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IoT BASED SMART LABEL FOR MEDICINE EXPIRY AND POTENCY PREDICTION

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Abstract: Medicines need proper storage conditions such as controlled temperature, humidity, and light to maintain their safety and effectiveness. In real-world situations, these conditions often vary during transportation and storage, which can speed up the degradation of medicines and reduce their potency before the actual expiry date. To address this issue, the proposed IoT-based smart label system continuously monitors environmental parameters using sensors and sends the data to a cloud platform for storage and analysis. Based on this data, the system estimates the degradation rate and predicts the current potency of the medicine, while dynamically updating its expiry status. Each medicine package is assigned a unique QR code that allows users to easily access real-time information through a mobile application. Additionally, the system generates alerts when storage conditions exceed safe limits. This approach enhances medicine safety, improves storage monitoring, and helps prevent the use of ineffective or degraded medicines.

I.INTRODUCTION

The global pharmaceutical industry is a cornerstone of modern healthcare, providing lifesaving medications that must adhere to rigorous quality and safety standards. However, the efficacy of these medications is not a static property; it is a highly volatile characteristic that is strictly dependent on the environment in which the medicine is stored and transported. Most pharmaceutical products are complex chemical compounds that are susceptible to degradation when exposed to conditions outside their narrow-recommended ranges. While manufacturers provide a "static expiration date", this date is essentially an estimate based on ideal, controlled laboratory settings.

It assumes a "perfect journey" from the manufacturing plant, through various warehouses and logistics providers, to the pharmacy, and finally to the patient's home. In reality, this journey is fraught with environmental fluctuations—extreme heat in shipping containers, high humidity in tropical regions, or excessive light exposure in pharmacies. These factors act as catalysts for chemical decomposition, leading to a "silent crisis" where a medicine may appear valid by the date on its label but has actually lost its therapeutic potency or, in some cases, transformed into toxic byproducts.

This paper introduces are volitionary paradigm shift by integrating Internet of Things (IoT) technology into pharmaceutical packaging. By creating a Smart Label powered by the NodeMCU platform, we enable dynamic, real-time potency tracking that replaces assumptions with data-driven certainty.

Problem Statement:

Traditional medicine labeling systems rely on fixed expiry dates determined under controlled laboratory conditions, which do not reflect real-world storage environments. During transportation, storage, and distribution, medicines are often exposed to varying temperature, humidity, and light conditions, which can accelerate their degradation and reduce their potency before the labeled expiry date. This can lead to the use of ineffective or unsafe medicines, posing risks to patient health. Additionally, there is a lack of continuous monitoring and real-time tracking of environmental conditions in existing systems. Therefore, there is a need for an intelligent solution that can monitor storage conditions, analyze environmental data, predict medicine degradation, and dynamically update the expiry status. Such a system should also provide easy access to real-time information and alerts to ensure proper handling, improve medicine safety, and enhance the overall efficiency of pharmaceutical storage and distribution.

Objective of the Paper:

The objective of this paper is to design and develop an IoT-based smart label system for effective monitoring and management of medicine storage conditions. It aims to continuously track environmental factors such as temperature, humidity, and light using sensors and transmit this data to a cloud platform for real-time analysis. The system focuses on predicting the degradation rate and estimating the current potency of medicines based on actual storage conditions rather than relying only on fixed expiry dates. It also seeks to dynamically update the expiry status and provide accurate, real-time information to users through a QR code-enabled mobile application. Furthermore, the paper aims to generate timely alerts when storage conditions exceed safe limits, ensure proper handling during transportation and storage, enhance pharmaceutical safety standards, and reduce the risk of using expired or ineffective medicines, ultimately improving healthcare reliability and efficiency.

Scope:

The scope of the proposed IoT-based smart label system focuses on monitoring the environmental conditions and stability of individual medicines throughout their storage lifecycle. It uses embedded sensors to track temperature, humidity, and light directly from the medicine package and sends this data to the cloud for analysis. Based on this data, the system predicts the medicine's potency and dynamically updates its expiry date in real time. It provides users with accurate information about medicine safety through a mobile application and generates alerts when conditions become unsafe or potency decreases. The system is designed to be lightweight, low-power, and easily integrated into medicine packaging, ensuring effective, continuous monitoring without affecting usability.

INTRODUCTION

The proposed work introduces an IoT-based smart label system designed to improve the safety and effectiveness of medicines by monitoring their storage conditions in real time. Medicines are highly sensitive to environmental factors such as temperature, humidity, and light, which can affect their stability and potency before the printed expiry date. To address this issue, the system uses embedded sensors within medicine packaging to continuously collect environmental data and transmit it to a cloud platform for analysis. Based on this data, the system predicts the degradation rate, estimates the current potency, and dynamically updates the expiry status of the medicine. Each medicine is linked to a QR code, allowing users to access real-time information through a mobile application. Additionally, the system provides alerts when storage conditions exceed safe limits, ensuring timely action. Overall, this paper aims to enhance medicine safety, improve storage monitoring, and reduce the risk of using degraded or ineffective medicines.

