Estrus Detection for Dairy Cow Using ZigBee-Based Sensor Networks

Chien-Hsing Chen and Hung-Ru Lin

***Abstract*—The reproductive performance of dairy cows is influenced primarily by estrus-detection accuracy. Effective estrus-detection systems are beneficial to increasing pregnancy rates, improving the reproductive performance of dairy cows. The most obvious external symptom of estrus in dairy cows is standing-heat behavior. The standing cows remain briefly motionless for several seconds when repeatedly mounted by mounting cow. Therefore, in this study, wireless sensor networks were used to develop a standing-heat signal detection and management system for dairy cows. This system detects the movement signals of mounting behavior by using a 3-axial accelerometer within a wireless sensor installed on the forefeet of cows. When signal of accelerometer exceed a threshold value, the ZigBee begins broadcasting signals to the surrounding sensor nodes. The received signal strength indicator (RSSI) between the broadcasting node and every sensor node is recorded. The ZigBee serial number and the RSSI for sensor nodes are then sent to a terminal database system, which compares the RSSIs in the batch to determine the serial number with the strongest RSSI, achieving the goal of estrus detection. In addition, the results of estrus detection also can be inquired by a smartphone-base system.**

***Index Terms*—Estrus detection, received signal strength indicator, standing heat, wireless sensor networks, ZigBee.**

I. INTRODUCTION

The insemination success rate of dairy cows depends on whether artificial insemination is performed at appropriate times during estrus. However, unlike bulls, humans do not have the ability to detect estrus in cows; therefore, they cannot judge the estrus times of cows accurately. This prevents the success rate of artificial insemination from improving. Inadequate estrus detection leads to mistimed breeding and reduces conception rates in cows, causing substantial losses from extended gaps between pregnancies. The optimal time for artificial insemination is 8 to 12 h after the first standing heat [1]-[3]. Thus, effective estrus detection is critical to profit in dairy farming.

The clearest signal of the estrus model in dairy cows is standing heat. When cows in estrus are mounted by bulls, they stand motionless for several seconds; the duration of standing heat varies substantially between cows and can vary from approximately 6 to 24 h, with an average duration of 16 h. If cows are observed only two or three times for 30 min each day to detect this estrus behavior, only approximately 12% to 19% of cows in estrus can be discovered [4], [5]. This is because more than 60% of mounting activity occurs between nightfall and morning. Therefore, in this study, wireless sensor networks (WSNs) were used to detect estrus in cows.

Over the past 10 years, research interest in WSNs has increased. Fields of application have included military affairs, health care, environmental monitoring, and monitoring of animal activity. A number of communication technologies have used WSNs. Of these, ZigBee has received the most attention [6]. ZigBee is a short-distance wireless communications technology that uses the 2.4 GHz band and has a simple structure, low cost, low power consumption, and low transmission rates [7]. The data transmission rate is between 20 Kbps and 250 Kbps. WSN sensing nodes are small and can thus be embedded in sensors, microcontrollers, and wireless transmitters. Therefore, not only does ZigBee have sensing applications, but it can also process and transmit data. However, WSNs still face a number of challenges in development and application. Sensor nodes must be arranged densely and have low reliability. In addition, WSNs have severe restrictions in electrical use, calculation, and storage [8].

WSNs can complete objectives within short distances through wireless transmission. Positioning of sensing points is also critical; if monitoring is performed in an unknown environment, the data obtained by sensors is meaningless. Positioning the sensing points effectively is a major research topic. The received signal strength indicator (RSSI) is commonly used to measure distance and positioning. RSSIs can be obtained directly from the beacon frames of communications and, unlike infrared and ultrasound measurement methods, no additional hardware measurement equipment is required; therefore, communications overhead, complexity, and cost are relatively low. A number of algorithms also use RSSIs as a distance function. Thus, RSSIs can be applied in WSNs, which have limited electrical power. Patwari *et al.* [9] and Elnahrawy *et al.* [10] indicated that signal attenuation and shielding effects adversely affect RSSIs, resulting in substantial changes. Therefore, a number of studies have investigated algorithms for improving the accuracy of RSSI positioning because RSSI misplacement results in substantial errors. Further data analysis is required to improve accuracy [11].

