Low-Cost Monitoring Device for Cold-Chain using Edge Computing

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***Abstract*—The cold chain suffers from a lack of reliability and operational safety. This problem poses risks to the pharmaceutical industry and human health, affecting supplies and vaccines. To improve this scenario, it is necessary to invest in new products. An arising possibility was to unite emerging technologies to propose a safe, efficient and low-cost solution. To address this challenge, it was necessary to research and unite processing devices and Bluetooth Low-Energy sensors in a solution that uses Edge Computing to locally process the data, and connect to the internet only when sending any remote problem alert to the manager's Telegram®.**

Keywords: Low Cost, Cold Chain, Monitoring, Telemetry, Efficiency

I. Introduction

The cold chain has this name due to the need for continuous refrigeration throughout the entire supply chain, which is crucial to maintain the quality, efficiency or physical and chemical properties of the product, raw material, substance or agent. A large part of the cold chain is made up of the food network, which suffers from the same problem as the pharmaceutical network: the lack of adequate temperature control when transporting or storing thermolabiles. Several studies show this adversity, both in the food network and in the transport of medicines. Although some propositions are made with the purpose to mitigate or improve the scenario, all of them are based on the need for continuous monitoring of the temperature of products as a decision support protocol against the need to act quickly to avoid losses [1]–[11].

The cold chain is responsible for transporting and storing thermally sensitive items, from their manufacture to consumption. Such elements can lose their properties when exposed to inappropriate temperatures for a specific time. Some of these products are easily compromised, especially vaccines and drugs. However, the cold chain is not restricted to the pharmaceutical industry, the transported products can be food, chemical products, viruses, bacteria, biological material for laboratory tests, blood bags, breast milk bags, etc.

This flow of refrigerated items has been modernized in recent years, as a result of technological advances, mainly linked to the Internet of Things - IoT. According to Robertson, between 2004 and 2016 there were numerous advances and innovations that led to new technologies for cold chain equipment. However, the technologies mentioned by the author are intrinsic to the operation of freezers and transport boxes, making this equipment more suitable for sensitive medications. This represents a major advance in equipment quality and loss prevention. However, there is a large cost involved in this security [8].

There are numerous national and international entities that aim to standardize the cold chain, establishing rules and criteria of good practices to avoid damage to the transported material. Among the main standards and legislation governing refrigerated supply logistics are NBR 14701, RDC 360, RDC 318, RDC 430, 21 CFR 205.50, 21 CFR 203.32, 21 CFR 203.36, 21 CFR Part 11, 21 CFR 211.150 and ISTA 2 .

A study carried out in 2017 on the panorama of the cold chain in Brazil showed that, in the evaluated scenario, the country has a great lack of transport capacity for these materials, with an estimated deficit of 38.5 Mm^3 in 2014. Another important point highlighted by the study is the incompatibility of the average temperatures found in the transport procedure, being up to 12 °C below what the NBR 14701 legislation determines for the type of transport analyzed [3]. In another study, this one carried out in São José do Rio Preto, showed that in 2017 almost 60% of the doses of vaccines in the municipality were lost [12].

Many technologies available on the market are inefficient or outdated, some of which require the user to continuously monitor in order to find important variations in the system, as they do not incorporate alarms. Others need to be connected via Universal Serial Bus - USB to download the internal data and then evaluate what happened. Another class of solutions requires a high technical level, as they have communication interfaces that are not widespread, such as RS-485 Modbus.

The user evaluates numerous aspects when choosing a monitoring product. Among the relevant points in a feasibility analysis, the following questions stand out:

- Will help identify hidden losses?
- Is the product easy to manage?
- Is it necessary to inspect the operation?
- Does it meet National Health Surveillance Agency (Brazilian) - ANVISA criteria?
- Will it help to better control the quality of processes and products?
- Will it reduce the loss of sensitive inputs?
- What is the reliability?
- What is the response time to problems?

The cost of acquiring a solution that meets the minimum expectations is around R$40 to R$600 per month, for a single measurement point. There are solutions that do not add monthly fees, however, in these cases there are two types of product: generic equipment without origin (brand) that delivers a good cost but does not add security to the customer; the second equipment is normally a Programmable Logic Controller - PLC from a well-known company, however, these equipments require a high investment, both for acquisition and maintenance, in addition to being more invasive and less focused on IoT.

