector connected to the PCB device was positioned outside the package. The connector assembly process is done by rotating the connector tightly to ensure that the connector is firmly seated and to ensure that the rubber seal is perfectly in place.

During the test installation of the connector in the package, there was a leak in the connector, characterized by the dripping of starch solution through the connecting gap of the connector compartment. This was caused by the rubber seal on the connector not completely blocking the solution due to improper installation [19] of the connector and the hole made manually on the packaging was too large so that there was a gap for the solution to escape from the packaging. Leakage in the connector can be seen in Figure 10.

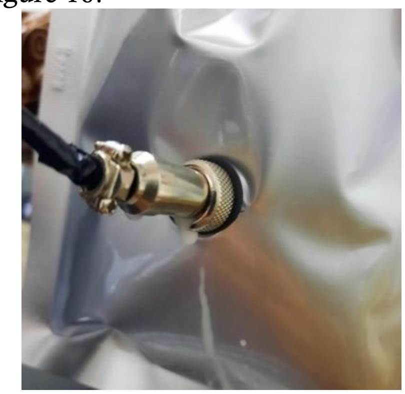


Figure 10. Leakage at the connector

The shortcomings in the development of the prototype are re-modification of the tool by adding coating materials and reducing the possibility of leaking through the packaging by perforating the packaging using a special punch tool. The specifications of the modified IoT-based data logger prototype can be seen in Table 2.

Table 2. Specifications of the IoT-based prototype data logger modification

Parameters	Temperature operating range : -200~220°C Temperature accuracy (-80~0) : ±1°C Temperature other: ±2°C
Ecosystem	IoT (Internet of Things)
Interface	Web platform (Diawan.io) and android application (Autentik)
Interval data storage	1 min (default)
Interfal backup data	±8 hour
Interval data transmission	±5 sec
Early warning system	Whatsapp messenger
Casing	ABS
Dimension	60,99x17,1 mm
Net weight	±50 g
Shipping weight	±302 g
Mounting	Desk and Wall
Antenna	Internal
Power	USB Type C 5VDC/3 A
Network	IEEE802.H b/g Wifi
Report file	Pdf, Xls, CSV
Cable lenght	5 meter
Connector	M12 Sealant
Varnish	Sirlak

The modification of the IoT-based data logger prototype was tested in the process of measuring the heat sufficiency number using an autoclave. The data logger sensor is inserted into a dummy containing 10% corn starch solution. IoT-based data logger testing is also accompanied by conventional data loggers as comparison data, this is because the goal in developing the IoT data logger prototype is to improve conventional data loggers so that they can facilitate users in measuring heat sufficiency numbers. Testing the modified IoT prototype is as follows. Conventional data loggers are measurement and recording instruments that operate independently by utilizing the internal memory of the microprocessor used. The recorded data can be stored permanently by transferring the data to another device for further analysis [20-21].

3.4. Comparative Data Analysis

Calculation of the heat penetration value is done by measuring the temperature at the core of the product, where the data logger is placed inside the package before the seaming process [2]. Computer and IoT simulations have been extensively utilized in the food industry to predict heat transfer characteristics during the heating process [22]. In an effort to improve measurement accuracy and efficiency, an IoT-based data logger has been redeveloped. This tool is equipped with a special connector, which allows more precise measurement of the temperature in the package or the heat penetration temperature of the product. In addition, with IoT technology, measurement data can be monitored in real-time, making it easier to monitor and analyze during the sterilization process [23]. To ensure the accuracy of heat penetration data recording during the sterilization process, a comparison was made with conventional data loggers (docking systems) that are commonly used. The comparison results of the temperature recorded during the sterilization process (heat penetration) can be seen in Figure 11.

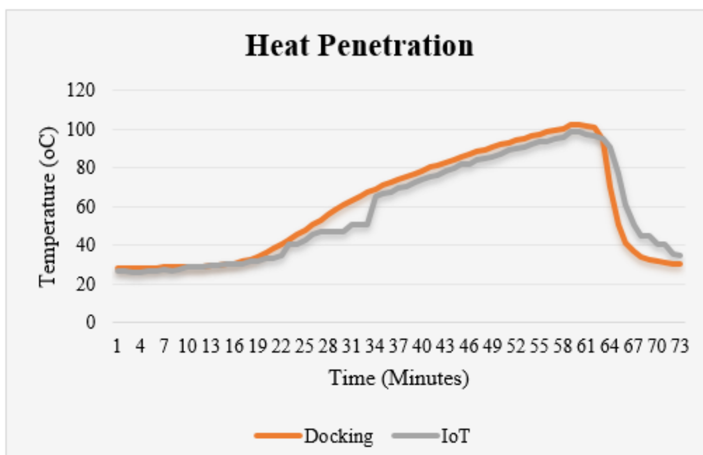


Figure 11. Comparison graph of IoT logger and conventional logger in heat penetration test

Based on the temperature graph of the modified IoT prototype heat penetration test, it can be seen that the prototype can record and transmit data properly. When compared to conventional data logger penetration temperature data, the difference in temperature recording of the IoT prototype is not significant. This illustrates that the temperature sensor detection in the IoT prototype is almost the same as the conventional data logger. In detail, the temperature recording data of the data logger can be seen in Table 3.

