Journal of KIIT. Vol. 16, No. 4, pp. 123-134, Apr. 30, 2018. pISSN 1598-8619, eISSN 2093-7571 123
http://dx.doi.org/10.14801/jkiit.2018.16.4.123

Monitoring Cattle Disease with Ingestible Bio-Sensors Utilizing LoRaWAN: Method and Case Studies

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This work was supported by Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry(IPET) through Advanced Production Technology Development Program, funded by Ministry of Agriculture, Food and Rural Affairs(MAFRA)(316078-03).

Abstract

Livestock diseases lead to the decline in farm income by causing lower farm productivity, chronic disease developments or even culling. Therefore, monitoring the health condition of livestock in real-time to predict and swiftly respond to any diseases is very important because it directly affects the profit and productivity of farms. For an effective disease prediction system, we propose a cattle disease monitoring method with orally administered bio-sensors utilizing Long Range Wide-Area Network(LoRaWAN). In addition, we provide case analysis by applying this prediction system on cattle. The bio-sensor used in the proposed method is orally administered and settles in the rumen, allowing for a stable measurement of core body temperature without the interference of external environment.

With the proposed method, cattle disease can be monitored on a regular basis and thus enable swift response to any disease occurrences. We expect this method to contribute in lowering the cost of economic damage caused by livestock diseases.

요 약

가축 질병은 가축의 생산성 감소를 야기하고 만성 질병으로 이어지거나 심한 경우 가축이 폐사 하기도 하며, 이는 농가의 직접적인 소득 감소로 이어진다. 따라서 가축의 건강 상태를 실시간으로 파악해 질병을 예찰하고 발병 시 빠르게 대응하는 것은 축산농가의 소득 및 생산성과 직결되므로 매우 중요하다. 본 논문에서는 효과적인 축우 질병 예찰을 위하여 Long Range Wide-Area Network(LoRaWAN)를 활용한 경구 투여용 센서 방식의 축우 질병 예찰 방법을 제안한다. 또한, 실제 축우에 적용하여 사례 분석을 수행하였다. 제안하는 방법의 경구 투여용 센서는 식도를 통해 축우 반추위에 안착되어 외부 환경의 간섭 없이 안정적으로 축우의 심부 체온 측정이 가능하다. 제안하는 방법을 통해 궁극적으로 축우의 질병을 상시 예찰함으로써 발병 시 빠르게 대응할 수 있으며, 질병으로 인한 경제적 피해를 절감할 수 있을 것으로 기대한다.

Keywords
LoRaWAN, ingestible bio-sensors, livestock disease, disease prediction

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Ⅰ. Introduction

The economic loss caused by livestock diseases is not limited to farms. It also brings about damage to the national level as the infectious disease spreads throughout the region. Thus livestock disease control has grown increasingly important. In general, the disease mortality rate(1.28~6.83%) of Korean native cattle, beef cattle and dairy cattle is lower than other kinds of livestock such as swine and poultry. However, the overwhelmingly high frequency of disease outbreaks in cattle makes a systematic disease management specialized for cattle very crucial[1].

On the global level, the frequent outbreaks of infectious livestock diseases such as foot-and-mouth disease(FMD), bovine spongiform encephalopathy (BSE), and avian influenza(AI) have caused massive economic damages. To minimize such damages, there is a growing necessity for a disease monitoring system that forecasts an illness in advance and also enables an immediate and integrated response to disease outbreaks in its early stages. Furthermore, the current global livestock trend shows the number of farms decreasing, but the number of cattle in each farm increasing, thus giving rise to the necessity of a livestock management system. Active research is currently carried out in various countries in Europe, the United States, and South Korea regarding livestock monitoring systems utilizing wireless sensor network technology and also livestock biometric big data[2].

In general, livestock such as cattle undergo body temperature changes when infected with a disease. Studies to determine the health condition of cattle utilizing such biometric indexes are increasing[3]. However, an accurate disease monitoring system is almost impossible in large-scale stock farms with vast numbers of cattle and frequent movements caused by data losses during transmission. Also, existing wireless sensor network technology Wi-Fi and RF communications technology may be high in speed but are expensive with short transmission distances that limit practical application.

