COVID-19 Vaccine Distribution Tracking and Monitoring Using IoT

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***Abstract*— A Covid-19 vaccine is so highly anticipated with the global pandemic status arise. Hence, distributing the vaccine is a challenging task, especially for an archipelago country like Indonesia. Until now, the vaccine distribution is an offline-based system, using paper-based monitoring reports, individual cold chain monitoring system, and no alert to prevents non-ideal vaccine conditions. This research focuses on enhancing the existing cold chain vaccine distribution system in Indonesia by leveraging the technology of the Internet of Things (IoT). As a result, vaccine distribution can be tracked precisely by deploying a LoRa-based tracker and monitoring sensor in the distribution trucks, and vaccine conditions can be maintained by alerting the responsible personnel.**

Keywords—COVID-19, vaccine, LoRa, IoT, temperature

I. Introduction

Humans' population overgrows. The world population is 4.4 billion, 6 billion, and 7.7 billion, respectively, in 1980, 2000, and 2020 [1]. Furthermore, more people need more space for living. Such inclination has been pushing humans to be living at the border of wild nature, and even humans are acquiring what used to be a wildlife preservation area into a productive area. Those conditions causing zoonoses are likely to happen over the years, such as Ebola, MERS-CoV, Zika virus disease, Novel coronavirus (2019-nCoV) alias Covid-19, SARS, etc.[2]. In recent times, the Covid-19 outbreak affects the global population regarding human interactions, way of life, economic turnover, etc.

The impact of the Covid-19 outbreak varies for each country depending on its healthcare system, cold chain system, the ability to get a vaccine, and more. This research is focused on Covid-19 cases in Indonesia. Indonesia has a relatively high number of Covid-19 confirmed cases. As we speak, Indonesia ranks 18th in terms of the Covid-19 confirmed cases [3]. Hence, Indonesia is an archipelago country, where the residents are spread among its 17000 islands, not to mention the geographical challenges within each province. Hence, vaccine distribution is not an easy task.

Ministry of the Health Republic of Indonesia has approved six vaccine producers in Indonesia: PT Bio Farma Tbk, Astrazeneca, Sinopharm, Moderna, PFizer Inc & BioNTech, and Sinovac Biotech Ltd. The Sinovac vaccine is the most-ready-to-be-used vaccine in Indonesia as they have it in just several months through a bilateral relationship. There are 1.4 million Sinovac vaccine shots that are used on Feb 24th, 2020. Most of it happened in a regional vaccine center distribution and focused on the health workers close to the regional cold chain.

Sinovac vaccine needs to be kept between 2-8 degrees Celcius; otherwise, the vaccine is a defect. Therefore, a cold chain to keep the vaccines in good condition is urgently needed. In terms of the existing logistical distribution, the vaccine cold chain business process is as follows: (1) the produced and imported vaccines are stored in nation-wide cold chain storage, (2) vaccines are distributed to the regional cold chain storage, at least one each province, (3) vaccines are forwarded to the hospitals, clinics, municipal public health office or service level stores, (4) finally, vaccines are given for vaccination. Under normal circumstances, the cold chain is capable of handling the required temperature and humidity of the vaccines.

Despite an end-to-end cold chain system, it relies on offline-based monitoring, reporting, and recapitulation. Hence, the vaccine could be obsolete while the system did not notify the maintainer if the non-ideal environment condition occurred. In other words, the existing system is not based on a preventive approach. Therefore, this research tries to enhance the existing system so the environment can be maintained accurately & precisely, real-time alerts & notifications are generated, and digital reports will be generated to replace paper-based reports.

The rest of the paper is organized as follows: Section II describes the related work. Section III and IV explain the methodology and implementation, respectively. Section V describes the result. Finally, section VI describes the conclusion and future works.

II. Related Work

The cold chain system is a vital part of vaccine distribution. There are currently three outstanding cold chain system issues: (1) Insufficient cold chain capacity, (2) lack of latest technology or optimal equipment, and (3) inadequate temperature monitoring and maintenance system [4]. With the emerging of the Internet of Things (IoT), those issues can be addressed.

World Health Organization (WHO) has defined some guidelines for handling vaccines as the extensive Essential Programme on Immunization (EPI). The EPI aims to strengthen vaccine programs, supply and delivery, and ensure transparent access to relevant vaccines for related stakeholders.