The aspects that concern the maintenance of these systems are inherent to each technology adopted. Today there is no system on the market that does not have a monthly fee and maintenance is simple or intuitive. As for solutions that require monthly fees, maintenance is included in this package.

The technical knowledge to operate, install and calibrate these devices is a major obstacle for the team that will use them. These points need to be improved, which creates a gap in the market for something simple, so that an employee without any technical training can be able to solve.

The scenario of technological development in the cold chain is still very incipient, fragile and with several opportunities for improvement. Among the problems involved in this field are the simplicity of installation and maintenance, which makes the customer choose to hire a company to manage this system, mainly due to their technical know-how. Another factor that is widely prevalent in existing solutions is the high cost inherent in the implementation and continuity of monitoring services, a point that is consistent with the motivation that leads to the low rate of monitored equipment. Among the existing solutions on the market, no one was found that consists of approaches aimed at simplifying the operation, installation, maintenance, operation, calibration and data traffic, or any open source initiative using edge computing and IoT.

For the development of a technological proposal in order to fill the existing gap, developing methods that simplify and redeem this scenario isochronically, taking more modern and efficient technologies to meet the repressed demand. Assessing the high prices and low technological level, it is essential to develop a solution that aims to condense this knowledge into a simple, efficient and safe product.

II. Bibliographic Review

There are several related works that share perspectives of monitoring and bringing more security to processes that involve the transport and storage of thermally sensitive materials. Such research involves several distinct concepts and technologies that have evolved as a result of technological advances. Driven by market needs, these solutions seek to solve the same problem, under the most diverse perspectives and priorities, making each one of them a unique monitoring perspective.

In the article entitled ”Internet of Things Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention”, the author brings a proposal that combines monitoring and safety as a strong point of the proposed project. Despite not bringing many details about the hardware used or the embedded software (tangible solution), the author managed to develop a proposal for a highly secure system. However, the model presented does not show signs of reuse, is limited to load monitoring, depends on a constant reading system by an operator, does not issue remote alerts, does not issue reports and contains several other limitations for a continuous monitoring system [10].

One of the first solutions for remote monitoring was the use of a controller connected to a cell phone. The proposal was to use the microcontroller to take temperature readings and communicate with the cell phone through specific protocols, making use of the device’s connectivity to send temperature data through Short Message Service - SMS messages to the user. The use of SMS messages comes up against the difficulty of scheduling, due to the high cost of maintaining a set of telephone lines. This issue does not occur in solutions that use Wi-Fi for information traffic. This scenario shows that SMS would be a more attractive solution only for transporting materials. A study along these lines was carried out by researchers at the University of Washington in 2012. This allowed for the advancement of several researches and was a fundamental step towards reaching the most modern concepts of the Internet of Health Things - IoHT. Soon this data sending feature became obsolete and is rarely seen in the consumer market [13]. Under the vision of Zhou, L. and Chakrabartty, S. [14], who developed a passive system entirely powered by Radio-Frequency IDentification - RFID tags, the use of a self-powered system, in the form of tags similar to those used in cards, would be sufficient. access or general consumer products. This system brings a substantial gain in terms of cost, ease of installation and operation, however, it is not possible to have remote monitoring, alarms, history, and numerous other essential tools for a continuous monitoring system.

In a work that evaluates the use of automatic reading devices, carried out in the southeast of Burkina-Faso and later another carried out in Albania, it shows the use of a ”data logger” system from the manufacturer Testo together with a second reader, this one from Fridge-tag, manufactured by Berlinger. Both are world-renowned products manufactured for drug monitoring. Both are endowed with similar features, have an internal battery that powers the product and this performs the reading and recording of information in its internal memory, which can later be connected to a personal computer for data transfer. Despite being robust equipment, known worldwide, some points weaken the better adherence of this product on a larger scale. Some of these points are: High implementation cost, a relatively specific niche, none of these systems have a remote alarm or intelligent connection with a monitoring center, which weakens the entire issue related to operational safety as it would avoid the loss of high-value inputs [15] [16] .

