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Intelligent Cold Chain Security: Nano Power Temperature Sensors, ESP32 and Telegram Bot Integration for Temperature Assurance and Environmental Harm Prevention

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ABSTRACT

The research aims to create a robust cold storage monitoring system for trucks, focusing on parameters like temperature, humidity, and harmful gases. Using nano power temperature, humidity, gas and LDR sensors, the system sets predefined thresholds for each parameter. The MS1089A features energy harvesting and a long battery life. The MS1089A has an I2C interface in addition to other time and power-saving features and it is accurate (±3 °C). By monitoring the temperature and safeguarding the surrounding environment, the nano power temperature sensor is ideal for environmental monitoring. When exceeded or fallen below, automatic notifications with GPS location are sent through Telegram to relevant authorities. Bidirectional communication *via* a Telegram bot allows users to remotely query sensor values. GPS technology enables live tracking for better cold storage unit management during transportation. The research is scalable, highlighting the potential of IoT in enhancing operational efficiency and reducing risks in cargo transportation. In summary, it integrates wireless sensors, an ESP32 microcontroller and Telegram messaging for a comprehensive cold storage monitoring solution, ensuring the safe transport of temperature-sensitive cargo.

Keywords: Cold chain management; Nano power temperature sensors; Environmental monitoring; Food protection**.**

1. INTRODUCTION

Nanotechnology plays a major role in everyday life. Nanotechnology in food sector plays an essential role. TiO_2 and silica dioxide have been used for food processing aids. Biosensors have proven effective in the efficient detection of contaminants, including pesticides, poisons and allergies. Advances in allergen detection have included nano techniques for identifying the Ara h1 peanut allergen in chocolate candy bars using an optical fibre surface plasmon resonance biosensor augmented with nanobeads (Das *et al.* 2019). The most widely utilised method for sequestering dyes is adsorption. Toxic pollutant magnetic separation is emerging as a promising technique for waste water clean-up. In order to remove dyes from aqueous solutions, magnetic composites (MCs) and magnetic nanocomposites (MNCs) are receiving a lot of interest these days (Sivashankar *et al.* 2014). Cold chain medicines are temperature-controlled and must be kept within a certain temperature range to preserve product integrity and quality; supply chain management is crucial. In addition to operational issues, cold chain management is not sufficiently addressed in Nigerian guidelines about medicine delivery. Validated quality monitoring systems for cold chain medications were not widely available or utilized (Chukwu *et al.* 2022). The trending cold chain technologies were evaluated, focusing on RF technologies and WSN (Badia-Melis *et al.* 2018). Temperature-sensitive products differ from dry cargo in a few key ways that make logistics management considerably more difficult (Behdani *et al*. 2019). Using the idea of the Internet of Pharmaceutical Things, a digital time, temperature and humidity indicator, a prototype for assessing and permitting the reuse of returned medications utilizing smart sensors and cloud connectivity was created (Hui *et al.* 2020). Developed a two-phase quality evaluation process for the distribution of premium chocolate. The first stage was keeping an eye on temperature changes as the candy was being shipped from production to the store. Variations that are susceptible to time might miss long-term effects, which could have an impact on the thorough evaluation of product quality (Manzini *et al*. 2019). Integrated RFID technology with irreversible visual color changes was used to create a unique CTI-smart sensor. Using integrated microfluidics, functionality was achieved (Lorite et al. 2017). Two primary methods for handling the logistics of perishable food were compared and contrasted; the management and technical options for supply chain temperature and timing control were investigated (Gogou *et al*. 2015).

1.1 Cold Chain Management

Using purposeful sampling, the cold storage facilities in the Greater Accra Region that store temperature-sensitive medications were identified, giving rise to a specific viewpoint on the issues associated with cold chain management. Real-time monitoring of goods in the cold chain was done by Luo *et al.* 2016. Cold chain tracking system was done for safety purpose (Montanari *et al*. 2008). Using phase change materials (PCMs) that absorb or release thermal energy will help the packaging's temperature stay steady. The high energy storage density of PCMs has made them a hot topic for research in the field of energy storage (Qi *et al.* 2022). Mohan *et al*. 2023 investigated postharvest losses (PHL) in the Indian tomato food supply chain using a case study methodology, concentrating on phases such as harvesting, storage, packaging and transportation. Full-history time-temperature indicator (FHTTI) was built using multi-colored plasmonic hydrogels that formed *in-situ* gold nanoparticles. More analysis is required to determine the possible financial effects of integrating the FHTTI into the distribution process on a wide scale (Shou *et al*. 2023). The usage of telegram plays a vital role (Nobari et al. 2021). Considering the low usage rate of such facilities in the region, an Arduino-based temperature and humidity monitoring system for small cold storage units in Yunnan was developed (Tang *et al.* 2020).

