健康畜禽 Healthy Livestock

A smart ear-attached sensor for real-time sows behavior classification

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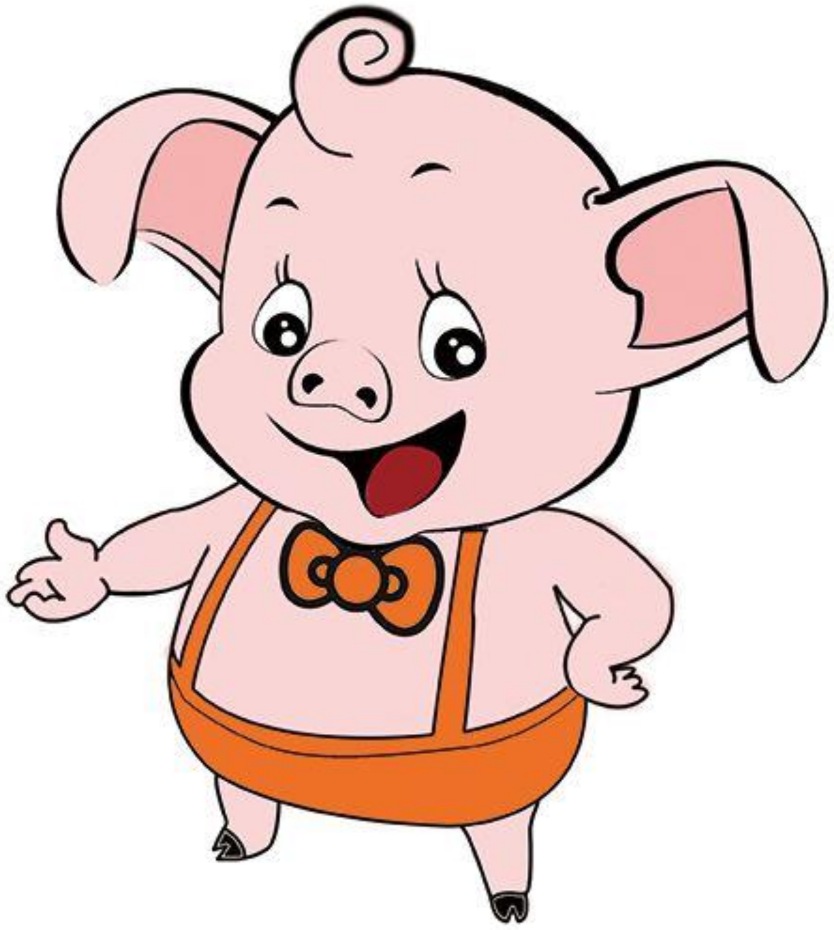

1. Introduction

- **Short battery life limits the applicability of wearable sensors in animal behavior monitoring.**

- **The aim of this research was to develop an ear-attached acceleration sensor of low power consumption for sow health and welfare related studies.**

2.1 Sensor design

- **The wireless acceleration sensor was composed of a low power three-axis accelerometer, a Bluetooth and an PCB antenna.**

