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개발 도상국을 위한 IoT 기반 백신냉장고 모니터링 시스템과 전력 최적화 자가학습 알고리즘

IoT based Vaccine Carrier Monitoring and Self-Learning Algorithm to Optimize Power Consumption in Developing Countries

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문 정 욱

Abstract

IoT based Vaccine Carrier Monitoring and Self-Learning Algorithm to Optimize Power Consumption in Developing Countries

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Vaccines are a very effective way of treating preventable diseases in developing countries where it is difficult to supply medical devices and medicines. However, despite the efficiency and benefits of these vaccines, factors such as lack of power supply, geographical ruggedness, and insufficient infrastructure have prevented the spread of vaccine coverage in developing countries. In this paper, based on the Internet of Thing (IoT) monitoring database constructed with a smart phone and the data obtained from sensors in vaccine carrier, it was possible to localize and optimize the vaccine carrier to be used in developing countries by using learning algorithms. The goal was to maximize the use time of the vaccine carrier by learning and predicting optimum power usage that maintaining the optimal vaccine storage temperature of 2℃to 8℃ in a low power supported environment.

Keyword: Vaccine Cold Chain, Internet of Things(IoT), Support vector machine(SVM), Peltier effect, Developing country

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Chapter 1. Introduction

1.1. Study Background

1.1.1 Vaccine and Cold chain

Despite the benefits of modern medical technology, there still remains a significantly high mortality rate in developing countries with poor supplies of medicine [1]. In these harsh conditions, the vaccination method is more effective than other medical methods. Despite these prominent efficiencies, vaccine coverage rates in developing countries are 70–80%, which is significantly lower than those in developed countries. There are many causes for this low penetration rate,

1) High vaccine wastage rate due to poor cold chain which is a temperature control supply chain.
2) Insufficient power infrastructure to support and maintain the cold chain.
3) Unclear management and monitoring of existing vaccine supply networks.
4) Delayed timing of vaccination
5) Lack of awareness of the importance of vaccination

In analyzing the root of the problems above, it can be seen that there are two ways to approach this problem: the administrative / social scientific solution, such as education, and a solution through the engineering approach. Based on these judgments, one of the most dominant causes in the engineering point of view is the poor performance of power supply. The appropriate temperature for the vaccine to be fully effective is between 2℃ and 8℃ [2]. If the temperature is higher than the above range, the vaccine will be destroyed. On the other hand, when the temperature falls below 2℃. The vaccine will be destroyed by the cold air. [3] [5] This is the fundamental cause

of the high vaccine wastage rate mentioned above. In order to avoid this unfavorable environment which can destroy the vaccines and establish an appropriate cold storage transportation network and cold chain, stable supply of electric power becomes very important. To solve this power shortage problem, the following two methods are proposed in this study.
Builds a system that can supply power from the generators of vehicles / motorcycles commonly used in developing countries.
Improve the self-cooling efficiency of the vaccine refrigerator, by optimizing power consumption efficiency

1.1.2. Recent researches on Vaccine carriers and its Limitations

Various approaches have been explored to derive to obtain high efficiency of vaccine storage devices. First of all, the vaccine carrier, which is commonly used in developing countries, especially in remote areas, is the most commonly used model approved by WHO; it is an ice box type that keeps the vaccines cold through ice packs. AVC-44 model [4] and the VCA9AF model, are some examples. These models use polyurethane as insulation and are designed to maintain-1.6L of vaccine for up to 40 hours or more using four ice packs. However, these icebox vaccine carriers tend to fall below the freezing point, leading to inevitable consequences of cold damage and thus a significant amount of vaccine destruction. Moreover, some statics show that the average vaccine wastage rate was 39.54% at the session site from 2010 field assessment in India. (BCG: 60.99%, DPT: 26.80%, TT 33.71%, HepB: 33.15%, OPV: 47.47%, Measles: 35.09%) [6]. In order to compensate for the deficiencies of the ice box type, there have been efforts to develop a transportable vaccine refrigerator capable of temperature control using electricity; researches have also been conducted on the use of Peltier devices as a cooling method.[7] The thermoelectric element was discovered by J.C.A.peltier in France in 1834. When a DC current is applied to both ends of two different devices, a potential difference occurs between the P.N type semiconductors. This phenomenon is based on a principle that the temperature difference is generated by taking away the energy that it possesses. These thermoelectric elements have advantages of high reliability due to solid structure and semi-permanent life time, but they also have disadvantages of high cost and low energy efficiency. According to another research, to overcome this low energy efficiency, researchers have increased the efficiency by using a graphene-based nanocomposite material as an insulation and a thermal conduction medium as a heat transfer gel.[8] Despite these tries, the significantly low efficiency of the thermoelectric device continuously motivates the researchers to find other alternative ways such as a photovoltaic power generation supporting system[9] or absorption refrigerator system using the evaporation heat. [11] [13]

1.1.3. Present trends of IoT and machine learning

The development of various information and communication technologies (ICT) has established an unprecedented worldwide network in all-human history. In addition, the development of various hardware technologies, such as sensors and miniaturized memory chips, have contributed to creation of the concept, internet of things (IoT). The internet technology has made several strides within the past decade, and the most commonly used version until recently has been a two-way communication system called Web 2.0. An important characteristic of Web 2.0 is that the users can participate in information exchange and production on the Internet, like web developers. For example, SNS (social networking service), blog, and wiki. Since then, the development direction of the Internet technology has been advancing to a new progress so-called Web 3.0 or Semantic Web, which aims to build a concrete connection point between the web and actual machines by making web contents in a machine acceptable form. Machines also have the ultimate target of current IoT technology to make mutual networks through communication means such as Wi-Fi, RFID, ZigBee, and Bluetooth and integrate them as one system. Various research methodologies are presented for the study of this IoT technology, and its scope is varied such as manufacturing process, health care, supply chain and logistics [12] On the other hand, the analysis of big data accumulated by IoT-based technology has become another issue. The main technology connected with these issues is the machine-learning field. Machine learning has emerged as a better technology due to the dramatic improvements in computing power and the reduction of hardware costs, It has become a key technology that enables us to make useful engineering models from large amounts of data collected in various ways. The vaccine cold chain discussed in this study is a similar system in which that vaccine carrier monitors various information through various sensors and antennas and sends it to the web to accumulate and analyze the data. Therefore, such IoT technology and machine learning technology is one of the applications that exactly matches the trend of development.

