

Quantification of Pre-parturition Restlessness in Crated Sows Using Ultrasonic Measurement

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ABSTRACT : This study presents a non-video, non-invasive, automatic, on-site monitoring system the system employs ultrasonic transducers to detect behavior in sows before, during and after parturition. An ultrasonic transmitting/receiving (T/R) circuit of 40 kHz was mounted above a conventional parturition bed. The T/R units use ultrasonic time-of-flight (TOF) ranging technology to measure the height of the confined sows at eight predetermined locations. From this data, three momentary postures of the sow are determined, characterized as standing-posture (SP), lateral-lying-posture (LLP) and sitting posture (STP). By examining the frequencies of position switch Stand-Up-Sequence (SUS) between standing-posture (SP), lateral-lying-posture (LLP) and sitting-posture (STP) rate can be determined for the duration of the sow's confinement. Three experimental pureblooded Landrace sows undergoing normal gestation were monitored for the duration of confinement. In agreement with common observation, the sows exhibited increased restlessness as parturition approached. Analysis of the data collected in our study showed a distinct peak in Stand-Up-Sequence (SUS, i.e. the transition from lying laterally to standing up) and sitting-posture (STP) rate approximately 12 h prior to parturition, the observed peak being 5 to 10 times higher than observed on any other measurement day. It is concluded that the presented methodology is a robust, low-cost, low-labor method for the continuous remote monitoring of sows and similar large animals for parturition and other behavior. It is suggested that the system could be applied to automatic prediction of sow parturition, with automatic notification of remote management personnel so human attendance at birth could reduce rates of sow and piglet mortality. The results of this study provide a good basis for enhancing automation and reducing costs in large-scale sow husbandry and have applications in the testing of various large mammals for the effects of medications, diets, genetic modifications and environmental factors. (*Asian-Aust. J. Anim. Sci.* 2005, Vol 18, No. 6 : 780-786)

Key Words : Sows, Parturition, Ultrasonic Transducers, Animal Husbandry

INTRODUCTION

As parturition approaches, sows exhibit uneasy, restless and Stand-Up-Sequence (SUS) rate increases, cause of nest building or cause of labor pains (Randall, 1972). To observed the behavior of sows can be divided into three periods including the gestation period before parturition, the parturition event itself and the lactation period after parturition. A sow's rate of Stand-Up-Sequence (SUS) and the sitting posture (STP) change characteristically during these periods.

To minimize piglet and sow mortality during farrowing, various researchers have attempted to predict parturition time so that human personnel can attend the birth. Research regarding parturition prediction for large mammalians includes that measuring caudal cervix width (Nagaoka et al., 2000; Breeveld-Dwarkasing et al., 2002; Singh et al., 2004) vasopressin concentration of plasma extracted from the jugular (Ramirez et al., 1995; Gebert et al., 1996; Gilbert et al., 2000; Khan et al., 2002; Ryu et al., 2003) udder

enlargement (Ramirez et al., 1995) and manual investigation of video-recorded data (Knight et al., 1995; Ramirez et al., 1995; Machado et al., 1997; Wechsler et al., 1997; Pedersen et al., 1998).

Undoubtedly, the examination of dilated caudal cervix width (Nagaoka et al., 2000; Breeveld-Dwarkasing et al., 2002; Singh et al., 2004) and plasma vasopressin concentration (Ramirez et al., 1995; Gebert et al., 1996; Gilbert et al., 2000; Khan et al., 2002; Ryu et al., 2003) are important contributions. However, these methods involve disturbance or intrusion into the body of the animal. Further, unexpected interruptions from the controller interfere in the normal rest of sows, so that observation of the actual natural behavior of the animals becomes quite difficult (Ramirez et al., 1995; Gilbert et al., 2000). These experimental systems also involve complicated, expensive and inconvenient instruments, making such systems difficult to simplify and commercialize. Additionally, video systems further require manual investigation and interpretation of recorded video data, consuming human time and resources.