Neck collar → Ear-attached

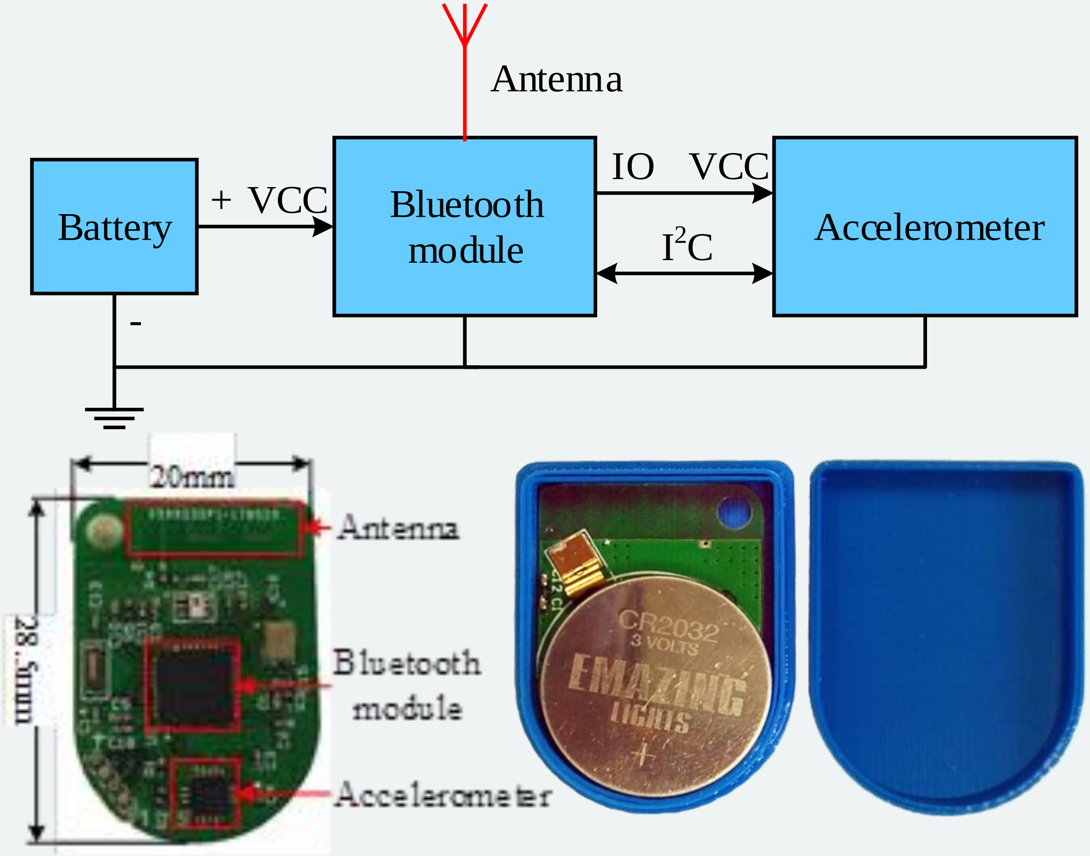

Fig. 1. The wireless acceleration sensor block diagram (top), front of the PCB (bottom left), back of the PCB with battery in the case (bottom center), and the case cover (bottom, right).

2.2 Wireless monitoring system design

- A wireless monitoring system was designed to perform field experiments on sows.
- It included multiple wireless acceleration sensors, a Bluetooth receiver, a serial device server, and a database server.