To overcome such limitations, we propose a cattle disease prediction system utilizing Long Range Wide-Area Network(LoRaWAN). Compared to existing technologies, LoRaWAN specializes in low-power, long distance transmission, and transmits in unlicensed frequency bands for minimum data loss[4].

In addition, the proposed method was designed to overcome the shortcomings of rectal thermometers and commercial systems with transmission issues and limitations for continuous and accurate measurements. Deep body temperature of cattle is measured by ingestible bio-sensors and the data is collected and transmitted to the server through LoRaWAN. Such data is transmitted in a manner to minimize the amount of data loss and allow for effective and accurate analysis to enable disease prediction.

The main contributions of this paper are as follows:

- We proposed a biometric data-based, orally administered method using bio-sensor tag technology that provides real-time measurement of core body temperature. Using this method, the body temperature of livestock can be measured in a regular and consistent manner without being influenced by the attachment method or location of the sensor. Also, the temperature data measured by the bio-sensor tag is transmitted through LoRaWAN with minimum data loss, enabling accurate data collection and efficient livestock disease monitoring.
- We applied the proposed method to real farms and cattle, and conducted case analyses. As a result, 3 cases of cattle illnesses were detected early, and the affected cows were treated. Such results show that the proposed method contributes to the early detection of livestock diseases, and also enable rapid response to any illnesses that may arise.

The organization of this paper is as follows: Chapter 2 examines related works, Chapter 3 explains the proposed cattle disease prediction system, and Chapter 4 describes the application cases and field tests. Lastly, Chapter 5 concludes this paper and mentions future works.

Ⅱ. Related Works

2.1 Existing Researches on Monitoring Livestock Disease

Various livestock health monitoring methods have been researched to prevent diseases in advance. Existing methods include the collection and analysis of milk, blood, and urine samples of cattle[5][6]. However, such biometric samples are difficult to collect and analyze, and also require professional manpower or specialized training, thus limiting its practical use.

Various studies have been conducted to manage livestock health and prevent diseases by collecting and monitoring biometric information such as livestock temperature and activity level. In general, most viral and bacterial diseases accompany symptoms such as body temperature rises in the initial stages of a disease. Table 1 is a chart of diseases that accompany increases in body temperature, and the range of body temperature change that occur with each disease[7]. Such information is useful for monitoring cattle disease.

The most common method for measuring the body temperature of livestock is the usage of rectal thermometer. The rectal temperature is measured by inserting a thermometer in the anal passage of a livestock. However, this method makes it difficult to measure many numbers of livestock at once. Also, changes in temperature cannot be tracked because temperature information is gained at the time of measurement. In addition, the person who measures the rectal temperature is positioned behind the livestock and is in danger of being kicked by the animal's hind legs. Measuring body temperature with the rectal thermometer requires much time and effort, and it also limits the activity of livestock and can even exacerbate a disease by causing stress.

Thermal cameras can also be used to measure the body temperature of cattle by installing thermal cameras in sheds[8][9]. Thermal cameras collect body temperature without approaching the cattle and thus enable repeated measurements. However, the skin surface temperature is measured from a certain distance, and so the ambient environment can affect the measurement results and accuracy of data. Also, the limited angle of the camera provides measurements for cattle only within its range, making it inadequate for large-scale breeding farms.

To overcome such limitations, temperature measurement methods utilizing insertion-type sensors that can provide consistent measurements of livestock body temperature have continued to undergo research. Insertion-type sensors are mostly inserted orally into the rumen. Other methods include the Cannula method that creates a hole in the rumen to connect it with a cannula, or sensors inserted in the vaginal area [10]-[13]. As the sensor is installed inside the body of a livestock, the tag is less likely to become damaged. Also, it can produce accurate measurements of core temperature without being affected by the external environment, and therefore provide more reliable data.

Regarding insertion-type sensor researches, there exist several technical issues such as long-term battery usage and communications problems. A communications problem between the sensor and gateway interrupts the smooth transmission of data to the server and decreases the reliability of data. And as a result, hinders the accuracy of disease monitoring.

