

Predicting Parturition Time through Ultrasonic Measurement of Posture Changing Rate in Crated Landrace Sows

J. S. Wang, M. C. Wu¹, H. L. Chang² and M. S. Young*

Department of Electrical Engineering, National Cheng-Kung University, No. 1, Ta-Hsueh Road, Tainan 701, Taiwan

ABSTRACT : This study presents an automatic system to predict parturition time in the crated sows. The system relies on ultrasonic transducers mounted from above along the length of the crate. Using a 40 kHz time of flight (TOF) single envelope wave, the momentary distances between the sensors are measured. Therefore, the local momentary height of the sow and the momentary posture, i.e. standing posture (SDP), kneeling posture (KP), sitting posture (STP) and lateral lying posture (LLP) are determined. Crated sows change their postures from standing to lying and vice versa which follows a characteristic pattern. As parturition approaches, sows exhibit uneasiness, restlessness and the stand up sequence (SUS, the posture transition from LLP to SDP) rate increases because of labor pains. In time series, the SUS rate demonstrates a peak and it happens approximately 0-12 h before parturition. In this paper, the basic parturition threshold value method (BPTVM) and the same hour method (SHM) are proposed for predicting parturition, both of which are based on the SUS rate. The BPTVM mainly detects the peak of the SUS rate. As the SUS rate exceeds the threshold value, the parturition becomes predictable. Moreover, the SHM calculates the difference in the SUS rates between a particular time of day and the corresponding time of the preceding day. Compared to the BPTVM, the SHM can eliminate the circadian rhythm of the SUS rate influenced by feeding behavior. Using the SHM the parturition can be approximately predicted within hours. In an attempt to define the threshold parameters of predicting parturition, a data set with 32 sows of the SUS rate are used to estimate assumable predicting probability. The results show the assumable probability of the parturition prediction within 9 h is 96.9% for the SHM and 84.4% for the BPTVM. Moreover, the SHM can even reach a 75% probability of prediction within three hours of parturition. We conclude that the SHM is more accurate and is more useful for parturition time prediction. When parturition is detected, the proposed algorithm generates a warning signal which can inform human personnel to protect the mother and newborn piglets. (**Key Words :** Sows, Parturition, Ultrasound, Postures, Basic Parturition Threshold Value (BPTV))

INTRODUCTION

Modern swine production has evolved into a highly competitive international industry that utilizes the latest technological and managerial systems to minimize costs and maximize productivity. Piglets' and sows' mortality rate during farrowing are major factors affecting profit. There are various researchers who have attempted to predict parturition time so that human personnel can attend to the birth and attempt to minimize mortality rate during farrowing. Personnel usually rely on experience to predict parturition time, using physical indicators to estimate the

parturition date of each individual sow. However, this technique is fairly inaccurate.

Traditionally, research regarding parturition prediction for large mammals has included measuring vaginal temperature (Aoki et al., 2005), caudal examination of dilated 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; Gilbert et al., 1996; Khan and Ludri, 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 and Hegglin, 1997; Pedersen et al., 1998). An inaccurately estimated parturition date can put the piglets and sows in danger, premature delivery, dystocia, hypothermia, stillbirth, asphyxiation and anoxia can result in death for new born piglets (Leenhouders et al., 1999; Lucia et al., 2002). The complicated manual inspection and the repeated intrusion by human observation can seriously

* Corresponding Author: M. S. Young, E-mail: msyoung@mail.ncku.edu.tw

¹ Taiwan Livestock Research Institute, No.112, Farm Road Hsinhua, Tainan 712, Taiwan.

² National Pingtung University of Science and Technology, No.1, Shuehfu Rd., Neipu, Pingtung, 91201, Taiwan.

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Table 1. Biological and environmental factors before and after parturition (n = 32).

Biological and environmental factors	Average	SD
Maternal age (month)	27.2	3.1
Parity (times)	3.4	1.2
Maternal weight before parturition (kg)	215.5	11.25
Maternal weight after parturition (kg)	195.3	12.45
Litter weight at birth (kg)	17.2	4.23
Maternal temperature (°C)	38.5	0.45
Fetal temperature (°C)	38.7	0.32
Environment temperature (°C)	25.0	4.2
Environment relative humidity (%)	78.0	10.0

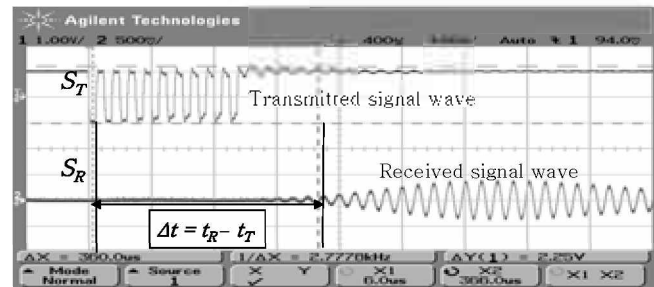
disturb the parturient sows (Ramirez et al., 1995; Gilbert et al., 2000). In addition, video monitoring systems require further manual investigation and interpretation of the recorded data which is both time and resource consuming.

Noninvasive ultrasonic equipment, which is cheaper and more convenient, has been previously used for measuring an animal's physical activity (Young et al., 1996). This technique is also effective for monitoring sows' behavior before parturition. As parturition approaches, sows exhibit uneasiness, restlessness and the stand up sequence (SUS) rate increases. This occurs because of labor pains or nest building behavior (Randall, 1972). In a previous study, we used ultrasonic transmitting/receiving equipment to measure the SUS rate during parturition. From the results, we confirmed that the SUS rate changes characteristically and demonstrates a distinct peak before parturition (Wang et al., 2005). The objective of the present study is to establish criteria and algorithms for predicting the parturition time using a series of SUS rates. Thus, based on the criteria and algorithms, an automatic stand-alone system for predicting parturition time and early warning can be achieved to maximize the sows' productivity.