MATERIALS AND METHODS

To avoid these problems, this study has designed a non-video recorded, non-invasive, adjustable system that can convert sow behavior into digital information and thus facilitate information analysis, management and application.

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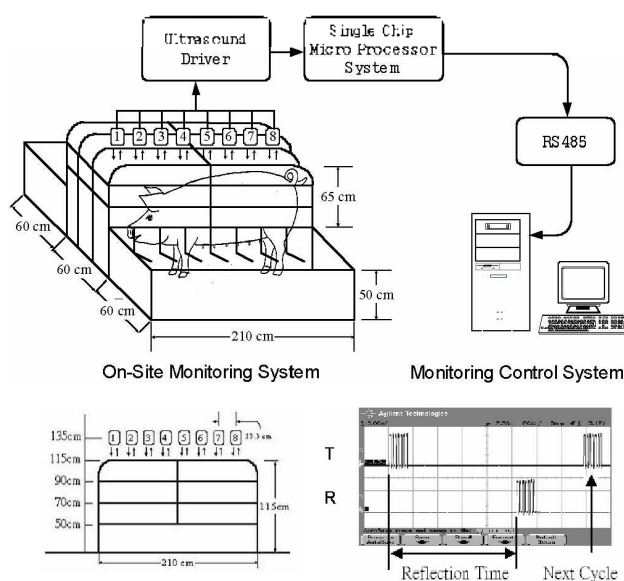


Figure 1. Block diagram of the system. The parturition bed has a length of 210 cm, width of 60 cm and height of 115 cm. Above are eight ultrasonic T/R circuits designed as independent modules, each with its own 89C51 microchip and address so they comprise a Local Area Network (LAN) which is connected by RS485 technology to a monitoring PC control station operating a lab view software program for system operation and data analysis.

Figure 1 shows schematically the farrowing crate used in this study. It is of a standard size used in Taiwan, with fixed length of 210 cm, width of 60 cm and height of 115 cm. Eight ultrasonic transmitting/receiving (T/R) pairs (the four plastic boxes mounted on the top of the crate in Figures 2 (a, b, c) are placed along the center of the long axis on top of the parturition crate, in such a fashion as to cause no interference with farm management. Because there is little space for the sow to move forward, backward, leftward or rightward, she has only the choice of standing up or lying down. The eight T/R pairs using ultrasonic ranging technology are able to provide the local distance to the sow's body. The system classifies the changes of measured distance to the sow's body in the parturition crate bed into three postural types, namely standing-posture (SP), lateral-lying-posture (LLP) and sitting posture (STP). Through statistics obtained by the presented system for postural changes over the six days before parturition and the four days following, many useful parameters for sow behavior can be determined, as will be elaborated in detail.

Animals

This study was conducted with the cooperation of the Taiwan Livestock Research Institute and the Department of Electrical Engineering, National Cheng-Kung University, Taiwan. The pureblooded Landrace sows undergoing normal gestation were selected for observation in this study. An automatic timed feeding system was used to reduce interference caused by livestock controllers.

Detecting distances with ultrasound transducers

The industrial community has used ultrasonic time-of-flight (TOF) and phase-shift (PS) methodology to detect distance of objects to plus/minus 0.05 mm (Huang et al., 1999; Young et al., 2000; Correa et al., 2001; Liu et al., 2002). The ultrasound detectors used in this system are a 400ET-180 transmitter and a 400ER-180 receiver (Huang et al., 1999; Young et al., 2000; Liu et al., 2002). The transmitted wave is a 40 kHz square wave. The T/R units are located in airtight aluminum packages and are resistant to the dust, moisture, foul air and methane commonly found in the farrowing rooms.