Table 1. Range of body temperature change according to cattle disease

Name of Disease	Dyspepsia, Milk Fever	Ketosis	Dyspepsia, Enteritis	Bronchitis	Pneumonia	Mastitis, Puerperal Fever
Range of Body Temperature Changes(℃)	36.0~38.0	37.8~39.0	38.0~38.8	39.5~42.0	40.0~42.0	41.0~42.0

Table. 2 Comparison of livestock body temperature measurement methods

	Rectal Thermometer[14]	Thermal Camera[8]	Attach-Type Sensor[15]	Orally Administered Sensor[17]
Measured Area	Rectum	Skin Surface	Ears, Neck, Heads	Rumen
Measurement Method	Manual	Manual	Automatic	Automatic
Data Credibility	High	Low	Low	High
Applicability in Large-Scale Farms	Low	Low	High	High

By analyzing preceding studies, we confirmed the researches of various systems to measure and monitor the temperature of livestock. Table 2 is a summary of a comparative analysis between the existing body temperature measurement methods and the proposed method utilizing orally administered bio-sensors. Table 2 compares the measurement site and method, data credibility, and applicability in large-scale farms. Compared to the method proposed in this paper, the rectal thermometer and thermal camera require longer measurement times and thus have low applicability. Sensors attached to the exterior of livestock pose limitations to the accuracy and credibility of the measured temperature data due to external environment conditions.

The proposed insertion-type sensor measures the rumen temperature and thus its measurement data is highly credible. The proposed measurement method also shows high applicability in large-scale farms[18]. However, if a communications problem arises during the process of data transmission, an accurate disease monitoring system will be difficult to maintain. Therefore, to enhance the efficiency of livestock disease monitoring system and the credibility of transmitted data, we propose a disease prediction system that utilizes an effective communications method.

2.2 LoRaWAN Application Case

Long Range Wide-Area Network(LoRaWAN) is one type of Low Power Wide Area Network technology that processes information with wireless communications using low power within long distance. Compared to existing wireless communications technology such as Wi-Fi or ZigBee, LoRaWAN has longer communications distance. With excellent receiver sensitivity LoRaWAN is recently being utilized in various fields[16]. Also, LoRaWAN functions in unlicensed frequency bands that enable accurate data transmission without the interference of other data frequencies. The unit cost of a LoRaWAN communication module is 1/5 of existing modules, and with no license costs, it is easy to set up.

In Korea, a telecommunications company set up the first LoRaWAN platform in July, 2016. The network is currently utilized in the following fields:

1) Measurement: LoRa module installed in reading system to offer telemetering service
   - Gas meter reading
2) Monitoring: Management and control of distribution facilities through LoRaWAN and control center
   - Sharing real-time parking information
   - Public lighting system management
3) Tracking: Confirming the location of objects using sensors with micro LoRa communications modules
   - Location based safety management service
   - Communications, security and asset management service

Notwithstanding the many applications of LoRaWAN in various fields, it has yet to be applied in the livestock management field.

Therefore, we propose a cattle disease prediction system that utilizes a bio-sensor loaded with a LoRa communications module. The proposed method enables accurate disease monitoring by transmitting body temperature data without loss.

III. Cattle Disease Prediction System

3.1 Proposed Method

In this paper, we propose a cattle disease prediction system with orally administered bio-sensors utilizing LoRaWAN that collects and monitors the biometric information of cattle in real-time. The system also compares and analyzes the measured data with the biometric big data of cattle categorized by disease to detect any abnormalities. The farm owner and veterinarian receive alerts of any abnormal data via mobile messages to enable instant response.

Fig. 1 is a diagram of the proposed disease prediction system. The system composed of the bio-sensor, LoRa gateway, LoRa system, cloud server, and mobile device. The bio-sensor is orally administered to the cattle, and the biometric information is transmitted to the LoRa system from the LoRa gateway.