1.1.4. Various machine-learning examples as a solution

Machine learning has been the most technologically advanced field in the recent years. It is widely being studied as a new solution to solve many engineering issues in accordance with the pace of recent development. Basically, machine-learning is very valuable as an alternative analytical method applied when the complexity of related factors between cause and effect of the phenomenon being studied is excessively complex or nonlinear. Due to this characteristic, machine-learning tools are used in various fields. For example, in the field of smart factory, which is the core object of industrial 4.0, this machine learning tool is used as the main means of interpreting numerous industrial data. It is used to make a model that manages and predicts the manufacturing process and the quality of the produced product. This technology has been used not only in the manufacturing sector but also in the energy sector. To build a model that predicts the generation of solar energy, machine learning algorithm is trained using a large amount of collected data on weather cycle to improve the efficiency of the photovoltaic power generation. [9] In other research, research related to making predictive models for increasing the efficiency of wind energy generation based on the data of irregular wind data is under way. [10]

1.2. Purpose of Research

The purpose of this study is to build a local monitoring system using a vaccine carrier, which is an important means of transportation for the cold chain, and propose an algorithm for self - learning based on the collected monitoring data. Through this algorithm, the vaccine carrier system can find the appropriate temperature setting to minimize the power consumption in order to maintain proper vaccine storage temperature of 2-8 degrees in the local environment with minimum power; the results will be analyzed in this study. To verify the validity of this concept, a smartphone-based monitoring system in built, and refrigerators designed to enable them to collect information on the GPS data, temperature, humidity, current usage to proceed the experiment will be introduced in this paper.

Chapter 2. Development of Vaccine carrier

2.1. Overview

The vaccine carrier was designed to proceed with this study. The factors that should be considered in the design process are summarized as follows.

1) Seeking a stable power supply method to use in developing countries
2) Design and search for a structure and method that is easy to transport.
3) Build a low−cost design.
4) Build a viable monitoring system in developing countries.

In consideration of these conditions, various versions have been developed since 2014 and now the design determined like Figure 1. In this chapter, the design contents of the developed vaccine carrier and its detailed design intention will be discussed.

2.2. Mobile based monitoring fridge system

In order to construct the refrigeration system for this study, the constituent components are designed in a systematic manner for each purpose. The developed vaccine carrier consists of some parts, such as a cooling module, which is the center of the cooling function, an insulated container that maintains the cooled internal temperature, and a data collecting and monitoring system that enables the location of the vaccine carrier and the internal freezing state to be verified. All parts have its own function and will be introduced in detail as follows.

2.2.1. Cooling module

As mentioned above, there are various refrigeration methods such as compression type, absorption type, etc. After several discussions, Peltier device was chosen for the refrigeration method, which is easy to transport and more independent from the external climate and environment. Of course, low efficiency due to high power consumption can be a problem, but it has the advantage of being able to be designed with a relatively small volume compared to the compression type refrigeration method, and has advantages that it does not depend on the external environment such as absorption cooling method. The Peltier device used in the design is the most commonly used model 'TEC1-12706', which is chosen as the easiest model to purchase. This may give us to fine appropriate approach ways to the developing countries. In this model, the maximum temperature difference ΔT_{max} (Q_c = 0) shows 67℃ performance and the cooling capacity and internal resistance are Q_{Cmax} 60 − 72W / 2.1 ~ 2.4Ω each.

2.2.2. Insulation Container

The containers used for the vaccine have been chosen in such a way that the vaccine carrier box, AVC-44, approved by WHO was used as it is. It is intended to be used for the purpose of reducing cost by using the existing vaccine carrier storage container as it is. Naturally, the vaccine carrier developed for this study is perched on the vaccine container to cover the lid and becomes a cooling source at the same time. The internal storage capacity of the container is 1.6 liters and polyurethane is used as the insulating material. The AVC-44 model using four ice packs is an available product that can maintain a cold life of up to 40 hours without removing the lid. It is typical vaccine carrier model to supply worldwide. So it is not necessary to pay for the container portion at the user side of the developing country, if our vaccine carrier design applied to the model, so that the cost reduction can be expected.

2.2.3. Data collecting and monitoring system

The Arduino Mega 2560 is used as the controller, built in the lab in the first place, for the collection of all the data of the vaccine carrier. The collected data is transmitted to the web via smartphone and the collected data monitors the extent of vaccination, the atmospheric temperature, and the temperature inside the vaccine storage container. Widely popular in the developing world, smartphones are very useful computing processors, allowing them to transmit and monitor all of the collected data of vaccine carriers with high probability even in poor communication networks like Nepal or Africa.

2.2.4. Battery and Charge/discharge system

As a source of energy for this vaccine carrier, a lithium ion battery of 12V, 10Ah capacity was used. Despite the capacity of these batteries, a more stable energy source must be secured in order to spread the vaccine to a more remote place. To overcome this problem, a 12V cigar jack is installed inside the vaccine carrier, which can be connected to vehicles or motorcycles. Through this recharging system, we can more easily find the rechargeable energy source in remote areas of developing countries to expand available vaccination area.