At a temperature of 25°C, the speed of sound in air is 346 m/sec. When the speed of sound is constant, the distance traveled by a sound wave is directly proportional to the time-of-flight (TOF). The time between the sending of an ultrasonic signal by the transmitter and the receiving of the signal by the receiver of a T/R pair is the time for sound to travel from the T/R pair to the sow and then back again to the T/R. The distance from the T/R pair to the sow can be computed by converting the T/R time into distance. This distance together with the height of the T/R unit from the floor can be used to compute the sow's height at the portion of her anatomy directly under the T/R unit (Huang et al., 1999; Carullo et al., 2001). The height from the floor of the farrowing crate to the top of the rail is 115 cm, while the distance from the rail top to the T/R unit is 10 cm. Consequently, the total height from the floor of the farrowing crate to the T/R unit is 115 cm+10 cm=125 cm. Total distance traveled by the sound wave is the speed of sound's time-of-flight (TOF). Because the sound wave travels from the transmitter to the sow and is reflected back an equal distance to the receiver, distance between T/R unit and sow may be computed as the speed of sound times time-of-flight (TOF) divided by 2. This distance d is converted into sow height at the point of measurement as

$$H = 125 \text{ cm} - d \quad (1)$$

For the eight T/R modules, eight height positions are measured for each sow. Thus

$$H_i = 125 \text{ cm} - (c \times \text{TOF}_i) / 2, \quad \text{for } i = 1 \text{ to } 8 \quad (2)$$

where i is an index indicating the number of the T/R module and c is the speed of sound (m/sec).

Behavioral test

Because eight T/R units are used mounted at fixed locations over a sow who remains in a relatively constant relationship to the T/R units, the system measures the sow's heights at eight pre-determined parts of her body. This study is concerned with monitoring three characteristic postures.

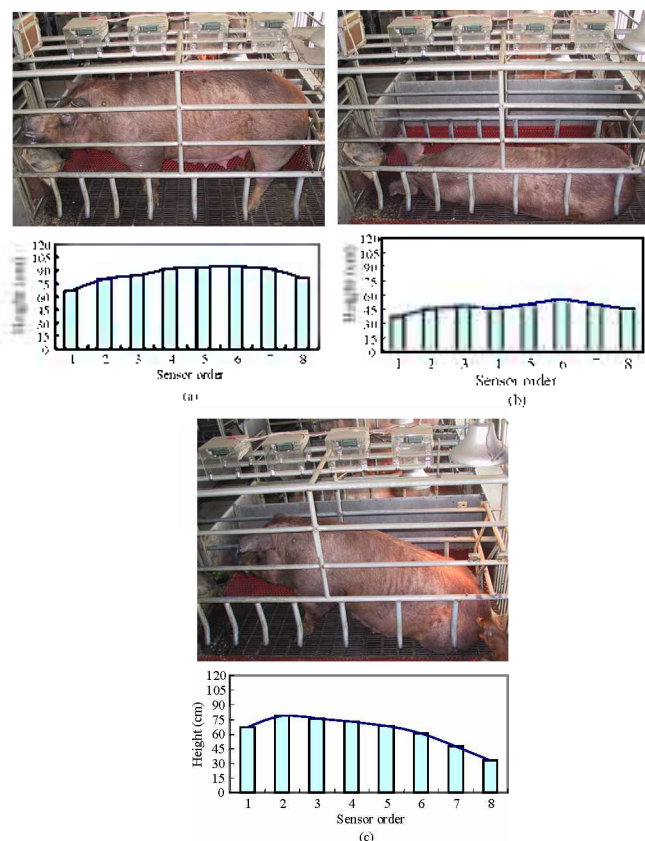


Figure 2. (a) Standing-posture (SP), (b) lateral-lying-posture (LLP), (c) sitting posture (STP).

the standing posture (SP), the lateral lying posture (LLP) and sitting posture (STP). The summed values of the eight heights were used to determine the posture of the animal. The sum of the heights for any one cycle of ultrasonic measurements is:

$$H_{i-total} = \sum H_i \quad \text{for } i = 1 \text{ to } 8 \quad (3)$$

Standing posture (SP)

For the Landrace sow-#1 during the typical SP condition, the eight heights as measured at the eight predetermined locations were 66.8 cm, 80.4 cm, 84.0 cm, 91.9 cm, 93.0 cm, 94.1 cm, 92.1 cm and 80.9 cm, with a summed value of 683.2 cm as in Eq. 3, or $H_{i-total-SP} = \sum H_i = 683.2$ cm for $i = 1$ to 8. The data was displayed graphically in Figure 2(a), where the bars indicate the height as determined by the local T/R pair. It can be seen that a line connecting the heights describes the uppermost profile of the sow in a standing position. All three sows have similar local body heights and thus similar total body heights. Thus, when the system measures a height sum $\sum H_i > 650$ cm, the monitoring PC system identifies the animal as being in the standing posture SP.

