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Real-Time Monitoring System for Transportable Cold Storages

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Abstract: The need of efficient transport is important to maintain product quality and safety for perishable items like food and pharmaceuticals. So, to enhance the integrity of cold chain logistics, Real-Time Monitoring System for Transportable Cold Storages (RTMCS) is given by this paper. The RTMCS includes environmental monitoring sensors with GPS technology, to ensure real-time tracking of temperature, humidity, and geographic location throughout the transportation. By providing the stakeholders with continuous access to the data, the system provides assistance for proactive decision-making and timely interventions to prevent damage and maintaining compliance with safety regulations. Results show that the RTMCS significantly reduces spoilage rates by ensuring that products are consistently kept within specified temperature ranges. The findings highlight the importance of adopting smart monitoring solutions to address the challenges associated with transporting temperature-sensitive goods. Ultimately, the RTMCS presents an innovation in cold chain management, improved accountability, traceability, and product quality during transit while contributing to overall operational efficiency.
Keywords: NodeMCU, WiFi, RC - 522, RFID Reader,smart motion sensors, Buzzer, Led Screen, Attendance Monitoring, IC2.

I. INTRODUCTION

The accurate temperature regulation is essential in cold chain logistics to maintain the quality and safety of perishable goods. This paper presents an economical over-temperature alarm system that utilizes an ANN model combined with multi-source data (MSD), which enhances the detection accuracy while keeping costs low in managing the food supply chain [1]. The distinct logistics requirements of temperature-sensitive products had to be assessed and analyzed for making an advancement in cold chain processes and technologies which aim at maintaining product quality [2]. These advancements will in turn promote sustainability as it reduces spoilage significantly. A specially designed passive RFID tag with copper-doped ionic liquid detects temperature breaches above 8°C during medical shipments, providing an irreversible status change and remaining unaffected by humidity variations [3 It develops a decision-making framework to optimize the cost-effective transport of fresh produce under temperature control, which in turn integrates sustainability into cold chain logistics and helps maintain the quality of food supplement [4]. Cold supply chain logistics can be realized by a system controlled by a microcontroller for adaptive temperature control and real-time condition monitoring. It can also include cloud-based access to data, GPS tracking, and breach detection to ensure product integrity, security, and effective tracking of the vehicle [5]. The substantial loss of perishable fruits and vegetables during storage is primarily due to poor monitoring of critical environmental conditions [6]. This paper offers an IoT-based Real-Time Intelligent Monitoring and Notification System (RT-IMNS) using Artificial Neural Networks for decision-making support with 99% accuracy in commodity classification and outperforming current models in performance. Seaports are central to global logistics, handling a high volume of cargo, including perishables. Maintenance of the cold chain is important to avoid spoilage of sensitive commodities like food, drugs, and chemicals, thus emphasizing the need for accurate temperature and humidity tracking in port logistics [7]. This paper proposes an IoT-based automation system aimed at tracking temperature and humidity in cold chain logistics to maintain product integrity. It evaluates the performance of the system under various scenarios like interference, condensation, and movement, offering useful insights for improving similar systems. This study examines the growing use of portable cold storage systems for perishable products, highlighting their energy efficiency, portability, and flexibility. It also examines the application of phase change materials (PCMs) in such units, their advantages, use, and possible developments in food, pharmaceutical, and health sectors [8]. An intelligent health monitoring system which is designed to track blood pressure and body temperature of the driver or in-charge of the transport can be integrated which can be directed to abate health hazards like hypertensive heart disease or other such disease if there is any [9]. Through integration of GSM and GPS technologies, the system provides real-time tracking and emergency alerts, enhancing patient care and allowing for timely medical intervention in smart cities [10]. A technique is presented for classifying transportation modes based on GPS trajectory data and GIS data, using feature extraction and machine learning classification.

Used on the GeoLife dataset, this method gains 91.1% accuracy, showing how GIS features add to inference precision with little usage of resources [11]. Convolutional Neural Networks (CNN) is one method that will predict transportation methods from raw GPS data, a limitation of earlier machine learning-based models. Through the use of a flexible input layer to extract key motion features, it maintains 84.8% accuracy, outperforming earlier models and being useful for transportation planning and demand analysis [12].