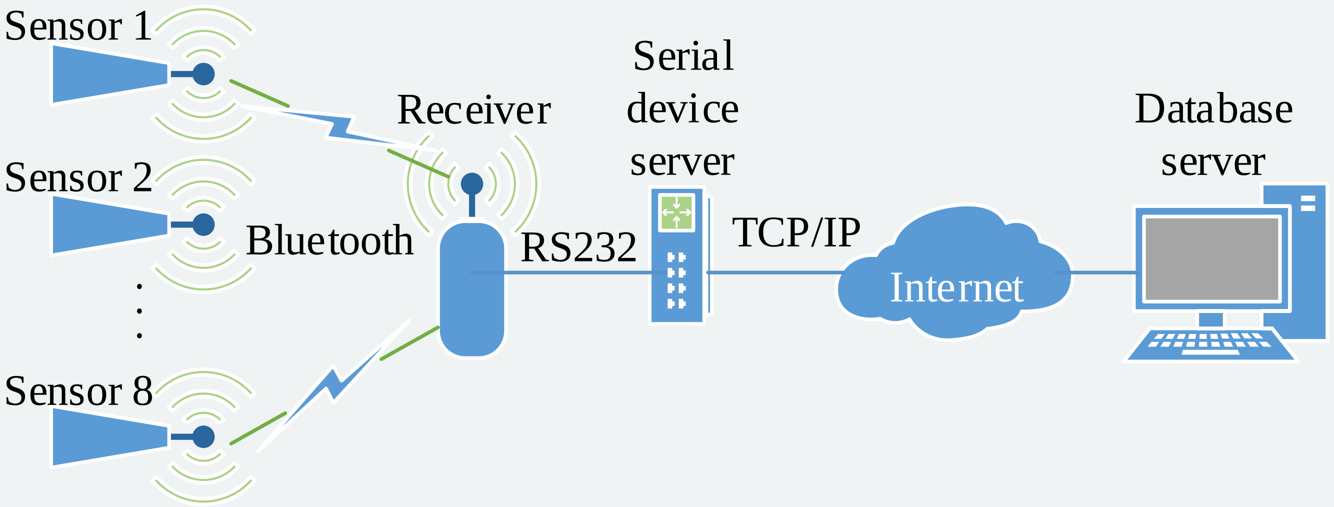

Fig. 2. The architecture of the wireless monitoring system.

2.3 Sensor operation modes

- In the continuous mode, the sensors read and transferred the acceleration data at a fixed frequency of 1 Hz.
- In the data-grouping mode, the sensors read all the acceleration data at 1 Hz and saved them in a memory for transmission.
- The power saving mode was designed to minimize the number of data for transmission by excluding the data when a sow was not in movement.

