Developing a sow estrus detection system using computer vision and deep learning

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Abstract

Successful swine breeding relies on timely and accurate estrus checks of sows and gilts. Estrus checks in current farms are usually performed using the back pressure test (BPT) method, which is labour intensive and inefficient due to the large animal-to-staff ratio. This study aimed to develop a smart sow estrus detection system for stall-housed sows (including gilts). The system consisted of a ceiling-mounted track system, a three-dimensional (3D) depth camera, a robotic platform, and an edge-computing system. The edge-computing unit (Raspberry Pi) was used to control the robotic system, connect the camera, and acquire imagery data. Imagery data were acquired at a 10-min interval from the back of sows housed in gestation stalls. Magnetic sensors on the track were used to indicate the position of each stall. Deep learning algorithms implemented on the edge-computing unit were developed to automatically process and analyse infrared (IR) and depth images to quantify sows' behavioural patterns and vulvar size. Behavioural patterns, including standing and lying, were calculated and used to indicate the onset of estrus. Preliminary study was conducted on 20 sows at a research farm where estrus was checked once a day on the 5th and 6th day after weaning. An estrus detection based on a support vector machine was trained using the daily difference in 20 sows' vulvar size, daily standing, and daily idle duration as inputs. Results showed that the behavioural patterns could be observed prior to the onset of estrus, such as an increase in daily standing duration and a decrease in daily idle duration. The trained model was validated on six new sows and results showed that overall training accuracy and test accuracy were 95.4% and 93.1%. False alarm for the onset of estrus occurred within one day prior to the detected estrus event. No distinct behaviour pattern was observed around returned estrus. The study indicated that the developed system could be used to help improve sow management efficiency and save labour consumption.

Keywords: swine reproduction, estrus check, robotic imaging system, 3D camera

Introduction

Timely and accurate estrus detection is crucial to a swine breeding farm's sustainability (Belstra et al., 2020). Due to the longevity of the sperm and eggs, insemination that occurs too early or too late relative to ovulation can result in a lower conception rate and smaller litter sizes (Knox et al., 2001; Rozeboom et al., 1997). Although estrus detection accuracy may be improved by checking sow more frequently (Kraeling and Webel, 2015), the amount of labour required by the current estrus detection method (back-pressure test: BPT) and the widespread local labour shortage in the swine industry (Black and Arruda, 2021) makes this manual estrus detection method difficult to be carried out more than once per day in a large herd (Johnson, 2007). Therefore, a more precise and efficient method for estrus detection is needed.

Behaviour patterns of sows can reflect their welfare and status such as thermal comfortableness, lameness, and the onset of estrus (Andersen et al., 2008; Grégoire et al., 2013; Xue et al., 2022). Therefore, monitoring sows' behaviour patterns can help improve a sow breeding farm's productivity from multiple perspectives. A recent study used behaviour patterns of sows for automated estrus detection after weaning and achieved 97.1% precision and 94.1% accuracy (Xue et al., 2022). Vulvar swollenness is a biological sign of approaching estrus (Zhang et al., 2022) and can be evaluated using 3D machine vision technology (Xu et al., 2023). According to a survey, farms that use vulvar swollenness, which is evaluated based on subjective visual observation, as one of the indicators for the onset of estrus can generally achieve a better farrowing rate (Young et al., 2010). Therefore, the goal of this study is to study the changes in behaviour patterns and vulvar swollenness for sows housed in gestation stalls after weaning to help identify estrus events.