II. LITERATURE REVIEW

Cold chain logistics (CCL) is required for safe transportation as over-temperature alarms provides alert in case the temperature exceeds the threshold value. Existing studies have emphasized increasing the accuracy of models by employing machine learning algorithms such as artificial neural networks (ANNs) with multi-source data (MSD), resulting in high recognition rates (97.4% to 98.6%).Yet such advancements have the propensity of leaving behind the cost of acquiring further information and computationally intensive algorithms. Recent work has started considering the accuracy vs. cost balance, discovering measures such as temperature of food prior to serving and acquisition intervals between data to impact results. There is a need for a more balanced strategy to maximize both performance and cost-effectiveness of temperature monitoring systems within the food supply chain [1]. Cold chain logistics (CCL) is needed to provide for the safe handling of perishable agri-food commodities, temperature being crucial in sustaining the quality of the product. Temperature, respiration, ethylene production, and transpiration affect the freshness and shelf life of products such as fruits, vegetables, and animals. Control of such factors such as ethylene and humidity is important to avoid spoilage. Ideal storage conditions, however, are costly and energy-intensive and hence there is a need to balance product quality, environmental sustainability, and cost-effectiveness [2][3]. Transport of perishable foods requires precise temperature control and real-time monitoring to preserve quality and prevent spoilage. Emerging technologies such as IoT sensors, RFID, and thermal scanning facilitate real-time traceability and tracking, freshening during transport. Although systems that are not temperature-controlled save on costs, they are not effective for hauls over large distances of perishables. Temperature-controlled systems with monitoring capabilities are more efficient but come with higher expenses, providing proactive measures to reduce food loss [4]. Cold chain logistics facilitate the secure transportation of temperature-sensitive products, including dairy, fruits, and vegetables, by maintaining optimal temperature and humidity conditions. Advanced technologies like IoT sensors, GPS tracking, and automated air management systems improve efficiency, reduce spoilage, and enable real-time monitoring. The industry is categorized by services (storage, transportation), temperature ranges (chilled, frozen), and applications (such as horticulture and pharmaceuticals). Modern tools, including cloud-based platforms and mobile applications, enhance tracking, environmental control, and data-driven insights, ensuring product integrity and customer satisfaction [5]. An affordable IoT-driven system designed for real-time monitoring of perishable goods by measuring key environmental parameters such as temperature, humidity, light intensity, and CO2 levels. The collected data is stored in Firebase, processed using an Artificial Neural Network (ANN), and categorized as "good," "unsatisfactory," or "alarming." Alerts are sent to personnel for critical conditions, while an Android application enables remote monitoring and informed decision-making. Through the use of sensors, wireless connectivity, and predictive analytics, the system seeks to enhance cold storage management and reduce spoilage [6]. The use of IoT in cold chain logistics (CCL) notably enhances real-time monitoring and management of temperature-sensitive products IoT applications utilize sensors (e.g., temperature and humidity) to capture data, which is computed in the cloud to provide more exact, scalable solutions with less human intervention. For instance, a system suggested for Istanbul Port utilizes RFID, IoT sensors, cloud technology, and Decision Support Systems (DSS) to enable real-time monitoring and decision-sensitive suggestions. Technologies such as RFID, IoT sensors, and high-quality communication networks (e.g., ZigBee and GSM) enable seamless data exchange. Low latency and high throughput were demonstrated through simulation results. The system enhances traceability of products, minimizes waste, enhances decision-making, and optimizes operation efficiency Despite that, challenges involve high initial investments and problems such as interference in signals. In general, IoT-based CCL systems will be able to render logistics operations more efficient and smarter [7]. The demand for real-time tracking in cold chain logistics (CCL) has increased to preserve product quality and meet customer needs. IoT systems for monitoring temperature and humidity data from warehouses have been designed, whose performance, including factors such as signal strength and environmental conditions, has been thoroughly tested. Such systems are suitable for tracking perishable goods, such as medicines in transit. The shelf life of agricultural produce, such as fruits and vegetables, is based on factors such as moisture level and temperature. Improper storage, especially exposure to elevated temperatures, speeds up spoilage. Various cooling technologies, including forced-air, hydro, vacuum, and sorption systems, are employed to preserve produce, each with its own set of benefits and challenges.

Evaporative cooling offers an environmentally friendly solution for tropical crops but is weather-dependent. Thermal energy storage (TES) systems, which retain energy in the form of sensible or latent heat, play a critical role in cold storage solutions. Vapor-compression and sorption cooling systems are commonly used, with vapor-compression being efficient but dependent on electricity. Sorption systems are more energy-efficient but less effective in cooling. The technoeconomic performance of these systems differs, with hybrid systems improving energy efficiency [8][9].