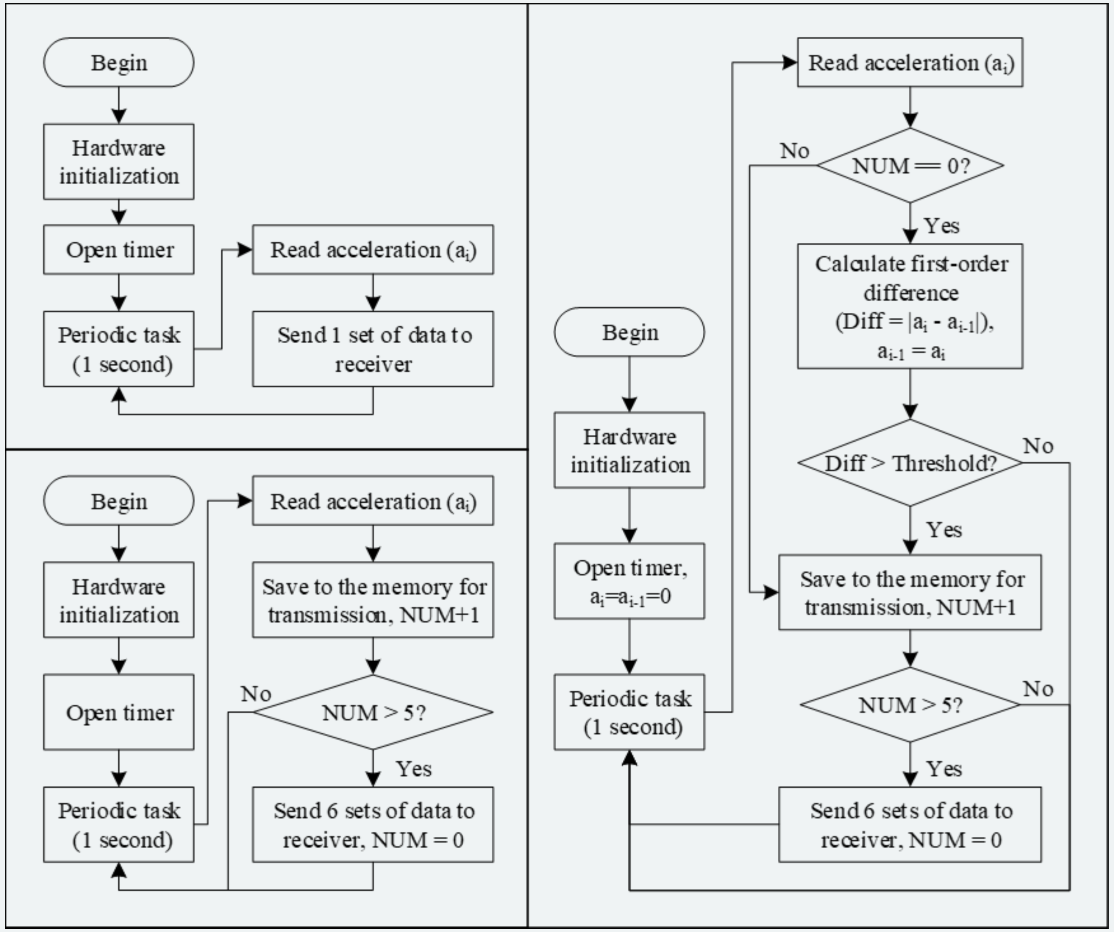

Fig. 3. Program flow diagrams of the continuous mode (left top), data-grouping mode (left bottom) and power saving mode (right).

2.4 Data saving threshold determination

- **A threshold was set to control whether the sensor should save a set of acceleration data after reading the data.**
- **A simple method to analyze a threshold setting with a first-order different acceleration of three typical sow behaviors. This was realized by comparing the current dataset with the previous dataset using Eq. (1).**

$$\Delta a_i = |a_i - a_{i-1}| \qquad (1)$$

- **The dataset at each time was not saved in the storage for transmission unless its first-order difference exceeded a pre-defined threshold.**

$$If\ \Delta a_i \geq \Delta a \rightarrow Save\ for\ transmission$$
$$If\ \Delta a_i < \Delta a \rightarrow Do\ nothing$$

2.5 Laboratory test of the sensor

- **A laboratory test was conducted to determine the power consumption of the sensors at the three different working states, i.e., sleeping, reading, and broadcasting.**

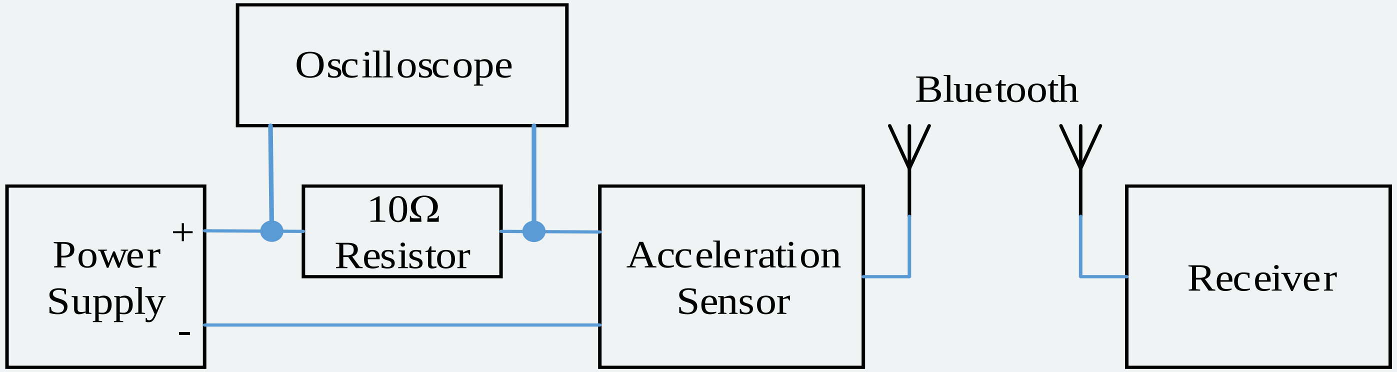

Fig. 4. Power consumption measure

$$I_a = \sum_{i=1}^{3} I_{Si} t_{Si} \Big/ \sum_{i=1}^{3} t_{Si} \qquad (2)$$

$$L = B / I_a \qquad (3)$$

2.6 Field test of the monitoring system on sows

- Eight wireless acceleration sensors were attached to eight sows in the two rooms.
- The sensor cases were glued to the RFID ear-tags using a cyanoacrylate glue.
- Continuous video recordings were also made to monitor the behaviors of the eight sows individually 24 h a day.