Materials and methods

Development of robotic imaging system

A robotic imaging system was developed to monitor individual sows and gilts housed in gestation stalls. The robotic imaging system consisted of a robotic platform, two Light Detection and Ranging (LiDAR) cameras (L515, Intel RealSense, Santa Clara, CA, USA), and an edge computing unit (Raspberry Pi 4B – 4G memory, Cambridge, UK). Figure 1 illustrates the architecture of the robotic imaging system, the ceiling-mounted rail track was made of V-slot linear rail aluminum extrusion profiles to support a robotic imaging system moving along a farm. The rail is extendable to required lengths based on the number of sows to be monitored. A robotic platform consisted of a stepper motor (NEMA23, OpenBuilds, Zephyrhills, FL, USA), a motor driver, roller wheels, timing belts, cable carriers, stall positioning sensors (Hall effect sensors and magnets). Magnets were attached to the rail at the locations aligning to the center position of each stall where images were taken. The motor driver and Hall effect sensor were connected to the GPIO pins of the Raspberry Pi. A control interface was developed to control the motor (open-loop control) moving to each imaging location and returning to the docking location after completing one data collection. The LiDAR camera were mounted on the robotic platform at 0.75 meters above the floor and 0.2 meters above the rear gate of the stall, with a horizontal field of view tilted 5 degrees downwards. The cameras were about 1.0 m from the metal stall and could take rear-viewed images of each sow in both rows. The cameras were connected to the Raspberry Pi through USB 3.0 interface and controlled using the *Pyrealsense2* Package (RealSense SDK 2.0, Intel, Santa Clara, CA, USA).

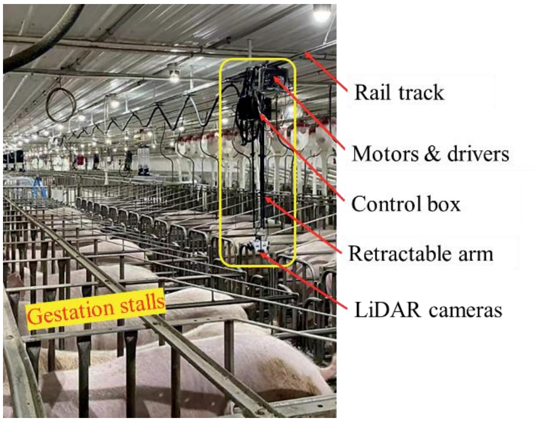

Figure 1: The overview of the developed robotic imaging system.

The LiDAR cameras could acquire red-green-blue (RGB) color, infrared and depth images simultaneously, and infrared and depth images could be collected at low-light conditions (e.g., night). A touch screen was used to visualize the images and system setup, e.g., traveling speed, sow information and camera parameters. The robotic imaging system worked at patrol mode to conduct routine data collection or manual mode as needed. Images of each sow were taken at every 10 min to quantify their activity patterns. The robotic imaging system can exit the workspace and park at a docking space when activities, such as estrus check, moving sows, and washing floor, need to be performed in the breeding room. The robotic platform left the docking station every 10 minutes. When a magnet sensor was detected, the robotic platform stopped, and the LiDAR camera was triggered to take a rear-view image of the sow in a stall. The robotic imaging system would return to the docking station after image acquisition for all the sows and wait for the next cycles.

Experimental data

The experiment was carried out in the Swine Research Complex of the University of Missouri-Columbia from July 26 to Nov 3, 2022. A total of 43 sows were monitored in this study. Each sow was monitored for about five weeks from weaning. All sows were managed according to the standard operating protocols of the farm. Estrus checks were performed using the back-pressure test with boar exposure by an experienced breeding technician at the morning of the 5^{th} day and the 6^{th} after weaning till estrus was detected. Sows received artificial insemination on the day of the detected onset of estrus and the day following (two doses). Pregnancy tests that were conducted using a transabdominal ultrasound machine at the fifth week of post-insemination.

Estrus detection model

An image processing pipeline (Figure 2) was developed to extract behaviour records and evaluate the sow's vulvar size from the collected imagery data. A decision tree model for estrus detection was implemented using behaviour and vulvar size records from 26 sows. The sows that were not used to train the estrus detection model were either not pregnant (based on ultrasound test) or did not have sufficient imagery data with suitable posture for vulvar size evaluation around the onset of estrus events. The postures refer to sows that are standing (not defecating), the vulvar region is not blocked by the tail, and the body orientation is centred in the camera's field of view.