The proposed smart health monitoring system is composed of two key functional blocks: one for gathering sensory data from the patient and another for processing, storing, and displaying this information to healthcare professionals. Various sensors are used to monitor vital signs such as heart rate, body temperature, and location, with the data being transmitted via GSM networks to healthcare providers. If any significant changes are detected, the system sends an SMS containing the patient's details and location to prompt immediate action, such as dispatching an ambulance. The system's hardware includes a Smart Embedded Board (SEB) integrated with sensors and an Arduino Uno microcontroller for system control. Additionally, a GPS module is used to track the patient's location in emergencies.

The second block consists of a web-based monitoring application for healthcare providers, built using a three-tier architecture to ensure scalability and flexibility. The front-end allows for real-time monitoring, the middle tier processes the data with PHP and MySQL, and the back-end securely stores patient data and alerts in a database for precise tracking [10]. Extracting GIS features plays a crucial role in identifying transportation modes from GPS trajectory data. Two primary approaches are typically used to calculate the distance to the nearest bus and subway stations.

The first approach involves a fast calculation algorithm that divides the city into 500-meter grids, with bus and subway station locations stored within each grid. The algorithm calculates the proximity of the GPS point by creating a 1500m-by-1500m candidate zone, enhancing efficiency by pre-calculating the relevant stations where possible. The second approach uses Point-Of-Interest (POI) query services from online mapping platforms to obtain station information and their distances from the GPS point. Both methods aim to improve the accuracy of transportation mode identification, especially in urban areas where public transit is commonly used [11][12].

VI. METHODOLOGY

The hardware components used in this method are -

1) DS18B20 Digital Temperature Sensor: The DS18B20 is a digital temperature sensor widely used for precise and reliable temperature measurements in various applications. It operates over a wide range of -55°C to +125°C with an accuracy of ±0.5°C in most of its range. The sensor communicates using the 1-Wire protocol, requiring only one data line (and ground) for communication, making it ideal for low-pin-count microcontrollers. It features unique 64-bit serial codes, enabling multiple sensors to connect on a single bus. Low-cost, efficient, and compact, the DS18B20 finds widespread applications in weather monitoring stations, cold storage monitoring, and other embedded systems.

Fig 1. DS18B20 Digital Temperature Sensor

2) XIAO C3 Board (Microcontroller): XIAO C3 is a small microcontroller board, supported by the Espressif ESP32-C3 chip, which is used for IoT and embedded system development. It offers Wi-Fi and Bluetooth Low Energy (BLE) connectivity, which makes it a suitable choice for wireless communication projects. The board has low power usage and compact dimensions, at just 21 x 17.5 mm. It comes equipped with several GPIO pins, SPI, I2C, and UART interfaces and ADC functions for it to interact with numerous modules and sensors. Its Arduino IDE and MicroPython compatibility ensures ease of use even for beginners as well as openness for sophisticated programmers

Fig 2. XIAO C3 Board

3) A9G Board (GPS/GPRS Module): The A9G Board is a small module with GPS and GPRS capabilities which make it particularly well-suited for IoT and tracking purposes. It features a quad-band GSM/GPRS chip for mobile communication and GPS-based tracking.The board provides SMS, voice, and data communication on cellular networks and onboard interfaces like UART, I2C, and GPIO to communicate with microcontrollers or devices. Because of its small size, low power consumption, and the fact that it can be connected in numerous various ways, it is heavily utilized for real-time location tracking, remote monitoring, and smart device projects.

Fig 3. A9G Board

The software components used in this method are –

a) Arduino IDE: The Arduino IDE (Integrated Development Environment) is an open-source software used to write, compile, and upload code to Arduino-compatible microcontroller boards. It is primarily used for IoT projects, prototyping and developing embedded systems among other applications. It supports microcontrollers like Arduino Uno, Mega, ESP32 boards and many others as being applicable by various operating systems like Windows, MacOS and Linux. In addition to this, sensors, modules and other components can be easily integrated because of its vast and prosperous library ecosystem. The Arduino programming language is supported by the IDE, the overall interface is clean and user-friendly, making it easy for both beginners and advanced developers.
b) Flask: Flask is an open-source, lightweight web framework for Python, which allows developers to build web applications quickly and efficiently. Its base rests on the WSGI (Web Server Gateway Interface) and Jinja2 template engine to offer simplicity of use and flexibility for projects ranging from small to large. Because of Flasks modular architecture, developers can select and incorporate extensions for functions like form processing database integration and authentication as required. In addition to supporting scalability for complex applications its minimalist design makes it perfect for novices and projects requiring custom solutions like dashboards microservices and APIs.
c) ThingSpeak: ThingSpeak is an IoT analytics platform that enables users to gather, display, and examine data of real-time from IoT devices or sensors. It provides user-friendly solutions for storing this data in cloud based channels, allowing the users to manage and control their devices remotely. ThingSpeak provides APIs for writing dats and allows MATLAB interaction for sophisticated data analysis and visualization.