Numerous studies have used RSSIs as a method of determining distance. However, the errors in results have been considerable. Parameswaran *et al.* [12] used experimental methods to estimate a reliable parameter for when an RSSI is unable to become a position sensing algorithm. Oguejiofor *et al.* [13] used the RSSI trilateration

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approach to position blind nodes in WSNs. A minimum of three anchor nodes was necessary to determine the positions of unknown points accurately. Based on the results of these studies, an RSSI positioning algorithm was not used in the present study to determine the distance between sensing nodes. Instead, the RSSIs received from a single batch were compared directly to determine which sensor node is the nearest to the broadcast node. Then, the nearest node can be identified as an estrus cow.

II. Methods

The goal of this study was the detection of standing-heat behavioral responses in dairy cows. WSNs, full-time video recording, smartphones, single chips, and a database system were combined to develop an effective signal detection and management system. Initial system testing was performed. Fig. 1 shows the dairy cow estrus detection system developed using wireless sensor technology in this study. Three-axial accelerometers within the sensing nodes placed on mounting cow were used to start external broadcasting in the ZigBee equipment [15]. The sensing nodes on nearby cows received the broadcasting signals from the mounting cow, and the RSSI values between the sensing and broadcasting nodes were recorded. The ZigBee serial numbers and the recorded RSSIs were transmitted to a remote database system. This system compared the RSSI strengths in the received batch to deter-mine the strongest RSSI. The corresponding serial number with the strongest RSSI was used as the identifier of the cow in heat, achieving the goal of cow estrus detection.

The wireless sensing device comprises a microcontroller module (Arduino Nano V3.0: ATmega 328), a ZigBee communication module (2.4 GHz Xbee S2), and a three-axial accelerometer module (MMA7445 -3Axis). As shown in Fig. 2, the three-axial accelerometer was used to detect mounting actions in cows in estrus. To reduce erroneous signals in the three-axial accelerometer caused by cow activity, the sensing apparatus was installed on the forearms of the cows' forelegs. This reduced the influence of cows' normal movement on the three-axial accelerometer, reducing erroneous signals caused by non-mounting behavior. Therefore, when mounting behavior occurred, the output value of the three-axial accelerometer on the mounting cow exceeded the threshold value set for the system. This initiated external broadcasting in the ZigBee communications module. Other ZigBee nodes within the broadcasting range received this signal. The sensing nodes that received the signal performed the AT command ATDB to obtain the RSSI between the broadcasting node and the receiving node [15]. The Xbee serial number and the RSSI were then transmitted to the remote database system for data processing.

When creating a WSN, the limited amount of power available for each sensing node must be considered. The effective conservation of power within the WSN is a critical research theme. The most common methods of power conservation are optimization of radio transmitter power, standby mode, and sleep mode. In this study, sleep mode was used to conserve power. Additionally, this system also included cameras for 24 h recording. The database system can be used for rapid viewing of the videos corresponding to the times of the detection results. These videos can be used to compare the accuracy of estrus detection.

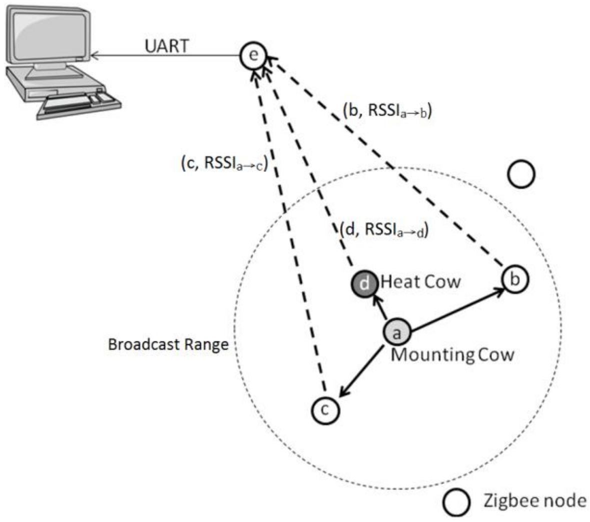

Fig. 1. WSNs for estrus detection system.