1.2 Sensor Monitoring with ESP32

ESP32 microcontroller applications offer a thorough analysis of the potential for developing data processing and measurement applications on this platform (Babiuch *et al*. 2019) The ESP32 board, several sensors, and appropriate wiring are components. Processing and reading data was made easier by programming, usually in C++ using the Arduino IDE. Home automation, industrial monitoring, environmental sensing, agriculture, and various IoT research are examples of common uses. The ESP32 board is used by an IoT-based real-time telemetry gadget to process measurement data (Megantoro *et al.* 2021).

2. LITERATURE SURVEY

Gillespie *et al.* 2023 showed an important development in the fight against food loss while transporting perishable commodities inside the EU is the IoT-based solution. It provides a promising solution to a pressing issue through the incorporation of cutting-edge technology and creative alerting systems, with the potential for wider adoption and greater environmental and economic benefit. The precision, range and response time of sensors used to measure temperature, humidity and other environmental factors may be constrained. These restrictions may impair the system's capacity to identify anomalies or quick changes in the environment.

Chu *et al*. 2023 research utilized Capsule-based colorimetric temperature monitoring system in cold chain management. It offers an adaptable, accurate and aesthetically simple solution for temperature monitoring across a wide range of applications by utilizing microfluidic technology and phase-change materials. This invention holds the ability to transform temperature monitoring procedures in a variety of businesses and shows promise for improving the quality and safety of goods carried within the cold chain. Outside of the normal temperature range, extreme temperatures may produce erroneous readings or no change in color. The colorimetric reactions could be influenced by outside variables including humidity, light exposure and air quality, which would reduce the precision of temperature monitoring.

Huang *et al*. 2023 addressed the freshness of the blueberries using an innovative approach, particularly in the context of blueberry cold chain logistics, which offered a significant improvement in the field of fruit freshness prediction. It is expected to transform how fresh produce is handled and transported, paving the way for more effective and sustainable food supply chains while assuring the highest standards of fruit quality and safety. This is due to its high precision, automation capabilities and data-driven decision-making. The performance of machine learning models can be strongly impacted by the precision and volume of data gathered from various sensors (temperature, humidity, etc.). Predictions may be wrong as a result of incomplete or noisy data (Kartoglu *et al.* 2014). To ensure that vaccinations remain a cornerstone of global public health initiatives, best practices in vaccine distribution and storage are being established and improved as a result of the difficulties presented by COVID-19 vaccines. The integrity of temperature-sensitive vaccines can be jeopardized by human error, such as inappropriate handling of the vaccinations or wrong set-up of the monitoring apparatus.

Cahyono *et al.* 2022 advocated for a low-cost, low-power microcontroller with an integrated camera and Wi-Fi, called ESP32 Cam. It is a well-liked option for IoT research, such as home security systems. Text messages, photos and videos can all be sent and received using Telegram - the well-known messaging program. The design and deployment of home security systems utilizing the ESP32 Cam and Telegram have been the subject of numerous research articles (Mayasari *et al.* 2023). Blood banks are essential for patients to provide safe and successful blood transfusions. Traditional temperature monitoring techniques in blood banks are frequently labor-intensive and manual. This could result in mistakes and carelessness. These issues can be resolved and temperature monitoring's effectiveness and accuracy improved with the use of automated temperature monitoring systems. Blood banks can create user-friendly and accessible temperature monitoring systems using Android applications. Real-time temperature data can be gathered from temperature sensors implanted in blood bank chambers using Android applications. The Android application interface can then display this data and notifications can be delivered.

