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Development of an Early Diagnostic Device for African Swine Fever through Real-time Temperature Monitoring Ear-tags (RTMEs)

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Abstract

Throughout the 20th century, the transition of pig farms from extensive to intensive commercial operations amplified the risk of disease transmission, particularly involving African swine fever (ASF). Real-time temperature monitoring systems have emerged as essential tools for early ASF diagnosis. In this paper, we introduce new real-time temperature monitoring ear tags (RTMEs) modeled after existing ear tag designs. Our crafted Pig-Temp platforms have three primary advantages. First, they can be effortlessly attached to pig ears, ensuring superior compatibility. Second, they enable real-time temperature detection, and the data can be displayed on a personal computer or smartphone application. Furthermore, they demonstrate excellent measurement accuracy, ranging from 98.9% to 99.8% at temperatures between 2.2 and 360°C. A linear regression approach enables fever symptoms associated with ASF to be identified within 3 min using RTMEs. The communication range extends to approximately 12 m (452 m^2), enabling measurements from an estimated 75 to 2,260 pigs per gateway. These newly developed Pig-Temp platforms offer singifcant enhancement of early ASF detection.

Keywords: African swine fever (ASF), Early diagnosis, Real-time temperature monitoring, Internet of Things (IoTs), Ear-tag

1. INTRODUCTION

The global population is steadily growing and is projected to reach 9.15 billion by 2050, leading to an increased demand for meat products[1,2]. In particular, the number of pig farms has increased to meet this increasing demand for pork, an important source of high-quality protein[3]. Accordingly, the nature of pig farming has evolved; in the latter half of the 20th century, pork production facilities transitioned from extensive to intensive commercial operations[4]. This substantial change amplified the risk of disease infection in pig farms[5], leading to severe consequences such as a mortality rate of ~20% in United States pig farms[6].

African swine fever (ASF) is among the most critical diseases affecting pigs. This severe viral disease is characterized by respiratory and digestive dysfunction, congestive bleeding[7], high fever > 41°C, and symptoms such as loss of appetite and lethargy[3]. Current ASF control strategies depend on early diagnosis because of the high infection and mortality rates, as well as the lack of a vaccine[3,8]. However, passive observation by farmers is often insufficient for early detection, particularly because fever-a key symptom of ASF-typically manifests at night when disease symptoms are more pronounced[9].

Methods for early ASF diagnosis have been the focus of extensive research. These can be broadly divided into polymerase chain reaction (PCR) methods and real-time monitoring methods. PCR methods, exemplified by the SWINOSTICS (Swine disease field diagnostics toolbox) project, can detect viral diseases such as ASF using pig oral fluid, feces, and blood[10]. Additionally, Lu et al. reported a portable ASF diagnostic method that involves extracting DNA from the blood and anus of ASF-infected pigs[11]. These PCR methods are highly sensitive to ASF, but they prioritize accurate diagnosis over early detection.

In terms of real-time monitoring, Pandey and colleagues described an ear tag-shaped wearable device in 2020, measuring 3.05 cm × 3.05 cm × 1.27 cm (L × W × H)[9]. This device can detect symptoms such as temperature, aggression, lethargy, and neurological disorders using a temperature sensor, accelerometer, and gyroscope. Through a Bluetooth low energy (BLE) module, the device reduces power consumption and can operate for 3 days. However, the resulting data are inadequate, particularly in terms of one-to-many communication and temperature measurement accuracy.

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In this report, we introduce ear tag-shaped real-time temperature monitoring devices that can track pig temperature in real time. The design of these real-time temperature monitoring devices is based on existing pig ear tags, thereby ensuring compatibility without additional modifications to the existing product. We evaluated the performance of these devices in vitro, considering factors such as temperature data detection, BLE communication range, and battery life.

2. EXPERIMENTAL

2.1. Prototype of RTME and gateway box

The RTME is designed with three key requirements. First, because the RTME must be inserted into the pig's ear, the metal pin is constructed with a very sharp shape (aspect ratio: ~80). Second, to effectively transmit the pig's body temperature through the RTME's metal pin, the pin should have good thermal conductivity and resist corrosion. Thus, the pin is constructed using stainless steel, which exhibits both anti-corrosion properties and high thermal transmission. Third, RTMEs must be highly compatible with existing pig ear tag products (e.g., ear-punches and name tags). To ensure this compatibility, a hole is drilled in the center of the upper plate of the RTMEs, and the size of the metal pin is fabricated to match the size of existing ear tags.