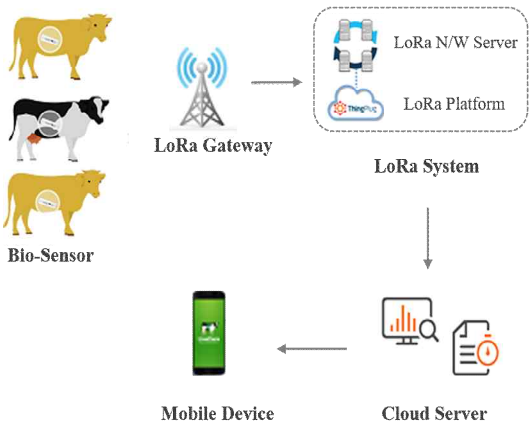


Fig. 1. Diagram of proposed disease prediction system

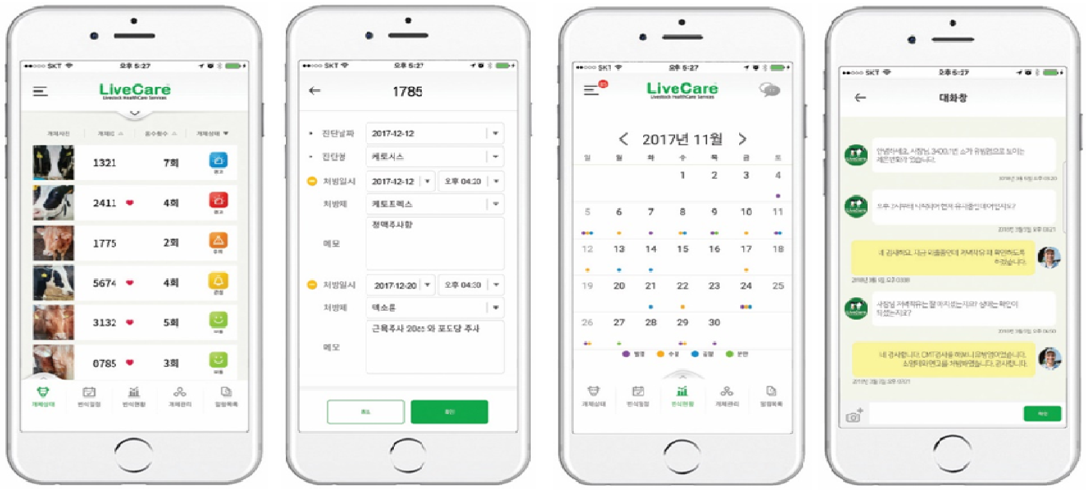
The LoRa system relays such transmitted data to the cloud server for analysis. And such analyzed information is delivered to application users via mobile device. The system's structure includes an ingestible bio-sensor located in the rumen measuring body temperature in real-time and transmitting such data to the cloud server through the LoRa gateway and network server. We utilized a LoRaWAN platform set up by a Korean telecommunications company.

The bio-sensor developed in this study is a cylindrical shaped tag that makes oral administration easier. Once it is inserted into cattle it settles safely in the rumen and its special design keeps it fixed in the rumen despite rumination and digestive activities. The bio-sensor remains in the cattle and can detect minute changes in core body temperature up to 0.1℃ without being influenced by the ambient environment. The sensor is installed in a non-toxic capsule to protect it from gastric fluids and pressure. The built-in battery can be used up to 6 years, and thus allows stable and repetitive usage until butchery. In the case of insertion type sensors, there is an issue of not being suitable for long-term monitoring due to its limited battery life.

However, the bio-sensor tag developed in this study includes a built-in battery that can run for more than 5 years, enabling long-term monitoring once a bio-sensor is inserted in livestock.

3.2 Mobile Application for Disease Prediction

A mobile application for disease prediction of cattle was developed to allow farmers to monitor the health conditions of cattle at all times[16]. This mobile application provides various graphs and numerical values of cattle information including body temperature, disease and breeding. If an abnormal body temperature is detected, the manager receives an alert for immediate action. Fig. 2 shows the mobile application screens.