In other research, the authors try to develop or adapt refrigerators to solve the problem in question [17] [18] [19] [20]. Although they get interesting proposals, using face recognition, solar panels for mobility and energy self-sufficiency and ultrasonic sensors to determine the location of objects in the refrigerator, these are prototypes in development. However, assuming that these products meet the defined proposal, they all lack some important aspects: price, ease of installation, handling and simplified maintenance. These are proposals that are still in a state of maturation and need improvement to make them commercially viable . All these proposals imply the physical modification of the refrigeration appliances, which entails a loss of warranty on the manufacturer's side.

In a case study carried out by researchers at the University of Medellin - Colombia, the use of a system that combines several technologies such as GPS, Bluetooth, Zigbee, RFID, Wi-Fi and 4G is proposed. This proposal promotes the union of several boards and circuits to deliver the functional solution. The base of the project is a Raspberry-Pi, responsible for integrating the peripherals and being the intelligent part of the solution. However, when analyzing the aesthetic aspects, portability, ease of handling, installation and maintenance and cost, the project stumbles on critical points from the customer's perspective. Despite being a proof of concept, apparently there was no market study, feasibility study or the creation of a QFD matrix to raise the essential requirements for the consumer market [21].

Brazilian authors carried out a research to introduce 2G-RFID (second generation of RFID devices), which brings some advantages over its predecessor, mainly because it does not work only in a passive way. This gain opens up possibilities for the use of technology, which by its essence manages to deliver valuable points to the market, such as: price, simplicity and practicality. But the use of RFID still leaves a lot to be desired in the other criteria, making it far from the expected scenario for a remote and reliable monitoring system [22].

The system proposed by Güriiler, H, uses a dedicated controller (PIC18F67J60) and external modules for user interface, temperature reading and other functionalities. It is one of the closest academic experiments to a commercial product. Such feature is denoted when evaluating that it is a low-cost solution. On the other hand, as this is a 2015 survey, the technology used is very outdated and makes it difficult to manage various equipment, in addition to the complexity of a possible repair or configuration. It is excellent equipment for 15 years ago [23].

In the context of the Internet of Medical Things (IoMT) or Internet of Health Things (IoHT), driven by the arrival of SARS-CoV-2, new technologies have arrived for the drug distribution and storage network. Among them is the use of local processing techniques to increase security, efficiency and decrease the traffic of important data to the cloud, as shown in the article by Saudi Arabia and Shamim Hossain, making use of EDGE Computing to read patient data and process locally, which significantly reduces the load on cloud servers, decentralizing processing [24].

III. Methodology

The selection, acquisition and development of materials and software for this application was carried out entirely in an embedded systems research laboratory, with the help of basic tools for electronic analysis, such as a multimeter, oscilloscope and logic analyzers. Systems integration and development for the most part was through empirical methods. Because, the manufacturers of these devices have some resistance in releasing confidential information about the operation of their communication protocols. As shown above, the market for thermal monitoring devices has a space to be filled. The proposal presented here aims to add value and reduce this identified gap.

The objective of this work refers to the development of a proposal that has low cost, simplicity, efficiency and modernity. Thus, there was an extensive search for technologies, so that, once condensed, they would be able to deliver these aspects. To obtain this result, the issue of technological maturity of each component, availability and technical feasibility was analyzed, which in turn resulted in the parts that best adhere to the project. These components were previously studied in their technical specifications and intrinsic characteristics of their technologies, aiming to guarantee the correct integration to minimize the possibility of errors and platform changes. Therefore, the communication protocols, operational logic levels, reading ranges, tolerances and necessary adaptations for integration were previously investigated. For the current research, the necessary components for the analyses, tests and validations were acquired in China, through the website aliexpress.com, among these items are:

- M5 StickC;
- BLE temperature sensors;
- Power supply.

The M5 StickC, as can be seen in Figure 1, is a product manufactured by M5Stack (m5stack.com), a Chinese company that proposes the creation of innovative products that accelerate the speed of development and allow high prototyping quality level. Thus, the company already considers itself a leader in the IoT segment, as it contains robust, accessible and open source solutions.