2.2.5. Satellite communication module

Despite the spread of such smart phones and the development of local communication infrastructure, many countries in developing countries have not yet operated telephony. In this area, the smartphone data communication cannot be used. To solve this issue, the vaccine carrier in this study was designed to be compatible with the satellite communication module. It enables vaccinations and transportation monitoring in all situations. Currently, the satellite communication module that links with the carrier uses the Iridium 9602 module of RockBLOCK (Rock Seven Mobile Service Ltd.) to construct the system that can transmit the collected data through satellite communication.

2.3. Design and manufacturing

Basically, the cover of the vaccine carrier is divided into four parts cooling part, control part, battery part and charge / discharge part. Each part has its own function. The overall refrigeration mechanism is a method in which cold air flows downward. This is based on the principle of thermodynamic properties in which heat rises and the other sinks down. And it is driven at the rated voltage of 12V and consumes 60W of power.

Figure.1 CAD design and manufactured Prototype for Nepal and Africa

2.4. Field test in developing countries

Since it was very important to test whether this vaccine carrier could operate locally, Nepal was selected as the main target and field tests were conducted from Tanzania and Malawi to Kenya for extension testing. Several prototype vaccine carriers were developed for this study, and they were tested in the Nepal Nuwakot district in 2015. At that time, we had two main tests: one was testing monitoring module attached on the AVC-44 model of the general vaccine carrier through satellite communication and GPS communication and the other was a testing the validity of the cooling performance and motorcycle based recharging system of the prototype vaccine carrier. The test results showed stable cooling from 4℃to 5℃ on the local site and GPS monitoring results using satellite communications were also collected. In addition, it was possible to confirm the possibility of a motorcycle charging system by installing a local motorcycle on the spot with a simple operation and charging the vaccine carrier.

Figure.2 Pre-prototype test at Nuwakot in Nepal (2016)

Then, in 2016, the vaccine carrier prototype, shown in Figure 2, was manufactured. In cooperation with the International Vaccine Institute (IVI), the Ministry of Health of Malawi and the local health center of Arusha in Tanzania and homa bay In Kenya, we conducted many field tests in different environments including Nepal. Through this progress, we could collect much more data to improve the vaccine carrier design and were able to confirm the applicability of the vaccine carrier to other areas as shown in Figure 3.

Figure.3 (a) Motorcycle test with Malawi Ministry of health.
(b) Testing in Kenya homa bay health post.

In 2017 February, we conducted a field test in Mathali Nepal and succeeded in local monitoring through a local smartphone in remote mountain communities where Internet communication is not possible. In addition, a vaccine that was refrigerated through the vaccine carrier was actually inoculated to local residents and its safety was verified. And the vaccination with prototype vaccine carrier take care more than 100 families around the village.

Figure 4 Vaccination at out−reach place in Manthali Nepal

The most recent field tests were conducted in the Arusha region of Tanzania, Africa, in the summer of 2017. As a result of the field test, stable cooling ability at 4 ℃ and monitoring communication conducted through local smart phone communication succeeded as shown in Figure 4. In cooperation with the local health center, we also visited the Masai tribal village of Olturumet for vaccination which take care more than 100 people in the village.

Figure 5 Tanzania Arusha vaccination result:

(a) topographic map (b) satellite map

(c) transportation vehicles (d) vaccination in Olturumet

2.5. Summary

To design the vaccine carrier which is a key factor of a vaccine cold chain, we defined all design factors that should be considered. The prototype vaccine carrier is made to reflect consideration of each part to refine the design. In order to verify the cooling performance and monitoring effectiveness of the manufactured vaccine carrier, the performance was verified through field tests in Nepal and Africa. All test was proceed with local medical partnerships who certified by government and international health institution to analysis the vaccine carrier's availability of vaccinations in the field.

Chapter 3. Monitoring and Machine learning

3.1. Overview

Among the five factors that impede vaccination as mentioned in the introduction, we summarized the factors as: 1) vaccine disposal rate due to temperature management failure, 2) development In the case of approach to the problem of poor power supply in the developing countries, 3) insufficient vaccination management, 4) lack of education at the time of vaccination, and 5) lack of overall awareness of vaccine. Unclear knowledge of vaccines among people in developing countries is causing them to misbehave, such as neglecting the vaccination cycle and over-vaccination. And the management of these vaccinations is kept in paper documents causing unsuitable management. These issues have been solved through the systematic management by using the database built with the smart phone and web server. However, research in this area is not further mentioned because it deviates from the main subject of this paper. Rather, the vaccine refrigerator in this study can be connected to the smartphone via Bluetooth communication to transmit the GPS data, internal temperature data, time and date installed in the carrier, and through this information, the vaccination date/ time and position can be monitored. This mobile-based approach is based on the concept of using smart phones that can be easily procured in developing countries like Africa as a medium of data processing and communication. Through this, it is possible to monitor the vaccine delivery situation in developing countries and to help vaccination management based on the recorded log records. Furthermore, since the accumulated data is the local environment information on which the vaccine carrier is operated, based on this information, it is intended to apply and test a self-learning method that maximizes the efficiency of the power consumption of the vaccine carrier.

3.2. Monitoring system

In order to monitor the vaccine carriers constructed in this study, we searched for internal communication means that can be used stably in developing countries. Basically, universal communication in developing countries is not good. However, there are many studies that solve the problems of various developing countries by using smart phones[14]. In this regard, the developed vaccine carrier, various sensors installed in health posts in each region, and smart phone communication network can be used to build a comprehensive developing country type IoT based monitoring system. The large amount of data collected is used as a learning data source for the machine learning process that locally optimizes the power consumption of the vaccine carrier. In this background, the overall monitoring flow chart proceeds as follows. As shown in Figure 6.

