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IOT FOR EFFICIENT VACCINE TRANSPORTATION AND MONITORING

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Abstract : Maintaining vaccine potency and guaranteeing successful immunization depend on efficient vaccine transportation and monitoring. Temperature swings, delayed anomaly identification, and a lack of real-time monitoring are some of the issues that traditional vaccine transport methods frequently encounter and can cause vaccine spoiling. This research integrates automated temperature management, real-time environmental monitoring, and cloud-based data access to offer an Internet of Things (IoT)-based solution to improve vaccine transportation. The technology transmits data to a secure cloud platform for immediate access while continuously monitoring temperature, humidity, and location. Temperature variations are adjusted by an automated cooling system, guaranteeing ideal storage conditions. Remote monitoring is made possible by a specialized mobile application, and in the event of network problems, a dual-alert system offers immediate notifications through both the app and SMS. Through the use of cloud computing, IoT, Using IoT, cloud computing, and real-time alarm systems, this solution strengthens cold chain management, decreases waste, and increases vaccine delivery reliability. Consequently, this enhances global immunization initiatives.

INTRODUCTION

As extremely delicate biological products, vaccines must be transported at a precise temperature to preserve their effectiveness. The majority of vaccinations should be kept between 2°C and 8°C, according to the World Health Organization [1], since exposure to extremely high or low temperatures might result in decreased effectiveness and waste. Conventional vaccine delivery systems frequently depend on manual monitoring and passive cooling techniques, which are vulnerable to logistical difficulties, equipment failures, and human mistake. According to studies, poor storage and shipping conditions result in the wastage of around 25% of vaccinations [5]. These inefficiencies show how urgently a cutting-edge, technologically driven solution is required to guarantee accurate environmental control and real-time monitoring.

By incorporating automation, cloud computing, and smart sensors into vaccination delivery systems, the Internet of Things (IoT) provides a revolutionary solution to these problems. Continuous temperature, humidity, and location monitoring is made possible by IoT-based solutions, which send real-time data to a cloud-based platform that can be accessed via a mobile application. Temperature fluctuations are controlled by automated cooling systems, and prompt action is guaranteed even in places with poor network coverage thanks to a dual-alert system that combines SMS alerts and mobile app notifications [2]. Furthermore, blockchain technology and GPS monitoring improve supply chain security and transparency by thwarting illegal handling and vaccine theft [3].

This project aims to enhance the reliability and efficiency of vaccine distribution by developing an Internet of Things (IoT)-based vaccine transportation and monitoring system. The proposed solution leverages real-time tracking, automated temperature regulation, and predictive analytics to minimize temperature fluctuations and reduce vaccine wastage. Successful implementation of this advanced technology will strengthen global cold chain management, ensuring the safe and efficient delivery of vaccines to healthcare facilities worldwide.

In order to preserve the effectiveness of vaccines during shipment, rigorous temperature control is necessary. The World Health Organization [WHO], 2021 states that traditional vaccine logistics systems frequently encounter issues such temperature swings, a lack of real-time monitoring, and delayed intervention, which can result in vaccine spoiling. According to studies, incorrect handling and temperature variations result in the waste of around 25% of vaccines [4]. According to WHO (2021), vaccines should be stored between 2°C and 8°C because even little temperature variations might reduce their effectiveness. To improve vaccine transportation efficiency, a technology-driven strategy is required because manual monitoring and passive cooling systems are unreliable and subject to human mistake [6].
Real-time tracking, automatic temperature management, and remote monitoring are made possible by the Internet of Things' (IoT) integration in vaccine delivery, offering a creative solution. The temperature, humidity, and location are continuously measured by IoT-based systems using smart sensors, which send the data in real time to a cloud-based platform for remote access [2]. When temperatures change, an automated cooling system modifies the environment to keep it within the ideal range. Furthermore, even

in places with spotty network coverage, a dual-alert system that combines SMS alerts and mobile app notifications guarantees prompt action [3]. These developments minimize financial losses, improve supply chain security, and lessen vaccine deterioration.