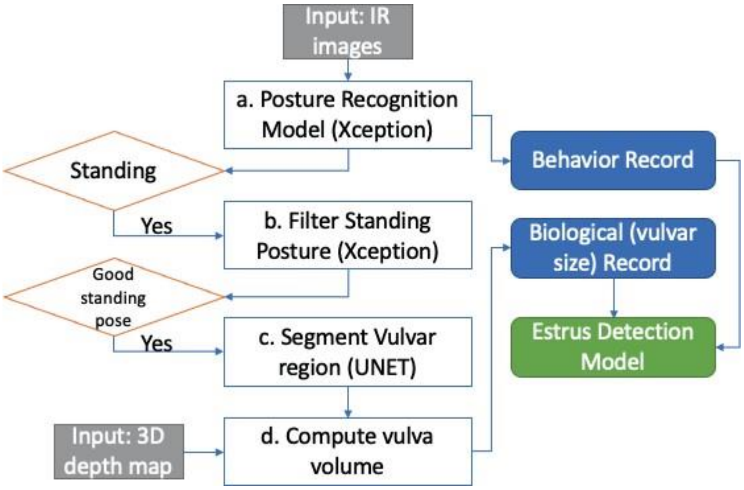

Figure 2: Robotic imaging system and image process pipeline.

A posture recognition model was developed to extract the behaviour patterns of sows, including *daily standing duration* (STA24: portion of standing posture in a 24-hour window evaluated at 12 PM) and *daily idle duration* (LL24: portion of lateral lying posture in a 24-hour window evaluated at 12 PM, noon). We also calculated the DLL and DSTA that were the daily difference in LL24 and STA24 (i.e., $DLL_{;Z\#\,!} = LL24_{;Z\#\,!} - LL24_{;Z\#\,!R\&}$). RLL and RSTA were the daily ratios in LL24 and STA24 (i.e., $RLL_{;Z\#\,!} = LL24_{;Z\#\,!}/LL24_{;Z\#\,!R\&}$). The sow's vulvar region was automatically identified using a UNET model. The vulvar volume was computed using the method described in a previous study (Xu et al., 2023). Daily vulvar volume (VA24) was defined as the average value of captured vulvar volume within a 24-hour window evaluated at 12 PM. In addition, the DV is the daily difference between two consecutive days' VA24 values, and PV was the daily percentage change in VA24 ($PV_{;Z\#\,!} = (VA24_{;Z\#\,!} - VA24_{;Z\#\,!R\&})/VA24_{;Z\#\,!R\&}$). Day from weaning (DFW) is considered as 0 for the first day that the sow was moved into the gestation stall and increment by 1 for each following day. Data from the second day after weaning to the day when the onset of estrus was detected for 20 sows were used to train an estrus detection model using a support vector machine (RStudio, 1.2.5033). Response variable Onset of Estrus (OE) is set as 0 (Class weight=1) for each day and set as 1 (Class weight=3) for the day when the onset of estrus was detected. Data from the other six sows were used as test samples.