RTMEs comprise a metal pin, top/bottom plates, printed circuit board (PCB), and lithium battery (see Fig. 1 (c)). The top/bottom plates are produced through a casting process using acrylonitrile butadiene styrene material and are fully sealed to prevent entry of external matter. They are designed to be 35 mm in diameter and 7 mm in height when assembled (including the PCB plate). The PCB is assembled with a microcontroller unit (MCU), a 3-V lithium button cell, and a temperature sensor. The temperature sensor is soldered to one side of the PCB, positioned to measure the temperature at the metal pin. The battery and MCU are soldered to the other side to protect the temperature sensor from the heat they generate. The MCU used is the CC2540 model, which supports wireless and BLE transmission. The temperature sensor is the TMP117 model, which provides a maximum resolution of 0.007°C and a maximum accuracy of ± 0.1°C within a temperature range of -20 to 50°C. The RTME circuit diagram is shown in Fig. 1 (e).

The gateway box comprises an antenna, a Bluetooth to Wi-Fi converter, and a wireless internet router (see Fig. 1 (e)). It connects to multiple RTMEs via BLE communication, collects

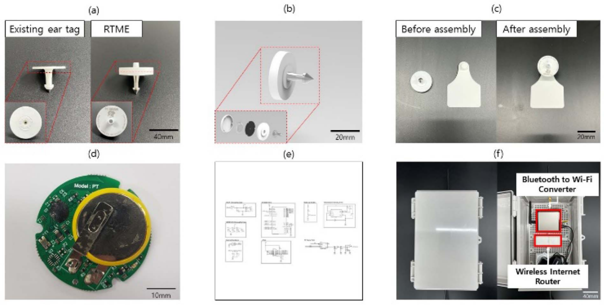

Fig. 1. RTME configuration: (a) existing ear tag and RTME, (b) device design, (c) name tag, (d) RTME PCB, (e) RTME circuit diagram, and (f) gateway box.

temperature data, and then transmits the data to the cloud server. The Bluetooth to Wi-Fi converter used is HYGATE's BGB-100 model, which can connect to multiple RTMEs. The wireless internet router is KT's Egg model, which collects Wi-Fi signals and uploads them to the cloud server.

2.2 Temperature measurement accuracy of fabricated RTMEs

The temperature measurement accuracy of the fabricated RTMEs was evaluated in both a refrigerator and an oven. The refrigerator used was the RT50K6035SL model from Samsung; the oven was a programmable forced convection oven, model JSOF-100, from JS Research. Variables were set in anticipation of Korea's livestock environment, and considering an error of approximately 5 °C, 2.2°C was designated as the average temperature in winter, 22.7°C as the average temperature in spring and fall, and 36°C as the average temperature in summer. The refrigerator was set to 2.2°C, whereas the oven was set to 22.7°C or 36°C. The RTME was placed in each oven and refrigerator for testing. Data were gathered after allowing the RTME metal pin to reach saturation temperature for 15 min. The temperature was subsequently recorded every minute for 18 min.

2.3. Environmental effects on fabricated RTMEs

An experiment to assess the environmental influence on the fabricated RTME was conducted in both a refrigerator and an oven. The experiment was conducted by putting the middle part of the metal pin on the finger, mimicking the conditions present when a pig wears the RTME. The hand with the inserted RTME was then placed in either an oven or a refrigerator for measurement. With the hand temperature at 27.5°C, the temperature measured in the refrigerator was 5.1°C. Conversely,

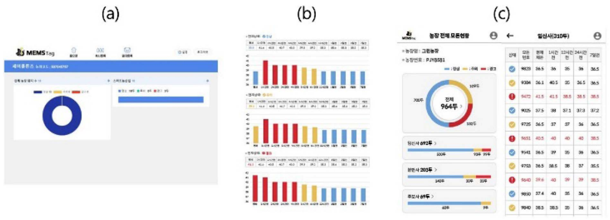

Fig. 2. Web site design: (a) main page, (b) detail page, and (c) app design for admin

with the hand temperature at 29.3°C, 34.2°C the temperature measured inside the oven was 22.3, 31.3°C. The temperature was recorded every minute for 23 min.

2.4. Pig-Temp Web site and application for admin

Fig. 2 shows the design of the web page ((a), (b)) and smartphone application (c), which allows direct monitoring of pigs' conditions. The main page displays the total number of pigs, as well as the status of each pig (Fig. 2 (a)). A blue color indicates a 'normal condition', a yellow color signals 'caution', and a red color means 'warning'. A farmer can register barns and pigs using the button at the top of the page. The detailed page shows the temperature measurement timeline for each hour, and the current status is displayed at the top of the page. The application also provides real-time updates regarding the farm's status. In the event of unusual signals from the pigs, a notification is sent through the smartphone application.