MATERIALS AND METHODS

Animals

This study is conducted with the cooperation of the Taiwan Livestock Research Institute and the Shui-Po Breeding Swine Farm (Tainan, Taiwan, ISO-9001:2000). An automatic timed feeding system is used to reduce interference caused by livestock controllers. Duroc sows were used for system setup and preliminary tests at the Taiwan Livestock Research Institute to confirm that the proposed system produces satisfactory results. In the experimental stage, Landrace sows (pedigree is from Sweden, and bred in Taiwan) undergoing normal gestation and natural parturition are selected for observation in Shui-Po Breeding Swine Farm (Tainan, Taiwan, ISO-9001:2000). The biological and environmental factors before and after parturition are shown in Table 1. At around 27 months old, 32 sows with parity times around 3-4 are selected for the

**Figure 1.** Continuous envelope wave of the single frequency modulate phase.

experiment. The weights of the sows are around 210 kg and maternal weights are collected both before and after parturition. The average litter weight at birth is 17.2 kg with a 4.23 kg standard deviation. The air temperature and humidity are controlled at around 25°C and 78% separately. The maternal and fetal temperature is also recorded daily during the whole experiment.

Postures measurement

Posture changing frequency is measured and counted by an automatic apparatus with ultrasonic sensors. The time of flight (TOF) methodology is applied to measure the distance between the sensors and the sow, from which it is easy to detect the momentary elevations of the head, neck, spine and buttocks of the crated sow. These elevation readings are translated into four basic postures: standing posture (SDP), sitting posture (STP), kneeling posture (KP) and lateral lying posture (LLP).

Figure 1 shows a test single frequency ultrasonic wave of the transmitted and received signals. Here, the S_T is a transmitted signal and the S_R is a received signal. The transmitted signal S_T is generated by a programmable integrated circuit (CPLD EX10K10, Altera Co. Ltd., USA) and sent to the transducer. This signal then reflects off the body of the sows. The TOF method is applied to detect the time between the signal sent and the signal received. After receiving the reflective pulses, Δt is calculated and the distance of the object can be found. This relation is described below,

$$\Delta t = t_R + t_T \quad (1)$$

where t_R is the transmitted time of S_T and t_T is the received time of S_R . The distance d is proportional to the time Δt (TOF). Thus the distance between the transmitter and the target can be calculated as $d = (c \times \Delta t) / 2$, where c is the sound velocity. Furthermore, with the use of a temperature sensor (LM75, National Semiconductor Co. Ltd., USA), the speed of sound c can be compensated for immediately by measuring the temperature in the crate.

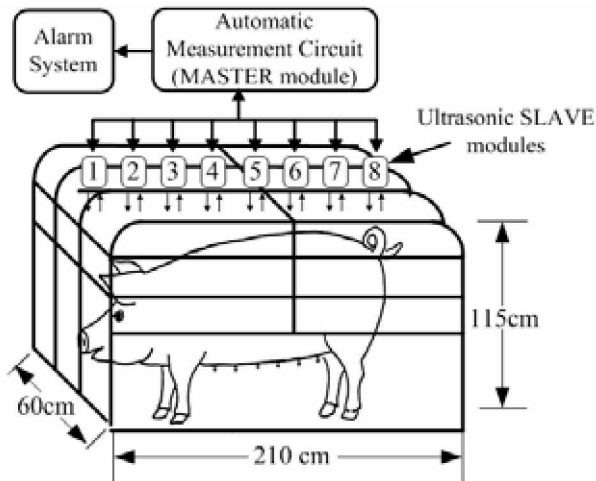


Figure 2. Dimensions of the farrowing crate, the layout of the MASTER module, alarm system and the eight ultrasound transmitting/receiving SLAVE modules.

Figure 2 shows the scheme of the farrowing crate used in this study. It is the standard size used in Taiwan with a fixed length of 210 cm, width of 60 cm and height of 115 cm. Typically, sows give birth 114 days after gestation and are sent into farrowing crates ten days before parturition. Because the space is small, there is very little room for lateral movement, she can only stand up or lie down. The momentary elevations of the 4 major parts (head, neck, spine and buttocks) of the crated sows are monitored during the whole experiment. In order to avoid noise and sensor error, the motion of every major part is detected by 2 sets of the ultrasonic sensor modules. Consequently, eight sets of ultrasonic sensor modules are installed above the long central axis (one dimension) in each farrowing crate to detect the large-scale characteristic motion of the sow. In the following investigation, each ultrasonic module is designated as a "SLAVE" equipped with a pair of 40 kHz transducers for transmission and reception. Figure 2 depicts the layout of the eight SLAVE's, which are positioned in a line along the top of the crate with 23.5 cm between each SLAVE.

The basic relations between sound and distance are accurate enough to use ultrasonic time of flight to calculate the height of the sows in question. In each crate eight SLAVES modules are set up, so the heights are measured at eight different positions for each sow. As a new sow enters the crate, the sensors detect different heights which start the ultrasonic measuring system. The H_{i-max} and H_{i-min} values of the eight SLAVES are recorded and updated cyclically. The value of H_{i-AV} is an average of H_{i-max} and H_{i-min} and is determined as:

$$H_{i-AV} = (H_{i-max} + H_{i-min}) / 2 \quad (2)$$

for $i = 1$ to 8

This value is computed and updated in every cyclic reading of the SLAVE. Upon entering a crate, the typical observed posture is the standing posture (SDP). After a few minutes, if the sow sits down or lies down, the new records of setting H_{i-min} and H_{i-AV} are established. At this moment, the H_{i-max} , H_{i-min} and H_{i-AV} are approximately equal. It is important to note that a new and unique H_{i-AV} is established for each individual sow, therefore this method is suitable for sows of varying heights and species. The record data of the values H_{i-max} , H_{i-min} and H_{i-AV} are used as a reference for analysis. These values are maintained and updated over the history of an individual animal. After repeated measurements are collected, the collective data contains several samples of all four basic postures of sows. As shown in Figures 3(a)-(d), the eight recorded data values of H_{i-max} and H_{i-min} approach a constant state and the averages of these H_{i-AV} values converge to the eight black dots. Each bar indicates maximum and minimum values of postures. The four characteristic postures, SDP, STP, KP and LLP are demonstrated in Figures 3(a), 3(b), 3(c) and 3(d), respectively. In standing posture (SDP), all eight sensors show H_{i-max} and in lateral lying posture (LLP) all sensors show H_{i-min} . As the results show, each individual sow has a unique H_{i-max} and H_{i-min} . Thus this technique is suitable for all sows, regardless of individual animal size.