Lateral-lying posture (LLP)

For the Landrace sow-#1 during the normal Lateral-

Lying Posture (LLP) condition, the eight heights as measured by the system at the eight predetermined locations were 37.1 cm, 44.9 cm, 48.1 cm, 46.2 cm, 50.2 cm, 55.2 cm, 56.1 cm and 44.8 cm, with a summed value of 376.6 cm as in Eq. 3 or $H_{i-total-LLP} = \sum H_i = 376.6$ cm for $i = 1$ to 8. The data was displayed graphically in Figure 2(b), where the bars indicate the height as determined by the local T/R pair. It can be seen that a line connecting the heights describes the uppermost profile of the sow in a lateral lying position. As above, the similar body size of the sows allows a summed height measurement $\sum H_i < 350$ cm to be identified as lateral-lying posture (LLP) by the monitoring PC.

Sitting-posture (STP)

For the Landrace sow-#1 during the typical sitting posture (STP) condition, the eight heights as measured at the eight predetermined locations were 66.8 cm, 79.4 cm, 76.0 cm, 72.9 cm, 68.0 cm, 61.1 cm, 47.1 cm and 32.7 cm, with a summed value of 504 cm as in Eq. 3, or $H_{i-total-STP} = \sum H_i = 504$ cm for $i = 1$ to 8. The data was displayed graphically in Figure 2(c), where the bars indicate the height as determined by the local T/R pair. It can be seen that a line connecting the heights describes the uppermost profile of the sow in a standing position. All three sows have similar local body heights and thus similar total body heights. Thus, when the system measures a height sum $\sum H_i$ between 460-540 cm, the monitoring PC system identifies the animal as being in sitting posture (STP).

System design

A block diagram of the structure of the study system is displayed in Figure 1. The system consists of two parts including the on-site monitoring system, responsible for obtaining and collecting information on sow behavior as well as the control system in the office, responsible for storing and analyzing information and providing conclusions for the system. The signals communicating animal behavior from the on-site monitoring system are transmitted to the PC at the control system via RS485 technology (Computer's serial interface communications). The information is processed by a LabVIEW (National Instruments, USA) software program designed by our group.

On-site monitoring system

The on-site monitoring system was installed on top of a farrowing crate, with the eight T/R module circuits aligned lengthwise over the backs of the sows as in Figure 1. Each T/R module is designed as an independent unit containing its own microprocessor with its own address. The eight T/R modules are connected as a Local Area Network (LAN) transmitting data upon request via RS485 to a remote PC. This design gives the combined system more adaptability.

