Wearable and Compact Wireless Sensor Nodes for Measuring the Temperature of the Base of a Calf's Tail

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Calves have low resistance to viruses or bacteria and are predisposed to respiratory diseases such as pneumonia. Respiratory disease is the number-one cause of death in calves. An effective method for the early detection of respiratory diseases is to measure the rectal temperature with a thermometer. However, this cannot be frequently conducted because it requires too much time and effort of the farmers. As a method requiring minimal time and effort, we have developed wireless sensor nodes to automatically measure the body surface temperature of a calf. The sensor nodes are designed to be compact by using a 3-axis accelerometer with a temperature-sensing function and a chip antenna, which can measure any body surface of a calf. The fabricated sensor nodes, which can measure both temperature and acceleration, are $18 \times 18 \times 7$ mm^3 and weigh 6.5 g including batteries. Their primary advantages are light weight and small size. Thus, we can easily attach the sensor nodes to the base of the calf's tail, which is one of the slimmest parts, and successfully measure the body surface temperature.

1.   Introduction

To achieve a safer and more secure society, wireless sensor network technology has been a promising approach for a variety of applications, such as structural health monitoring, human body monitoring, and animal health monitoring.[1–6] Structural health monitoring is for improving the safety and reliability of buildings, bridges, and lifeline systems by detecting damage before it reaches a critical state; the damage is detected by many wireless sensor nodes set on structures.[1,2] Human body monitoring detects sleep disorders, Parkinson's disease and so on by obtaining information on daily walking and posture using a triaxial sensor, GPS and a magnetic sensor.[3] These technologies have

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been introduced into agriculture, including animal health monitoring.[4–6] Animal health monitoring systems have enormous potential to prevent the spread of avian influenza and death from illness or injury due to their ability for early detection,[7–10] thereby allowing rapid cures. To achieve these applications, wireless sensor nodes consuming minimal power for chickens,[8] multifunctional sensor nodes for GPS, magnetometers and accelerometers for cattle,[9] and bolus-type sensor nodes have been developed.[10] However, these sensor nodes for cattle cannot be easily used. Multifunctional sensor nodes are difficult to attach to cows due to their size. In addition, bolus-type sensor nodes require dedicated tools.

The aim of this study is to develop wearable wireless sensor nodes that can be attached to adult cattle as well as calves using a simple attachment. Because calves are less able to fight respiratory diseases such as pneumonia, the death rate from respiratoy disease is the highest amog all accidents. Nevertheless, there are no fuss-free methods of measuring the body temperature of calves. Thus, we have developed wearable wireless body temperature sensor nodes that can be easily attached to calves. The developed sensor nodes, which can measure both temperature and acceleration, are $18 \times 18 \times 7$ mm^3 and weigh 6.6 g with batteries. Their primary advantage is their compact and small size, allowing easy attachment to any part of the calf. In this work, we attached a sensor node to the base of a calf's tail, and confirmed changes in body surface temperature and activity over a period of one day. In addition, we performed continuous monitoring for 16 d, and compared the daily maximum temperature with the daily maximum rectal temperature.

2. Materials and Methods

2.1 *Design of wearable and compact wireless sensor nodes*

Wearable wireless sensor nodes need to be less than 10 g to allow the sensor nodes to be attached to any part of a growing cows' body, such as the ears, neck, and tail. In particular, it is difficult to attach the sensor nodes to the tail, which is one of the slimmest parts of the calf's body. We designed the sensor nodes to be compact to satisfy these conditions. Figures 1(a) and 1(b) show a photograph and a block diagram of the sensor nodes, respectively. The 3-axis accelerometer uses a H30CD (Hitachi Metals Ltd.), which has a 5 μA current consumption level when in sleep mode. The H30CD can measure temperature with an accuracy of ±3 °C. The microcontrol unit (MCU) and transceiver IC are an M430F2232 (Texas Instruments, Inc.) with a 16-bit analog digital converter (ADC) and a TXC 101 (RF Monolithics, Inc.), respectively. The operating frequency of this transceiver is 315 MHz because the permeability of radio waves at that frequency is high for humans and animals.[7] The communication distance was about 50 m without obstacles. The size and weight of the sensor nodes were $18 \times 18 \times 7$ mm^3 and 2.1 g, respectively, without batteries. In this report, the battery used was CR1632 (4.5 g), and the total weight of the sensor nodes was therefore 6.6 g. The activity (G) is calculated as