Postures determination

Through comparison of momentary sensor values with H_{i-AV} (the eight black dots in Figure 4), a flow chart shows how Rule 1 and Rule 2 determine the postures of SDP, STP, KP and LLP, respectively. In the same figure, Rule 3 provides a logic value suitable for establishing the SUS rate. Data that do not fit the parameters of the rules, are discarded immediately and the system moves to the next data set.

Rule 1. Standing-lying determination : Figures 3(a) and (d) detail the sensor conditions of H_{i-AV} for SDP and LLP. Rule 1 is a decision process comparing SLAVE values of the most recent cycle of H_{i-AV} . It is used for determining the animal posture in either SDP or LLP. If true, then the algorithm goes to Rule 3. If false, then the algorithm goes to Rule 2.

- i) If $H_i > H_{i-AV}$, then State = SSDP and go to Rule 3, for $i = 1$ to 8 (see Figure 3(a)).
- ii) If $H_i < H_{i-AV}$, then State = SLLP and go to Rule 3, for $i = 1$ to 8 (see Figure 3(d)).
- iii) If neither, then go to Rule 2.

Rule 2. Kneeling-sitting determination : Figures 3(b) and (c) detail the sensor conditions of H_{i-AV} for the postures of KP and STP. This rule compares the values of the first and last three sensors of H_{i-AV} . When the conditions of H_1-H_3 are smaller and H_6-H_8 are larger than H_{i-AV} have detected.

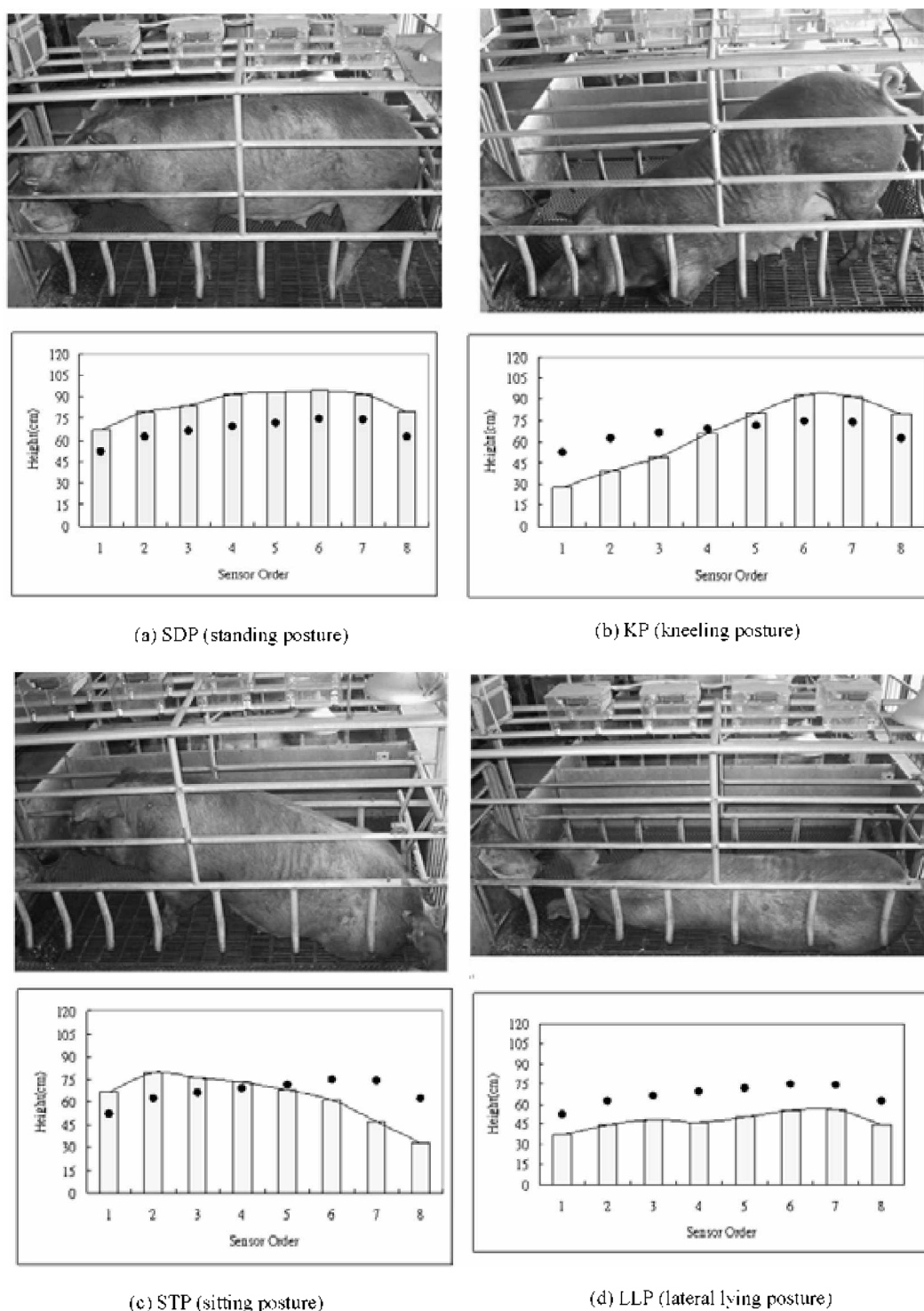


Figure 3. Photographs and graphed numeric data of the crated sow in four characteristic postures, SDP, KP, STP and LLP. Bars indicate measured height. Black dots are H_{i-av} . (a): If $H_1 > H_{i-av}$ then SDP. (b): If $H_1 - H_3 < H_{i-av}$, and $H_6 - H_8 > H_{i-av}$, then KP. (c): If $H_1 - H_3 > H_{i-av}$, and $H_6 - H_8 < H_{i-av}$, then STP. (d): If $H_1 < H_{i-av}$ then LLP.

the posture KP is decided. The posture STP is decided when $H_1 - H_3$ are larger than H_{i-av} and $H_6 - H_8$ are smaller than H_{i-av} .

i) If $H_1 - H_3 < H_{i-av}$ and $H_6 - H_8 > H_{i-av}$, then State = S_{KP} and go to start (see Figure 3(b)).

ii) If $H_1 - H_3 > H_{i-av}$ and $H_6 - H_8 < H_{i-av}$, then State = S_{STP} and go to start (see Figure 3(c)).

The data of the KP and STP is not used in this paper and this methodology will be applied in subsequent advanced studies.