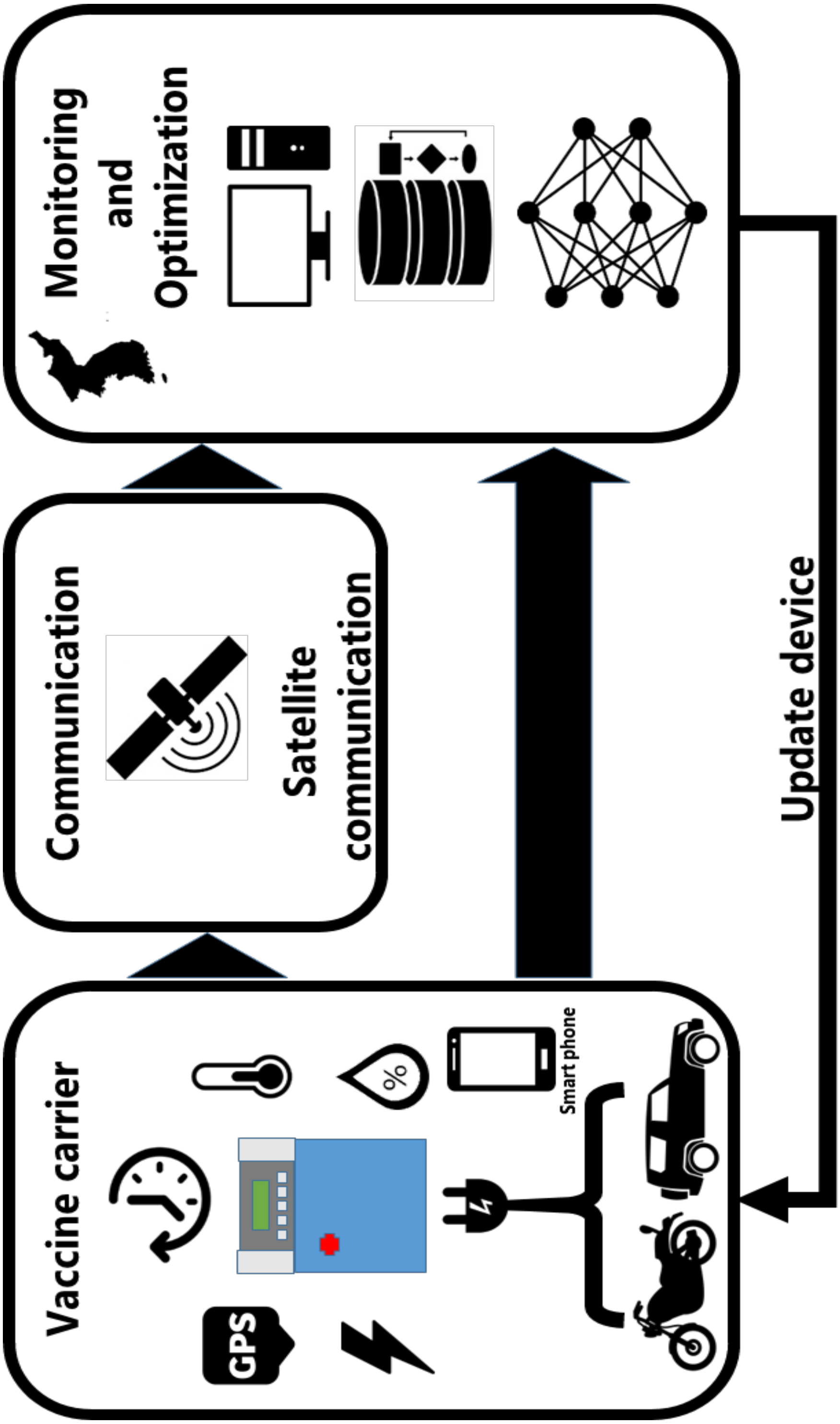


Figure.6 Vaccine monitoring and optimization flow chart

As shown above, the data collected through various sensors installed around the vaccine carrier are transmitted through Bluetooth data communication with the carrier smartphone and then the data is transmitted to the web through smart phone communication network. In case of malfunction of local telecommunication system, the satellite communication operate to transmit all the data. We also implemented a method to use satellite communication module for the environment where smartphones cannot communicate. Through the collected monitoring data, the vaccine monitoring system was constructed so that the local medical institutions can be notified about the progress of the vaccine delivery to the area and the transportation status.

3.3. Self-learning algorithm

The main optimization of this study is in the form of learning. Based on all the data gathered through the monitoring system constructed, the model is used to build the optimization model and to operate the vaccine carrier again. However, in order to compensate for the difference between the past data and the present data, the algorithm of this study is complemented by two prediction methods. First, it is a method to predict the temperature change trend through the latest temperature information collected through the internet and carrier monitored data. Figure 7 is the temperature change in the Arusha region of Tanzania, Africa on December 14, 2017.