(a) (b) (c) (d)

Fig. 2. Mobile application screens

Fig. 2(a) shows a screen with a list of each cow's health condition. The user can check the body temperature, the number of water intake, and pregnancy status of each registered entity. By clicking each entity displayed on the screen, additional basic information such as breed and monthly age is offered along with a body temperature graph.

Fig. 2(b) is a disease management screen that allows the user to record the diagnosis details of a disease and its prescription, and thus manage cattle disease regardless of time or place.

Fig. 2(c) is a breeding schedule provided in calendar format so the user can easily check the breeding schedule. The user can register and manage breeding information regarding estrus, fertilization, pregnancy, and parturition. By selecting a specific date, the user can check the breeding information of cattle registered on that date.

Fig. 2(d) is a chatting screen for the communication between the farm manager and personnel. Whenever an abnormal temperature or disease is detected, the farm owner or manager receives immediate feedback.

Ⅳ. Case Studies

4.1 Materials and Method

We proposed a cattle disease monitoring method utilizing LoRaWAN for effective disease prediction. We conducted a field test by applying this method to real cattle. The test to monitor cattle disease was conducted for two months from December 26, 2017 to February 25, 2018. Table 3 displays the information of cows that underwent the test. The entities included a total of 10 Holstein cows, 5 pregnant and 5 nonpregnant cows, raised in a dairy farm in Sancheong-gun, Gyeongsangnam-do, Korea. All of the entities were fertile, adult cows in various ages, and were confirmed to be in healthy conditions before the test.

Table 3. Information of Entities

Entity	Breed/ Sex	Age (months)	Pregnancy Status	Expected Calving Date
1	Holstein/ Female	27	Nonpregnant	–
2		31	Pregnant	08/19/2018
3		35	Pregnant	04/17/2018
4		37	Nonpregnant	–
5		44	Pregnant	10/16/2018
6		49	Pregnant	04/09/2018
7		67	Nonpregnant	–
8		85	Nonpregnant	–
9		95	Pregnant	07/17/2018
10		106	Nonpregnant	–

Fig. 3. Farm with LoRa gateway installed

Bio-sensors loaded with LoRa modules were orally administered to 10 cows using a bolus gun. The bio-sensors settled in the rumen and measured the body temperature of the cows in ten-minute intervals. The test was set up to measure body temperature every ten minutes, thus collecting 144 temperature data per day for each cow. At the end of the test, a total of over 80,000 temperature data was accumulated.

Fig. 3 is a photo showing the installed LoRa gateway in the tested farm. The body temperature data measured by the bio-sensor is transmitted to the integration server through the LoRa gateway. If abnormal temperature continues and a disease inflicted cow is detected, the mobile application alerts the farm manager with a warning message or chatting function. And the veterinarian diagnoses the cow in question.

4.2 Results and Analysis

None of the cows showed any abnormal behavior nor showed any physical side effects after the bio-sensor was orally administered. At the end of the test period all 10 cows were in healthy condition. During the 60-day testing period, all 10 bio-sensors provided stable temperature measurements without being damaged or loss from rumination or defecation.

Table 4 is a summary of the test results showing the average body temperature monitored by the bio-sensor, abnormal changes in body temperature, disease alert action, and disease prediction results such as diagnosis date, and name of disease.

As shown in Table 4, the monitoring results of body temperature although different among all 10 cows, were in the normal range of 38.5℃~39.5℃. However, 3 cows experienced abnormal temperature changes higher than the normal temperature range, and thus disease alert messages were sent to the farm manager. According to veterinarian diagnosis, all three cows had mastitis. Thus, abnormal temperature changes by the arrow, entities #1, 8, and 3 showed abnormal increases in body temperature during the latter half of the testing period.

Fig. 4 is a graph showing the daily average of the body temperature collected by the bio-sensors of each entity. As seen in the graph, the core temperatures of the cows were measured in a stable manner during the two-month test period. Generally, a pregnant cow maintains a higher body temperature than normal. Entity #1 maintained a higher body temperature than other entities until its calving on February 2. Entity #8 also had a similar pregnancy period and calving date, and thus maintained a higher body temperature until it slowly decreased after February 10. As marked by the arrow, entities #1, 8, and 3 showed abnormal increases in body temperature during the latter half of the testing period.