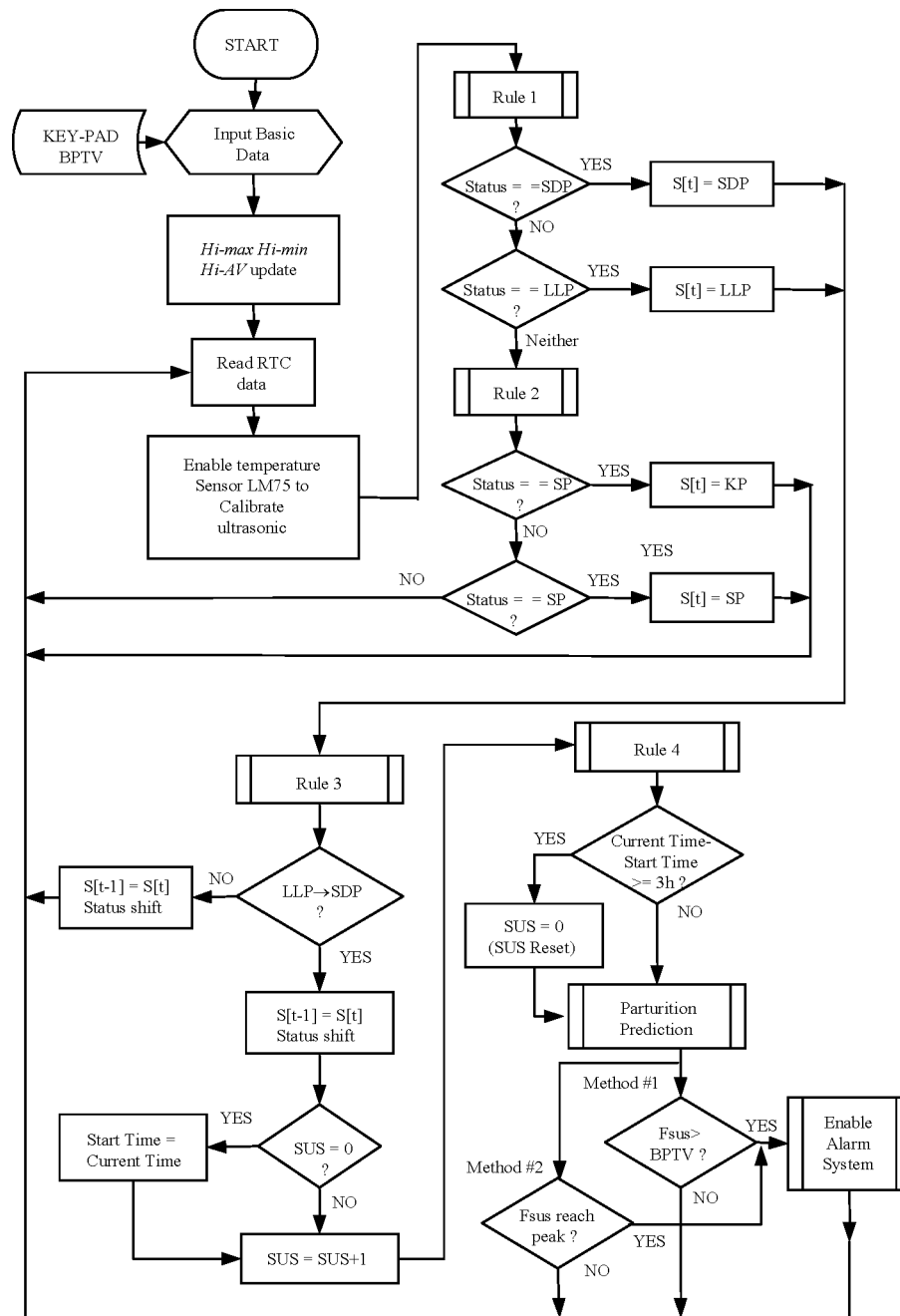


Figure 4. Block diagram of system algorithm Rule 1 to Rule 4.

The frequency of stand up sequence (SUS)

In Figure 4, the Rule 1 determines SDP state and the Rule 3 compares the previous and present SDP states. If SDP transition is determined, then the SUS counter is incremented by one. If this SUS counter is correlated with the time scale, then the frequency of SUS (i.e. SUS/time) is calculated and indicated as F_{SUS} . For reasons of precision and desired time between warning and parturition, a time range of three hours is taken, i.e. 24 h are divided into 8 parts. Thus the F_{SUS} is obtained by

$$F_{SUS} = SUS/3 \text{ h} \tag{3}$$

In the following observations, the day before parturition is referred to as the B-number-day, the day after parturition is referred to as the A-number-day and the parturition day is referred to as the P-day. Farrowing starts when the first pig is born, humans observe the pigs every three h to determine whether or not farrowing has commenced. Figure 5 shows the mean of the SUS counts for normal days, where $n = 32$. The horizontal axis indicates the time while the vertical axis shows number of the F_{SUS} events. The usual feeding time of

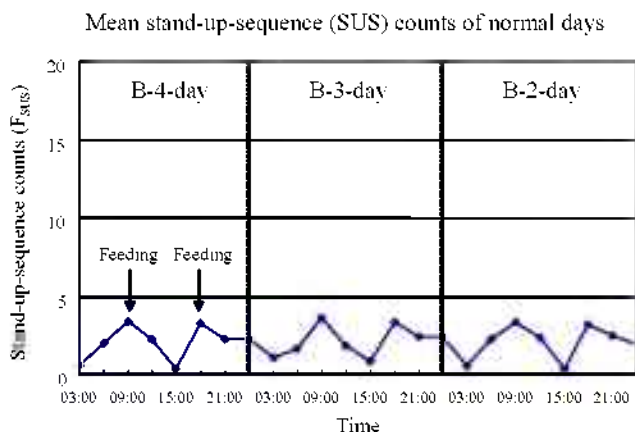


Figure 5. The mean of the SUS counts ($n = 32$) in normal days. The horizontal axis indicates the time, while the vertical axis shows the number of the SUS events. General feeding times are at 8:00 AM and 16:00 PM. At all other times the sows present an LLP posture. The SUS rate near feeding time normally ranges from 3 to 7, and with an average SUS rate of 4 per three h. In this study the SUS rate did not exceed 10 per 3 h.