Fig. 4. An acceleration sensor is attached to the RFID ear-tag on a sow.

3.1 Sensor performance

- A sow was usually more active during two major periods on a day, in the morning from 4:00 to 10:00 and in the afternoon from 14:00 to 21:00.
- The behaviors of a sow before farrowing was noticeably different as detected by the acceleration sensor.
- The wireless sensor could be effectively used for monitoring and predicting sow farrowing.

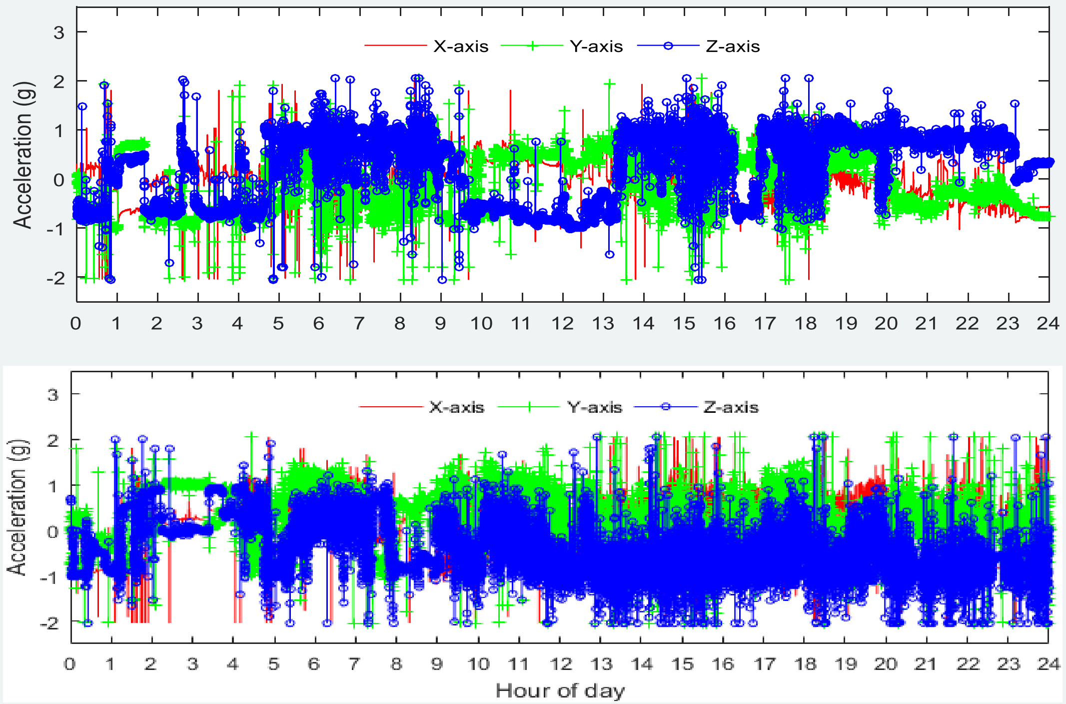

Fig. 5. Two typical days of acceleration data measured on two sows. Top: typical activities of a sow. Bottom: activities of a sow on the day before farrowing at 2:00 AM the following day.