Table 4. Summary of Test Results

Entity	1	2	3	4	5	6	7	8	9	10
Average Temperature (℃)	38.87	38.52	38.55	38.55	38.53	38.60	38.62	39.17	38.57	38.61
Abnormal Changes in Temperature	O	X	O	X	X	X	X	O	X	X
Disease Alert	O	X	O	X	X	X	X	O	X	X
Disease Diagnosis Date	02/14/2018	-	02/19/2018	-	-	-	-	02/18/2018	-	-
Name of Disease	Mastitis	-	Mastitis	-	-	-	-	Mastitis	-	-

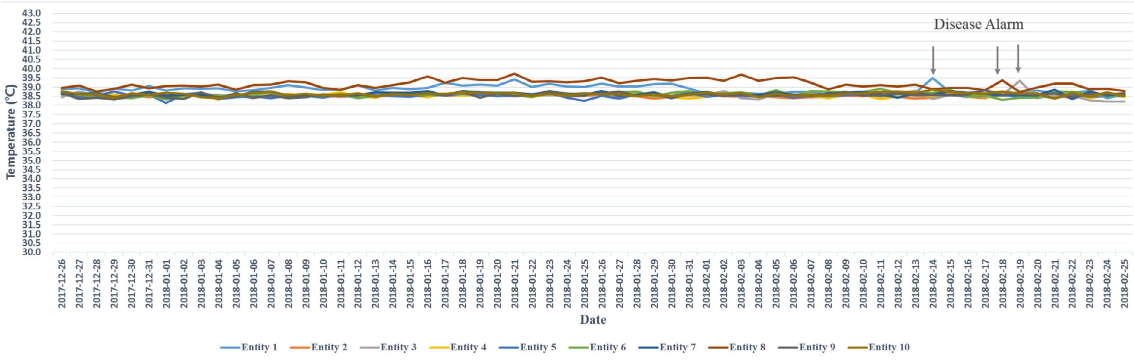


Fig. 4. Daily average body temperature of all entities

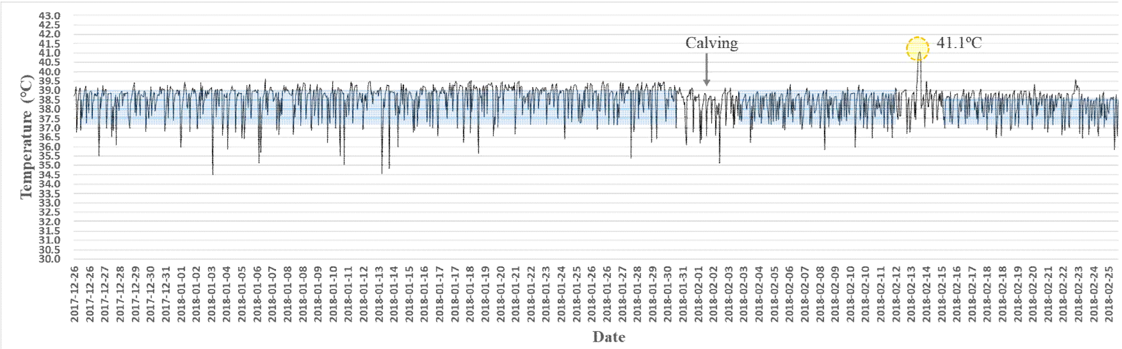
Fig. 5 is a collection of graphs depicting the detailed changes in body temperature of several entities measured in ten-minute intervals. In Fig. 5, the condition of each entity can be checked in more detail, compared to the daily average body temperature graph in Fig. 5. Fig. 5(a)~(c) are the body temperature graphs of entities that were inflicted with diseases. For comparison, Fig. 5(d) is a detailed body temperature graph of one of the entities that did not experience illness.