Referring to the logistical support system, WHO requires vaccine monitoring from the production facility to the last facility before the vaccination injection. Fig. 1 depicts the recommended implementation of the vaccine monitoring system. Some sensors are deployed in a cold/freezer room controlled by a processing unit enough to trigger an offline alarm and send data to the server/PC. This system must be equipped with a battery as this must be active all the time [5]. In fact, the certified products are mostly offline-based systems.

In Uttar Pradesh, India, a pilot project was conducted from March 2014 to September 2015 to enable the existing cold

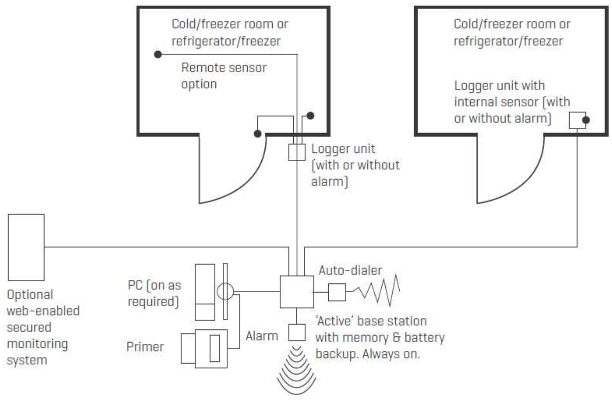


Fig. 1. WHO's Recommended System Architecture

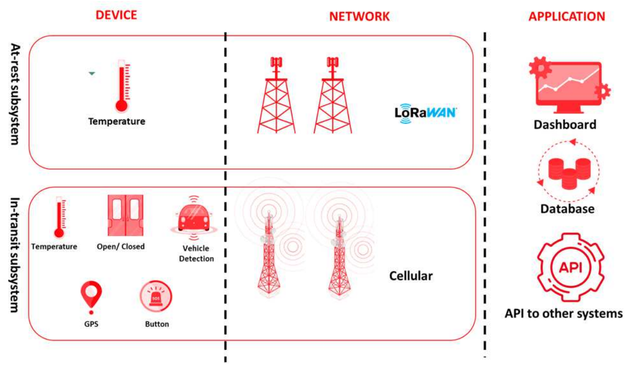


Fig. 2. Device-Network-Application System Architecture

chain system [6] digitally. The implemented system was firstly tested in Karnataka, India, in 2012. It consists of mobile/web software, operating system, browsers, transmission channels, and connectivity scenarios. This project focused on utilizing GPRS, SMS, and WIFI as the transmission channels [7]. A similar approach has also been made with the extend of the tracking feature. Location is determined by the GPRS and GSM modules. If any unplanned route occurs during transportation, it will send notifications to the supervisors through SMS and mobile apps [8].

LoRa is a wireless modulation for long-range, low-power, low-data-rate applications developed by Semtech. Hence, LoRa is specific to physical layer protocol only. The extensive utilization of the LoRa physical layer is LoRaWAN. It is a full-stack application layer protocol that characterizes a Low Power and Wide Area (LPWA) networking protocol designed to wirelessly connect battery-operated 'things' to the Internet in regional, national, or global networks. It targets the key Internet of Things (IoT) requirements such as bi-directional communication, end-to-end security, mobility, and localization services [9].

Rawat et al. [10] recommend utilizing LoRa and LoRaWAN as the underlying protocol for Covid-19 monitoring and tracking system. LoRa and LoRaWAN are making business efficiencies and improving lives far and wide. This research focuses on LoRa and LoRaWAN utilization for vaccine distribution.

III. Methodology

A. System Architecture

The system adopts the device, network, and application (DNA) ecosystem approach. Fig. 2 describes the system architecture. The device and network layers together create two distinct subsystems and feed data to the application layer.

The main intention of the tracking system is to monitor the temperature and location of the vaccines. As vaccines are continuously distributed between places and stored in chillers or cool boxes before it is finally injected to patients, the device and network layers create two subsystems: at-rest and in-transit. The at-rest subsystem is a moment when vaccines are being stored in chillers at storages, such as regional, local, and hospital storages. The in-transit subsystem is a moment vaccines are being transported between storages, such as from regional storage to hospital or community health center storages. A Distribution Order (DO) document is created to inform how many vaccines are taken from which source storage and delivered to which destination storage. After this document is created, vaccines will have a journey and must be kept tracked, both location and temperature. Each subsystem has different characteristics, thus, has a different approach to track the temperature and location.