3.2 Current and energy consumptions in three sensor working states

- **All the current peaks of approximately 1.8–4.9 mA for a duration of 100 ms were during sensor broadcasting.**
- **The current consumptions of the other states were all below 0.9 mA, mostly only 0.002–0.05 mA.**

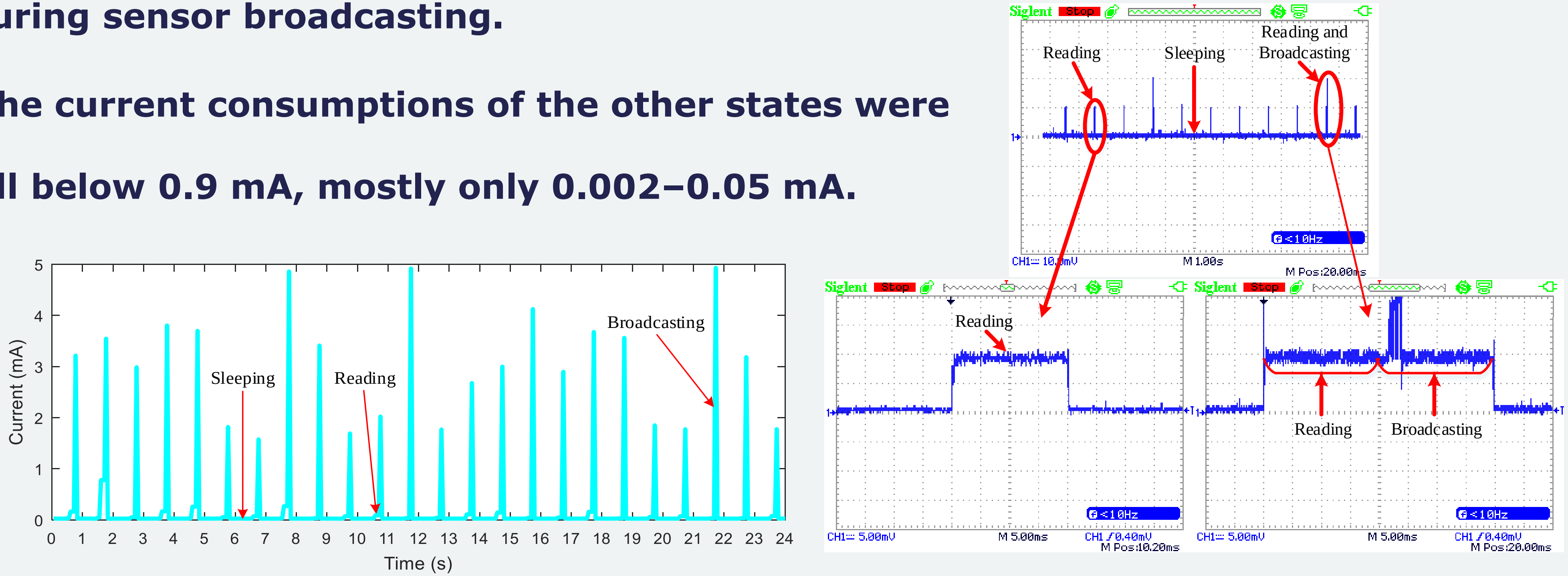

Fig. 6. An example of currents of the sensor at three working states.

3.2 Current and energy consumptions in three sensor working states

- **The energy consumptions during the sleeping and data reading states were only 0.5 and 1.9%, respectively, of the total. The broadcasting state consumed as much as 97.6 % of the total power consumption.**
- **This demonstrated that the sensor battery life could be significantly extended if the power consumption in the broadcasting state could be reduced.**

Table 1. Mean current and energy consumptions of the three operating states based on three days of measurements on sow behaviors.

Operating state	Current (mA)	Operation time (ms)	Energy consumption (%)
Sleeping	0.00213	738	0.5
Data reading	0.037	162	1.9
Broadcasting	3.03	100	97.6

3.3 Data saving threshold

3.3.1 Characteristics of accelerations and three sow behaviors

- **The first-order different acceleration was near zero for the data recorded during sow resting.**
- **The differences between the two adjacent sets of acceleration data were mostly very small.**