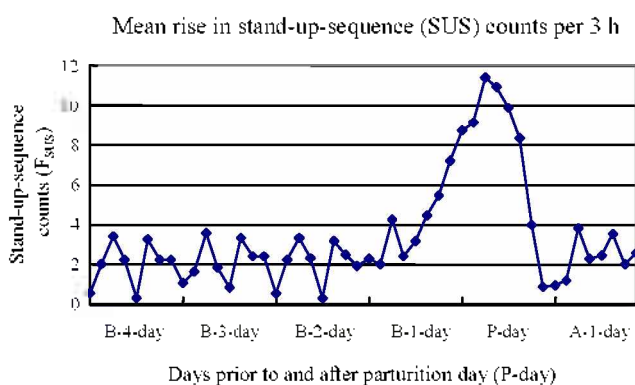


Figure 6. The mean of the SUS rate increases and demonstrates a peak as parturition approaches, where $n = 32$. During normal days, the SUS rate demonstrates a circadian rhythm during feeding time.

sows is at 8:00 AM and 16:00 PM. From the accumulated data set from the normal days (not near the date of parturition), we find the SUS rate (F_{SUS}) is relatively high during feeding time, but at other times sows present LLP resting postures. The SUS rate near feeding time normally ranges from 3 to 7 and with an average of 4 per three h. The experimental results show that the highest accumulated SUS rate does not exceed 10 per 3 h. Figure 6 shows the mean of the SUS rate increases and demonstrates a peak as parturition approaches, where $n = 32$. As parturition approaches, sows exhibit uneasiness, and restlessness due to labor pains which causes the SUS rate to increase. During the normal days the SUS rate demonstrates a circadian rhythm which corresponds to the sows' sleeping and eating patterns.

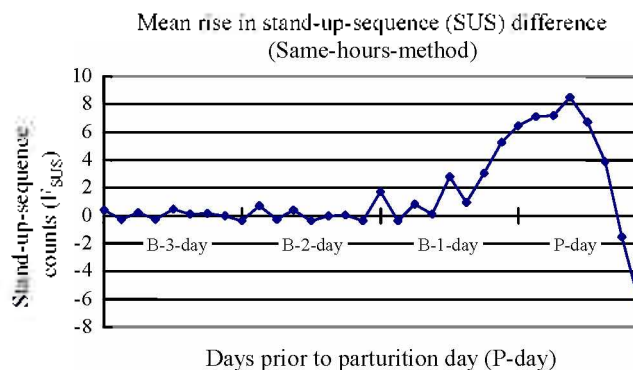


Figure 7. The Same-hour-method (SHM) calculates the difference in the SUS rates between a particular time of day and the corresponding time of the preceding day. The SHM can eliminate the circadian rhythm of the SUS rate influenced by feeding behavior. The mean of the SUS rate difference also increases and demonstrates a peak as parturition approaches, where $n = 32$.

Statistical analysis

The variations of data are analyzed by SPSS (Statistical Analysis Software, SPSS Institute Inc. USA). The statistical tests of the biological and environmental factors (Table 1) are executed using the correlation analysis. Consequently, the biological and environmental factors before and after parturition have no significant effect on the SUS rate ($p > 0.05$). The elapsed time on the SUS rates is analyzed with one-way ANOVA. The result shows a significant effect for the elapsed time on the SUS rates from B-4-day to A-1-day, where $p = 0.014$. The SUS rates from B-4-day to A-1-day are then compared individually using Fisher's LSD test (posteriori comparisons).

Parturition time prediction

Two different methods of predicting parturition time, BPTVM and SHM, are presented in this section. When the value of F_{SUS} exceeds a basic parturition threshold value (BPTV), the first method is applied. The BPTV is a statistical parameter for parturition characteristic of different species of sows. In this study, the value of F_{SUS} is checked if the F_{SUS} exceeds the value of BPTV during a three hour time interval. The second method is SHM. The SHM calculates the difference in the SUS rates between a particular time of day and the corresponding time of the preceding day. As shown in Figure 7, the SHM can eliminate the circadian rhythm of the SUS rate influenced by feeding behavior. The mean of the SUS rate difference also increases and demonstrates a peak as parturition approaches, where $n = 32$. The alarm is set as the peak of the SUS rate is detected, which allows for a more precise prediction. As the scheme in Figure 4 demonstrates, Rule 4 is performed at the end of each three hour interval for parturition time prediction by BPTVM and SHM, whereupon the counter of the F_{SUS} and the time are reset to zero.

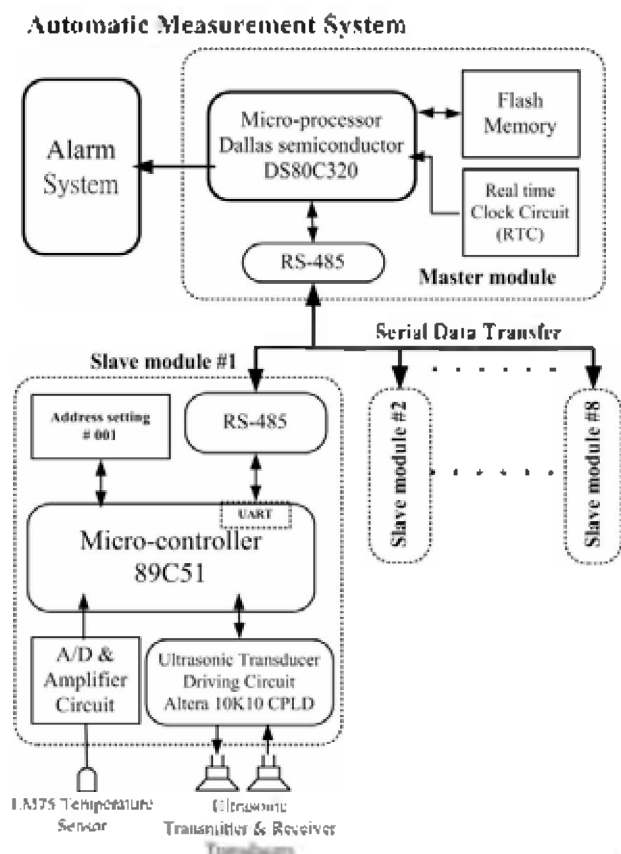


Figure 8. The structure of automatic measurement systems include a MASTER control unit, SLAVE modules, an alarm system, temperature sensors and an ultrasonic system.