Gangwar *et al.* 2023 gathered data by IoT-based air pollution monitoring devices from several sources. The stations are often positioned in strategic locations throughout a city or region; they collect data on a range of air pollution. Data collection from regions that are challenging to reach with permanent stations can be accomplished with the help of these stations, which can be mounted on vehicles or drones. Individuals can wear these devices, and they can be used to gather information about their exposure to air contaminants. Different machine learning techniques can be used by IoT-based air pollution monitoring systems to analyze data and produce projections. Deep learning algorithms that use neural networks can be applied to various tasks such as classification, regression and forecasting (Zakaria *et al.* 2023).

2.1 Research Gap

Microfluidic technology (for precise temperature monitoring) could not explore the accuracy and precision of temperature monitoring. Vaccine cold chain management do not directly relate to the critical issue of ensuring the quality and integrity of vaccines during their cold chain journey. Comparing the methods in predicting blueberry freshness, the machine learning-based approach focuses on data integration and predictive accuracy, whereas the colorimetric system emphasizes simplicity and real-time monitoring. While machine learning integrates multiple data sources for nuanced predictions, the colorimetric system offers immediate, visually intuitive insights, both bridging gaps in real-time cold chain monitoring needs. Machine learning tackles the complexity of multi-source data, offering deep insights but potentially raising implementation challenges.