For the purpose of increase cold chain efficiency and guarantee the safe and dependable delivery of vaccines, this project attempts to design and assess an Internet of Things-based vaccine transportation and monitoring system. The suggested solution improves vaccination security, transparency, and traceability by combining blockchain technology, smart sensors, cloud computing, and GPS tracking. According to preliminary research, IoT-driven systems greatly enhance cold chain management, real-time reaction, and temperature adjustment [9]. Predictive analytics powered by AI may be investigated in future studies to better optimize vaccination delivery and save energy usage. By ensuring that vaccines remain effective from production to administration, the implementation of IoT-based vaccine logistics can help to boost international immunization programs.

The goal of this project is to create an Internet of Things (IoT)-based vaccination transportation and monitoring system that guarantees automated control mechanisms, improved cold chain efficiency, and real-time temperature tracking. Conventional vaccine delivery methods frequently experience temperature fluctuations, human error, and intervention delays, which result in vaccine deterioration and decreased effectiveness [1]. This system seeks to continually monitor environmental conditions and send real-time data to a cloud-based platform by combining smart sensors, cloud computing, and GPS tracking. This will allow for remote access and prompt intervention [2]. Furthermore, an automatic cooling system will be put in place to dynamically control temperature variations and lessen the need for human monitoring [4]. Blockchain technology will be utilized to produce tamper-proof records of vaccine transportation, prohibiting unlawful handling and guaranteeing traceability, in order to improve security and transparency [3].

LITERATURE SURVEY

2.1 Cold Chain Management by Hand

Conventional vaccine delivery methods are based on manual cold chain management, in which logistical staff and medical professionals keep an eye on temperature conditions and periodically document them. In order to maintain their effectiveness, vaccines need to be stored and delivered between 2°C to 8°C, according to the World Health Organization [1, 4]. It shows that manual monitoring is quite vulnerable to misreporting, human error, and delayed intervention when temperature swings occur. Moreover, vaccine waste results from temperature breaches that happen during transportation but are frequently missed until the vaccinations arrive at their destination.

2.2 Temperature sensors and data loggers

Temperature sensors and data recorders have been widely used to enhance temperature monitoring. Temperature variations during transit are captured by these devices. Electronic temperature monitoring devices (ETMDs) aid in preserving past temperature data, enabling medical professionals to examine variations [2]. The fact that these technologies do not offer real-time alerts the collected data is only examined after transportation is a significant disadvantage, though. Vaccines are susceptible to spoiling if there is a temperature breach during transportation because there is no quick fix.

3. GPS-Powered Monitoring Devices

GPS tracking technology is used by several vaccine distribution systems to keep an eye on vaccine shipments. These technologies aid in tracking cargo delays, optimizing routes, and guaranteeing on-time delivery. [3] claim that by increasing supply chain transparency, GPS-based vaccine tracking has greatly enhanced logistics. Not withstanding its advantages, GPS by itself is unable to monitor temperature, thus vaccinations may still be exposed to hazardous situations undetected. Additionally, GPS tracking necessitates consistent internet access, which is not always possible in rural or isolated locations.

4. Blockchain for Transparency in the Vaccine Cold Chain

Blockchain technology is being investigated to improve vaccination logistics security and transparency. Blockchain guarantees that temperature records, transit histories, and handling conditions cannot be changed or misrepresented by storing data on an immutable ledger.[6] Blockchain-based vaccine monitoring systems, improve accountability by giving all parties involved (manufacturers, distributors, and healthcare practitioners) access to verifiable records of vaccine conditions. This is particularly helpful for guaranteeing adherence to legal requirements and stopping vaccine fraud. However, integrating blockchain technology with the current healthcare infrastructure is difficult because to its high computational resource requirements.

Challenges and Future directions

High implementation costs, network dependence, cybersecurity threats, infrastructure integration problems, and data privacy issues are some of the obstacles facing IoT-based vaccination delivery. Obstacles include sensor accuracy, environmental sustainability, and regulatory compliance. Cost-effective IoT solutions, blockchain for safe data management, AI-driven predictive analytics, and hybrid connectivity for remote monitoring are the main areas of attention for the future. Efficiency can be increased using sustainable solutions like smart packaging and solar-powered refrigeration. For adoption to be smooth, international regulations must be standardized and in line with WHO and CDC recommendations. AI, blockchain, and cloud-based IoT are highlighted as being crucial to revolutionizing vaccination logistics in studies [2,4].