$$G = \sqrt{a_x^2 + a_y^2 + a_z^2},$$ (1)
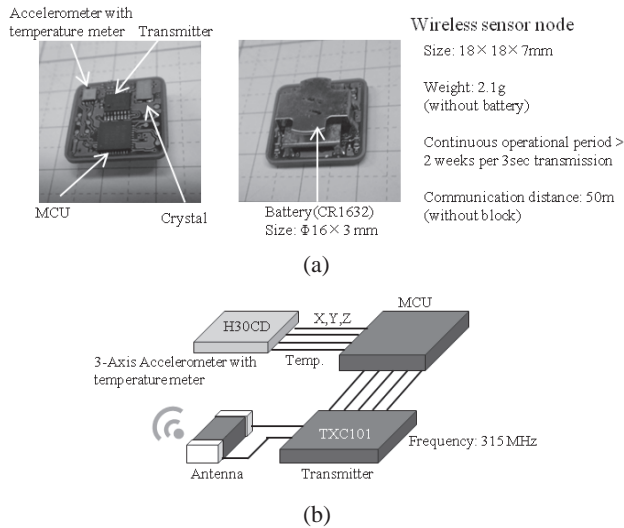
Fig. 1.   Fabricated wireless sensor node. (a) Photograph and (b) block diagram.

where a_x, a_y, and a_z are the 3-axis accelerations.   The measurement and transmission interval was set at 3 s.   The data transmitted was the activity (G) and the temperature. We confirmed that the lifetime of the sensor nodes was longer than 2 weeks.

2.2   *Experimental procedure*

In Fig. 2, a photograph of the evaluation experiment is shown.   The experimental object is a calf [Fig. 2(a)].   Since calves are much smaller than adult cattle, the size of the wearable sensor nodes needs to be sufficiently small.   The measurement is taken at the base of the tail as shown in Fig. 2(b), since this part indicates a high body surface temperature.   As the tail is one of the slimmest parts of the calf, the sensor nodes should be smaller.   We can easily attach the sensor nodes to the base of the tail using sporting tape [Fig. 2(c)].

To confirm the measurement stability, we measured the body surface temperature and activity for a single day in the first experiment.   The second experiment, which focused on the measurement stability of the body surface temperature, was performed by continuous monitoring for 16 d.   In addition, to compare the body surface temperature with the rectal temperature, we measured the rectal temperature twice a day using a thermometer.

3.   Results and Discussion

Figure 3 shows the data measured over one day.   The temperature (upper line) and activities (lower line) of the calf are shown.   The sensor indicated that the maximum temperature change was about 2 °C per hour, for example, from 19:00 to 20:00 (dashed circle in Fig. 3).   This result shows that the sensor temperature reflects the skin

<center>(a)   (b)   (c)</center>
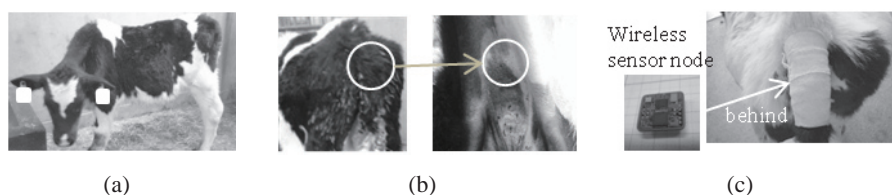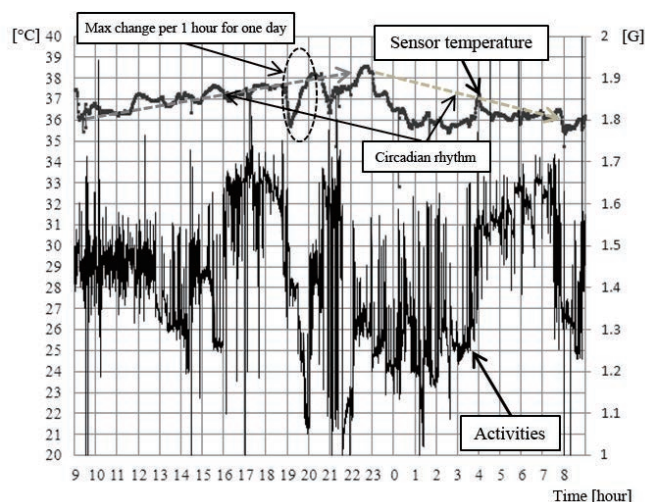
Fig. 2.   Our test calf.