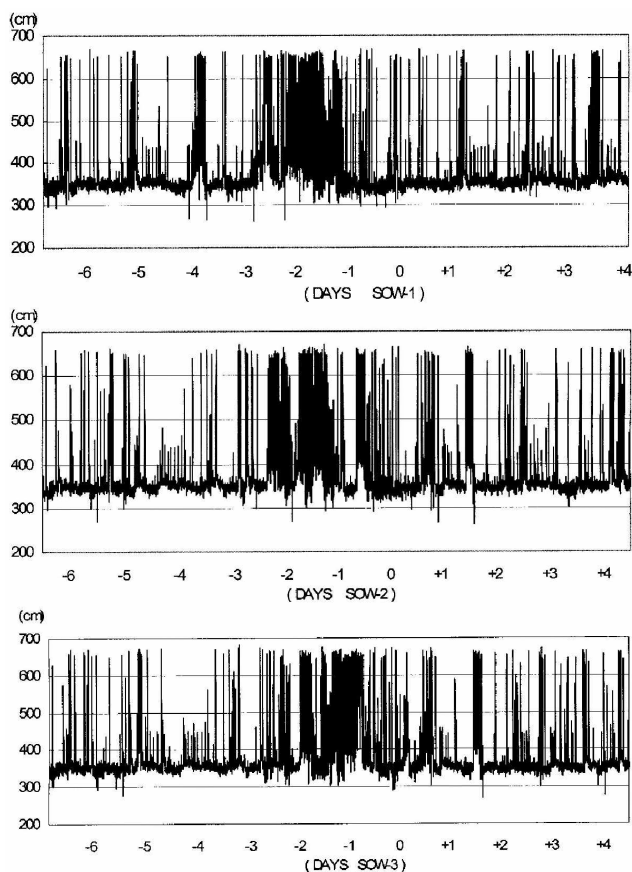


Figure 3. Summed heights ΣH_i of the confined three sows as measured over the period of confinement. A total of 76,032,000 pieces of data were obtained for the frequencies of switches between lying-down and standing-up. Day 0 is the day of parturition. In the vertical axis: 350 cm represents lying-down, 650 cm represents standing-up, 460-540 cm represents sitting-posture (STP).

making it easy to expand the number of modules so that a large array of sows in various late-gestation states can be monitored for imminent parturition.

To record animal heights for monitoring standing posture (SP) and lateral-lying posture (LLP) postures, the T/R modules measure the range upon command from the coordinating PC. The operating program in the PC circuit system makes sure that the 40 kHz square-wave distance-ranging signals are sent sequentially, transmitted only after receiving the returned signal of the previously transmitted signal. The PC also ensures that at least 0.1 seconds occur between each transmission, to avoid mutual interference between transmitted signals, enhancing accuracy.

Control system in the management-office

A conventional IBM-compatible PC with our LabVIEW software was used to collect and archive information and to control the monitoring system. Using Eq. 3, the software obtains the summed value of the eight heights as measured from T/R's #1 to #8 of the latest cycle of measurement. This

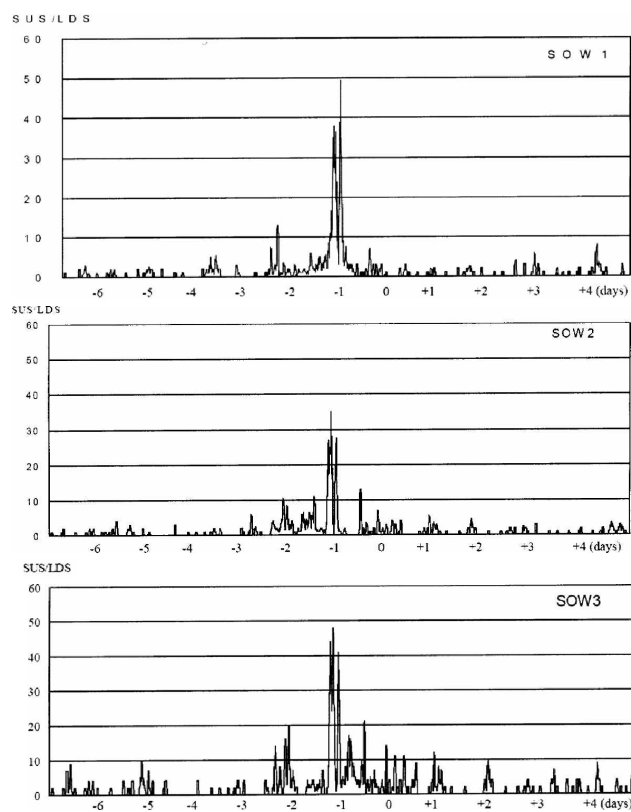


Figure 4. The horizontal time axis represents the number of days, taking each 3 h as a unit range-time of the period six days before parturition and period four days after the parturition day. Day 0 is the day of parturition. Meanwhile, the vertical axis represents the frequency of switches between lying-down and standing-up.

sum was used to determine whether the animal changed from standing posture (SP) to lateral lying posture (LLP), and vice.

