Development of a design for a real-time internal pulse and respiration monitoring device for sows

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Abstract

Modern hog production has no current means to collect swine pulse or respiration rate other than to train and task an individual to conduct manual data collection. Respiration and pulse rates are key physiological indicators that are correlated with multiple health issues, including heat stress. However, they require significant manpower to measure and record, and these data are impractical to collect for large commercial operations. Based upon their previous livestock instrumentation experiences, researchers at Purdue University have developed a vaginal device to collect deep body thermal data, which is believed can also be used to determine pulse and respiration through the inclusion of acoustical measurement. A fresh prototype design will add a microphone and audio processor to the current intravaginal thermal device. Heart and diaphragm noises within the body will initially be compared to externally derived signals and human measurement, to baseline the premise's performance. The new device, used within a farrowing barn environment, could automatically transmit these new sow data channels to a central computer at regular intervals, so that real time decision making could occur. This paper will detail the background and design of the current device, the developmental tests that have been performed so far, and the design focus for a next generation prototype device.

Keywords: body temperature, intravaginal sensor, precision livestock instrumentation, pulse rate, respiration rate

Introduction

Improvement in the early detection of mild heat stress in sows using internal measurements could have substantial positive economic impacts. An initial sow response to heat stress is increased respiration rate, with the intended result of transferring sensible and latent heat from the mother (McConn et al, 2022). Increased internal body temperature is a subsequent symptom, indicating moderate heat stress, which has more substantive implications for the sow's wellbeing and productivity, including reduced feed consumption, reduced milk production, late estrus recovery, and increased risk of mortality (Johnson et al., 2018). This means there is material incentive to detect mild heat stress when intervention can be more impactful (McConn et al, 2022). Notable contemporary methods to monitor respiration rate are to manually register flank movements (Johnson et al, 2018) and to develop machine vision systems to continuously derive these values (Jorquera-Chavez et al, 2021). Although both methods have their advantages, they both have prominent drawbacks stemming from the use of labor either to collect respiration data or train an artificial intelligence to cope with field conditions. Manual data collection is labor-intensive and vulnerable to human subjectivity and skill. Alternatively, computer vision approaches still encounter abundant challenges from occlusion and segmentation in the video stream, which can interrupt sow-level continuous monitoring.

None-the-less, with improved analysis codes, vision-driven AI systems may still provide impactful support in behavioral monitoring (Nasirahmadi et al, 2017).

An improved solution would be capable of automated, real-time collection, while robustly providing information at the sow level. This could be possible with a vaginal device, delivering data over a long range wide area network (LoRaWAN), with a piezoelectric disc positioned perpendicular to the cervical entrance. A microphone-inspired system to collect body sounds paired with onboard processing could deliver physiologically relevant signals for farm management. Electronic stethoscopes and machine learning techniques have made progress in analyzing respiratory sounds from clinical settings in humans, continuously monitoring heart and respiration data from external mounts (Kim et al, 2021; Erdenebayar et al, 2017; Yilmaz et al, 2020). Unfortunately, swine behavior is most likely incompatible with these sensitive instrument systems described in the literature. In particular, exterior instrumentation sensors attached to sows' skin are liable to become a source of physical annoyance and irritation from the animal's perspective (Duchy College Rural Business School, 2018), becoming a target of scratching and 'raking' motions to try and remove the devices. Swine are intelligent and curious animals, drawn to destructive behavior with novel objects and many times requiring 'enrichment' toys to limit these vandalistic tendencies (Camerlink, 2019). An external sensor suite located on a sow's body in a farrowing barn certainly has the potential to become an object of curiosity the other animals and would require robust construction and attachment to remain in place and operational.

The current research team has significant experience using external sensors from the development of individualized swine cooling pad technology (Schinckel and Stwalley; USPTO #11,219,192: Purdue University OTC, 2022). These units contain electronic sensors and operate on refined protocols for the collected thermal information. Accurate temperature measurements in technology-based interventions are critical from the animal physiology and production perspectives. The accuracy of thermal measurements has an effect of the design of the device (Cabezon et al., 2022; Cabezon et al., 2021; Field and Stwalley, 2021; Field et al., 2018), as well as the operational protocols (Johnson, et al., 2021; Field et al., 2021; Cleaver, et al., 2021; Field et al., 2020; Field et al., 2019). Typical electronic thermal sensors have been proven to be orientationally-biased and not isotopic (Seidel et al., 2020). Because of the fine temperature gradations required in cooling animals through direct contact, the rigid placement of the sensors and their calibration in position are critical to precise outcomes (Cabezon et al., 2018; Cabezon et al., 2017). The calibration of the instrumentation is vital, as decision-making for individual animals, based upon their specific measured characteristics, can be based upon decision points requiring ±1 °C discrimination. The research team has utilized the external sensor arrangement to great success. Precision livestock instrumentation has led to improved conditions for lactating swine (Graham et al., 2021; Jansen et al., 2021; Johnson, et al., 2021), gilts (Cleaver, et al., 2021), and boars (Shirley, et al., 2021; Hedrick, et al., 2021), but the cost has been meticulous attention to the physical integrity of equipment for the collection of continuously accurate data. This route may not prove practical in a commercial setting.