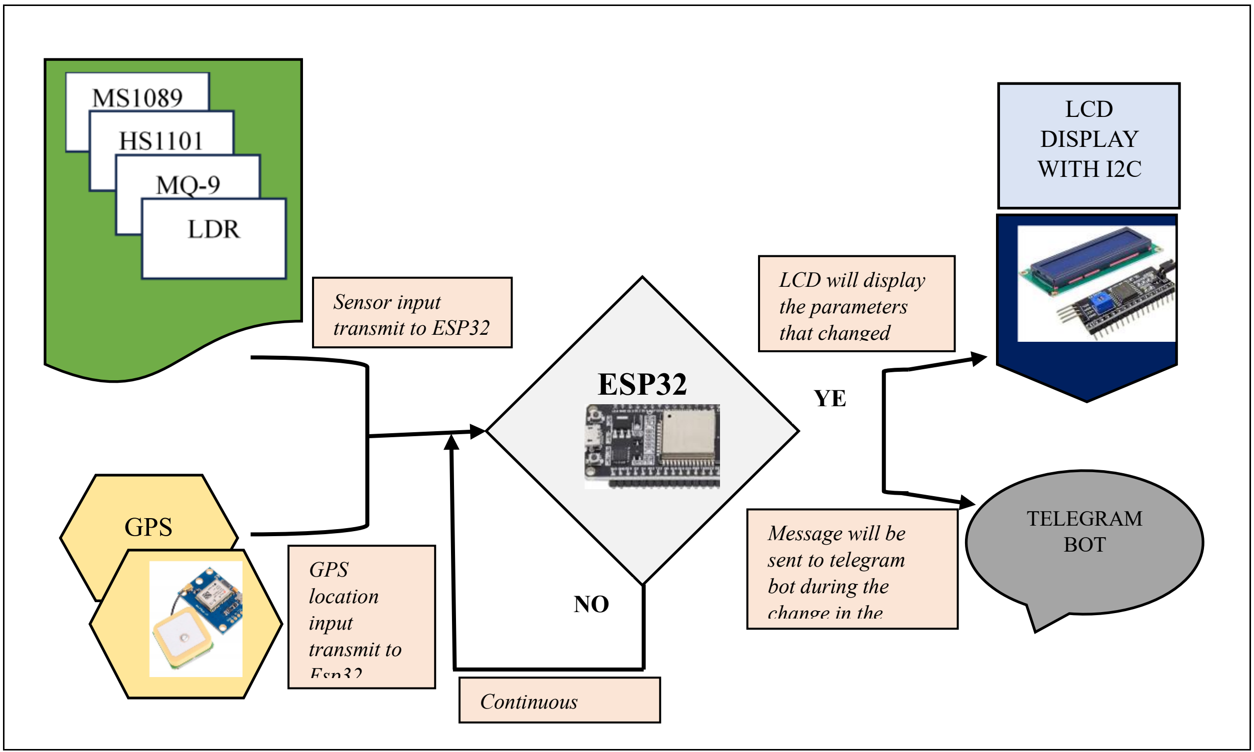

Fig. 1: Block diagram of proposed method

3. PROPOSED METHOD

The block diagram of the proposed method for cold chain management in the truck by using ESP32, Temperature sensors, Humidity sensors, LDR Module, GPS tracking system and Telegram Bot is depicted in Fig. 1. By using multiple sensors, the temperature and other values are detected and checked with the optimized value. Using ESP32 the value will be sent to Telegram bot and when there is a change in the current value with the optimized value the bot will receive a message from the ESP32 controllers to the authority; it is user-friendly, with two-way message communication. By using ESP32 the cost for the system is also low and it has inbuilt Bluetooth module.

3.1 Hardware Connection

Instead of connecting all the 16 pins (LCD display) to the ESP32, I2C is used. It reduces the connection of all 16 pins. In I2C there is 16 pins so the pins in LCD is connected to the I2C. From I2C to ESP32 the ground, supply, SDA and SCL are used. SDA (Serial Data Line) is used for data transfer and SCL (Serial Clock Line) is used for clock. From the power supply ESP32 uses 5V and from this ESP32 through I2C 5V is given to the LCD. For all the connections from I2C to Arduino and LCD to I2c the wires used were male to female pins. For power supply and ground for ESP32 normal wires were used. ESP32 can perform as a complete standalone system or as a slave device to a host MCU, reducing communication stack overhead on the main application processor. ESP32 can interface with other systems to provide Wi-Fi and Bluetooth functionality through its I2C / UART interfaces. ESP32 will work in by getting the supply from the battery inside the truck through an inverter. The truck battery has 12V to 24V but ESP32 will get damaged in 12V supply. The nano power temperature sensor (MS1089A), humidity sensor (HS1101) and gas sensor were connected to ESP32. Next, MQ9 sensor was linked to the 5V supply and ground. The MQ-9 sensor's analog output pin and the ESP32's analog input pin can be linked. LDR Module was used to get the intensity range inside the truck to keep the food products safe. The LDR module analog pin was connected to the D18 pin in the ESP32 to get the variable output. The ground and supply of 5V was connected to the LDR, the ground to the earth and the VCC to the supply. Next, the GPS's transmitter pin was linked to the ESP32's receiver pin and the ESP32's transmitter pin to the GPS's receiver pin (Fig. 2).

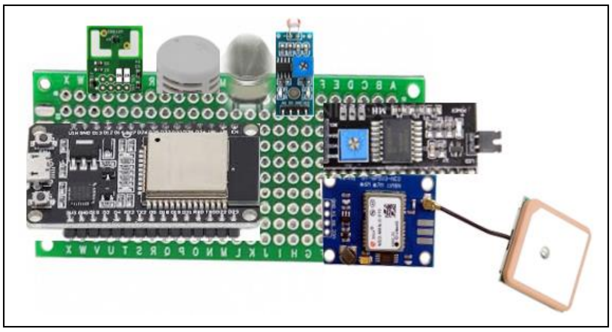

Fig. 2: Integration of sensors with ESP32

3.2 Nano Power Temperature Sensor

To measure the temperature inside the truck nano power temperature sensor called MS1089A can be used. MS1089A is a low-power temperature sensor with I_2C interface. It is available in Chip-Scale-Package (Fig. 4). After the power-up, it will initialize to reset phase in 2.1 ms. For this condition it requires 150 µA. The reset pin will require a supply voltage of 1.6 V. The relation between the supply voltage and reset power voltage is shown in Fig. 3. MS1089A has three resolution temperature measurements: 0.1 °C (11 bit), 0.05 °C (12 bit), and 0.025 °C (13 bit). It has an accuracy range of -0.3 to +0.3 °C from 0 to 60 °C; at this accuracy, the voltage supply can be ≤2.2 V. MS1089 has a temperature measuring range of -40°C to +85 °C. It has the fast measurement time of <30 ms. It will consume zero power in the sleep mode. The peak current during measurement is 70 µA. The average current for one measurement per minute is 27 nA. MS1089 (Fig. 4) has a supply range of 1.8 V to 3.6 V.