Figure 1: M5StickC

As the sensing is the heart of the project, this fact makes the chosen sensor an important item, mainly due to its responsibility in the fidelity of the readings, being this reason more than enough for a special and more conservative care to be adopted in the selection procedure. Thus, five different sensor models were acquired, as shown in Figure 2, which were chosen according to the following assumptions, present in Figure 3:

- Have Bluetooth® connectivity;
- Battery powered;
- Dimensions less than 50 x 50 mm;
- Operating range between -20 and 40 °C;
- Price less than $10.00;
- Have certifications (RoHS and FCC);
- Availability;

- Aesthetics;
- Provenance from known company;
- Longevity;
- Practicality;
- Simplicity.

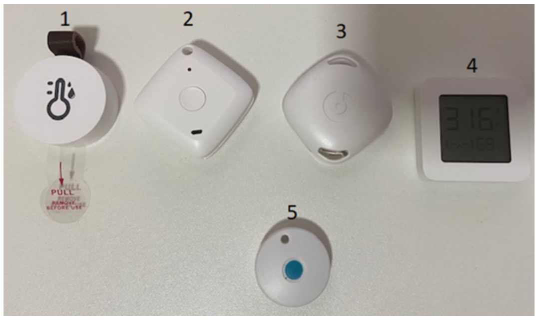

Figure 2: Sensors purchased for testing

SENSORS \ REQUIREMENTS	1	2	3	4	5	6	7	8	9	10	11	12
1	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
3	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES	YES
4	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES	YES
5	YES	YES	YES	NO	YES	NO	NO	YES	NO	NO	YES	YES

Figure 3: Comparison of sensors

Among the models studied, validated and purchased, model 1 was chosen, due to its better cost-benefit ratio and because it meets the requirements of the proposal. This sensor is called WS07. It is manufactured by Seven Like (seven-like.com). It's powered by a 3V model CR2477 battery that looks a lot like a coin. It has dimensions of 38 mm diameter and 16 mm wide, reads between -20 and 60 °C with an error of ± 0.5 °C and also holds a humidity sensor (0-100%) that will not be used in this study. It has an interface with an iOS or Android application provided by the manufacturer. The concomitant use of the application with the telemetry system proposed here does not result in any incompatibility. The WS07 sensor will be fixed inside a refrigerator and communicates with the M5StickC using the BLE4.2 wireless protocol, as seen in Figure 4, which does not identify any customer data or which equipment it is monitoring. Following the principles of EDGE computing, data will not be transferred directly to the cloud. Data will be registered, processed and evaluated locally, avoiding unnecessary transfer and the consequent exposure of sensitive information. The sending of information to the cloud is only due to the momentary and occasional need to notify those responsible for problems encountered. Such alerts will be generated in M5StickC and sent to the registered user on Telegram® through an API called BotFather. This API is responsible for securely managing a connection for sending data directly to a smartphone, using the Telegram® server as an intermediary. In this way, employees who wish to receive alerts can form a group and be notified at the same time, as shown in Figure 5. An overview of the solution can be seen in Figure 6.

Figure 4: BLE connection between sensor and M5StickC

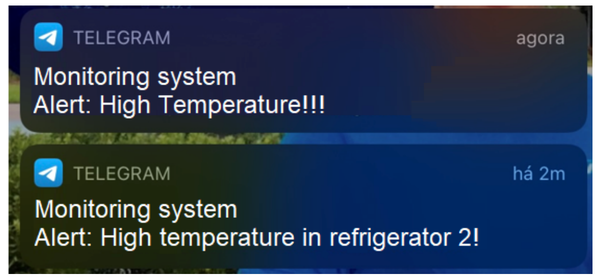

Figure 5: Telegram® remote notification example

After recording data in a refrigerator that already had a monitoring service, aiming to observe trends in temperatures recorded by thermometer A (WS07) and thermometer B, the measurements were properly ordered according to the day and time recorded. Thus, the line graph shown in Figure 7 was obtained.

Thus, in order to observe in detail the behavior of the temperature variable according to each thermometer, we have the following analysis. Even identical sensors can take slightly different readings for the same measurement point. The thermal gradient caused by heat exchange inside a refrigerator, generates warmer and colder areas. For this reason, the refrigeration equipment must undergo a thermal qualification and adopt an acceptable coefficient of variation, according to each process. Considering these aspects and the great similarity in the graphic behavior of the two sensors, it is possible to be sure that they behave in a similar way. This offset between sensors is easily adjusted via software, according to the calibration certificate or other adopted mechanism.