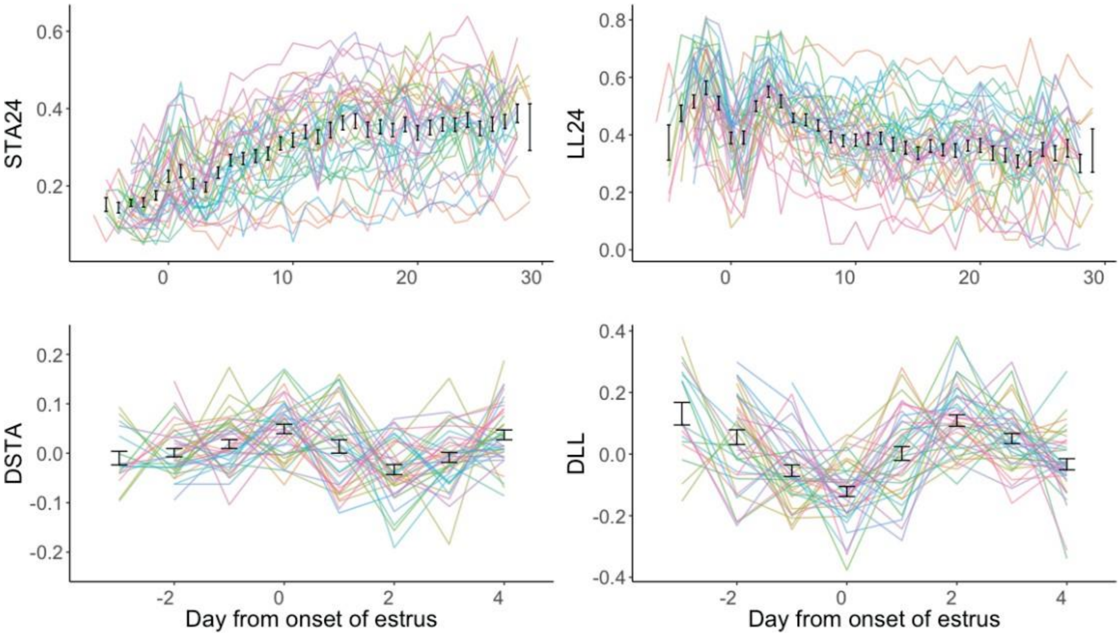

Figure 3: Daily standing and lateral lying duration after weaning and daily difference in standing and lateral lying duration around onset of estrus.

Results and discussion

Behavioural traits after weaning

Figure 3 shows the behavioural patterns of the 38 confirmed pregnant sows during the experiment. Daily standing duration (STA24) would increase before the onset of estrus and then start to decrease on Day 2. After estrus, STA24 would slowly increase (from Day 3 to Day 14) and then remain stable for the rest of the monitored period. Around the estrus events, most sows showed a positive increase in daily standing duration (DSTA) on Day 0 (onset of estrus). For the sows that showed a negative increase in STA24 on Day 0, a positive increase in STA24 was observed on the day before (Day -1). After weaning, the sow's daily idle level (LL24) would first increase. LL24 would then decrease as estrus approaching and then increase from Day 1 to Day 3. Two days after the onset of estrus, LL24 would slowly decrease from Day 4 to Day 10 and then remain steady. The negative change in daily idle duration (DLL) was observed on the day of onset of the estrus event for the majority of the sows. For the sows that showed a positive increase in LL24 on Day 0, a negative increase was observed on Day -1.

One difference between the daily standing duration and daily idle duration is that the daily idle duration first increased after the sows were moved into the gestation stall (Day -5 to Day -2), whereas the daily standing duration remained relatively stable. One potential explanation is that when moved to a new environment after weaning, sows would pay more attention to the new surrounding environments and therefore spent less time in the lateral lying position (completely inactive). As sows became familiar with the environments, the daily idle duration continuously increased until estrus was approaching. However, during this early phase (right after weaning), the sow might be weak to physically react (standing) to the surroundings, hence no significant difference ($p > 0.1$) in daily standing duration was observed during this period. Therefore, to use behaviour patterns as one of the indicators to detect the onset of estrus, we recommend moving the sow into a gestation stall for monitoring purposes at least three days prior to the expected arrival of estrus. If the sows were moved into the gestation stall 1-2 days prior to the onset of estrus, the system might not be able to observe any significant decrease in daily idle duration or increase in daily standing duration.

Biological (vulvar swollenness) traits after weaning

Daily vulvar volume records of the pregnant sows are shown in Figure 4. An increase in vulvar volume can be observed before the onset of estrus. According to the TukeyHSD test, vulvar volume on Day -1 (one day before the onset of estrus) is significantly higher ($p < 0.05$) than vulvar volumes from Day -3 to Day -6. The peak of vulvar volume record in general would be found 0-1 day before of detected onset of estrus for each sow. No significant difference ($p > 0.1$) in vulvar volume was observed from Day 17 to Day 25, that expected return estrus time frame of the non-pregnant sows.