The Real-Time Monitoring System for Transportable Cold Storages technology integrates hardware and software components to efficiently monitor and regulate the storage conditions of perishable goods during transportation. Based on the components provided, below is a detailed approach for it,

- The system continuously monitors the temperature inside the transportable cold storage and compares it to predetermined threshold levels. A warning is displayed when the temperature rises above or below the set threshold.
- The A9G module transmits GPS data that tracks and displays the location of the refrigerator truck on a map as also displaying its co-ordinates on the interface.
- A dashboard interface which is developed using Flask, provides a continuous live display of all the necessary data including temperature inside the truck, diesel level as well as the vehicle location.
- The system is designed to notify the appropriate authorities via emails if any of the parameters like temperature or diesel level surpass the predetermined threshold levels set by the user.
- The web application on the internet provides a simple to use interface for monitoring the cold storage conditions and allows users to remotely access data from anywhere.

The Real-Time Monitoring System for Transportable Cold Storages consists of several components to ensure continuous environment monitoring. The XIAO C3 microcontroller controls the data acquisition and transmission, and the DS18B20 sensor ensures precise temperature data. The A9G GPS/GPRS module ensures that the module offers proper position tracking using vehicle location co-ordinate information. Software components like Arduino IDE, Flask, and ThingSpeak ensure seamless data collection, visualization and the generation of alerts or warnings for effective cold storage monitoring. Ensuring the integrity of perishable goods and ensuring proper transportation of them in their appropriate conditions relies on this system.

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VII. RESULTS AND DISCUSSIONS

The system effectively allows real-time monitoring of cold storage environment temperature and diesel levels for safe transportation of perishable products. Temperature and location sensor data are sent to the cloud platform ThingSpeak through the XIAO C3 microcontroller, which also serves as the central processing unit of the system. customers are able to view real-time data, chart temperature trends, and monitor the truck remotely with ThingSpeak. Alerts are generated when the temperature is outside the set limit (either below or above normal levels), thereby instant attention can be provided to ensure the quality of goods while in transit. The web-based application developed through Flask is a front-end to monitor and has a user-friendly interface to display important statistics such as temperature, diesel level, and site. The web-based dashboard is a simple way to view data, receive alerts, and manage a number of cold storages with movable locations real-time, as illustrated in Fig. 4.

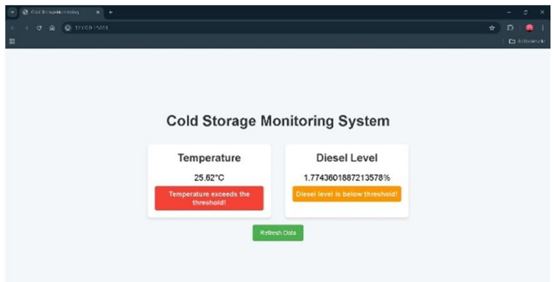

Fig 4. Webpage for real time monitoring

The system provides alerts whenever the temperature crosses set limits or when the diesel level drops below the set limit. The alerts are sent to the affected parties through email, enabling timely actions to avoid any damage to the commodities stored.

Fig 5. Email received to the authorities for low diesel level

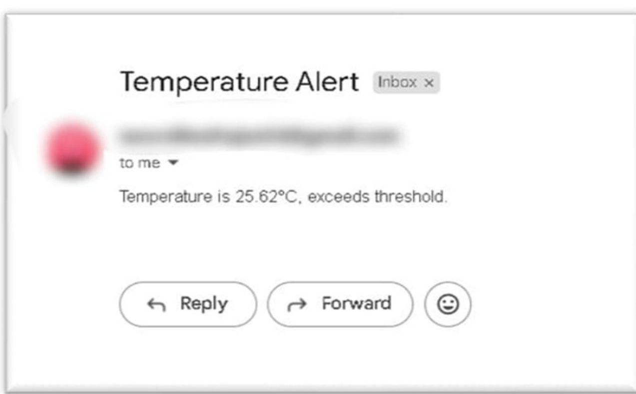

Fig 6. Email received to the authorities for temperature higher than threshold

The Real-Time Monitoring System for Transportable Cold Storages efficiently integrates the hardware and software modules to form an efficient and responsive solution for monitoring the environmental status of perishable products in transit. Through the application of the DS18B20 temperature sensors, XIAO C3 microcontrollers, and A9G GPS/GPRS module, the system offers real-time temperature and location monitoring, maintaining the cold storage environment in the optimal state throughout the transit process.