PROPOSED METHODOLOGY

For vaccinations to remain effective and avoid spoiling, proper shipping is essential. Using the NodeMCU microcontroller, our Internet of Things-based vaccine transportation and monitoring system offers real-time tracking and environmental monitoring across the vaccine supply chain. The system continually monitors vaccine storage conditions while in transit by combining temperature and humidity sensors, GPS modules. This keeps them from being exposed to adverse circumstances that can lessen their effectiveness [1]. Sensor data is processed by the NodeMCU microcontroller, which is well-known for its integrated Wi-Fi connectivity, and then sent to a cloud-based platform like Firebase or AWS IoT [10]. This enables real-time remote monitoring,

allowing logistics teams and healthcare professionals to track shipments, identify temperature changes, and take preventative action. By ensuring that all data is safely stored, cloud storage facilitates trend analysis and boosts supply chain effectiveness [15].

When conditions surpass safe limits, this system's real-time alarm mechanism automatically notifies users by SMS and an app [7]. Stakeholders receive rapid alerts in the event of a temperature variation, security breach, or mishandling, enabling prompt remedial action. This prompt action guarantees that vaccines get at their destinations in ideal conditions and helps prevent vaccine waste [11]. Proactive decision-making is made possible by machine learning algorithms that use previous data to forecast temperature variations, transit delays, or system faults [7]. Blockchain technology can also be utilized to provide a transparent and impenetrable vaccine supply chain, guaranteeing authenticity and adherence to GMP and WHO guidelines [14].

The NodeMCU-based system is a perfect choice for vaccine transportation in both developed and distant places because it is both affordable and scalable [12]. The system's Wi-Fi connectivity and low power consumption allow for dependable real-time monitoring at low operating expenses. Alternative communication modules like LoRa or GSM can be incorporated to provide continuous data transfer in areas with poor internet connection [12]. This system offers a complete, effective, and safe solution for vaccination transportation and monitoring by combining blockchain, cloud computing, IoT, and predictive analytics. It guarantees that vaccinations stay viable until they get to their destination, reduces vaccine waste, and improves supply chain transparency. By greatly enhancing worldwide vaccine logistics, this invention supports immunization campaigns and protects public health [1].

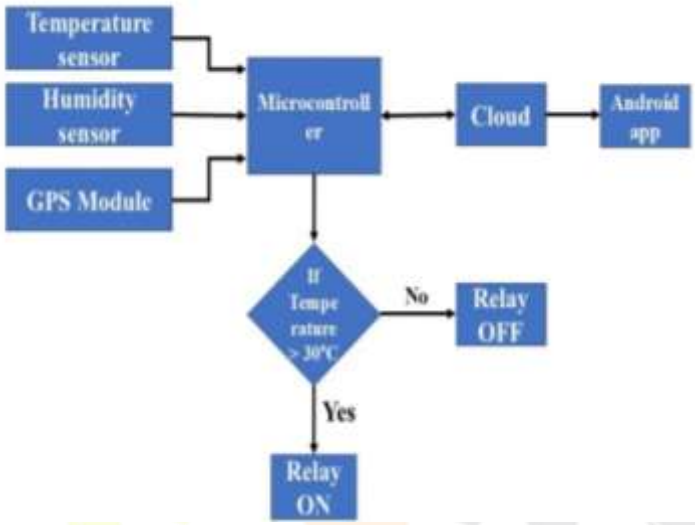

Figure-1. flow chart for system design

CONCLUSION

In conclusion, the system successfully ensured the safe storage and real-time tracking of vaccines during transit. By maintaining stable temperature conditions and providing continuous environmental monitoring, the system helped prevent potential vaccine degradation. The integration of real-time data transmission and alert mechanisms enhanced transparency and allowed for immediate interventions in case of deviations. Despite minor issues like power consumption and sporadic network delays, the vaccine transportation and monitoring system proved to be an effective solution for protecting temperature-sensitive medical supplies.