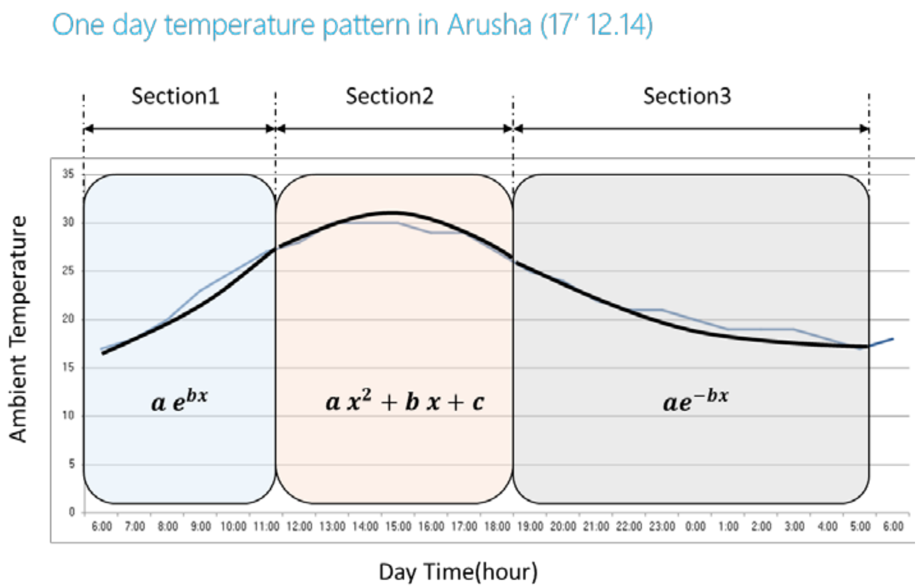


Figure.7 Short term predict by daily local data

All global environments can be divided into three parts: a rising curve (section1), a turning point (section2), and a falling curve (section3) throughout the day and night. By setting the trend estimation function according to each section, the initial data can be applied to find the coefficient and make a short-term prediction. The obtained short-term predicted temperature / humidity data is used as a primary predictive index. Secondly, the forecasting is carried out through large-scale historical data accumulated through the monitoring system. The installed sensors measure the factors that directly or indirectly affect the cooling of the vaccine carrier by using smartphone and satellite communication. The monitored objects are date, internal temperature (T_i), ambient temperature (T_o), GPS latitude, GPS longitude, charging module current (I_{re}), humidity (H), hour, minute, Peltier current consumption (I_{Pel}). So all data collected by sensors in the vaccine carrier rearranged as a data array as follows:

Year Month Day	GPS Longitude	GPS Latitude	Inner Temperature (℃)	Time	Peltier On/off Status	Ambient Temperature (℃)	Humidity (%)	Recharge Current (A)	Peltier Current (A)
'20171215'	'+00.0000'	'+00.0000'	'07'	'00:00'	'1'	'25'	'20'	3.0	2.2

Table.1 Data array in monitoring system

There are several methods for machine learning algorithms, and among these methods, we had to find the most effective tools for this study. Measuring the temperature reduction and power consumption of Peltier by various complex factors is a key to the vaccine carrier, which is the subject of this study. We apply the Classifier classification model among various machine learning prediction models. We have decided to use the Support Vector Machine model, which is the most commonly used and shows stable performance model among classification models. In order to implement such a self-learning model, it is necessary to set the input elements that are the object of learning and the output elements that are the result of the learning. For the purpose of this study, which is optimize power consumption by self-learning should be defined as the result of learning it can also be represented by the formula as follows:

$$P_{rate} = \frac{\partial I_{Pel}(date,\ T_o\ ,GPS\ ,I_{re}\ ,H\ ,hour\ ,minute)}{\partial T_i} - Eq(1)$$

As described above, the amount of current consumed by the Peltier device in relation to the temperature change rate inside the carrier is defined as a new parameter (P_{rate}), which is defined as a learning object through the self-learning algorithm. Also, as shown in the above model equation, the current consumed by the Peltier device is dependent on the date (season), the atmospheric temperature and humidity at the time of operation, the location, and the time (morning, afternoon, evening). All these factors in model are represented by a nonlinear multidimensional function. In order to analyze this nonlinearity, the final goal of the self−learning algorithm is to classify a large amount of monitoring data and to derive an appropriate temperature setting value for optimal power consumption through the SVM model.

3.4. Summary

This chapter discusses the monitoring process and how the collected data can be used to optimize the power consumption of the vaccine carrier. First, we discuss how to overcome the problem of communication infrastructure, which is a major problem in monitoring in developing countries. Second, to build a learning model based on collected data, we propose a more accurate and practical prediction model by proposing algorithm that predicts change rate and predictive value using big data in a complementary manner as shown in Figure 8