The at-rest subsystem has some characteristics: relatively stable temperature, static location, and the possibility of power loss. The temperature only fluctuates when the chiller is being opened by the pharmacist. Empirical data recorded that opening the chiller from one to two minutes did not much affect the temperature. Therefore, capturing the temperature every 10 minutes is sufficient. Hence, this scheme is helping the battery life. The second characteristic allows us to use a sensor with minimum capability, which only sensing the temperature. There is no requirement to actively report the current location of both the chiller and the vaccine. The chiller location can be set statically, and the vaccine location can be known based on the last distribution document of the vaccine.

The method to sense temperature is to use a probe that is plugged into a glycol-filled vial. This method is suggested by NIST [11] because it mimics the actual vaccine temperature and will not fluctuate quickly when the chiller is being opened. However, if the system uses a sensor that monitors the air temperature inside the chiller (without glycol) like DHT-based sensors, the temperature will rise rapidly when it is opened.

Besides the basic temperature measurement, the device can alert when the temperature rises above or dive below the threshold. When this study is written, Indonesia begins to use the Sinovac vaccine [12]. This vaccine requires the storage to be at 2-8 degrees Celcius; otherwise, the alert system is raised to the authorities.

From the above at-rest subsystem characteristics, the LoRaWAN network is chosen to transmit the data. The coverage area per gateway is like the one provided by the cellular network; however, the power requirement is considered much lower than the cellular network due to (1) no connection association mechanism, that is, by using ABP authentication, (2) no need to maintain the connection, that sensors can send data directly, and (3) 1% duty cycle and 20 dBm maximum EIRP regulation from Indonesia government [13], that practically limits the required power.

The distinct characteristic of the in-transit subsystem is a dynamic location. It requires (1) a GNSS sensor to determine the location data and (2) frequent updates about the latest location per 10-second interval. Temperature data can be sent along with the location data, although it is also relatively stable as it is in the chiller. These two requirements consume much power that needs a rechargeable automobile battery.

From the above in-transit subsystem characteristics, a cellular network is chosen to transmit data. Its wide coverage across the whole country becomes the main reason. It provides a high-speed data rate to transmit a large amount of data in a shorter interval. In addition to that, there is no power constraint from the device layer as it already plugged into the vehicle's power point.

The additional features of the in-transit subsystem are (1) alert mechanism when the temperature is outside the range, (2) alert mechanism when the vehicle stop in the middle, the engine shuts off, and the container door is opened, (3) SOS mechanism when the driver is being threatened during the delivery. When vehicles are not moving, frequent location updates may not be required, and energy can be saved. The frequency is reduced to be every 15 minutes under this situation.

The application layer on the server side receives data transmitted by the devices, stores data in a database, and visualizes data based on user levels. In handling the incoming traffic with potential spikes, a queue mechanism is deployed before actual processing servers. It minimizes the data loss when the processing servers already have high traffic. The web servers provide different views for different user levels, such as government (nation-wide, province, city), the vaccine manufacturer, transporters, and chiller storage owners. The application layer raises notifications to external parties, such as military and police stations, when drivers push the SOS button.

The application is using cloud computing and is designed by four means: (1) geo-redundant servers providing high-availability and failover mechanism when a natural disaster occurs, underlying hardware has a problem, or the application becomes unresponsive for any reason, (2) auto-scaling servers to handle spike traffic, (3) segregation of production and development servers, and (4) the infrastructure is created based on a template stored as code, also known as Infrastructure as Code (IaC), ensuring consistent specification and configuration between development and production servers.

IV. Implementation

A. At-Rest Subsystem

There are two device models used in this research. One is fabricated Milesight-IoT's EM500-PT100 [14] devices, and another one is based on an Arduino prototype board. Both models use the AS923-2 frequency plan. Devices from both models are installed outside chillers, but its temperature probes in glycol-filled vials are installed inside chillers, as shown in Fig. 3. The vials are just beside COVID-19 vaccine boxes. Despite being installed indoors, both models have IP66 rating protection. Sensor readings are calibrated to readings from OnSet's inTemp CX402 [15], an ISO-17025-compliant temperature data logger.

The first model regularly sends temperature data every 10 minutes and battery data every three days. The data are encoded in a byte array. It needs 4 bytes to send temperature data. In addition to regular frames, devices send temperature data at shorter intervals when the temperature is outside the 2-8-degree Celcius range. With ADR enabled, some devices can send data using up to SF7 data rate.