BACKGROUND

Pharmaceutical stability and efficacy verification is a major challenge that directly industry and consumers have relied primarily on a static "best before" or "expiration date" printed on medication packaging at the time of manufacture. While this method provides a basic safety guideline under assumed ideal conditions, it has several limitations. A static date cannot account for actual, real-world storage conditions. Medicines are often exposed to detrimental environmental factors like temperature excursions, high humidity, or light during transit, storage, and within the patient's home, all of which accelerate degradation. The current approach cannot detect this exposure, nor can it provide real-time updates regarding a medicine's true potency. Additionally, it does not offer any dynamic communication support to warn a patient before they ingest an ineffectual or potentially harmful medication. With the rapid growth of embedded systems, flexible electronics, and Internet of Things (IoT) technology, smart pharmaceutical packaging and monitoring devices have become more practical and accessible.

affects patient health and safety. For many years, the IoT allows physical objects—in this case, medicine packaging—to collect environmental data, communicate over the internet, and provide intelligent predictive responses. This technological advancement has opened new possibilities in the field of smart healthcare and stability monitoring, especially for sensitive biopharmaceuticals or temperature-controlled medications. Previous research and developments in this area have focused on environmental data logging, often using large, expensive, and rigid loggers suitable only for whole shipments or large storage units, requiring manual data analysis. However, many earlier solutions lacked individualized tracking, dynamic cloud connectivity for instant processing, and efficient automated alert mechanisms directly targeting the end-user or patient. The IoT Based Smart Label for Medicine Expiry and Potency Prediction is developed to overcome these limitations. By combining individualized micro-sensors (temperature, humidity, light), a wireless microcontroller, advanced cloud-based predictive analytics, and mobile interfaces, the system provides not only detailed environmental monitoring but also dynamic, real-time potency prediction and proactive safety alerts. This integration enhances pharmaceutical safety, improves visibility into actual stability, and increases patient assurance. The background of this paper is rooted in the need to create a reliable, affordable, and intelligent safety system that supports effective medication therapy management. By leveraging IoT technology, the proposed system represents an advancement over traditional static expiration dates and contributes to improving the quality of pharmaceutical care and patient health outcomes.

LITERATURE REVIEW

I.R. Bouazzi, "Medication Cold Chain Improvement by Using IoT-Based Smart Tracking: A Case Study in KSA," Engineering Research Express, 2025.

This paper investigates the use of IoT-based smart tracking to improve medication cold chain management and ensure drug safety. The authors, including Imen R Bouazzi, analyze the limitations of traditional pharmaceutical monitoring systems that rely on manual inspection and fixed expiration dates, which often fail to reflect actual storage conditions. The study explores IoT-enabled solutions that use sensors and wireless technologies to continuously monitor environmental factors such as temperature, humidity, and light during storage and transportation. It discusses how real-time data collection and cloud-based analysis help maintain optimal conditions and generate alerts when deviations occur. Furthermore, the paper highlights the use of predictive models like the Arrhenius equation and machine learning techniques to estimate drug degradation and enable dynamic expiration dates. It also emphasizes the role of QR codes and RFID systems in improving transparency by providing easy access to medicine information and storage history.

B . Pradhan, S. Bhattacharyya, and K. Pal, "IoT-Based Applications in Healthcare Devices," Journal of Healthcare Engineering, 2021.

This paper explains how IoT improves healthcare by enabling real-time monitoring, data collection, and better decision-making through connected devices. It describes a three-layer system where sensors gather health data, communication technologies transmit it, and applications analyze it for monitoring and alerts. IoT is widely used in wearable devices, remote patient monitoring, and smart hospitals, including tracking medicine storage conditions. However, challenges like data security, connectivity, and lack of standardization remain. The proposed system differs by focusing on monitoring medicine conditions to predict expiry and potency rather than patient health.

Rahaman, M. M. Islam, and M. R. Islam, "Development of Smart Healthcare Monitoring System in IoT Environment," SN Computer Science, 2020.

The paper presents an IoT-based smart healthcare monitoring system that uses sensors (heartbeat, temperature, humidity, and gas) connected to an ESP32 microcontroller to collect and transmit real-time patient and environmental data to the cloud. Healthcare providers can access this data remotely, and the system shows reliable performance with less than 5% error. However, the system mainly focuses on patient health monitoring and not on medicine safety or pharmaceutical management. It is also relatively complex and costly due to multiple sensors and does not support features like medicine expiry prediction or storage monitoring. In contrast, the proposed system focuses on monitoring medicine storage conditions such as temperature and humidity to predict medicine potency and dynamic expiry. It uses IoT devices, cloud analysis, and QR-code-based smart labels to provide real-time information, alerts, and improved pharmaceutical safety, making it more suitable for medicine quality management.