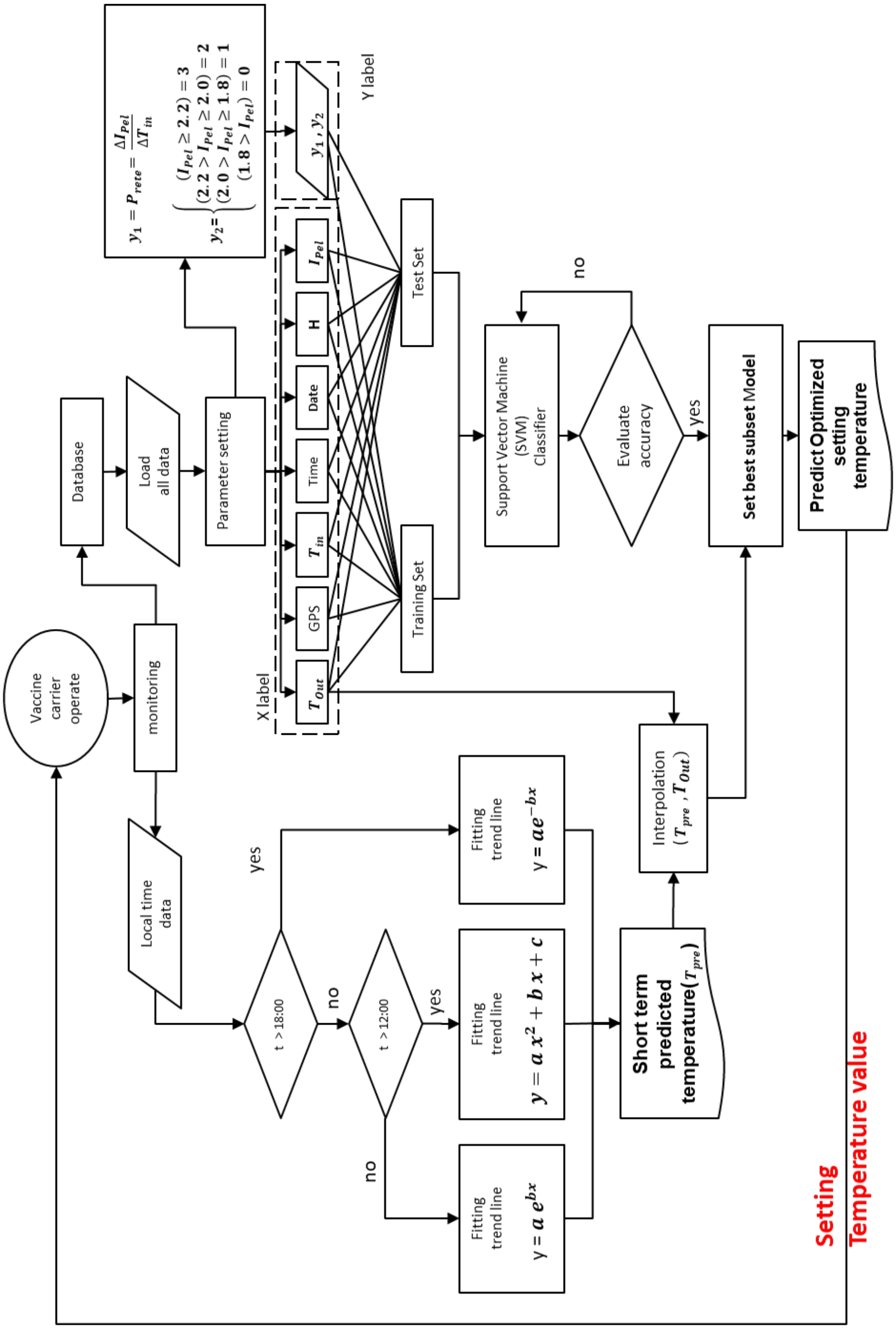


Figure.8 Main algorithm for vaccine carrier optimization

Chapter 4. Experiment and result

4.1. Overview

The goal of this study is to establish a vaccine carrier monitoring system developed for vaccine delivery in developing countries and to use this machine−learning tool to find the optimum point of power consumption. In order to prove the availability of this study, significant experiments should be designed. Experimental environment groups of vaccine carrier were divided into 3 categories.

1) Testing cooling performance inside the carrier due to various external temperature (humidity) conditions
2) Testing the amount of power consumed when maintaining certain specific temperatures under certain external temperature (humidity) conditions
3) Testing the amount of power consumed when maintaining a specific temperature according to various external temperature (humidity) conditions

Finally, we tried to verify the validity of the constructed system through SVM model based on the collected data. The experiment was conducted in a controlled laboratory environment through a thermos−hygrostat (model name basis), and the relationship between the cooling capacity of the vaccine carrier and the external environment is deduced and the possibility of constructing a statistical model using machine learning is examined.

4.2. Experiment

4.2.1. Vaccine carrier temperature analysis

In order to characterize the cooling performance of the vaccine carrier, the first experiment is the temperature change experiment of the vaccine carrier under the external temperature change. The vaccine carrier developed in this study uses a Peltier device as a core component of cooling. In using this device, the most dominant factor in the cooling performance is how to efficiently cool the hot-section of the device. And the most important factor in cooling is the atmospheric temperature itself.

Figure.9 Humidity chamber for experiment (DWTH-155, DAIHAN-BRAND)

The first experiment in this background compares the time taken to reach the optimal vaccine storage temperature of 8℃ at 20℃ in a fully controlled external environment using a thermo-hygrostat. The external temperature setting, which is an independent variable compared with the atmospheric temperature, is calculated by comparing 5 experimental groups of 25℃, 27℃, 30℃, 32℃ and 35℃, respectively, in order to include all the temperatures expected in the atmospheric environment of developing countries

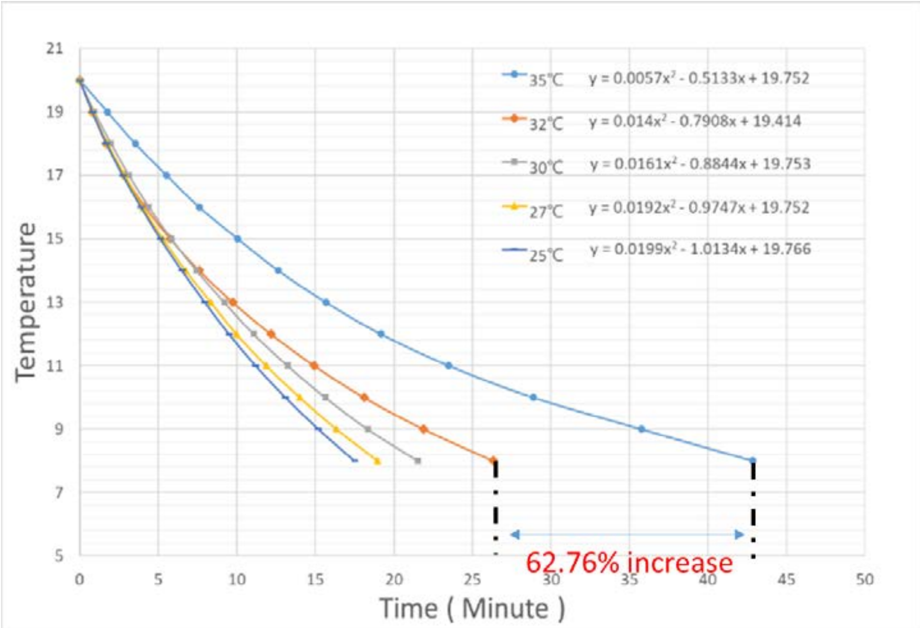


Figure.10 Cooling result graph under various temperature

Temperature	Complete time (min:sec)	General trend line equation		
		$Y = \alpha X^2 + \beta X + \gamma$		
		α	β	γ
25℃	17:30	0.0199	− 1.0134	19.766
27℃	18:58	0.0192	− 0.9747	19.752
30℃	21:32	0.0161	− 0.8844	19.753
32℃	26:20	0.014	− 0.7908	19.414
35℃	42:52	0.0057	− 0.5133	19.752