The second model is built using Arduino with the AM2305 temperature sensor and Semtech SX1276 LoRa chip. It sends both temperature and battery data every 10 minutes. The data are in JSON format, 49 bytes in size. This model does not use ADR and sends data in a fixed DR2 data rate. Algorithm 1 describes the generic flowchart of both device models.

Outdoor LoRaWAN gateways are deployed nearby the devices. Most deployments are on Telkom's premises and towers. However, for chillers in blank spot areas or cities without any LoRaWAN coverage, indoor LoRaWAN gateways are deployed and installed in the same area as the chiller. The gateways send data to network servers using either optical fiber, cellular, or both mediums. The network servers, already located in the cloud, forward the data to the application layer using IPv4 protocol, agnostic to the underlying media.

B. In-Transit Subsystem

Devices used in the in-transit subsystem are from Teltonika brands. The FMB130 model [16] is deployed for motorcycles, and the FMB140 model [17] is deployed for cold chain refrigerated trucks. Both models use cellular (GPRS) as the communication protocol to transmit data.

In this subsystem, glycol-filled vials are not used. Instead, the probe captures the air temperature, as shown in Fig. 4a. The vehicle's movement, especially motorcycles, may allow the glycol to leak from the vial's top. Therefore, it is acceptable to acquire only the air temperature.

Besides capturing the air temperature, devices in trucks also capture location data based on GNSS satellites, engine status (on/off), and container door (open/close). The engine status is taken from the vehicle's electrical cable that supplies voltage when the key is in the ON position. The container door sensor is placed nearby the hinges of the first opened door, as shown in Fig. 4b.

Some trucks require the right door to be opened first before the left door, some require the otherwise, and others only have one door. When the engine offs or the container door opens during the journey, an alarm will be raised to authorities.

Fig. 3. The installation of both model

Algorithm 1. Algorithm for Data Collection and Sending

```
start
while true then
 currentTime = now();
 if lastCollectTime - currentTime > collectInterval then
  lastCollectTime = currentTime
  temp, battery = collectTempAndBatteryData();
  if lastSendTime – currentTime > sendInterval then
   lastSendTime = currentTime;
   sendDataViaLoRaWAN(temp, battery);
  else if temp < 2 or temp > 8 then
   lastSendTime = currentTime;
   sendDataViaLoRaWAN(temp, battery);
  end
 end
end
```

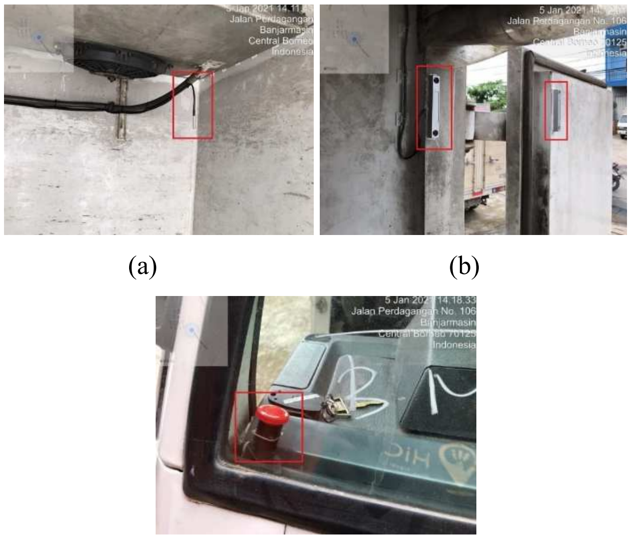
The SOS button is installed near the driver's seat to ease the driver from asking for help quickly when a threat comes. SOS button placement example is shown in Fig. 4c. To save battery usage when the vehicle is immobile and the engine off, the sending interval is increased to be 15 minutes, comparing to 15 seconds when the vehicle is moving.

Devices in motorcycles capture air temperature data inside portable cooler boxes. Fig. 5 shows a temperature probe is available to be inserted into the delivery boxes. These boxes contain the actual COVID-19 vaccine boxes. Motorcycles also have engine and location sensors, like in trucks. However, it does not have an SOS button and door sensor. The SOS button is not required because drivers do not bring many vaccines in one journey. Moreover, the journey itself is relatively much shorter than the trucks' journey.