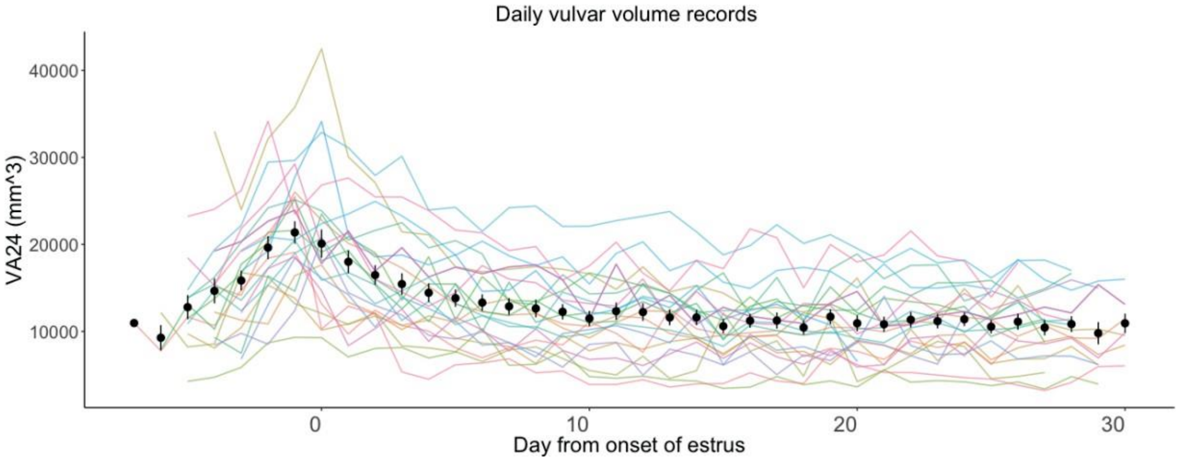

Figure 4: Daily vulvar volume records for sows during the experiment.

Examples of daily vulvar records (with standard deviation) and behaviour records of the two non-pregnant sows are shown in Figure 5. A significant increase in vulvar size ($p < 0.05$) was observed for both sows prior to the detected the onset of estrus. The daily idle duration and daily standing duration was decreasing and increasing, respectively, which was similar to the pregnant sows before their arrival of estrus. The results suggest the detected onset of estrus was accurate or not far off, but sows did not become pregnant from artificial insemination. A significant increase ($p < 0.05$) in vulvar volume was observed for both sows around the expected time for return estrus (Figure 5a, Day 22, Figure 4b, Day 23). This could allow detection for returned estrus, early identification of non-pregnant sows, greatly reduce non-productive days, and potentially reduce the labour consumption for the pregnancy test. Sows are normally kept in the gestation stalls for about 4 – 5 weeks, and pregnancy tests can be conducted before they are moved to a group pen (Koketsu and Iida, 2017). Therefore, if no return estrus was detected (no vulvar swollenness), the sow may no longer need to be kept in a gestation stall for more than four weeks and thus help improve animal welfare. The local maximum daily vulvar value (VA24) around the expected time for return estrus was slightly lower ($p < 0.1$) than the local maximum daily vulvar value around the first onset of estrus. This may be due to the lack of boar exposure around the returned estrus. No distinct behaviour pattern**s** (STA24 and LL24) were observed prior to the returned estrus. One potential explanation is that sows have already regained strength 3 weeks after weaning which allows them to react sensitively to the surrounding environment**s**. As a result, standing and lateral lying duration may not be able to reflect the sow's growing interest in seeking a boar around the return estrus and, therefore, may not be used as indicators for returned estrus.

Although vulvar swollenness prior to estrus events can be detected using the method presented in this study, it is difficult to assert the recorded VA24 is true to the actual size of the vulva due to the high standard deviation within vulvar volume records evaluated in the 24-hour window. Potential causes for such high standard deviation include the sow's distance to the camera, the sow was previously in a sitting posture, and slightly miss-aligned body orientation with regard to the camera's field of view. Therefore, to reduce the high standard deviation and improve the certainty of the computed vulvar volume, we suggest evaluating a sow's vulvar size continuously when the sow is consuming feed (i.e., stop at each stall for 30 seconds, capture 30 frames of imagery data for vulvar size evaluation when given feed). This would not only allow daily vulvar size evaluation to be conducted when the sow is at a consistent distance from the camera to reduce variation in the recording but also help ensure all sows have vulvar volume records during the early phase after weaning where the sows may have low activity level.