Table.2 Trend line coefficient list

Experimental results show that the temperature decreases with each consistent trend line according to each external temperature. A noteworthy point is that for the 25℃ ~ 30℃ period, the time to reach the target temperature increased slightly (25℃, 27℃ have respectively 8.38% and 13.5% increase). On the other hand, the time was greatly increases 22.3%

under 32℃ as the setting point and we can see an even greater increase by 62.78% compared to 32℃ by 35℃. These experimental results show that there is a point where the cooling capacity of the carrier decreases sharply when the external temperature / humidity exceeds a certain critical point. These results support the need for optimization compromise pursued in this study.

4.2.2 Cooling Power consumption test

The reduction characteristics of the cooling capacity shown in the previous experimental results inevitably lead to a correlation with power consumption. In such a background, observation of power consumption according to the cooling capability of the carrier becomes very important. Experiments on power consumption were carried out at 25℃ and 15% humidity using a thermo-hygrostat. The amount of consumed current was monitored when the target temperature was maintained at 8℃, 7℃, 6℃, 5℃, and 4℃ for 30 minutes. If the target temperature is set, the developed vaccine carrier operates as a basic control method in which the Peltier is turned off when the target temperature is reached, and turned back on when exceeded. As a result of the experiment in this environment, the following experimental results can be confirmed as shown in Figure 11.

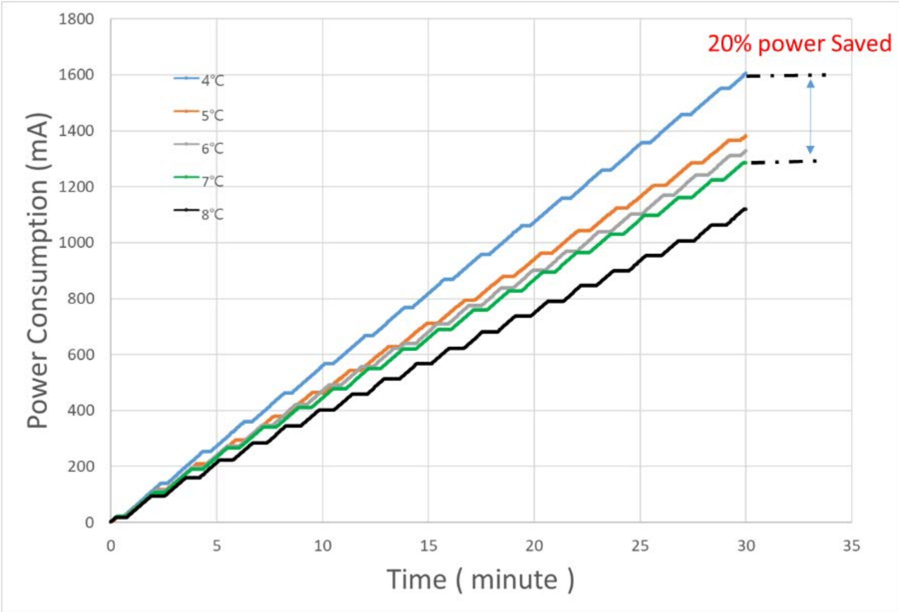


Figure 11 Power consumption result graph under various temperature

As shown in the above graph, a step-like graph is formed as shown due to the process of performing automatic control at the target temperature. In this process, it can be confirmed that the trend line according to each temperature is revealed. This trend line shows the power consumption rate and can be expressed as a graph shown Figure 12.

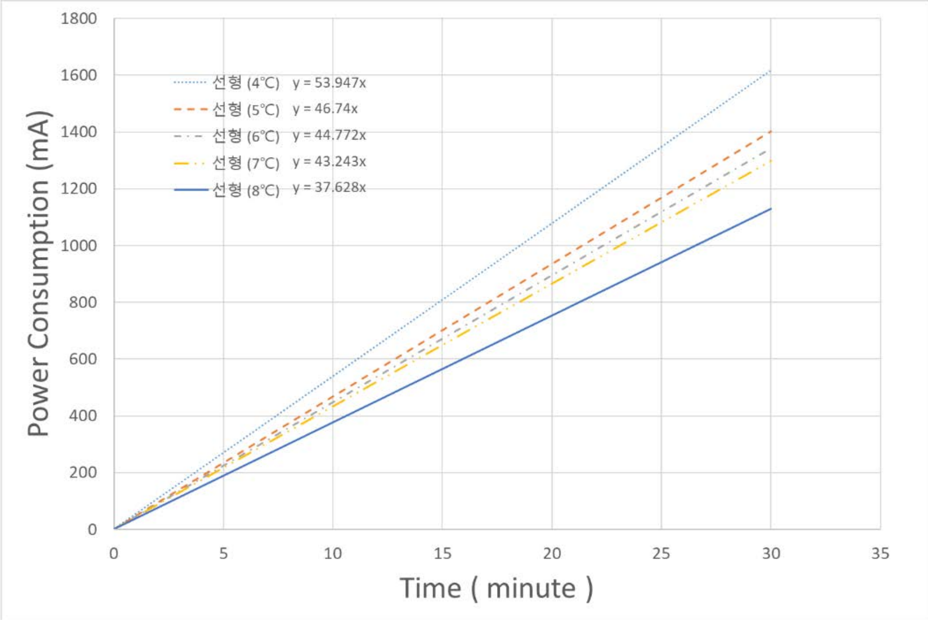
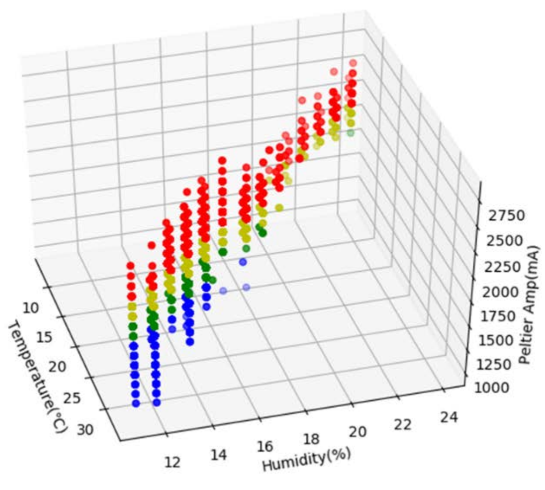