To statistically verify whether temperature variations actually occur in a similar way in the two thermometers, we have the following hypotheses:

H0: Temperatures vary equally between the two devices.

H1: The temperature range is different for each device.

Since the data are not adequately described by a normal distribution, the appropriate test to verify equality of variances is the Levene Test. This test is an inferential statistical method, used to assess the similarity of variances of a given variable with a stop with another. If the result of this test (p-value) is greater than the value normally adopted as a significance level (0.05), it is possible to infer that there is similarity between

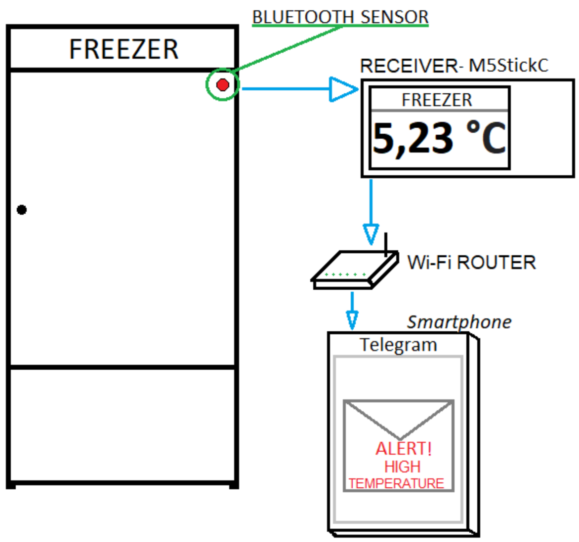

Figure 6: Big Picture

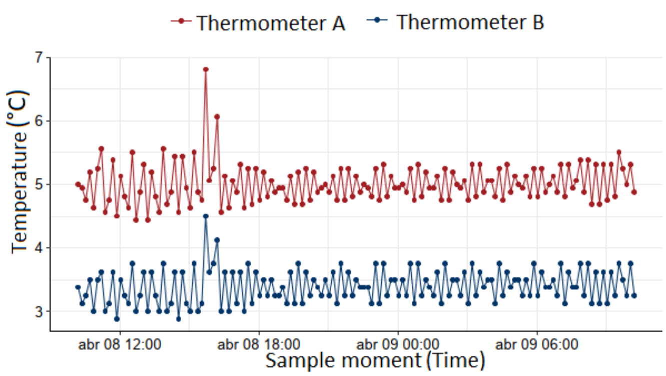

Figure 7: Graphical comparison between sensors

the samples.

IV. Results

After the studies, it was possible to develop a solution that combines recent technologies at very low cost, in order to simplify and make the entire process of temperature monitoring of sensitive inputs more efficient. It was not necessary to develop a new product, this helped to make the research easily replicable and adherent to market reality. Existing products were used and the innovation was in their integration, in order to be able to achieve numerous objectives at once to the proposed solution:

- Cheap;
- Popularize;
- Modularize and reduce maintenance cost;
- Add technology;
- Facilitate interventions;
- Add security layer;
- Improve operational reliability.

To design the proposed solution, some implementation steps were followed, as the developed algorithm (C Language) had to be tested and validated. It was necessary to compose an algorithm that inherited the functionalities tested and validated in field and laboratory tests; merging them with the functions that needed to be developed for the end-user interface, along with other parts that make the system stable and robust, such as redundancy and security. These steps are listed below:

- M5StickC RTC Update;
- Local data storage;
- Temperature requisition and verification;
- Data recovery;
- Remote alarm sending by Telegram® if the temperature goes outside the established range;
- M5StickC parameterization;
- Sensor registration.

As for the validation of the fidelity of the readings, a visual inspection when superimposing the graphs showed that the biggest observation to be made from the graphical visualization is that the temperatures tend to vary similarly in the two thermometers, so that it is possible to observe at the peak, between 3:40 pm and 4:15 pm on the first day of testing, which occurs similarly in both, as seen in Figure 8.