A practical solution to these problems might be to remove the devices from the animal's access and to collect the data internally. In the case of sows, it was determined that the most potential for success was with an intravaginal precision instrument suite which could function wirelessly and across the span of sow lactation. It is anticipated that respiration rates extracted from the acoustic data will have comparable accuracy to metrics collected from humans, with higher fidelity when collected internally than externally. This configuration should improve the temporal resolution of data, permitting continuous monitoring and identification of sow distress. This paper will justify the current slate of design choices and describe the anticipated pilot and validation tests with respect to technical and deployment functionality. The overall objectives of this project will be to generate a sensor-based system which can collect and extract respiration rates, prove data collected continuously internally is superior to data collected manually or from external sensors, and craft a system capable of evaluating the relationships between respiration rate and macroenvironmental trends.

Materials and methods

The microcontroller used for this device (Feather M0 900MHz LoRa; Adafruit Industries, New York, NY) was identical to the unit from prior work, designing a continuous internal temperature probe (Field, et al., 2022). Previously, the device was verified as safe, able to maintain connectivity, and capable of lasting through the weaning period on battery power. Using a microcontroller with a 915 MHz LoRa radio and delivering data packets every 12 min at 17 dBm transmit power, a 2000 mAh battery should last the entire 21 d weaning period (Field et al, 2022). The device will also store data locally to a 32 GB microSD for redundancy (Adalogger FeatherWing - RTC + SD Add-on; Adafruit Industries, New York, NY), which could accommodate over twice the space needed for 21 d of raw timestamped data sampled at 1 kHz. Acquiring the body-sounds will be collected using a piezoelectric disc force sensor (27 mm diameter; resonant frequency = 4.6 kHz ± 0.5 kHz, capacitance @100 Hz = 16,000 pF) with a resistor. Establishing the optimum level of resistance for the sake of signal sensitivity will be done during the pilot study. Acoustic data deals with vibrations, typically through air, and the acoustical and vibrational will be used interchangeably in this paper. However, it is more accurate to describe collecting sounds propagating though liquids, gelatins, solids, or mixtures of all three, such as flesh, with force sensors instead of traditional microphones (Bruel and Kjaer, 2022).

Considering the sow as a stakeholder, the design had to be compatible within the limitations of swine vaginal dimensions. According to anecdotal scientific interviews with research farm personnel, sow vaginas under parity 3 would not be dilated enough to continuously receive the 3 cm diameter probe housing of the existing microcontroller setup. Reducing the device's diameter might be possible in the future with custom PCB boards. As shown on the left in Figure 1, the device was originally housed in a polycarbonate shell, with wings to engage with the vaginal walls, as implemented by other investigators (Johnson and Shade, 2017). While acknowledging the success of this device for continuous monitoring of vaginal body temperature, the initial prototype design's components and assembly were overly complicated and redesigned, as in the center of Figure 1. A paradigm shift occurred when the functional requirement of stabilizing the device within the vagina was reexamined. It proved possible for a deformable media object to add girth to the superior portion of the device, while preserving the minimum diameter required to house the electronic components. Following this thread, the electronics housing was cast in a medical-grade silicone (Dragon Skin 20; Smooth-On Inc, Macungie, PA), on the right in Figure 1. The actual device shaped from silicone can be tailored to vaginal dimensions of more mature parities in future studies.

Figure 1: Intravaginal instrumentation device parts and assembly, with the initial hard-shell design and wings on the left, improved hard-shell design in center, and covered with silicone and internal components on the right.