Fig. 5(a) is a detailed body temperature graph of entity #1, and as mentioned above, its calving date was February 2. In general, the body temperatures of pregnant cows gradually decrease as calving approaches. Fig. 5(a) shows the body temperature of entity #1 dropping around the calving period. After calving, entity #1 maintained a normal body temperature of 37~38.5℃, but in the morning of February 14, its temperature rapidly rose to 41.1℃. Such an abnormal temperature change prompted an alert message to the farm manager. After conducting CMT, the veterinarian diagnosed entity #1 with mastitis. Entity #1 was immediately prescribed and treated with a fever reducer.

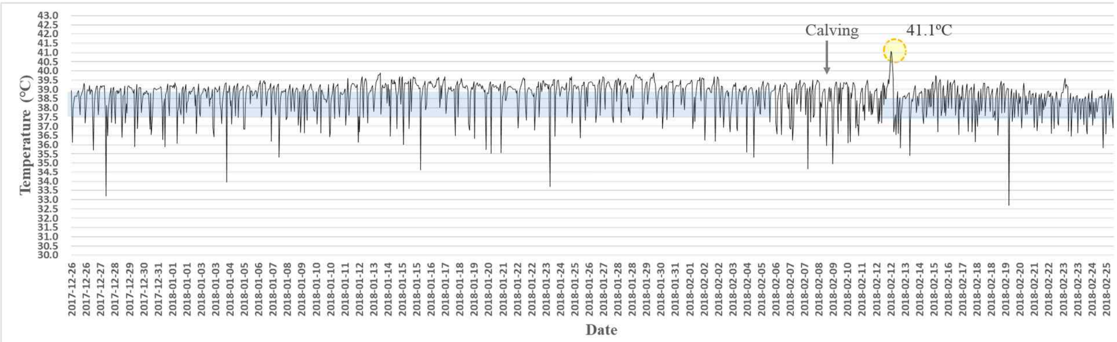
Fig. 5(b) is the body temperature graph of entity #8 that calved on February 10. Similar to entity #1 in Fig. 5(a), the body temperature of entity #8 decreased around the date of calving. But a week later on February 18, its body temperature rose to 41.1℃. An alert message prompted by abnormal temperature changes was sent to the farm manager. And the veterinarian diagnosed entity #8 with mastitis after conducting CMT. Entity #8 was immediately prescribed and treated with an anti-inflammatory drug and ointment.

Fig. 5(c) shows the body temperature graph of entity #3 that was pregnant and scheduled for calving on April 17, 2018. Other than entities #1 and #8, entity #3 showed a normal body temperature pattern during the test period. However, on February 19 its abnormal temperature change prompted a disease alert message to be sent to the farm manager. After conducting CMT, the veterinarian diagnosed entity #3 with mastitis and prescribed and treated it with ointment.

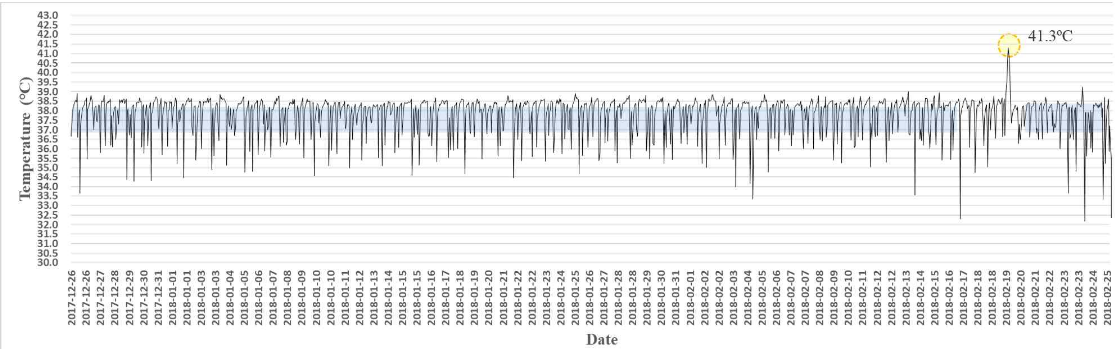
Fig. 5(d) is the body temperature graph of entity #2 which is scheduled for calving on August 19, 2018. Entities #2 and #3 are similar in monthly ages and compared to entity #3, entity #2 showed normal temperature changes during the test period while entity #3 showed a rapid rise in temperature around February 19 when it was diagnosed with mastitis. According to the test results, the ingestible bio-sensors accurately measured the deep body temperature of the cows by 0.1℃. Through real-time monitoring, a total of 3 cows, 1 pregnant and 2 nonpregnant, were confirmed with abnormal body temperature rises. Diseases were detected in advance and immediately treated. Abnormal temperature rises were confirmed to be unrelated to pregnancy in cows.