C. Application Layer

Fig. 6 shows the components of the application layer. A queue service is deployed to handle the unpredictable traffic from the device layer. It reassures the application service handles the traffic. The queue service is developed using Apache Kafka. The data from the queue are claimed by an application service to be processed, built using Node.js. An auto-scaling group service monitors the set of application services and can scale out the number of services when the average CPU utilization of all services is above 70%. This can happen during the daytime when many moving vehicles deliver the vaccines, so increasing the number of sent messages is necessary. During the nighttime, because almost nothing is delivered, vehicles send data at a longer interval. Therefore, the auto-scaling group can set the number of application services to be a minimum.

The application service itself stores data to the central database implemented using PostgreSQL, which later be copied to its read replica. The purpose is to increase the read capacity while not disturbing the write capacity of the central database. The second job of the application service is to show the data via the dashboard to the end-users, and it is differentiated based on the user privilege level. The third job is to notify the respective personnel when something wrong occurs. For example, a chiller has crossed the temperature threshold. The local pharmacist will be notified. Another example, when an SOS button is pressed, a notification will be sent to the nearby police office and pharmacist of the vaccine source and destination office. The last job is to provide data to other systems. It exposes APIs to be consumed



(a) (b) (c)

Fig. 4. The installation of sensors in trucks

Fig. 5. The installation of temperature sensor in motorcycles

by either a legacy monitoring system or another system that monitors the vaccine production batches.

V. RESULTS EXPECTED

The dashboard shows the incoming data from the device layer. It begins as a map showing the location of chillers, trucks, and motorcycles, as shown in Fig. 7. Users can zoom in and click either chiller or vehicle to see the status. Fig. 8a shows five chillers' temperature and battery status at a site. During normal time, the data have grey shading. When the temperature crosses the threshold, red shading will be used. As an additional feature, the history of temperature data can be seen as well. Fig. 8b shows an installation example at a truck. The text in green shading showed when the latest data

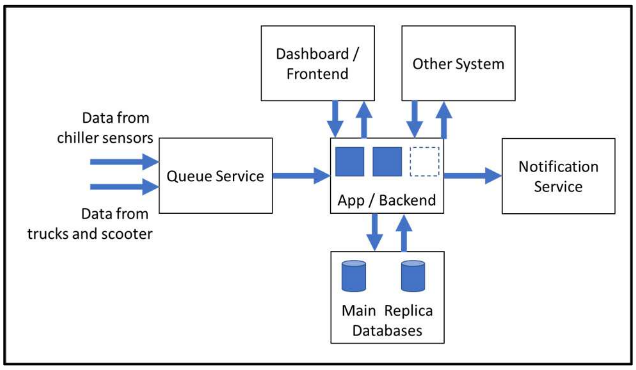
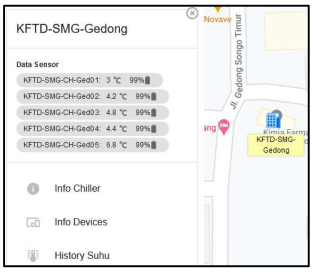


Fig. 6. The components inside the application layer

Fig. 7. The distribution map of chiller and vehicles



(a)

(b)

Fig. 8. The current status of a chiller and a truck

was received compared to the current time. The rest shows the actual timestamp (date and time), vehicle's speed (in km/h) and engine status (ON / OFF), temperature inside the container (ºC), and container door status (OPEN / CLOSE). By the time the picture is taken, the temperature is above the threshold, and the SOS button is pressed. When the door is opened, red shading will be used to alert the dashboard user.

Besides the sectoral view on each vehicle and chiller, the dashboard can show the vaccine distribution journey described by Distribution Order (DO) document. It is shown on the History DO menu. One example is a DO called IGM241220, shows in Fig. 9. Users can see the truck journey along the way, along with the alerts, if any.

VI. Conclusion and Future Works

This paper shows the beginning work of comprehensive vaccine distribution tracking and monitoring. At this step, the system can guarantee that when storages, both chillers, and vehicles, have a temperature above or below the threshold, there is an alarm raised to respective personnel. When there is no alarm, users can rest assured that vaccines are still effective. However, the work is not done. As vaccines are continuously stored and distributed until injected to patients, the future works are to develop a comprehensive track and trace vaccine system. A system that syncs with the Distribution Order so every batch can be monitored either, used, being transported, defected, etc. Hence, same-batch defected vaccines can be withdrawn as soon as possible.