3. RESULTS AND DISCUSSIONS

3.1. RTME System

The Pig-Temp platform consists of real-time temperature monitoring ear tags (RTMEs), a gateway for communication, a cloud server for data collection and analysis, and a web server for data display. Fig. 3 illustrates the real-time temperature monitoring process using the Pig-Temp platform. Initially, an RTME and a name tag are affixed to each punched portion of a pig's ear. Next, the RTME and name tag are hung on the pig's ear via piercing. Real-time temperatures are subsequently measured by the installed RTMEs; the data are transmitted to a gateway, then forwarded to a cloud server using Bluetooth Low Energy (BLE) wireless communication. Finally, the data are analyzed and displayed on a dedicated web server.

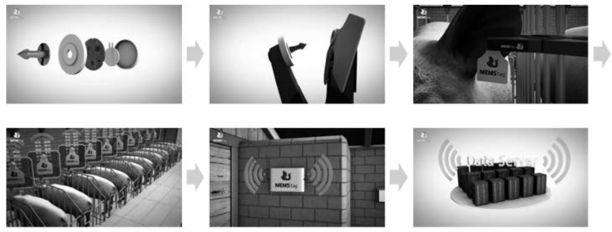

Fig. 3. Pig-Temp platform for African fever swine monitoring in pig farms

The Pig-Temp platform offers several advantages: First, the RTMEs are highly compatible with existing ear tag punches because their design mimics the shape of a pig ear tag, facilitating attachment to pig ears. Second, they enable real-time temperature measurements via the Pig-Temp platform. Third, the data can be displayed on a personal computer; alerts can be sent to a personal smartphone when unusual signals are detected in pigs. Consequently, early diagnosis of ASF (where high fever is a key indicator) is feasible, potentially minimizing the number of infected pigs.

3.2 In vitro experiments

3.2.1. Temperature measurement accuracy of fabricated RTMEs

Experiments were conducted to evaluate the temperature measurement accuracy of RTMEs (Fig. 4). These in vitro experiments were performed within a refrigerator and an oven; ambient temperatures ranged from 2.2°C to 36°C. The 2.2°C condition was tested in a refrigerator, whereas the 22.7°C and 36°C conditions were tested in an oven. The temperatures measured by the RTMEs were 2.22 ± 0.49°C under the 2.2°C condition, 22.73 ± 0.08°C under the 22.7°C condition, and 35.86 ± 0.08°C under the 36°C condition. The accuracy of ambient

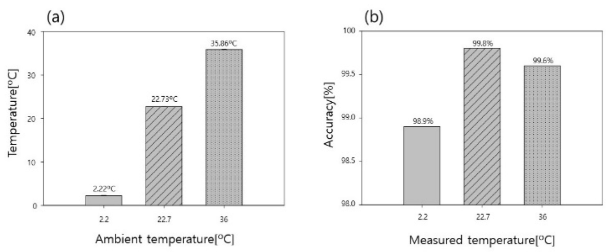

Fig. 4. Performance of fabricated RTMEs (a)Data collected from ambient temperature measurements using RTMEs. (b)Analysis of accuracy comparing measured data against ambient temperature.

temperature measurement was calculated using the following Eq. (1):

$$\text{Accuravy(\%)} = \frac{\text{Ambient temperature} - |\text{Ambient temperature} - \text{Measured temperature}|}{\text{Ambient temperature}} \times 100 \quad (1)$$

The accuracies were approximately 98.9% at 2.2°C, 99.8% at 22.7°C, and 99.6% at 36°C. These results indicate that the resolution of RTMEs is approximately ± 0.5°C, with ~99% accuracy. The normal temperature for pigs is typically around 39°C, but ASF can elevate this temperature to approximately 41°C. Therefore, using the developed RTMEs, a clear distinction can be made between normal temperatures and the unusual temperatures caused by ASF.

3.2.2. Environmental effects on fabricated RTMEs

The exposed end of the RTME could be influenced by the ambient temperature because of its exposure to the external environment. To assess this effect, an experiment was conducted to record changes in RTME measurements in response to shifts in the external temperature. This experiment was to determine the temperature convergence time when the RTME was first worn, and the measurement was started with the RTME left in the refrigerator (approximately 5°C).

The experiment was conducted by putting the middle part of the metal pin on the finger, mimicking the conditions present when a pig wears the RTME. Measured temperatures were 27.28 ± 0.32°C in group A and 29.05 ± 0.15°C in group B and 33.86 ± 0.05°C in group C. These results indicate that, although measurements were influenced by the external environment, the approximate error rate was ≤ 0.8%. Despite external exposure of the end part, the measurements converge toward body temperature as they pass through the section in contact with the pig's ear.