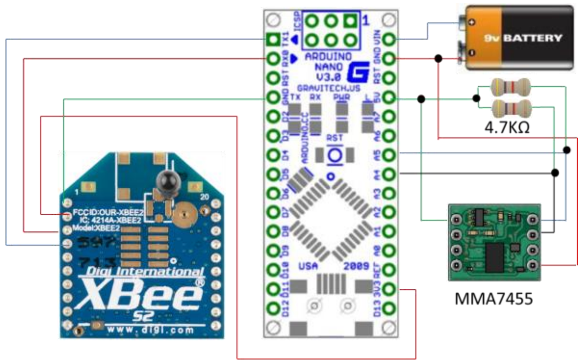

Fig. 2. Wireless sensor device.

III. Results and Discussions

In this study, WSN technology was used to develop a cow-estrus detection system based on ZigBee. This system included wireless sensor equipment, a database system, and a cellphone inquiry system. The Microsoft Visual C# programming language was used to develop the database system. Fig. 3 shows the graphical user interface (GUI) of this database system, which can record ZigBee identifiers, RSSIs, receiving times, and video. In addition, it can compare the RSSI strengths from a batch of received data to determine the corresponding identifiers of the strongest RSSI to detect cows in heat.

Fig. 3. GUI for database.

The GUI of the database system can link the recorded estrus times to the video recorded at the corresponding times. Thus, managers have only to click a recorded time position in the system and the system shows video from that point. Managers do not need to spend substantial time viewing all of the recorded video. Thus, they can view videos of cows in heat quickly to judge the accuracy of the estrus detection system.

In addition, when the database system has finished recording a batch of data, the system transmits its comparison results to a specified email address. Managers can use their cellphones to receive these emails, allowing them to view cow-estrus developments immediately. Managers can also use an estrus inquiry system on their smartphones to view dairy-cow-estrus detection results in a timely manner. Fig. 4 shows that this application allows inquiries into estrus developments within specific time ranges; the inquired time range form is sent to specified email addresses. The database system reads these emails automatically and performs data-query processing. The inquiry results are then sent to the email addresses of the managers.

Fig. 4. Mobile phone APP for estrus detection inquery.

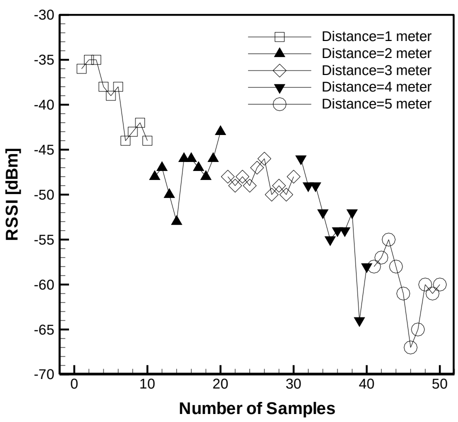

Fig. 5. Changes in XBee RSSI at different distances.

Regarding the feasibility of using RSSI as a method of detecting estrus in dairy cows, because the distance between the sensing nodes on the mounting cows and mounted cows is approximately 1 m, an experiment was performed with a broadcasting node set in a fixed position to simulate the position of a mounting cow. Five reference nodes were placed at positions from 1 to 5 m from the broadcasting node. The RSSI between the broadcasting node and the reference nodes at corresponding distances was measured. For each measurement, each reference node was located on the same horizontal plane but not on the same azimuth. A total of 10 measurements were recorded to simulate the influence of actual environments. Fig. 5 shows the relationship between corresponding distances and RSSIs. As the distance increased, RSSI values decreased. These results are consistent with those of past studies [13], [14].

In addition, the equation (1) was used to obtain the standard deviations (σ) of the RSSIs at corresponding distances.