By using ThingSpeak as the data collection and visualization platform, and a web interface built with Flask for effortless access and monitoring, the system provides an ease of use for operators. When a critical level in temperature or in diesel level is achieved, alarm signals are activated to ensure speedy action to guard against any such compromise in safety of the shipped commodities.Overall, the system enhances efficiency, safety, and reliability of transporting perishable products with optimal conditions of cold storage and real-time information regarding transport status. This is a solution that has potential uses in logistics, food safety, and pharmacy, for example, where there is a need to have certain environmental conditions.

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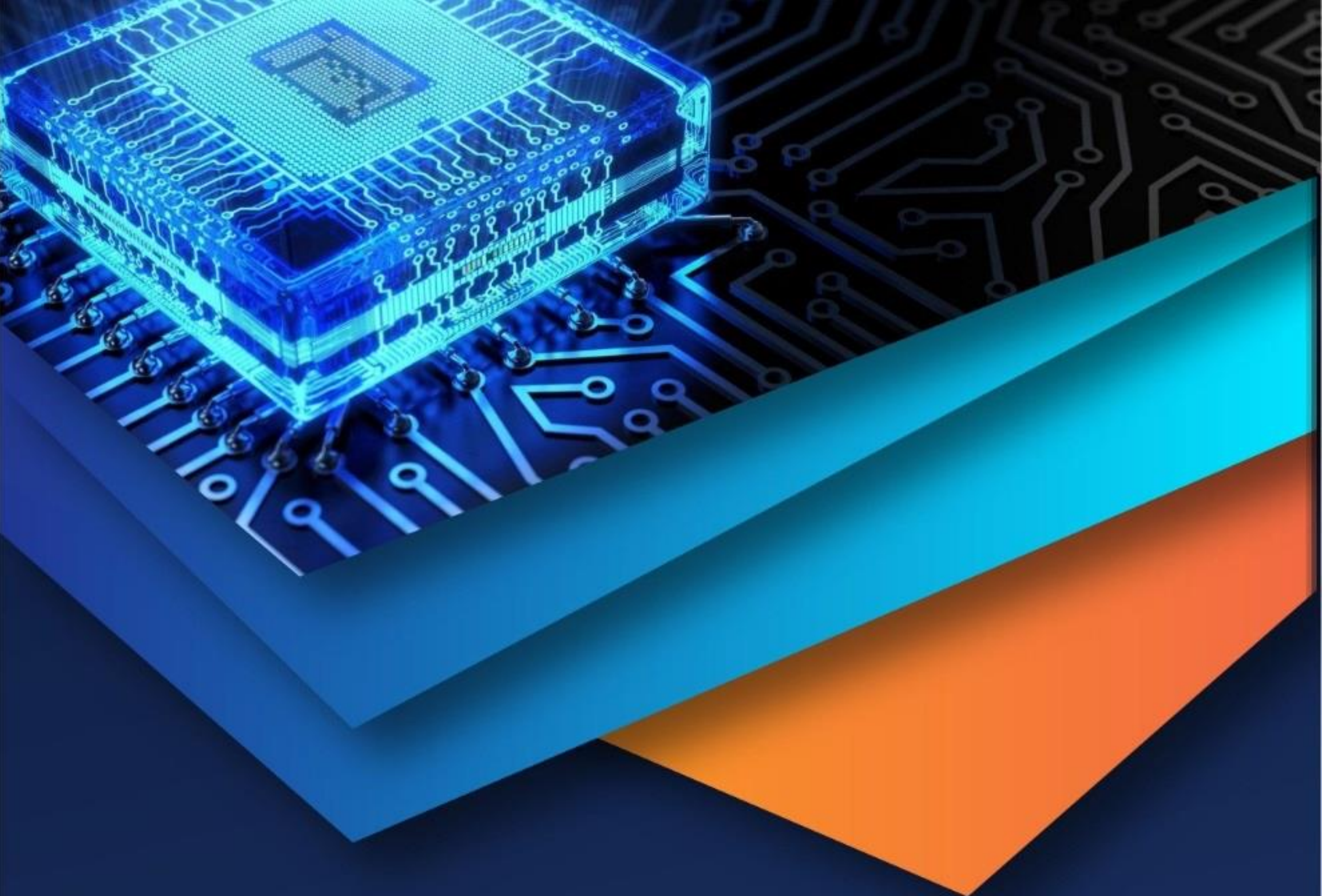

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