Calibration for temperature factor in the system presented here

This study starts with an assumed basic air temperature value of 25°C. However, the actual speed of sound depends on the air temperature, which may vary at different times of the year. The temperature in our facilities is considered optimal at 25°C, but often ranges $\pm 15^\circ\text{C}$ over the 24 h of the day, giving a nominal range of 10°C to 40°C.

Actual air temperature at the moment of measurement is automatically detected by an LM75 (National Semiconductor, USA) temperature-sensor located with each T/R pair. This temperature data is used by the monitoring PC to improve system accuracy by incorporating temperature when recomputed the speed of sound for each height measurement by the formula,

$$c = 331 - 0.6 \times T \quad (4)$$

where c is the speed of sound and T is the environmental temperature ($^\circ\text{C}$).

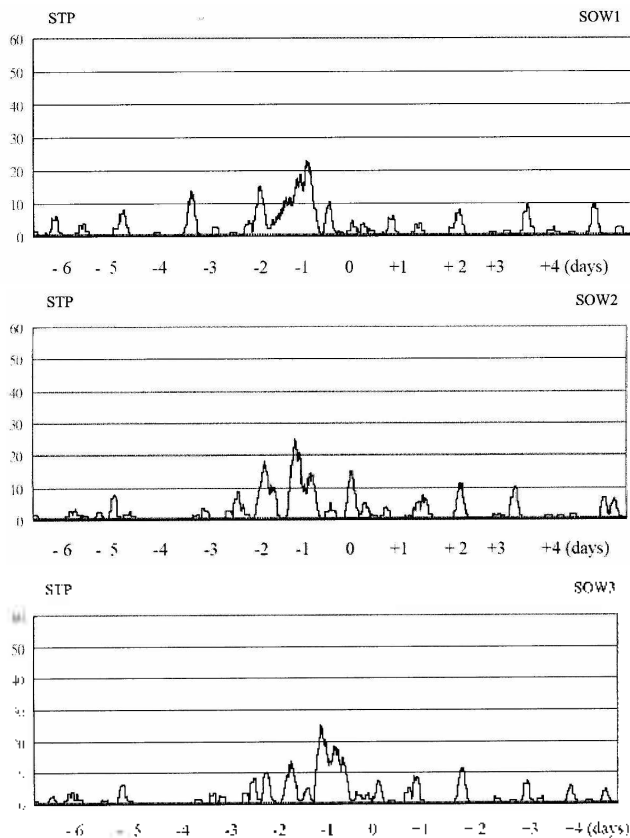


Figure 5. Obtained for the frequencies of sitting-posture (STP) count for continuous monitoring of days, taking each 3hr as a unit range-time of the period six days before parturition and period four days after the parturition day. Day 0 is the day of parturition.

RESULTS

SUS rate from day-6 before to day-4 after parturition

Figure 3 displays the measured ΣH , height data for all three sows for the six days before parturition, the day of parturition, and the 4 days after parturition, a total of 11 days. The number of individual ΣH , measurements is 76,032,000 per sow. In the Figure 6 expresses six days before parturition, 0 expresses the day of parturition, +4 expresses four days after parturition. We discriminate the Stand-Up-Sequence (SUS) and sitting-posture (STP) with the ΣH , height from Figure 3, and display in Figure 4 and 5 respectively. The choice of a time unit of three hours simplifies computation. Comparison of the three sows shows that all exhibit similar behavioral characteristics with regard to Stand-Up-Sequence (SUS) rate. Figure 4 displays the Stand-Up-Sequence (SUS) rate, defined as changes from standing posture (SP) to lateral lying posture (LLP)