Table 3. Data logger heat penetration record data

Time (Minutes)	Prototype IoT (°C)	Convensional (°C)	Temperature Difference
1	26.4	28.5	-2.1
2	26.5	28.49	-1.99
3	26.3	28.48	-2.18
4	26.3	28.48	-2.18
5	26.9	28.48	-1.58
6	26.7	28.52	-1.82
7	27.4	28.58	-1.18
8	27	28.68	-1.68
9	27.2	28.78	-1.58
10	28.91	28.91	0
11	29.07	29.07	0
12	29.26	29.26	0
13	29.5	29.5	0
14	29.8	29.8	0
15	30.15	30.15	0
16	30.66	30.66	0
17	30.6	31.54	-0.94
18	31.5	32.76	-1.26
19	31.8	34.33	-2.53
20	33.5	36.15	-2.65
21	33.5	38.17	-4.67
22	34.6	40.41	-5.81
23	40.8	42.91	-2.11
24	40.9	45.39	-4.49
25	42.6	47.91	-5.31
26	45.4	50.52	-5.12
27	47	53.18	-6.18
28	47	55.89	-8.89
29	47	58.57	-11.57
30	47	60.98	-13.98
31	50.8	63.25	-12.45
32	50.8	65.29	-14.49
33	50.8	67.19	-16.39
34	65.3	69.04	-3.74
35	66.4	70.78	-4.38
36	67.1	72.43	-5.33
37	69.7	74.04	-4.34

Time (Minutes)	Prototype IoT (°C)	Convensional (°C)	Temperature Difference
38	70.6	75.62	-5.02
39	72.4	77.17	-4.77
40	73.9	78.71	-4.81
41	75.8	80.18	-4.38
42	76.4	81.6	-5.2
43	78.2	82.96	-4.76
44	79.8	84.34	-4.54
45	81.7	85.68	-3.98
46	81.7	87.02	-5.32
47	84.2	88.32	-4.12
48	84.6	89.59	-4.99
49	85.8	90.81	-5.01
50	87.3	91.99	-4.69
51	89	93.16	-4.16
52	89.8	94.29	-4.49
53	90.8	95.41	-4.61
54	92	96.48	-4.48
55	93.3	97.51	-4.21
56	93.9	98.49	-4.59
57	94.9	99.43	-4.53
58	95.5	100.33	-4.83
59	98.6	102.22	-3.62
60	98.6	102.23	-3.63
61	97.5	101.48	-3.98
62	96.8	100.96	-4.16
63	95.1	94.32	0.78
64	90.7	70.42	20.28
65	76.9	50.73	26.17
66	60.8	41.39	19.41
67	50.8	36.57	14.23
68	44.9	33.93	10.97
69	44.9	32.42	12.48
70	40.9	31.53	9.37
71	40.9	30.98	9.92
72	35.4	30.64	4.76
73	35	30.44	4.56

The difference in temperature reading data on the IoT prototype with conventional data loggers can be further tested related to validation and temperature calibration on the data logger.

Figure 12 is illustrating the temperature difference (Delta) over time. The trend highlights the early stable phase, the increasing deviation in the middle phase, and the sharp reversal in the final phase, which aligns with the hardware issue described. Let me know if you'd like further insights or additional visualizations. During the temperature recording test the prototype data logger can run well, but in its use there is damage to the data logger tool, characterized by disconnection at the end of the connector. This was caused by the installation of the connector which was too close to the seal boundary causing the connecting cable to be in a bent position. The temperature data analysis reveals distinct trends in the IoT prototype's performance. In the initial phase (Minutes 1-16), the IoT logger showed minor discrepancies, consistently recording temperatures slightly lower than the conventional logger. As the test progressed (Minutes 17-33), the differences increased significantly, peaking at -16.39°C, indicating potential calibration drift or environmental influence. The middle phase (Minutes 34-60) saw more stable discrepancies of around -4°C to -5°C. However, in the final phase (Minutes 61-73), an abrupt reversal occurred, with the IoT prototype showing higher readings than the conventional logger, peaking at +26.17°C. This deviation aligns with the reported sensor disconnection issue, attributed to a bent connector cable near the seal boundary. Strengthening the sensor cable and ensuring proper installation effectively mitigated this problem in subsequent tests.