Existing System

Traditional medicine stability verification relies on a fixed expiration date printed on packaging, based on controlled laboratory testing and ideal storage conditions. This method does not account for real-world variations. To improve monitoring, electronic data loggers are used in supply chains to track temperature during transport, mainly for bulk shipments. Additionally, passive indicators like time-temperature indicators (TTIs) or vaccine vial monitors (VVMs) show color changes based on exposure to heat over time, but they require manual inspection.

Proposed System

The proposed IoT-based smart label system monitors medicine quality in real time using sensors that track temperature, humidity, and light. Unlike traditional fixed expiry dates, it detects environmental changes at the individual package level to prevent the use of degraded medicines. A microcontroller processes sensor data and sends alerts to a mobile application when unsafe conditions or reduced potency are detected. The system is lightweight, energy-efficient, and easy to attach to medicine packaging. With IoT connectivity and cloud-based analysis, the system predicts remaining potency and dynamically updates the expiration date, allowing users and healthcare providers to monitor medicine safety and storage history in real time.

SYSTEM DESIGN

The IoT-Based Smart Label system for medicine expiry and potency prediction is an advanced solution designed to enhance pharmaceutical safety and ensure the effectiveness of medicines throughout their lifecycle. At its core, the system continuously monitors environmental conditions that can affect medicine stability, using the **IoT Sensor Module**. This module integrates temperature, humidity, and light sensors to collect real-time data, detecting deviations that could compromise medicine quality. The sensors are carefully calibrated to ensure high accuracy and consistency, and their low-power design allows for continuous long-term monitoring. Additional sensors, such as gas or pressure sensors, can be incorporated if required, making the system adaptable to a wide range of pharmaceuticals. By collecting accurate environmental data, the sensor layer provides the foundation for predicting medicine degradation and dynamically updating expiry dates. The **Microcontroller Module** serves as the system's central control unit, receiving raw data from the sensors, processing it, and transmitting it to the cloud platform using reliable communication protocols such as MQTT or HTTP. It also performs basic decision-making by comparing sensor readings against predefined thresholds and triggering

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immediate alerts for any abnormal conditions. This module ensures efficient power management, allowing the system to operate continuously with minimal energy consumption, and supports firmware updates to enhance performance or add new features. Additionally, the microcontroller filters and organizes data to reduce overload, enabling smooth and stable communication between hardware components and cloud services, while handling multiple sensors simultaneously. Once the data reaches the **Cloud Processing Module**, advanced algorithms analyze the environmental readings to determine the impact on medicine stability. This module predicts remaining medicine potency and calculates dynamic expiry dates based on real storage conditions, a significant improvement over traditional fixed expiration labels that assume ideal storage. The cloud platform also detects unsafe environmental conditions and generates instant alerts for patients, caregivers, and pharmacists. It stores historical data to improve predictive accuracy over time, supports real-time processing for immediate response, and ensures secure data handling through encryption and authentication. The **Database Module** complements this by securely storing all medicine and sensor data, including batch numbers, manufacturing dates, original expiry, and environmental readings with timestamps. It integrates with QR codes attached to medicine packages, allowing users to quickly retrieve relevant data, analyze trends, and generate reports for better decision-making. Finally, the **Mobile Application Module** provides a user-friendly interface for patients, caregivers, and healthcare providers to interact with the system. By scanning QR codes, users can access real-time information on medicine potency, dynamic expiry dates, and storage conditions, and receive alerts for any potential hazards. The application supports dashboards to monitor multiple medicines, offline data access, and secure user authentication, making it practical and accessible for daily use. Together, these modules create a comprehensive, intelligent system that not only improves medicine safety but also reduces wastage, supports efficient pharmaceutical management, and empowers users with actionable information. Its scalable, low-power design and cloud connectivity make it adaptable for future enhancements, positioning it as a reliable tool for modern healthcare environments.