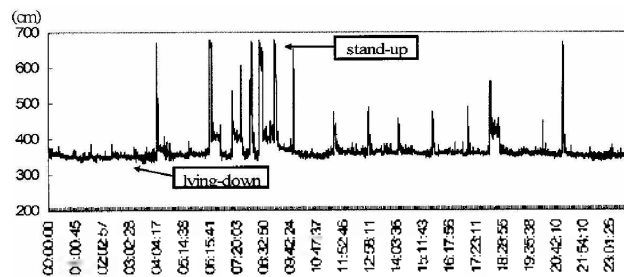


Figure 6. Stand-up-sequence (SUS) count for continuous 24-h monitoring period four days before parturition. The increased Stand-up-sequence (SUS) activity correlates with the 8 AM automated feed delivery time, and the sow is eating in standing posture. Without the external feeding interference, the sow remains sleeping in the lateral-lying-posture (LLP) posture for approximately 97% of the 24-h day. A value around 350 cm represents lateral-lying-posture (LLP); while a value above 650 cm represents SP.

per three hours. Figure 5 displays the sitting-posture (STP) rate per three hours. In all three cases, the Stand-Up-Sequence (SUS) rate on the day before parturition rises dramatically to a peak 5 to 10 times higher than on any other day during either the gestation or lactation periods.

General behavior before parturition

The monitored data is suitable for determining the general percentage of time that the experimental sows spend in a lying position during their period of confinement in the parturition bed. Figure 6 shows height measurements over 24 h between days -3 and -2 for the Landrace sow-#1. A single peak in the image may represent a cluster of standing events. Careful analysis of the standing posture (SP) conditions during the 24 h period gives a total standing posture (SP) count of 33. Particularly notable was feeding time 8:00 h, around which time there is a cluster of standing events. This cluster clearly precedes the feeding time, suggesting that the sow remembers and anticipates her regular breakfast time. In general, without external interference such as feeding, the sow remains in the lateral lying posture (LLP) posture for most of the time, in this case approximately 97% of a 24 h day. Table 1 displays the statistical data for the percentage of standing time per day for the 11 days of confinement.

Behavior the day before parturition

On the day prior to parturition, for reasons of labor pain or for nest-building behavior, the sow frequently changes from lying-down to standing-up postures. This can be seen

Table 1. Statistical data for the percentage of standing time per day for the 11 days of confinement (Day 0 is the day of parturition)

Day	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4
Sow 1 (%)	3.14	2.63	4.31	3.38	17.62	32.39	2.94	3.32	1.224	3.23	3.83
Sow 2 (%)	3.96	7.27	1.21	8.40	26.73	26.44	4.22	11.54	6.49	2.71	8.06
Sow 3 (%)	6.73	4.43	0.55	4.50	20.22	37.09	5.25	6.10	9.64	7.18	5.60

Table 2. Statistics table for 6 days before and 4 days after parturition of daily frequency switches between standing-up and lying-down. (units: switches per day)

Day	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4
Sow 1	13	15	22	10	67	221	20	17	11	18	23
Sow 2	10	19	6	20	76	143	33	28	15	9	22
Sow 3	34	40	12	20	88	254	76	38	36	30	36

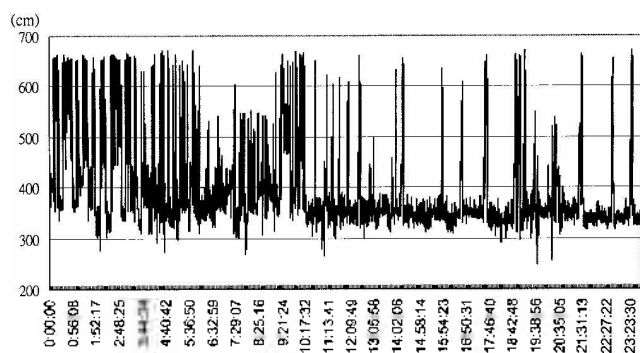


Figure 7. Stand-up-sequence (SUS) count for continuous monitoring of the 24-h period in the eve parturition day before parturition onset. The frequent changes of position from lateral-lying-posture (LLP) to standing-posture (SP) are assumed related to labor pains and nesting behavior. Above 650 cm represents Standing-posture (SP); 350 cm represents lateral-lying-posture (LLP).

in Figure 7 and Table 2, where the total standing posture (SP) count is 221 for the 24 h period. From the viewpoint of a casual observer, the sow would seem to be exhibiting restlessness particularly characterized by frequent postural shifts between lying-down and standing-up. Clearly, this behavior is quite different from the behavior exhibited in Figure 7 and Figure 4. All three monitored sows behaved in a similar manner.