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (1)$$

In this equation, n is the number of samples, x_i is the RSSI value for the ith sample, and is the average RSSI value. Table I shows the average RSSI values and standard deviations for the corresponding distances. The XBee RSSI exhibited a relatively small error of ±1.26 dBm at a distance of 3 m. It exhibited a relatively large error of ±5.1 dBm at a distance of 4 m. The errors at 1 m and 2 m were smaller than the general RSSI error range mentioned in the literature (between ±4 dBm and ±8 dBm) [14]. Fig. 6 shows the range of average RSSI values and standard deviations at corresponding distances. The experimental results show that a clear difference existed between the RSSIs between the broadcasting node and the reference node at 1 m and those of the reference nodes at corresponding distances. Fig. 7 shows the relative differences between the RSSI at 1 m and other distances. These results are consistent with the trends mentioned in the literature [13], [14]. Because the sensing nodes of the mounting cow and the cow in heat were closest when mounting occurred, the corresponding serial numbers of relatively strong RSSIs can be used as identifiers of cows in heat. This proves that using the strength of RSSIs within a single batch to detect dairy cows in estrus is feasible.

TABLE I: DISTANCE, AVERAGE RSSI [DBM] AND STANDARD DEVIATION FOR XBEE MODULE

Distance	1m	2m	3m	4m	5m
Avg. RSSI	-39.4	-47.4	-48.4	-53.3	-60.2
St. Deviation	3.60	2.67	1.26	5.10	3.61

Based on the results of this experiment, RSSI is unnecessary when calculating the relative gap between broadcasting nodes and a reference node. Cows in heat can be identified by simply comparing the stengths of RSSIs within a single batch. In the future, sensor nodes can be installed on cows and three-axial accelerometers can be used to observe the behavior of cows. When cows lie down, the ZigBee of the sensing nodes within the WSNs automatically enters sleep mode to conserve power until the cows stand up. The cameras are be used to record their activity to verify the efficacy of the estrus detection system in actual environments.

This system is expected to facilitate the successful detection of the optimal times for breeding measures, increasing the pregnancy rates of dairy cows.

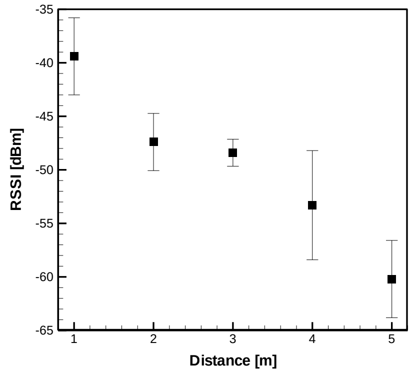

Fig. 6. Changes in average XBee RSSI with distance. The error bar indicates the standard deviation at each point.

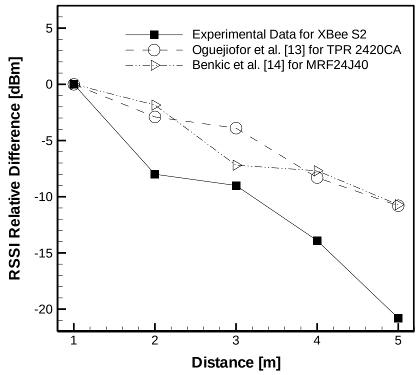

Fig. 7. Amount of difference in RSSIs between the position at 1 m and the other positions.

IV. Conclusions

In this study, WSNs, a database system, 24 h image recording, and smartphone application development were used to develop an effective system for automatically detecting heat standing in cows. The results of this study indicated that the strengths of the RSSIs within a single batch can be compared as a potential method for monitoring estrus in cows. The experimental results indicated that the RSSI measured at a distance of 1 m clearly differed from results at other distances. The strengths of the RSSIs within a single batch can be compared to determine the cows in heat closest to mounting bulls. Thus, this system can be applied to estrus detection in cows to improve the deficiencies of human visual detection and to reduce the breeding losses of extended gaps between pregnancies caused by human detection errors.

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