RESULTS

Fig. 6.2-Admin Login Page:

Fi. 6.3-Admin Dashboard:

Fig. 6.4-Registered Medicine Details

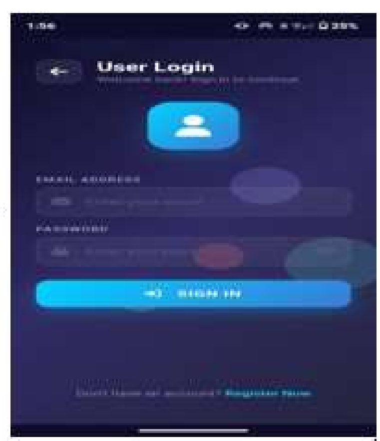

Fig. 6.5-User Login Page:

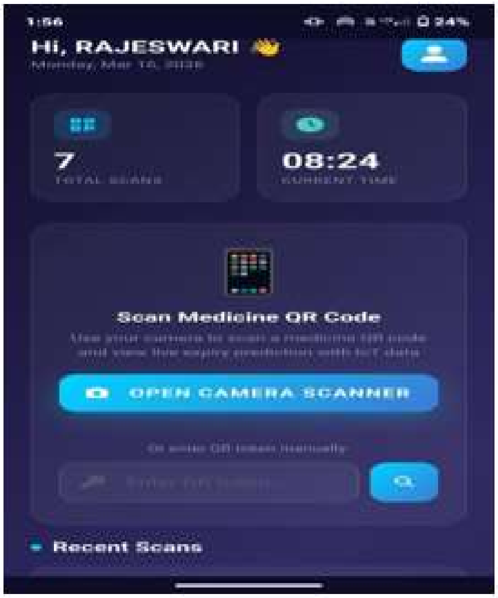

Fig. 6.6-QR Code Scanner

Fig. 6.7-Real Time Shelf life –Safe Conditions:

Fig. 6.8Fig 6.8. Real Time Shelf life –

Unsafe Conditions:

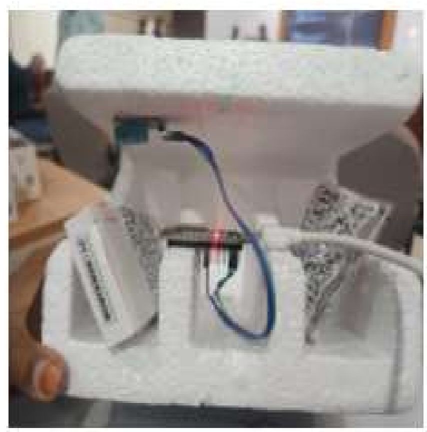

Fig. 6.9. IoT Device:

APPLICATIONS

Real-Time Environmental Integrity Tracking

Real-time environmental tracking is one of the primary IoT applications in this Paper. Embedded sensors continuously capture critical factors like temperature and humidity immediately surrounding the medication, and the wireless microcontroller transmits this data to the cloud. Patients and healthcare providers can view the live storage conditions through a mobile application or web dashboard.

Remote Potency Monitoring System

The smart label constantly collects data through environmental sensors. Using IoT connectivity, this information is sent to the cloud in real time. Advanced predictive algorithms on the cloud platform use this data to calculate the medication's true potency. Users and pharmacists can remotely monitor the integrity and predicted efficacy of the medicine. If conditions deviate severely from safe storage requirements, immediate action can be taken before the medication becomes ineffectual, adding safety layer beyond a local visual check.

Emergency Potency and Safety Alerts

The immediate alert system is a critical IoT-based feature of this work. When the processing layer detects a severe breach in storage conditions (such as a temperature excursion) or when the predictive models determine that potency has fallen below a safe threshold, an emergency alert is generated instantly. This critical information is transmitted via the cloud to the patient's mobile application and to healthcare contacts. This real-time communication capability ensures a faster response—such as replacing the medication—significantly improving patient safety.

Cloud-Based Pharmaceutical Data Storage and Analysis

All-important data, including detailed environmental exposure logs, historical potency predictions, and emergency records, is stored securely on a cloud platform. This allows stakeholders to access information anytime and ensures that a complete audit trail of the medication is not lost. The stored data can also be analyzed by manufacturers and supply chain managers to identify vulnerabilities in handling, optimize storage guidelines, and improve dynamic shelf-life models over time.

FUTURE SCOPE

Although the proposed system demonstrates effective performance, several improvements can be implemented in future versions. Machine learning algorithms could be integrated to improve the accuracy of degradation prediction models. Blockchain technology could be used to create tamper-proof records of medicine storage history. Additional sensors could be added to monitor environmental factors such as air quality and vibration. Integration with pharmaceutical supply chain systems could allow monitoring of medicine conditions during transportation. The system can be further enhanced by integrating advanced data analytics for better decision-making and long-term trend analysis. Artificial intelligence techniques can be used to provide personalized recommendations for optimal storage conditions. The system can be expanded to support large-scale deployment in hospitals, pharmacies, and warehouses for centralized monitoring. Integration with automated control systems can help in adjusting temperature or humidity levels automatically when unsafe conditions are detected. In addition, the mobile application can be improved with features like voice alerts, multilingual support, and user-friendly dashboards. Cloud security can be strengthened using advanced encryption techniques to protect sensitive data. The system can also be connected with wearable or smart devices for instant notifications. These improvements will make the system more intelligent, scalable, and efficient in ensuring medicine safety and quality.

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