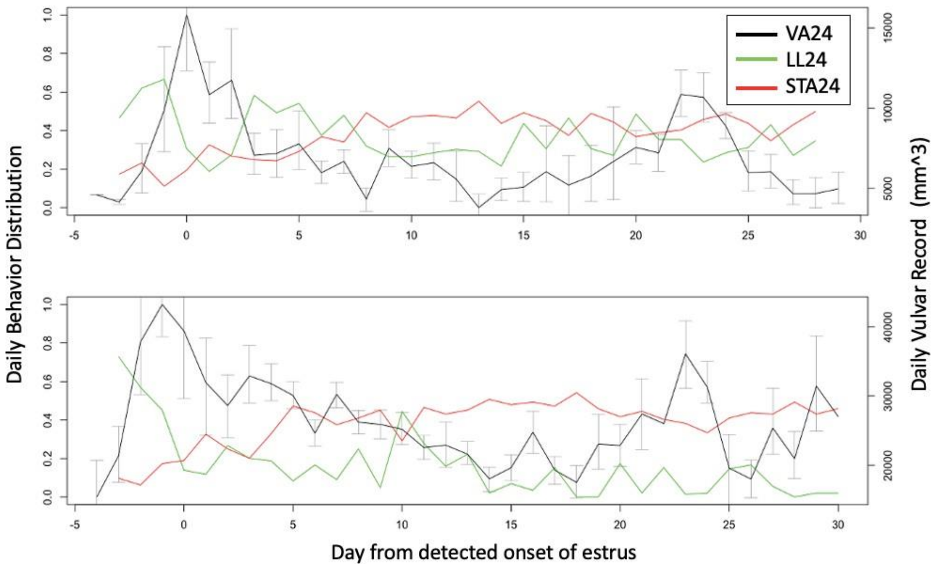

Figure 5: Daily vulvar and behavioural records of two non-pregnant sows.

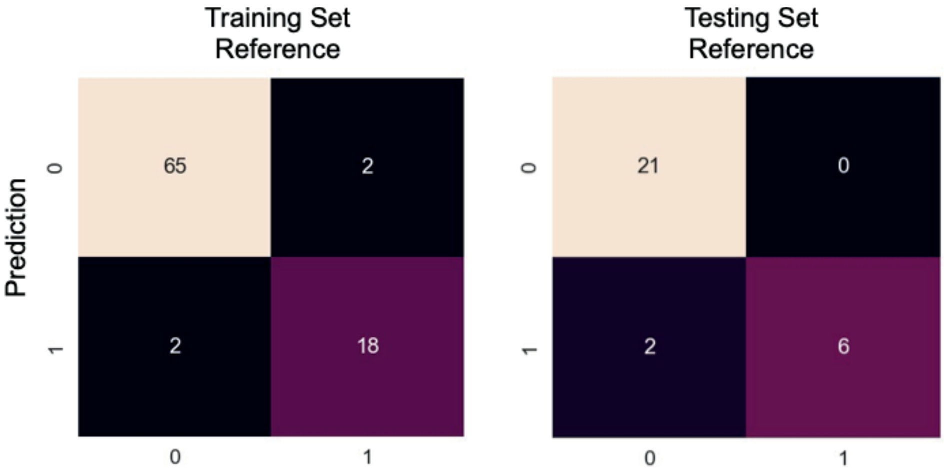

Figure 6: Confusion matrix of estrus detection model.

Estrus detection model analysis

The result of the trained estrus detection model using a support vector machine is shown in Figure 6. Overall training accuracy is 95.4%. Training accuracy for the onset of estrus detection is 90% where 2 out of the 20 onset of estrus events were not detected by the model. For one of those two sows, the model identified the onset of estrus one day prior to the manually detected onset of estrus. Both false alarms occurred one day before the detected estrus events. The training specificity of the model is 0.97. The training sensitivity, precision, and F1-score for identifying the onset of estrus events are 0.9. For the 6 sows in the testing dataset, the estrus detection model successfully identified estrus events for all 6 sows. Two of the sows' onset of estrus were identified one day before the manually detected onset of estrus. The overall test accuracy of the model is 93.1%. The test specificity of the model is 0.91. The test sensitivity, precision, and F1-score for identifying the onset of estrus events were 1, 0.75, and 0.857.

Conclusions

This paper proposed a method that uses a robotic imaging system to automatically monitor a sow's behaviour and vulvar size. The daily change sow's vulvar size, standing, and lateral lying duration can be used to identify the onset of estrus with 95.4% training accuracy and 93.1% testing accuracy. Behaviour patterns may not be a reliable indicator for returned estrus. The presented robotic imaging system can also identify vulvar swollenness around the returned estrus if a sow failed to conceive from the artificial insemination in the previous estrus cycle, and therefore has the potential to significantly reduce labour consumption on estrus detection and pregnancy test and reduce non-production days.

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