Automatic measurement system

Figure 8 shows the hardware structure of the automatic measurement and alarm system. Each automatic system contains one MASTER circuit module and eight discrete SLAVE modules. The RS-485 (Computer serial interface

transmission communications) technology relays signals between MASTER and SLAVE modules.

Each SLAVE is built by an 89C51 microcontroller IC, a temperature detection sensor (LM75, National Semiconductor, USA), an ultrasonic transducer pair and a programmable integrated circuit (CPLD EX10K10, Altera Co. Ltd., USA) which is used for ultrasonic signal driving and analysis. An address number is assigned to each SLAVE. Eight of these SLAVE modules, from SLAVE module 1 to 8, are located around the centerline of the long axis.

The inner hardware of MASTER module includes a microprocessor (DS80C320, Dallas Semiconductor, USA), a real time controller IC RTC (DS12887, Dallas Semiconductor, USA) and a flash memory. The microprocessor calculates the results from Rule 1 to Rule 4 and performs the parturition prediction. Real time data are provided by the RTC module. If parturition is predicted, the alarm system informs the husbandry controller and passes the information of how many sows are near parturition and specifies their location.

RESULTS

SUS rate from B-4-day to A-1-day

All of the tests using the proposed system demonstrate a peak in the SUS rate approximately 0-12 h before parturition. The statistical tests of the biological and environmental factors (Table 1) are executed using the correlation analysis. Consequently, the biological and environmental factors before and after parturition have no significant effect on the SUS rate ($p > 0.05$). The elapsed time on the SUS rates is analyzed with one-way ANOVA. As the results show in Table 2, there is a significant effect on the elapsed time of the SUS rates from B-4-day to A-1-

Table 2. Daily stand up sequence (SUS) for sows near the date of parturition. (n = 32)

Days near parturition	Stand-up-sequence (SUS) counts per day (mean±SD)	Comparison of the day near parturition	Probability*
B-4-day	16.3±7.52	P-day vs. B-1-day	<0.01**
B-3-day	17.1±6.56	P-day vs. B-2-day	<0.01**
B-2-day	16.4±7.52	P-day vs. B-3-day	<0.01**
B-1-day	20.0±8.31	P-day vs. B-4-day	<0.01**
P-day	74.25±24.1	P-day vs. A-1-day	<0.01**
A-1-day	15.5±7.00	B-1-day vs. A-1-day	0.12
		B-1-day vs. B-4-day	0.26
		B-1-day vs. B-3-day	0.35
		B-1-day vs. B-2-day	0.30
		B-4-day vs. B-3-day, B-2-day, A-1-day	0.82
		B-3-day vs. B-4-day, B-2-day, A-1-day	0.77
		B-2-day vs. B-4-day, B-3-day, A-1-day	0.83

The day before parturition is referred to as the B-number-day, the day after parturition is referred to as the A-number-day and the day of parturition is referred to as the P-day.

* Adjustment for multiple comparisons: Least Significant Difference.

** The mean difference is significant at the 0.01 level. ($p < 0.01$)

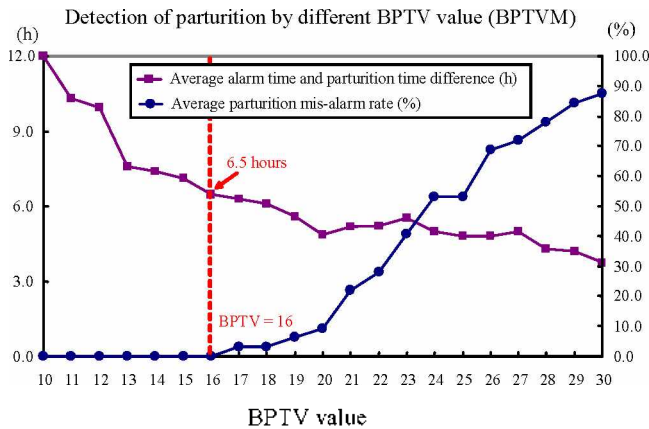


Figure 9. The detection of parturition is based on the basic parturition threshold value method (BPTVM). The average time difference between alarm and parturition, and the parturition mis-alarm rate are compared with different BPTV values (n = 32). The time difference decreases but the mis-alarm rate increases as the BPTV increases. In order to obtain the most precise detection with zero mis-alarm rates, the BPTV value is selected as 16, where the mean time difference is 6.5 h.

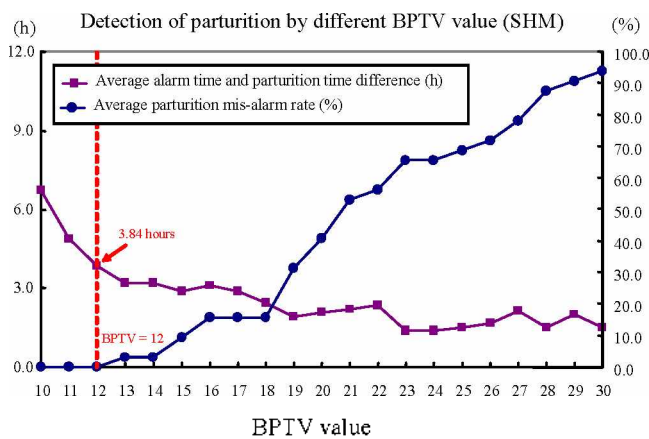


Figure 10. The detection of parturition is based on the same hour method (SHM). The average time difference between alarm and parturition, and the parturition mis-alarm rate are compared with different BPTV values (n = 32). In order to obtain the most precise detection with zero mis-alarm rates, the BPTV value is selected as 12, where the mean time difference is 3.84 h.

day, where $p = 0.014$. The SUS rates from B-4-day to A-1-day are then compared individually using Fisher's LSD test. The results show significant differences ($p < 0.01$) in days: (P-day versus B-4-day), (P-day versus B-3-day), (P-day versus B-2-day), (P-day versus B-1-day) and (P-day versus A-1-day). That is, the SUS is higher near parturition than it is on normal days.