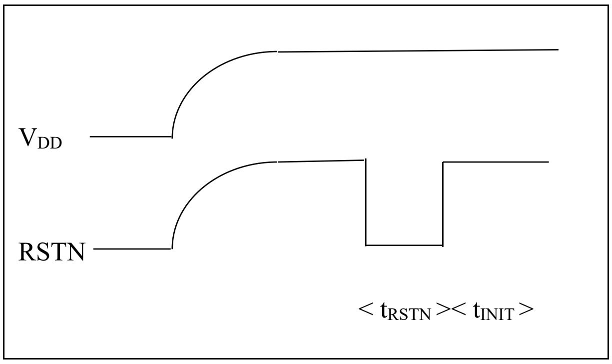

Fig. 3: MS1089A reset with RSTN pin

The resulting temperature data value (TD) from the output was an unsigned 16-bit integer. The actual temperature value is calculated by using the formulae:

$$T(°C) = \frac{TD}{40} - 80$$

$$T(°F) = \left(\frac{TD}{40} - 80\right) \times 1.8 + 32$$

Fig. 4: MS1089A evaluation board

The sensor signals are available on the connectors JP 1 (Jumper 1) and JP 2 (Jumper 2). The use of jumper pins is listed in Table 1.

Table 1: Representation of pins in Jumper 1 And Jumper 2

Pin number	Jumper 1	Jumper 2
1	SCL	TM
2	SDA	RSTN
3	VDD	A0
4	GND (VSS)	A1

3.3 Working of ESP32 with Telegram

In the proposed method, the Arduino IDE software should be installed in the computer and then the library used for MS1089, HS1101, MQ9, etc. A Telegram bot was created *via* Bot Father and the API token for the bot was noted; every bot has a unique API token. A program was written for Telegram Bot in the Arduino software. Also, note the Wi-Fi name and the password were noted for (ESP32 connection). A program for Wi-Fi connection was written and the optimistic value for the particular sensors in the controller used for data checking was initialized. The GPS module was enabled to track the truck movement. All the sensors were integrated with cables through which each change of value will affect each other sensors. The changes in the value were checked with the optimized value. If there are no changes in the sensor value, the ESP32 will continue the process; if there are any changes, it will immediately send the message through the telegram bot. The values and the parameters affected by the change were recorded and reported to the user through the telegram community (Fig. 5). LCD is also used to show the changes to the driver; sending the warning message along with the GPS location will help in finding out the truck that gets changes in the optimized value.

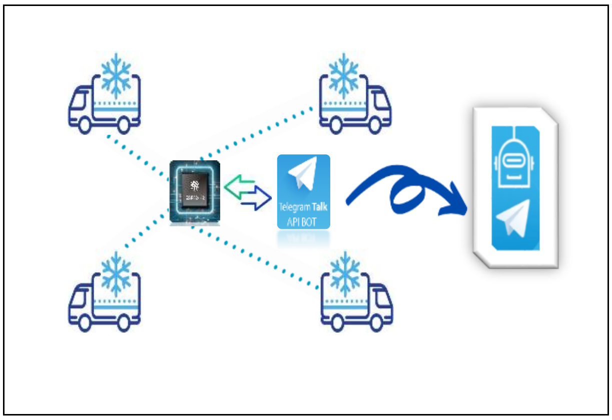

Fig. 5: ESP32 process with telegram bot

4. RESULTS AND DISCUSSION

A fresh Telegram bot was built to create a new bot and navigated to the bot father chat. The bot father /start was given. After a while, the bot father will then respond, giving the choice to either edit the existing bot or build a new one. "Make a new bot" option was chosen from here, and it will prompt, "How are we going to call it? A name was given to a bot. Ripona_bot is the username associated with this bot as shown in Fig. 6. The name "Info-tech" will then be granted. This allows the creation of the bot, and the bot father will respond with the bot's API token.