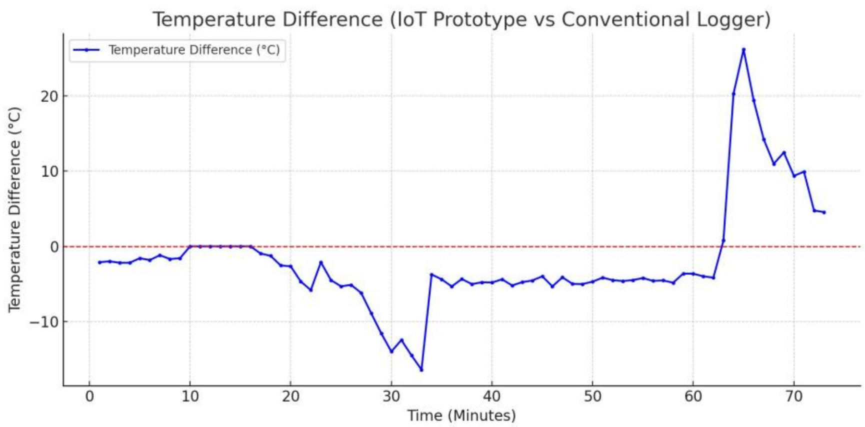


Figure 12. Temperature difference trend highlighting sensor disconnection impact

To overcome this problem, the sensor cable and connector were reinstalled to strengthen the connection and reduce the risk of damage during the research process (Figure 13).

Figure 13. Connector damage

Damage to the connector is overcome by further modification of the connector by adding a thicker coating material so as to increase the durability of the IoT-based data logger prototype. Modifications to the connector can be seen in Figure 14.

Figure 14. Modifications to the connector

The IoT-based prototype data logger with design modifications that meet the regulations for measuring heat sufficiency can be used to measure the heat sufficiency number of food samples in the packaging more efficiently [24]. Temperature monitoring can be directly monitored through the application in real time so that it can facilitate users in processing and analyzing the value of the heat sufficiency number. The prototype of the IoT-based data logger used in heat penetration can be seen in the Figure 15.

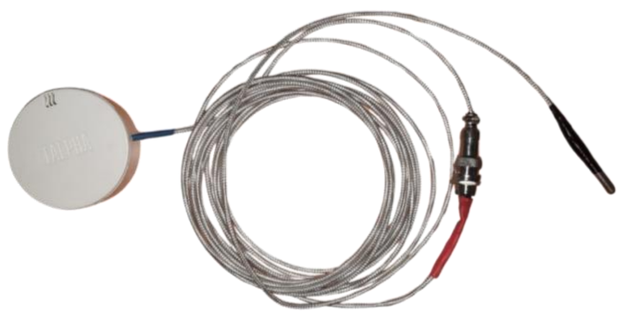


Figure 15. Modified prototype IoT-based used in heat penetration

Overall, based on the research conducted, the IoT-based data logger prototype showed potential for accurate temperature monitoring with some necessary improvements. The addition of waterproof sealants, enhanced connector installation, and sensor coating effectively reduced data discrepancies caused by disconnection issues. Despite initial temperature deviations, the improved prototype closely matched conventional data logger readings after modifications. These results align with previous studies emphasizing the importance of sensor durability and connectivity.

The improved IoT prototype holds promise for environmental monitoring, industrial applications, and agricultural processes, though further testing under various conditions and enhanced calibration are recommended to improve reliability and accuracy. Furthermore, the IoT prototype demonstrates potential for further development. With improved sensor calibration, enhanced durability of connectors, and robust installation methods, the device can provide accurate and reliable temperature monitoring. Future advancements may include integrating automated calibration systems, improved data transmission stability, and enhanced materials to withstand environmental stress. These improvements would position the IoT prototype as a viable solution for long-term temperature monitoring applications [25-30].

4. Conclusion

The research findings indicate that the IoT-based data logger prototype requires further development to enhance performance. Heat distribution data was successfully transferred, with improvements made by adding waterproof sealants and adjusting the design to meet regulatory standards, including connector enhancements and sensor coating. Initial tests showed slight temperature discrepancies compared to a conventional logger, which worsened due to a bent connector cable causing disconnection. After reinforcing the connector, the readings became stable and consistent.

The heat penetration test demonstrated that, when functioning properly, the prototype recorded temperature data comparable to a conventional logger. With further refinements in calibration, sensor stability, and structural design, the prototype shows strong potential as a reliable temperature monitoring tool.

5. Acknowledgement

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