Fig. 3.   Experimental results. Measurements taken over a single day.

temperature of the calf since the skin temperature changes easily. We also observed a circadian change in the temperature, which increased until approximately 22:00 (dashed arrowed line in Fig. 3), and decreased late at night. Thirdly, the 3-axis accelerations could measure the activities (G) for one day. From these results, it is seen that there are no problems in the measurements of temperature and activity over a single day.

Next, we conducted 16 d of continuous measurements to confirm the measurement stability of the body surface temperature. In addition, we compared the sensor temperature (body surface temperature) with the rectal temperature. In this experiment, we measured the rectal temperature of the calf twice a day. Figure 4(a) shows the measurement results. The small dot indicates the sensor temperature and the big dot the rectal temperature. The sensor temperature is 2–3 °C lower than the rectal temperature. It can be seen that the sensor temperature was high when the rectal temperature was high. Similarly, we see that the sensor temperature was low when the rectal temperature was low. However, it can also be seen that the sensor temperature is too low in some cases [dashed circle in Fig. 4(a)]. This seems to increase over time. This may be caused by the movement of the wireless sensor node.

Figure 4(b) indicates the relationship between the daily maximum rectal temperature and the daily maximum sensor temperature over 16 d. A strong correlation is indicated.
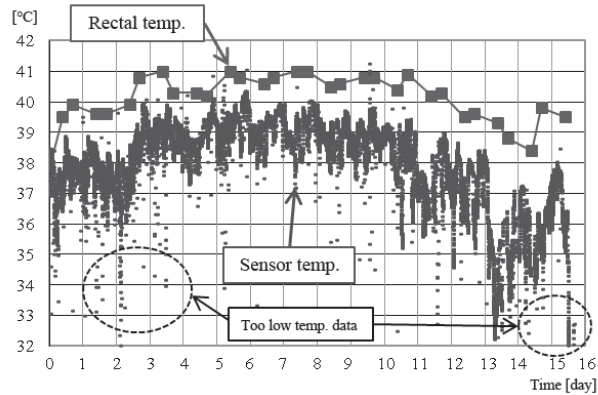
(a)
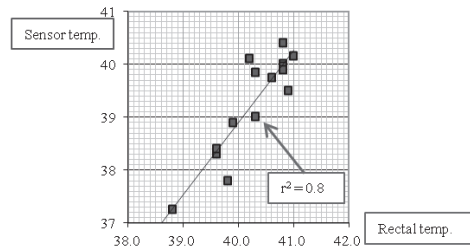
(b)

Fig. 4.   Experimental results. (a) Continuous monitoring over 16 d. (b) Relationship between daily maximum sensor temperature and daily maximum rectal temperature over 16 d.

There are many symptoms that accompany a fever. Thus, it is important to measure the skin temperature and correlate it with the rectal temperature. Calves are likely to develop a fever caused by pneumonia.

4.   Conclusion

In this paper, we describe wearable and compact wireless sensor nodes that monitor the health condition of calves. The base of the calf's tail indicates high surface temperature, but the tail is one of the slimmest parts of the calf. Thus, it is difficult to measure the base of the tail. We designed the sensor nodes such that the size and weight are $18 \times 18 \times 7$ mm^3 and 6.5 g including batteries, respectively. Thus, we could attach the sensor node to a calf's tail, and succeeded in measuring the skin temperature and activity.

However, the wireless sensor nodes indicated a temperature that was too low in some cases, and the frequency of this low estimation increased over time. The cause could be a gap between the skin of the calf and the temperature sensor part of the wireless sensor node. The gap is attributed to the 7 mm thickness of the sensor nodes. Thus, future work will focus on separating the temperature sensor part from the sensor body and make the temperature sensor flexible to achieve measurement stability.

Acknowledgements

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