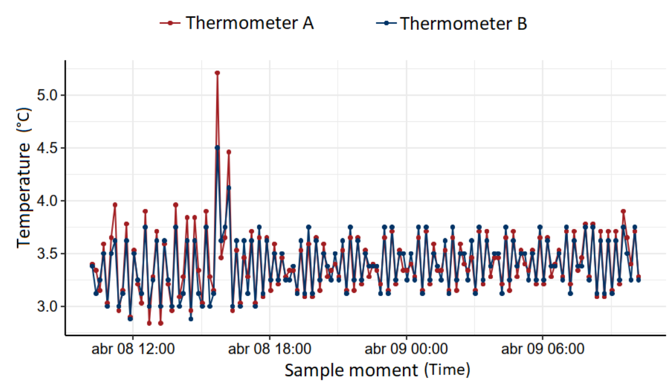

Figure 8: Graphical comparison without the Off-Set (1.6 °C)

The analysis arising from the result of the Levene test, shown in Figure 9, indicates a p-value greater than the significance level considered for the test decision (0.05), thus confirming that in both thermometers the temperature variation is very similar.

Variables	Levene test	Test result
Temperature - Thermometer A Temperature - Thermometer B	0.56	do not reject *H0*

Figure 9: P-value of the variance equality test

Logo: this deviation is attributed to the variables inherent to the test:

- Distance between sensors;
- Sensor calibration;
- Thermal inertia;
- Calorific gradient;
- etc.

Therefore, the sensor readings of the equipment's telemetry system and the reading of the WS07 sensor are statistically similar, and thus the quality of the sensor could be validated, which will be able to implement, via software, the corrections of deviations that the calibration certificate may present. As for the solution's security, this was a largely favorable factor, as the processing was concentrated in local mode, using EDGE Computing and removing the possibility of an external intrusion.

V. Conclusion

The proposal presented was successfully achieved in all its aspects, and it was possible to conceive a device with the necessary characteristics to fulfill the market's need, mainly aimed at the storage of thermolabiles. All parts were validated, and modern concepts were implemented, thus enabling longevity and simplicity of the low-cost system. As simple as the system has become, it is still not simple enough for a nurse or administrator to quickly configure the equipment. In contrast to the proposed solution, there are some points to improve, these are as suggestions for future work: Implement alerts sent via 3G network, development of device configuration by Telegram® and implement data history on a free server.

References

[1] E. Abad, F. Palacio, M. Nuin, A. G. De Zarate, A. Juarros, J. M. Gómez, and S. Marco, "Rfid smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain," *Journal of food engineering*, vol. 93, no. 4, pp. 394–399, 2009.

[2] M. M. Aung and Y. S. Chang, "Temperature management for the quality assurance of a perishable food supply chain," *Food Control*, vol. 40, pp. 198–207, 2014.

[3] C. S. Bresolin, P. S. Schneider, R. Rego, and E. P. Bandarra Filho, "Brazilian cold chain panorama," *International Journal of Refrigeration*, vol. 90, pp. 145–155, 2018.

[4] D. Chandra and D. Kumar, "Prioritizing the vaccine supply chain issues of developing countries using an integrated ism-fuzzy anp framework," *Journal of Modelling in Management*, 2019.

[5] Q. Lin, Q. Zhao, and B. Lev, "Cold chain transportation decision in the vaccine supply chain," *European Journal of Operational Research*, vol. 283, no. 1, pp. 182–195, 2020.

[6] S. Mercier, S. Villeneuve, M. Mondor, and I. Uysal, "Time–temperature management along the food cold chain: A review of recent developments," *Comprehensive Reviews in Food Science and Food Safety*, vol. 16, no. 4, pp. 647–667, 2017.

[7] N. Ndraha, H.-I. Hsiao, J. Vlajic, M.-F. Yang, and H.-T. V. Lin, "Time-temperature abuse in the food cold chain: Review of issues, challenges, and recommendations," *Food Control*, vol. 89, pp. 12–21, 2018.

[8] J. Robertson, L. Franzel, and D. Maire, "Innovations in cold chain equipment for immunization supply chains," *Vaccine*, vol. 35, no. 17, pp. 2252–2259, 2017.

[9] A. Saif and S. Elhedhli, "Cold supply chain design with environmental considerations: A simulation-optimization approach," *European Journal of Operational Research*, vol. 251, no. 1, pp. 274–287, 2016.