Fig. 5 (e) illustrates the response time relative to ambient temperature. The response time was evaluated by determining when the measurement was within 10% of the ambient temperature. The response times were 19 min in group A and 16 min in group B and 13 min in group B. Using the linear regression method, we analyzed the response time from a normal body temperature of 39°C to a feverish body temperature of 42°C. The linear regression method utilized the following Eqs. (2) and (3):

T = Temperature [°C], t = Time [min]

$$Error\ function = \sum_{i=1}^{n} (at_i + b - T_i)^2 \quad (2)$$

$$[a \quad b] = \begin{bmatrix} \sum t_i T_i \\ \sum T_i \end{bmatrix} \begin{bmatrix} \sum t_i^2 & \sum t_i \\ \sum t_i & \sum 1 \end{bmatrix}^{-1} \quad (3)$$

Under group A conditions, the response time needed for the temperature to increase from 39°C to 42°C was approximately 3 min. Under group B conditions, the response time needed for a similar temperature increase was approximately 2 min. Under group C conditions, the response time needed for a similar temperature increase was approximately 2 min. These results imply that if a pig develops ASF-related fever symptoms, the change can be detected within 3 min using the RTME.

3.2.3. BLE communication distance of RTME

We evaluated the communication distance in an obstacle-free

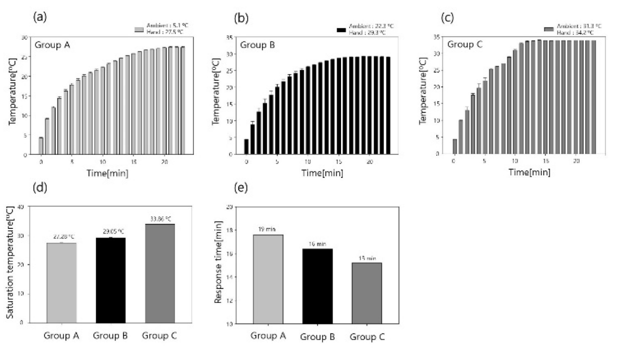

Fig. 5. Mean accuracy of saturation temperature measurement according to ambient temperature: (a) Group A measurement data: ambient temperature, 5.1°C; hand temperature, 27.5°C. (b) Group B measurement data: ambient temperature, 22.3°C; hand temperature, 29.3°C, (c) Group C measurement data: ambient temperature, 31.3°C; hand temperature, 34.2°C. (d) Mean saturation temperature. (e) Response time.

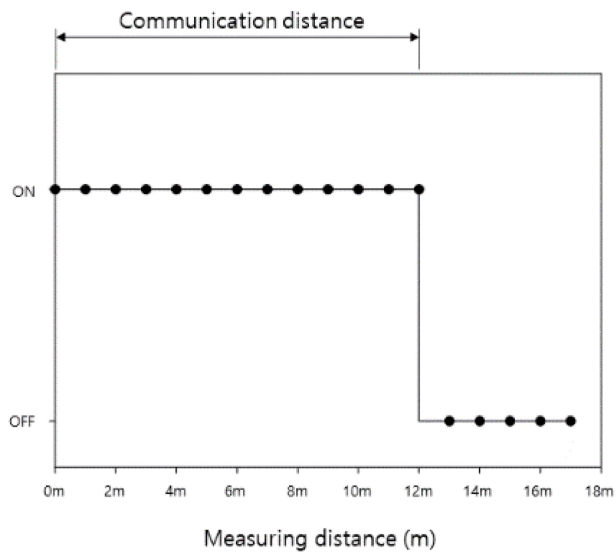

Fig. 6. RTME communication distance data

environment, measuring distances from 0 m to 18 m. The results showed that the RTME could achieve communication up to approximately 12 m, thereby covering an area of ~452 m². In South Korea, there are specific regulations concerning the amount of space allocated for each pig; these regulations vary according to pig type. Typically, boars require ~6 m² each, pregnant pigs need 1.4 m², farrowing pigs need 3.9 m², lactating pigs need 2.3 m², piglets need 0.2-0.3 m², growing pigs need 0.45 m², and finishing pigs require 0.8 m². Using these standards, it is possible for a single gateway to monitor ~75 to ~2,260 pigs.

4. CONCLUSIONS

In this study, we developed an RTME for early detection of ASF. Our Pig-Temp platform offers several advantages: it can be easily attached to pig ears, provides real-time temperature sensing, and presents the data through a personal computer or smartphone application. Considering its accuracy of 98.9–99.8% within a temperature range of 2.2–36°C, the RTME can clearly distinguish between normal temperatures and fever temperatures indicative of ASF. Our linear regression analysis showed that ASF-related fever symptoms can be detected within 3 min using the RTME. The RTME can maintain communication up to approximately 12 m, or 452 m², implying that it can monitor between 75 and 2,260 pigs per gateway.

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