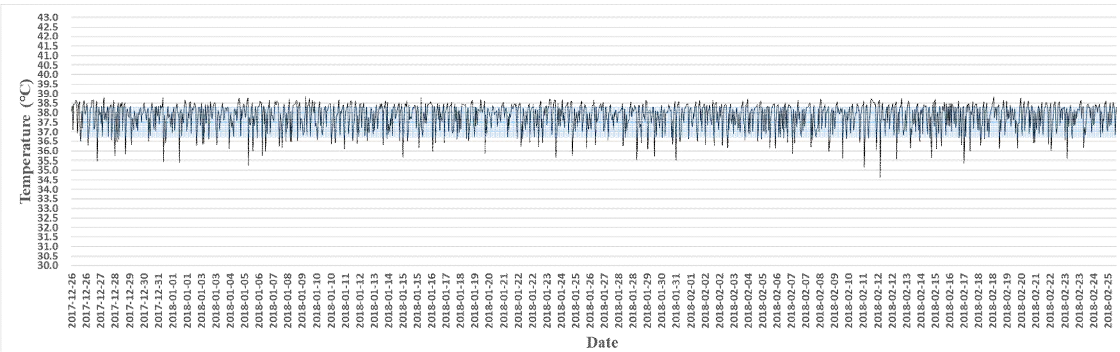
(a) Entity #1



(b) Entity #8



(c) Entity #3



(d) Entity #2

Fig. 5. Detailed body temperature

In particular, all 3 cows that showed temperature rises recorded body temperatures over 41℃. This pattern in temperature change was similar to that of mastitis among cattle diseases, and thus mastitis was suspected for the 3 cows. The diagnosis results show that the forecast was correct. In addition, the test showed that LoRa gateway had vast recognition distance and could be utilized in large-scale farms with cattle movements.

Through this research and test, the proposed method was shown to be more effective in monitoring the health condition of cattle than existing temperature measurement methods. Also, the proposed method collects body temperature data for each entity, and thus enables a more accurate disease monitoring system[17].

Ⅴ. Conclusion and Future Works

The economic loss caused by livestock disease outbreaks are not limited to farms but also brings about damage to the national level as the infectious disease spreads throughout the country. Researches on livestock disease control methods have increased but in terms of practicality, there has been a limit to applying such monitoring systems to real farms.

Therefore, this paper proposed a disease prediction system with ingestible bio-sensors utilizing LoRaWAN to effectively monitor cattle disease. The orally administered bio-sensor of the proposed method safely settles in the rumen. And this allows for minimal temperature change detections without the interference of the ambient environment. The body temperature data is transmitted to the integration server through the LoRa gateway that has limitless recognition distance. With the proposed method, the health conditions of cattle can be monitored in real-time and thus enable rapid detection of cattle diseases.

We conducted a test on 10 cows by orally administering bio-sensors with LoRa communication modules and collecting body temperature data for 60 days. The inserted bio-sensors measured each cow's body temperature and transmitted such data without loss to the server through the gateway to monitor the health conditions of the cows. The monitoring results showed 3 cows experiencing abnormal temperature changes with alert messages immediately sent to the farm manager. These cows could be treated in advance after being diagnosed with mastitis by a veterinarian.

The proposed method is expected to contribute in preventing the spread of cattle diseases through early disease detection and prompt response through real-time body temperature monitoring. This method is also anticipated to lower the cost of financial damage by reducing treatment costs and mortality rates of cattle.

In the future, we plan to collect various biometrics of cattle other than body temperature to create and analyze a cattle biometrics big data to upgrade the algorithm for cattle disease prediction.

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