References

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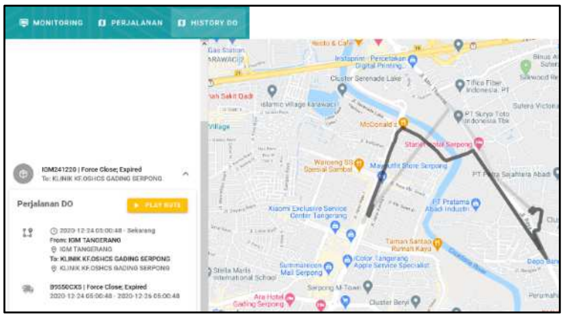

Fig. 9. Example of tracking based on Distribution Order

References

[1] worldometer, "Current World Population." [Online]. Available: https://www.worldometers.info/world-population/. [Accessed: 13-Mar-2021].

[2] WHO, "Pandemic and epidemic diseases." [Online]. Available: https://www.who.int/emergencies/diseases/en/. [Accessed: 13-Mar-2021].

[3] WHO, "WHO Coronavirus (COVID-19) Dashboard." [Online]. Available: https://covid19.who.int/table. [Accessed: 13-Mar-2021].

[4] A. Ashok, M. Brison, and Y. Letallec, "Improving cold chain systems : Challenges and solutions," Vaccine, vol. 35, no. 17, pp. 2217–2223, 2017.

[5] WHO, "How To Monitor Temperatures In The Vaccine Supply Chain, WHO/IVB/15.04," WHO Vaccine Manag. Handbook, Modul. VMH-E2-01.1, pp. 1–44, 2015.

[6] S. Skye, N. Thakare, A. Ramanujapuram, and A. Akkihal, "Assessing stability and performance of a digitally enabled supply chain : Retrospective of a pilot in Uttar Pradesh , India q," Vaccine, vol. 35, no. 17, pp. 2203–2208, 2017.

[7] A. Ramanujapuram and A. Akkihal, "Improving Performance of Rural Supply Chains Using Mobile Phones: Reducing Information Asymmetry to Improve Stock Availability in Low-Resource Environments," in Proceedings of the Fifth ACM Symposium on Computing for Development, 2014, pp. 11–20.

[8] R. T. Hasanat and N. Mohammed, "An IoT based Real-time Data-centric Monitoring System for Vaccine Cold Chain," 2021.

[9] LoRa Alliance, "What is LoRaWAN Specification." [Online]. Available: https://lora-alliance.org/about-lorawan/. [Accessed: 13-Mar-2021].

[10] A. S. Rawat, J. Rajendran, H. Ramiah, and A. Rana, "LoRa (Long Range) and LoRaWAN Technology for IoT Applications in COVID-19 Pandemic," 2020 Int. Conf. Adv. Comput. Commun. Mater., pp. 419–422, 2020.

[11] M. J. Chojnacky, W. M. Miller, and G. F. Strouse, "Methods for accurate cold-chain temperature monitoring using digital data-logger thermometers," AIP Conf. Proc., vol. 1552, no. 1, pp. 1014–1019, 2013.

[12] Ministry of Health Republic of Indonesia, "COVID-19 Vaccine Arrives in Indonesia," 2020. [Online]. Available: https://www.kemkes.go.id/article/view/20120700001/covid-19-vaccine-arrives-in-indonesia.html. [Accessed: 23-Feb-2021].

[13] Ministry of Communication and Information Technology Republic of Indonesia, "Technical Specification of Low Power Wide Area Telecommunication Devices," 2019. [Online]. Available: https://web.kominfo.go.id/sites/default/files/users/3997/PERDIRJEN SDPPI NO 3 TAHUN 2019 LPWA.pdf. [Accessed: 23-Feb-2021].

[14] Milesight-IoT, "EM500 PT100," 2021. [Online]. Available: https://www.milesight-iot.com/lorawan/sensor/em500-pt100/. [Accessed: 23-Feb-2021].

[15] Onset Computer Corporation, "CX402-VFCxxx," 2021. [Online]. Available: https://www.onsetcomp.com/intemp/products/data-loggers/cx402-vfcxxx/.

[16] Teltonika, "FMB130." [Online]. Available: https://teltonika-gps.com/product/fmb130/. [Accessed: 23-Feb-2021].

[17] Teltonika, "FMB140." [Online]. Available: https://teltonika-gps.com/product/fmb140/. [Accessed: 23-Feb-2021].