BPTV value for BPTVM and SHM

The SUS rate is monitored every three consecutive hours and the parturition is detected by the BPTVM and the SHM algorithms as the SUS rate begins to increase. The

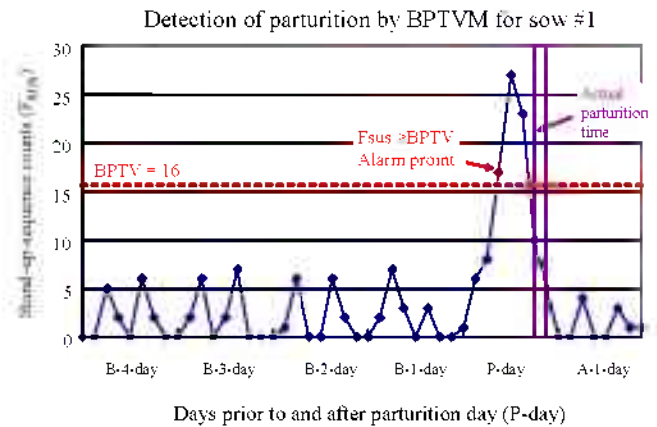


Figure 11. The example of detection of parturition by BPTVM for sow #1. When the F_{SUS} rate exceeds a basic parturition threshold value (BPTV = 16), an alarm is set to inform the husbandry dealer that parturition will occur within hours. The actual parturition time is within 9-12 h after alarm is given for sow #1.

actual start of farrowing (when the first pig is born) is observed by humans at the same time as the automatic measurement system (every three consecutive hours). In an attempt to define the threshold parameters of parturition predicting, a data set of the SUS rate of 32 sows is used to define the BPTV value. As the results show in Figure 9, the detection of parturition is based on BPTVM. The average time difference between alarm and parturition, and the parturition mis-alarm rate are compared with different BPTV values. The mis-alarm means that a sow begins to farrow before the alarm is sounded. It can be seen from the data analysis results that the time difference decreases but the mis-alarm rate increases as the BPTV increases. In order to obtain the most accurate detection with zero mis-alarm rates, the BPTV value is selected as 16, where the mean time difference is 6.5 h. Figure 10 shows the detection of parturition which is based on SHM. The average time difference between alarm and parturition, and the parturition mis-alarm rate are also compared with different BPTV values (n = 32). In order to obtain the most accurate detection with zero mis-alarm rates, the BPTV value is selected as 12, where the mean time difference is 3.84 h.

Figure 11 shows the example of detection of parturition by BPTVM for sow #1. When the F_{SUS} rate exceeds a basic parturition threshold value (BPTV = 16), an alarm is set to inform the husbandry dealer that parturition will occur within hours. The actual parturition time is within 9-12 hours after the alarm for sow #1 is sounded. Figure 12 shows the example of detection of parturition by SHM for the same sow. When the F_{SUS} value exceeds 12 (BPTV = 12) from the proceeding day, parturition is predicted. The alarm is set as the peak of the SUS rate is detected (i.e., when the slope of F_{SUS} turns from positive to negative). The actual parturition time is within 3-6 h after the alarm is given for sow #1.

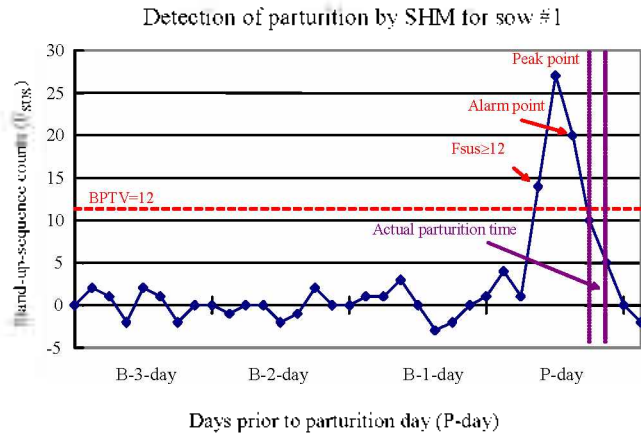


Figure 12. The example of detection of parturition by SHM for sow #1. When the F_{SUS} value exceeds 12 (BPTV = 12) from the preceding day, the parturition is predicted. The alarm is set as the peak of the SUS rate is detected. The actual parturition time is within 3-6 h after alarm is given for sow #1.

Comparison of BPTVM and SHM

From the results of the Landrace sows in Table 3, the BPTVM shows that parturition occurs 6.47 h (average) after the SUS rate exceeds BPTV (selected as 16 for the zero mis-alarm rate). The SHM method can signal an alarm within 3.84 h (average) before parturition (for zero the mis-alarm rate, the BPTV is selected as 12). From the average time difference of BPTV = 10 to 30, the SHM also more precisely predicts time of parturition within 2.61 h on average compared to 6.26 h on average with the BPTVM. The assumable predicting probability uses 32 sows in these experiments which are shown in Table 4, the assumable probability of the parturition prediction within 9 hours is 96.9% for the SHM (BPTV = 12) and 84.4% for the BPTVM (BPTV = 16). Moreover, the assumable probability of the parturition prediction within 3 h is 75% for the SHM

but 34.4% for the BPTVM. While both methods are useful for predicting parturition time by measuring the SUS rate, the SHM requires is more accurate than the BPTVM. It was observed that the SHM was able to predict the time of farrowing 37.5% of the time, and the BPTVM 3.1% of the time. However, because the actual start of farrowing is observed by humans at the same time as the automatic measurement system, every three consecutive hours, within this 3 h interval, sows give birth and the alarm is sounded, but from the current data it is not clear which one happens first.