Figure 12 Power consumption result trend graph

As a result of the experiment, it was found that the correlation between the characteristic correlation of the cooling capacity according to the specific temperature and the power consumption according to the specific temperature are driven with certain rules. However, it is very difficult to obtain a general model equation because the time to reach the target temperature or the rate of change of power consumption is very nonlinear. In addition, it can be easily deduced that the complexity and nonlinearity increase dramatically when considering all the additional factors, such as date, time, GPS location, and humidity collected by the system in this research. In order to solve this problem of complexity, we intend to solve the problem for power consumption optimization by introducing the system of this study into the machine learning tool.

4.2.3. Support vector machine (SVM) simulation.

Previous experiments have shown that the external temperature and humidity have the nonlinear pattern with the cooling performance and power consumption of the vaccine carrier. In order to optimize this, we tried optimization simulation in the laboratory. SVM is a prominent algorithm that shows very good performance for classification among many statistical prediction algorithms. It classifies the multidimensional data under specific criteria and constructs a prediction model. Then, it operates when new input data is collated from local environment and predicts the result. In this study, as mentioned above, dates, time, GPS information, ambient temperature, humidity, and charging current were selected as the input factors, and as the output factors, the Peltier current value and the P_{rate} value proposed in this study were selected to constructed for this learning algorithm. However considering that the input data required for complete learning should be collected at least more than one year to find the local environmental pattern. Also, we should consider that there are many restrictions imposed on the laboratory. For these reasons, this experiment only uses the temperature and humidity of the room as input data.



$$y_1 = P_{rete} = \frac{\Delta I_{Pel}}{\Delta T_{in}}$$

$$y_2 = \begin{cases} (I_{Pel} \geq 2.2) = 3 \\ (2.2 > I_{Pel} \geq 2.0) = 2 \\ (2.0 > I_{Pel} \geq 1.8) = 1 \\ (1.8 > I_{Pel}) = 0 \end{cases}$$

Figure 13 Classify figure by SVM

4.3. Summary

In order to optimize the power consumption of the vaccine carrier, experiments were carried out under various experimental conditions to grasp the basic characteristics of the carrier. Through some experiments, it was found that there is a certain pattern between external temperature, humidity, etc., and the cooling performance of the carrier, as well as the amount of current consumed by the Peltier. Moreover, we can also know that the patterns are nonlinear. To analyze the patterns for optimization, we implemented a self-learning modeling process using support vector machine (SVM).

Chapter 5. Conclusion

The vaccine is a highly effective method of vaccination against disease, and this study began with the goal of increasing vaccine coverage in developing countries. Vaccine carrier is a key component of the vaccine cold-chain. We analyze the factors that hinder the increase of vaccine penetration rate in developing countries and define the problem. We tried to solve the problem through three kinds of technical approaches. The first is the development of a vaccine carrier that meets the requirements for developing countries. The second is the IoT-based monitoring technology that enables systematic identification of vaccine supply status. The third is power optimization through machine learning based on collected local data. These technologies create a comprehensive vaccine delivery system for developing countries. Experiments and simulations have shown that up to 21% of power savings can be expected through this proposed algorithm.

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초 록

의료 기구 및 약품 보급이 어려운 개발도상국 오지에서 백신은 매우 효과적인 위생 보건방법이다. 하지만 이러한 백신 보급의 효율성과 이점에도 불구하고 전력 공급 부족, 지형적 험준함, 미비한 인프라 등의 요소들이 개발 도상국의 백신 보급률의 확산을 막고 있는 실정이다. 현재까지 이러한 문제들을 극복하고자 여러가지 연구가 진행된 바 있고 그러한 연구 결과들을 기반으로 특별히 이 논문에서는 스마트폰으로 구축된 사물인터넷(IoT) monitoring 데이터베이스와 이 데이터들을 근거로 개발도상국 현지에 사용될 백신캐리어의 현지화 및 최적화를 기계학습 알고리즘을 통하여 해결법을 탐색하고자 한다. 궁극적으로 도달하고자 하는 목표는 백신 캐리어가 사용될 개발도상국 저전력 오지 환경에서 적정 백신 저장 온도인 2도~8도를 유지하는 최적의 전력 사용을 학습 및 예측하여 백신캐리어의 사용시간을 극대화 하는데 있다.

주요어: 백신냉장운송, 사물 인터넷, 기계학습, 펠티어 효과, 개발도상국.

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