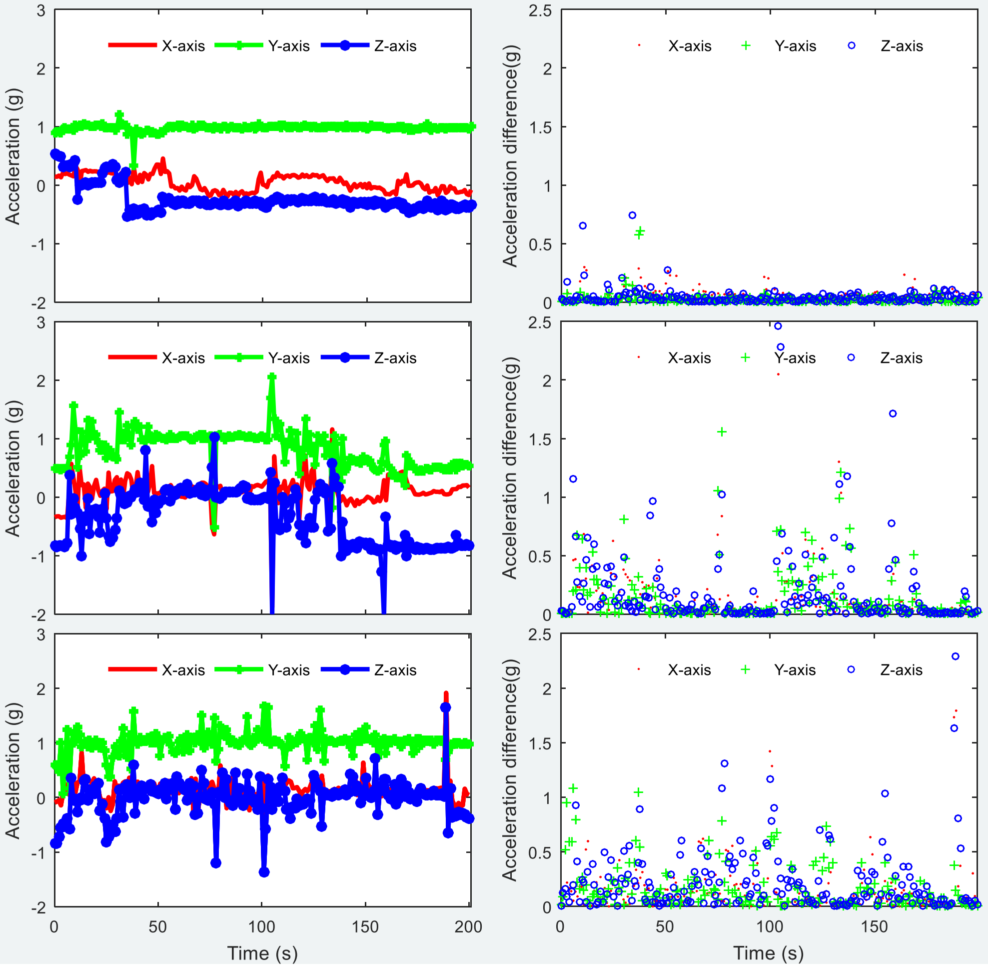

Fig. 7. Typical acceleration waveforms of a sow at resting (top left), moving (middle left), and eating (bottom left). First-order different accelerations of a sow at resting (top right), moving (middle right), and eating (bottom right).

3.3 Data saving threshold

- **The averages of mean-moving and mean-eating in three axes were 0.162 g and 0.184 g, respectively. The difference between two adjacent acceleration data of these two behaviors were more than 0.162 g. By averaging 0.043 g and 0.162 g, an optimal threshold of approximately 0.1 g was obtained.**

Table 2. Standard deviations (STD) and mean values of the first-order difference related to the three behaviors in three typical days of acceleration data.