DISCUSSION

In this study, we confirmed that when sows are about to enter parturition they become uneasy and restless, which correlates with the characteristics of animal behavior before parturition (Randall, 1972; Wang et al., 2005). That is, the SUS rate is higher near parturition compared with normal days. With a criterion to continuously monitor if the value of SUS rate exceeds a basic parturition threshold value (BPTV), the parturition time can be predicted (BPTVM). However, the circadian rhythm of the SUS rate is influenced by feeding behavior, which makes this method less reliable. The previous study demonstrates good results by using "same hours method" (SHM) to overcome circadian rhythm of the vaginal temperature which is shifted by feeding behavior (Aoki et al., 2005). In order to overcome the feeding effect, we also adopt the SHM in this study by comparing the differences of the SUS rate between a particular time of day and the corresponding time of the preceding day. In addition, SUS demonstrates a distinct peak before parturition (Wang et al., 2005). That is, combining peak detection with threshold criterion would improve the accuracy. As a result, we also add the peak

Table 3. Detection of parturition by BPTVM method and SHM method, where n = 32

Alarm and parturition time difference (h)	BPTVM method		SHM method	
	BPTV = 10~30	BPTV = 16	BPTV = 10~30	BPTV = 12
Mean	6.26	6.47	2.61	3.84
S.D.	2.17	3.42	1.31	4.77
Maximum	12.00	12.00	6.75	24.00
Minimum	3.75	0	1.36	0

Table 4. Number of sows delivered within 3, 6, or 9 h after the alarm was given by BPTVM (BPTV = 16) and SHM method (BPTV = 12)

Predicting methods	Number of sows delivered (probability)				
	The same time	Within 3 h	3-6 h	6-9 h	>9 h
BPTVM method	1 (3.1%)	10 (31.3%)	9 (28.1%)	7 (21.9%)	5 (15.6%)
SHM method	12 (37.5%)	12 (37.5%)	4 (12.5%)	3 (9.4%)	1 (3.1%)

Predicting methods	Accumulated number of sows delivered (probability)				
	The same time	Within 3 h	Within 6 h	Within 9 h	All
BPTVM method	1 (3.1%)	11 (34.4%)	20 (62.5%)	27 (84.4%)	32 (100%)
SHM method	12 (37.5%)	24 (75%)	28 (87.5%)	31 (96.9%)	32 (100%)

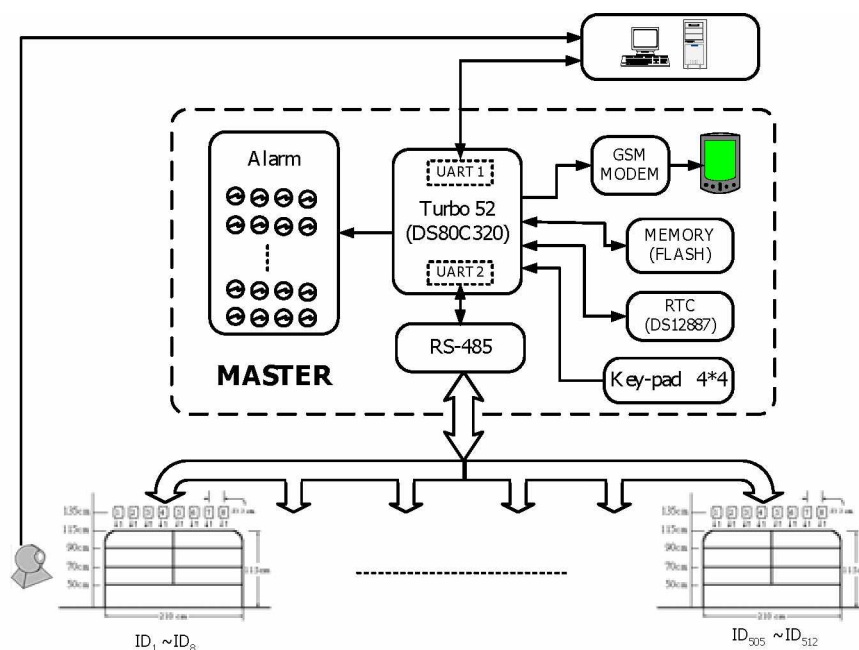


Figure 13. The structure of the automatic alarm system includes a MASTER control unit, SLAVE modules, an alarm system and an optional PC. The alarm system could notify the husbandry controller by an LED array, a PC or remote alarm via GSM modem interface.

detection algorithm of the SUS rate in the SHM, to achieve a higher accuracy of parturition prediction. From the result, the assumable probability of the parturition prediction within 9 h is 96.9% for the SHM and 84.4% for the BPTVM. Moreover, the SHM can even reach a 75% probability of prediction within three hours of parturition. We conclude that the SHM is more accurate than the BPTVM for parturition time prediction.

In the present study, for experimental convenience, the time interval is set as 3 h for system prediction and human observation. However SHM can accurately predict the time of birth 37.5% of the time (Table 4). That means within this 3 hours interval, sows give birth and the alarm is sounded, but from the current data it is not clear which one happens first. In order to overcome this issue and improve the resolution to the time interval between farrowing and alarm must be shortened. This might increase the frequency of human observation for actual parturition time in the experiment stage. The BPTV value for shorter time intervals also needs to be re-defined, but for the implemental stage, it will improve the resolution and precision.

The proposed method has been proven effective for automatic observation of individual crates or crate arrays in adverse environment. It works regardless of lighting conditions. Good interfacing of the proposed ultrasonic sensor system, continuous real-time monitoring of crated animals and a suitable warning system for human personnel have also benefited the husbandry industry to save piglets and sows, as well as time, effort and money. Figure 13

demonstrates the structure of an automatic parturition prediction and alarm system, which is suitable for breed swine farms with high numbers of sows. Alarm system could notify the husbandry controller by an LED array, a PC or remote alarm via GSM modem interface. The LED array consists of 64 LEDs, one LED for each crate. The lighting of an LED notifies the husbandry controller that a sow is close to parturition and indicates which crate she is in. The PC can be equipped with an optional video camera that observes the first crate. The camera is used to confirm ultrasonic data and the proper operating of the alarm system. The prototype alarm system can be used to monitor 64 sows at the same time and can be easily extended for large breed swine farms.

This study is designed to establish characteristic behavioral baselines for sows. We have successfully implemented the system on two different breeds of sows, Duroc and Landrace. We used Duroc sows for system setup and preliminary tests and then implemented the system and collected the whole experimental data from Landrace sows in different breeding swine farms. The system can also be applied to the investigation of animals' responses to diet, drugs, genetic modifications and environmental factors (Krsiak et al., 1970). The system uses a matrix sensor system to track the animal's movement; general horizontal and vertical activities were developed by previous research works (Young et al., 1993; Young et al., 1996). In the present study, we use a one dimensional sensor array to detect motion and postures of farrowing sows in small enclosures. In the future, we could apply this technology to

farrowing sows in larger enclosures using a two dimensional sensor array which could detect movements as well as postures of sows. Other measuring methods such as infrared-ray (IR) sensors are not suitable for the current environment because of their sensitivity to light (Young et al., 1993). In the future, if the noise effect could be reduced, infrared ray technology could be another economical method for parturition prediction.

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