[10] R. Singh, A. D. Dwivedi, and G. Srivastava, "Internet of things based blockchain for temperature monitoring and counterfeit pharmaceutical prevention," *Sensors*, vol. 20, no. 14, p. 3951, 2020.

[11] J. Zhang, E. Pritchard, X. Hu, T. Valentin, B. Panilaitis, F. G. Omenetto, and D. L. Kaplan, "Stabilization of vaccines and antibiotics in silk and eliminating the cold chain," *Proceedings of the National Academy of Sciences*, vol. 109, no. 30, pp. 11 981–11 986, 2012.

[12] F. d. S. Patine, L. G. Lourenção, A. D. Wysocki, M. d. L. S. G. Santos, I. C. Rodrigues, and S. H. F. Vendramini, "Análise da perda de vacinas por alteração de temperatura," *Revista Brasileira de Enfermagem*, vol. 74, 2021.

[13] R. Chaudhri, G. Borriello, and R. Anderson, "Pervasive computing technologies to monitor vaccine cold chains in developing countries," *IEEE Pervasive Computing. Special issue on Information and Communication Technologies for Development*, vol. 10, 2012.

[14] L. Zhou and S. Chakrabartty, "Self-powered continuous time-temperature monitoring for cold-chain management," in *2017 IEEE 60th International Midwest Symposium on Circuits and Systems (MWSCAS)*. IEEE, 2017, pp. 879–882.

[15] C. Sow, C. Sanou, C. Medah, M. Schlumberger, F. Mireux, I. Ouédraogo, S. Ouédraogo, and E. Betsem, "Challenges of cold chain quality for routine epi in south-west burkina-faso: An assessment using automated temperature recording devices," *Vaccine*, vol. 36, no. 26, pp. 3747–3755, 2018.

[16] Ü. Kartoğlu, E. Nelaj, and D. Maire, "Improving temperature monitoring in the vaccine cold chain at the periphery: An intervention study using a 30-day electronic refrigerator temperature logger (fridge-tag®)," *Vaccine*, vol. 28, no. 24, pp. 4065–4072, 2010.

[17] V. Shadangi and N. Jain, "Medical internet refrigerator," in *2015 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT)*. IEEE, 2015, pp. 363–366.

[18] J. J. Henriques, B. T. Foster, W. G. Schnorr, and R. Barton, "Implementation of a mobile vaccine refrigerator with parallel photovoltaic power systems," in *2012 IEEE Global Humanitarian Technology Conference*. IEEE, 2012, pp. 128–131.

[19] S. Hossain and A. Abdelgawad, "Smart refrigerator based on internet of things (iot) an approach to efficient food management," in *Proceedings of the 2nd International Conference on Smart Digital Environment*, 2018, pp. 15–18.

[20] E. V. Pérez, O. B. Ortega, and J. Villa, "Iot circuit design to monitor cold chain refrigerators," in *2019 Latin American Electron Devices Conference (LAEDC)*, vol. 1. IEEE, 2019, pp. 1–5.

[21] M. G. Palacio, L. G. Palacio, J. J. Q. Montealegre, H. J. O. Pabón, M. A. L. Del Risco, D. Roldán, S. Salgarriaga, P. Vásquez, S. Hernández, and C. Martínez, "A novel ubiquitous system to monitor medicinal cold chains in transportation," in *2017 12th Iberian Conference on Information Systems and Technologies (CISTI)*. IEEE, 2017, pp. 1–6.

[22] S. Monteleone, M. Sampaio, and R. F. Maia, "A novel deployment of smart cold chain system using 2g-rfid-sys temperature monitoring in medicine cold chain based on internet of things," in *2017 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)*. IEEE, 2017, pp. 205–210.

[23] H. Gürüler, "The design and implementation of a gsm based user-machine interacted refrigerator," in *2015 International Symposium on Innovations in Intelligent SysTems and Applications (INISTA)*. Ieee, 2015, pp. 1–5.

[24] M. A. Rahman and M. S. Hossain, "An internet of medical things-enabled edge computing framework for tackling covid-19," *IEEE Internet of Things Journal*, pp. 1–1, 2021.