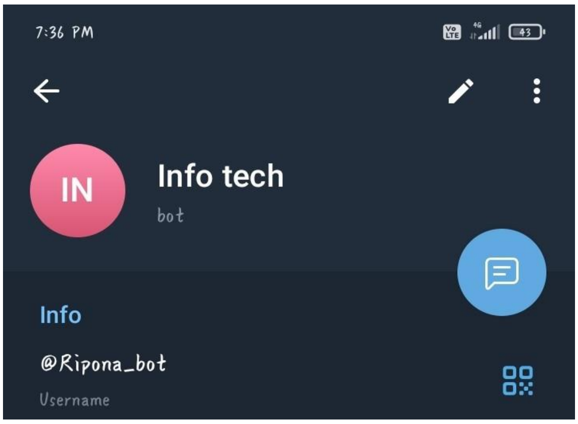

Fig. 6: Telegram Bot created named Info-tech

The collected data from the sensor was sent to the ESP32 (Fig. 7). Through this the data will be checked with the given value in the ESP32. The message will be sent to the authority through the Telegram bot when the parameters get changed. Through ESP32 the data was checked and if there are no changes in the parameter then the checking process will be continued.

Fig. 7: Cold Container with Integrated sensors

The temperature gets changed at every time instant owing to the climatic conditions. Fig. 8 depicts the time variations during winter and summer conditions.

During various summer profiles, the temperature variations are as follows: constant temperature is 32 °C and the summer variation temperature will be 21°C, constant temperature will be 40 °C and the summer profile is same; at 45 °C constant temperature, the summer profile will be 55 °C, for 59 °C constant temperature, 62 °C is the summer profile. After the summer profile, winter profile will exist. For 111 °C constant temperature, 115 °C will be the winter profile. For the constant temperature of 61°C, 62 °C will be the winter variation; for 40 °C constant temperature, 39 °C be the winter variation value; for 34 °C constant temperature, 37 °C will be the winter variation value.

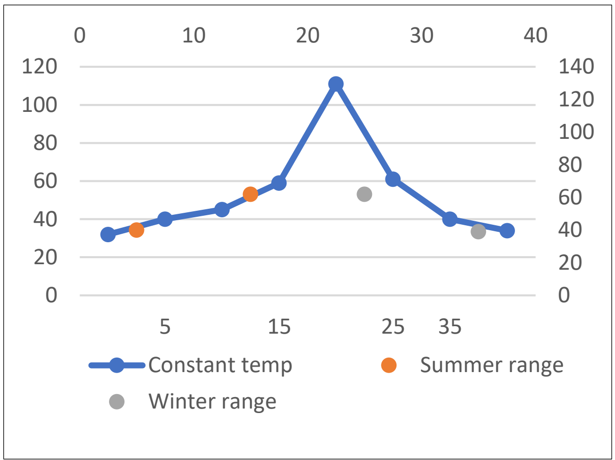

Fig. 8: Temperature changes with various climatic conditions

The temperature ranges for various products are shown in Fig. 9. Fruits have an optimal temperature range of 13 °C, vegetables, 20°C; vaccines have an optimal range of 8°C, dairy products, 5°C, meat, 7°C and pharmaceuticals,8°C. It is important to remember that these are only approximate ranges. Furthermore, elements including ventilation, relative humidity and the presence of fruits and vegetables that produce or are susceptible to ethylene might affect storage conditions.

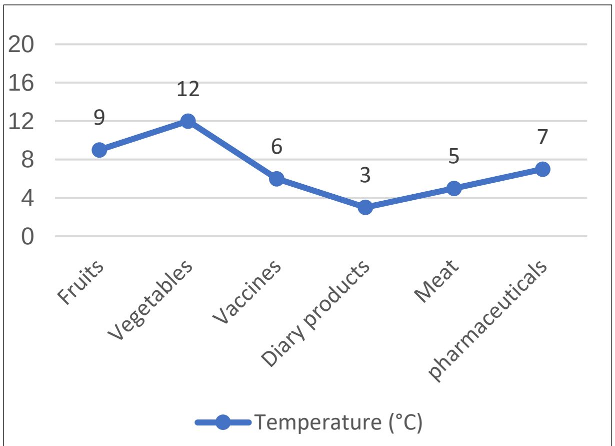

Fig. 9: Temperature ranges for various products

The humidity ranges for varies products is shown in Fig. 10. Fruits have an optimal humidity range of 97%, vegetables, 96%, vaccines, 55%, dairy products, 99%, meat, 96% and pharmaceuticals, 60%. This humidity value has to be maintained to get the proper food products. The humidity for dairy products is high and for pharmaceuticals the humidity ranges are low. If the humidity changes during transit changes, a telegram bot will notify the appropriate authority about the change in humidity.