Suggestions for the future by establishing a tamper-proof, decentralized ledger for storing temperature logs, location data, and warnings, blockchain integration can improve data security, transparency, and traceability. In addition to preventing data manipulation and guaranteeing adherence to legal requirements, smart contracts may automate checks and sound an alarm in the event that circumstances change. Real-time monitoring would also be possible in remote locations because to the development of communication technologies like LoRa (Long Range), which would allow for low-power, long-distance data transfer. The scalability and robustness of the system would be greatly increased by using satellite-based communication as a backup, which would further guarantee dependable data delivery in areas with inadequate mobile network coverage.

RESULT AND DISCUSSION

The vaccine transportation and monitoring system successfully maintained storage conditions and enabled real-time tracking. Temperature stability was consistently achieved, ensuring vaccines remained within the required range. The system responded promptly to fluctuations, restoring optimal conditions within a short period. Monitoring of environmental factors such as ambient temperature and humidity provided a comprehensive assessment of storage conditions, ensuring vaccines were not exposed to adverse environments.

Real-time data transmission allowed continuous monitoring, enabling stakeholders to track vaccine transportation efficiently. The system provided accurate location updates, ensuring transparency and security throughout the journey. Notifications and alerts were delivered reliably, even in areas with limited connectivity, allowing for timely interventions when needed. This ensured that any critical deviations in temperature or environmental conditions were addressed before affecting the vaccine's integrity.

While the system performed effectively, some challenges were identified. Power consumption was slightly higher than expected, indicating a need for optimization in energy efficiency. Occasional delays in data transmission were observed in low-connectivity areas, which could be improved by integrating backup storage to preserve data until synchronization is restored.

Figure-2. output image of android app

Figure-3. SMS notification alert

REFERENCES

[1] World Health Organization (WHO), 2021. Guidelines on the international packaging and shipping of vaccines. WHO Press.

[2] Kumar, D., & Verma, A., 2021. Cloud-enabled IoT monitoring for vaccine storage systems. Journal of IoT and Healthcare, 7(4), 205-21.

[3] Singh, R., Malhotra, P., & Roy, S., 2022. Blockchain and IoT in vaccine logistics: Enhancing transparency and efficiency. Journal of Emerging Technologies in Healthcare, 15(1), 33-50

[4] Pathak, R., Singh, P., & Kumar, A., 2022. Cold chain management of vaccines: Challenges and technological advancements. Journal of Healthcare Logistics, 10(2), 45-58.

[5] Sharma, V., & Gupta, R., 2020. IoT-based monitoring solutions for vaccine cold chain logistics. International Journal of Smart Healthcare, 8(1), 112-126.

[6] Patel, M., & Roy, N., 2023. Securing vaccine supply chains with blockchain and IoT. Journal of Medical Technology, 9(2), 122-138.

[7] Sharma, L., Gupta, M., & Raj, K. (2022). Real-time alert systems in vaccine logistics: An IoT-based approach. Smart Healthcare Technologies, 7(3), 112-129.

[8] Jain, S., & Kumar, V. (2022). LoRa and GSM-based vaccine transportation monitoring in low-connectivity areas. Wireless Sensor Networks, 10(1), 67-80

[9] Chen, H., Li, X., & Zhang, Y., 2021. Predictive analytics in IoT-driven vaccine transportation. Smart Healthcare Systems, 14(3), 75-92.

[10] Ali, M., Khan, S., & Ahmed, R. (2021). IoT-enabled monitoring of vaccine cold chain logistics: A real-time approach. International Journal of Smart Healthcare, 3(2), 45-58.

[11] Khan, R., Patel, N., & Singh, A. (2021). Smart vaccine logistics using IoT and real-time tracking. IEEE Transactions on Healthcare Technology, 12(3), 98-110.

[12] Rahman, T., Alam, M., & Chowdhury, S. (2021). Cost-effective IoT-based vaccine monitoring system using NodeMCU. Sensors and Healthcare IoT, 8(2), 54-72.

[13] Patel, S., & Singh, D. (2020). AI-powered predictive analytics for cold chain logistics. International Journal of Artificial Intelligence in Healthcare, 5(1), 87-102.

[14] IBM (2021). Blockchain for healthcare and supply chain transparency. IBM White Paper.

[15] Gupta, P., Verma, R., & Sharma, A. (2020). Cloud-based vaccine transportation tracking using IoT: A case study. Journal of Medical Technology, 15(4), 123-137.