DISCUSSION

Behavior of sows can be divided into three periods including the several days before parturition, the day of parturition itself, and the several days after parturition. The behavior of sows in the days before parturition is of special interest since it is desirable that humans attend the birth to minimize mortality among both sows and piglets. The observation of restlessness cause of nest-building is commonly used as indicators of pending parturition (Randall, 1972). However, relatively little quantifiable information exists on the specific actions or the frequency distribution of these actions during these three periods.

In this study, a novel methodology for ultrasonic measurement and monitoring of the position of large animals has been applied to sows confined in parturition beds. This study further quantifies this behavior with regard to the rate of postural change from standing to lying, showing that there is a distinct peak in this behavior in the day prior to parturition, this peak in the present data being

approximately 12 h prior to the onset of parturition. However, it should be remembered that the rate is calculated as SUS/3-h. Thus, the highest possible accuracy in this study is ± 1.5 h. Further, the data herein is from a limited study group of only three purebred Landrace sows. This is enough to verify the proposed methodology and to suggest that the methodology is suitable for industrial animal husbandry. However, further work is desired to establish a standard deviation for a large population of Landrace sows, with comparative studies for other breeds.

The main contributions of this study including this system is based on a low cost ultrasonic detector that uses a non-video, non-invasive approach to measure large animal behavior and thus overcomes problems regarding adverse environmental conditions such as dust, moisture, foul air and methane in the farrowing room. RS485 technology transmits signals directly from the onsite monitoring system, eliminating the need for humans to manually examine the sows or even visit the farrowing room for monitoring purposes. This is an advantage both to human workers and to sows. The RS485-based technology is easy to expand, allowing a single monitoring control station in a remote location to monitor a large number of sows in diverse locations. Thus, the system is of interest to large-scale animal husbandry. This kind of modular design gives the hardware of this combined system more adaptability. The system can perform continuous 24 h monitoring in unlit environments, particularly at night and poorly lit environments. Behavioral data for sow parturition is automatically digitalized and automatically archived, facilitating management and information analysis. In the technical field of recording and analyzing animal behavior, the experimental data derived from this system are reliable, useful, and applicable to other animals. Applications could include the testing of various medicines, diets, and environmental conditions.

CONCLUSIONS

The present study has presented a novel ultrasonic methodology for low-cost, automatic, non-invasive, non-video, continuous monitoring of large mammals. This method has been applied to the collection of behavioral data of gestating sows confined to parturition beds. Analysis of the collected data confirms conventional observations of increased restlessness in the several days prior to parturition.

Further, the data shows a specific peak in SUS rate approximately 12 h before parturition, this peak being 5 to 10 times stronger than on any other day during the experimental period. The strength and reliability of the peak suggest it could be monitored specifically to prediction parturition and automatically notify management so human attendance at the birth could reduce sow and piglet mortality. In the future, this study system will be refined to specifically study the prediction of sow parturition, whether the pregnancy is successful or not as well as sow performance in feeding. We conclude that the methodology used in this study is valuable for parturition behavioral modeling of sows. The analytical results of this study can enhance benefits of detecting the farrowing-time beforehand sow's to be on the point of parturition and reduce costs in future large-scale sow husbandry. The methodology is also useful to overall understanding of animal physiology and psychology. In the text of this study, we provide the experimental data that exhibits significant behavior of three pureblooded Landrace sows before parturition to verify this system could operate properly. Furthermore, it confirms the common notion that sows about to enter parturition are uneasy and restless.

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