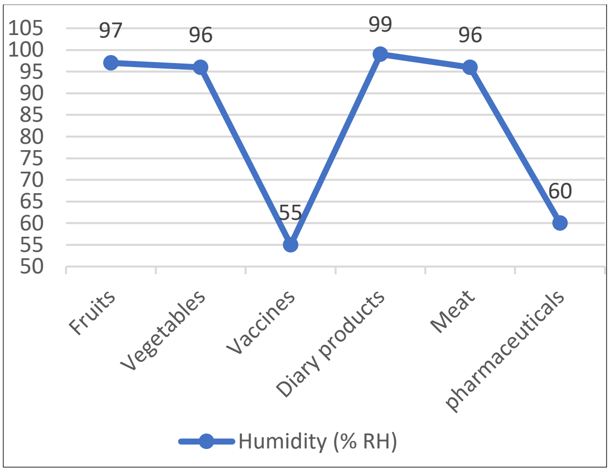

Fig. 10: Humidity ranges for various products

During the changes in the optimum value of the temperature and humidity, the ESP32 will automatically send the message to the authority with the temperature and humidity ranges. During the transportation of the food products, the system will get started and the nano power temperature sensor and humidity sensor start sensing the temperature and humidity inside the truck; it will constantly check the real-time temperature value with the optimized value. If there are any changes with optimized value, the ESP32 will send the message with temperature and humidity range to the authority or the user. The temperature message will be sent like “TEMPERATURE gets changed: 26.30 °C” and the humidity message will send like “HUMIDITY gets changed: 64.10%” (Fig. 11).

Fig. 11: Message of temperature and humidity during changes

There would be a change in the CH4 content according to the changes in the seasonal temperature. CH4 will increase when the temperature increases. In the month of May, the methane content will be 0.061%, in June the methane content will be 0.086%, in July it is 0.131%, in August the methane content will be 0.148%, in September month the methane content will be 0.114, in October, 0.095%, in November, 0.054% and in December month the methane content will be fully reduced to zero. By this the methane content will exponentially increase and decrease according to the seasonal changes. In August month the methane content will reach its peak and in December it drops down to zero (Fig. 12).

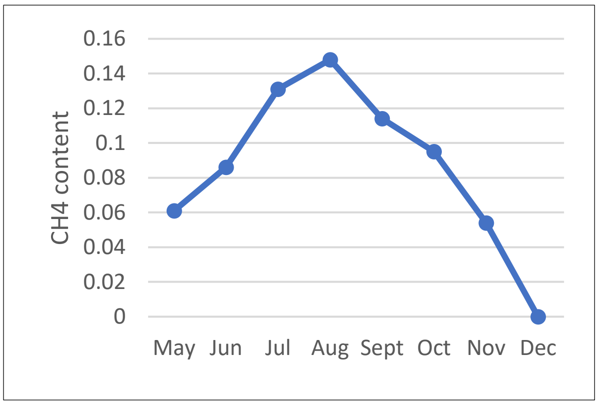

Fig. 12: CH_4 changes with seasonal temperature changes

There will be variations in the CO and CH_4 concentrations due to abrupt shifts. A very dangerous gas called CO will leak out of the truck if it is damaged and it may spoil the products inside the truck. It can be seen by using a serial monitor (Fig. 13). Due to this sudden change, the CO and CH4 content will vary. If it gets damaged the CO which is a very harmful gas will release. If the truck transports any important medicine or any other chemicals, due to the gas leakage the substance gets spoiled and the use of the medicine or products may also cause death. Fig. 13 will show the value of carbon monoxide and methane gas content inside the truck. The optimum carbon monoxide gas will be 9-10 ppm for less than 8 hours shift. Methane will be <1000 ppm.