Statistics	Axis (g)			Average (g)
	X	Y	Z	
STD resting	0.14	0.059	0.226	0.142
STD moving	0.251	0.322	0.478	0.35
STD eating	0.209	0.207	0.32	0.245
Mean-resting	0.055	0.029	0.044	0.043
Mean-moving	0.154	0.147	0.184	0.162
Mean-eating	0.154	0.171	0.226	0.184

3.3 Data saving threshold

3.3.2 Optimal data saving threshold

- **In the 0–1 g range of first-order differences for the three behavioral conditions, the proportions of 0–0.1 g in the X-, Y- and Z-axis for sows at resting were 86%, 97.5%, and 93.5%, respectively.**
- **Therefore, the sensor was programmed to send an acceleration dataset if any first-order difference of the three axes was greater than 0.1 g. This could save up to 86% of battery power.**

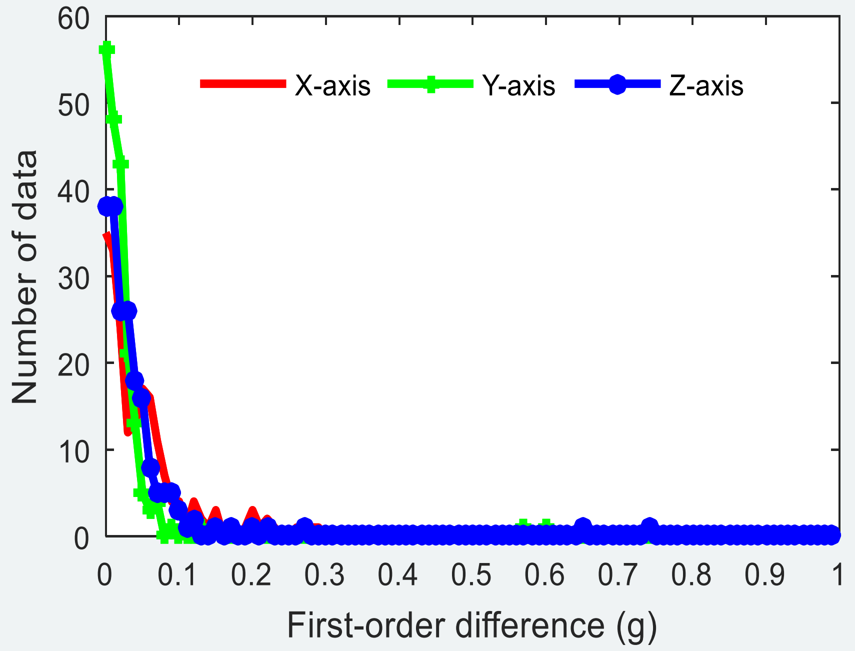

Fig. 8. Distribution of number of data versus first-order differences for a sow at resting shown in Fig. 7 top right.

3.4 Current consumptions at three sensor operating modes

- **Analysis of the field test data revealed that the average mean number of broadcasts per day at power saving mode was only 8.7% of that at the continuous mode, and 52.2% of that at the data grouping mode for the six sows.**

Table 3. Analysis of average currents of the three operating modes for six sows.

Sow number and operating mode	Number of broadcasts ($n\ d^{-1}$)	Average current (mA)	Battery lifetime (d)
#1-6 continuous	86400	0.311	31
#1-6 data-grouping	14400	0.058	183
#1 power saving	10204	0.0435	220
#2 power saving	9419	0.0408	234
#3 power saving	6104	0.0292	328
#4 power saving	6807	0.0316	303
#5 power saving	5957	0.0287	333
#6 power saving	6644	0.031	309
Mean for #1–#6 power saving	7523	0.034	288

4.1 Conclusions

(1) Acceleration data of the sows revealed three major behaviors (resting, moving, and eating) and there were variations in the time durations of these behaviors among different sows.

(2) Data broadcasting of the sensors consumed 97.6% of total energy at the continuous operating mode and the battery life was only about 31 days.

(3) The average battery life could be extended to about 288 days at power saving mode when the first-order difference threshold was set at 0.1 g.

4.2 Future improvements

- Develop an algorithm to adopt dynamic thresholds;
- Optimize data reading frequencies to balance between battery life and animal behavior study requirement;
- Upgrade the acceleration sensors to behavior sensors by using on-sensor intelligent data analysis.

Thank you!

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