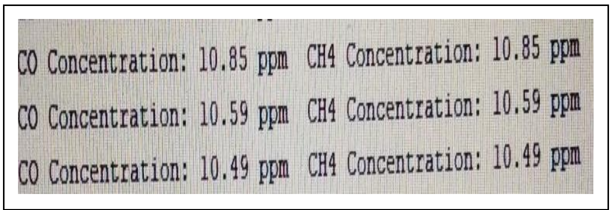

Fig. 13: CO and methane gas indication

If the GPS is not working or if the weather condition is not good, then the GPS will send the message according to the program. If the GPS does not get the satellite signal, then the ESP32 controller will send the message according to the program. If the signal gets lost then the location of the truck cannot be detected. Then if the truck gets lost or any accident happens, the location cannot be detected and there is a great loss for the association. It may represent like "SIGNAL FAILURE" in the Telegram bot according to the condition given in the program (Fig. 14).

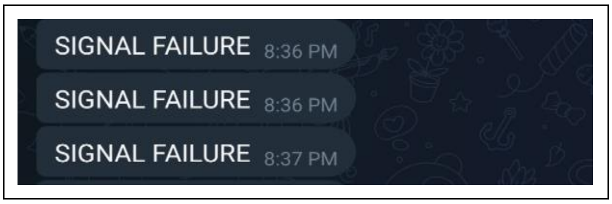

Fig. 14: Message in telegram when GPS location get lost

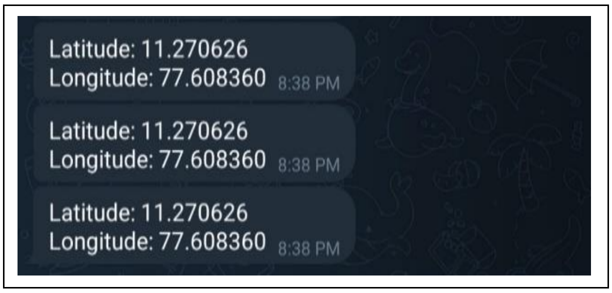

Fig. 15: GPS location with latitude and longitude

Fig. 16: Input from the user and output from ESP32

The ESP32 controller will transmit the message if the GPS detects a satellite signal. It is challenging to locate the position when multiple trucks are traveling in the same area. The precise location of the truck, including its placement and route, may be found by utilizing the latitude and longitude coordinates. The accurate GPS location with latitude of 11.270626 and longitude of 77.608360 will be sent to the user or the authority (Fig. 15). The ESP32 will transmit the location during the changes in the temperature or humidity

The user's input is received by the Telegram bot, which then forwards it to ESP32 (Fig. 16). The reply to a

Telegram bot, a Telegram bot, and a Telegram bot will be sent to the user from this ESP32. When the parameters depart from the optimal value, the ESP32 will deliver a message. If the user provides particular input, it will provide that data. Once the ESP32 gets started, the message will be sent to the telegram bot as "Started". If the user wants to check the temperature content, the message "/temp" will be sent. If the user wants to check the intensity, then "/ldr" has to be typed. If the user type "/gas" then the carbon monoxide and methane range will be displayed in the telegram bot; for "/track", the link with GPS location will be sent to the telegram bot from the ESP32. Then if the user type "/alldata" then all the parameters like temperature, humidity, intensity, carbon monoxide and methane will be displayed.

5. CONCLUSION

This research has effectively created an all-inclusive method for keeping an eye on the critical parameters in cold storage units inside of trucks. The system incorporates various sensors such as gas, nano power temperature, humidity and LDR sensors and uses the Telegram messaging platform for instantaneous communication. This allows the system to efficiently gather data, send automated alerts, and forward crucial information, including GPS coordinates, to the appropriate authorities when thresholds are surpassed or dropped below acceptable values. Users can access and query sensor data remotely, thanks to the bidirectional communication capability, and GPS tracking improves monitoring capabilities. This research additionally shows how nanotechnology plays a major role in everyday life, IoT technologies can be scaled and adapted to improve operational efficiency, lower hazards, and improve freight transportation in dynamic logistics to protect the environment. By this method, one can manage the transport of different types of food products using the trucks by adjusting the threshold values or setting up the parameters at our convenience. This one-time change helps in monitoring the changes in the parameters. This is achieved by enabling an efficient communication system or method.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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