The final piezoelectric disc orientation will be selected and validated based on how effectively it captures thoracic sounds. Respiration sounds recorded from the chest, in humans, are mostly characterized by noises in the bandwidth from 60-100 Hz to 2 kHz (Vannuccini et al, 2000). Basic signals for human heart sounds are found between 20 and 100 Hz (Reichert et al, 2008). Positioning the piezoelectric disc perpendicular to the cervix will be ideal for capturing thoracic sounds propagating inferiorly down the torso. The snug contact of the device to the vaginal walls could provide quality data by using the body as an insulator from environmental noise. A piezoelectric disc secured to the exterior of the animal on the thoracic surface, akin to a stethoscope, will be used for continuous comparison measurement. This validation channel data has raised skepticism with sow behavior specialists regarding the ease of collection, but the quality of the externally collected data should be investigated for comparison. The investigation will consider the trade-offs between functionality and invasiveness by crafting metrics that will quantify animal comfort and preferences, based upon vaginal stretching to accommodate the probe, attempts to expel the instrumentation, and the absence of infections or complications during post-farrowing recovery.

Numerous details about the implementation of this new sensor suite remain works in progress and will be formalized as development continues. The Purdue University Office of Technology Commercialization has initiated intellectual property protection for this precision livestock instrumentation suite (PU OTC D2020-0103). Prior to the pilot study, researchers will establish device insertion and affixation protocols. This will be done by consolidating information from interviews and partnerships with animal scientists and technicians. Additionally, guidelines will be developed to empirically synchronize the external, internal, and manual data streams.

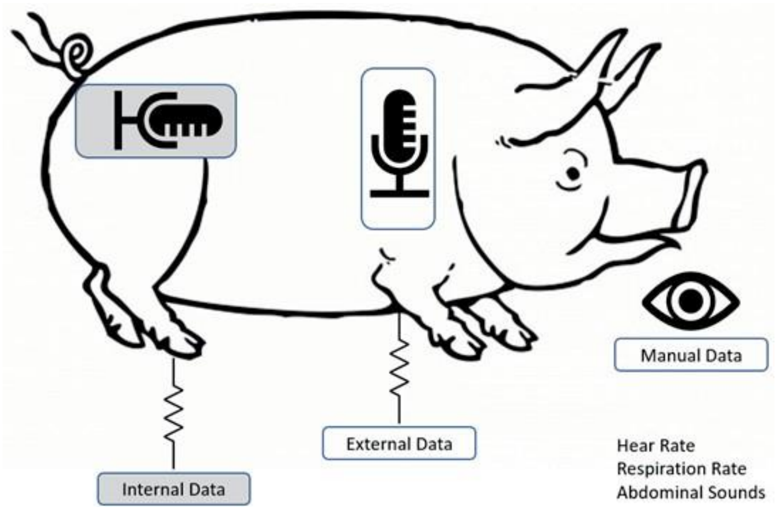

Figure 2: Experimental set up of pilot study, comparing manual vs internal vs external data collection of respiration rates.

Experimental design

A pilot trial and a validation trial will be necessary for an initial evaluation of this proposed solution for the collection of continuous pulse and respiration rates. In both the pilot and validation trials, a multiparous sow will be the experimental unit and her ID will be the random effect. The sows will be housed within individual farrowing crates in a single room of the Purdue University ASREC Farrowing Barn. The dependent variable will be the piezoelectric disc voltage data, which will be continuous. The manual collection of respiration rate and heart rate from an ear clip will be the discrete control variables, and these data will be collected every four hours between 6am and midnight and should be representative of a variety of animal activities. The objectives of the pilot study will be to implement the refined data collection protocols, identify optimal resistances for internal and external data collection, and quantify the performance of all of the data collection systems. The independent variables will be sensor position (categorical, 2 levels: internal, external), as depicted in Figure 2. Due to limited access to experimental animals and the necessary equipment, the preliminary pilot experiment should be run with at least three sows. Data would be collected in units of 20 s, with ten replicates per sensor position. Since the objective of this study is a comparison of data acquisition techniques, all data will be downloaded into a single database for further analysis.

The anticipated data comparisons of the expected manual, internal, and external data are displayed in Figure 3. A lag is expected for changes in respiration rate when monitored by acoustic data as the sampling window progresses forward in time, but due to the human error in the collection of manual respiration data, the overall quality of the continuous acoustic data is expected to exceed that of manual collection. Manually collected rates are generally close to the estimated 'truth' (Parois, et al., 2018), but they can be severely limited by their intermittent nature (Fraser, 2008). The external data should mirror the internal data, but it is expected that it will contain more noise in the form of higher frequencies from the environment and gross perturbations by the sows.

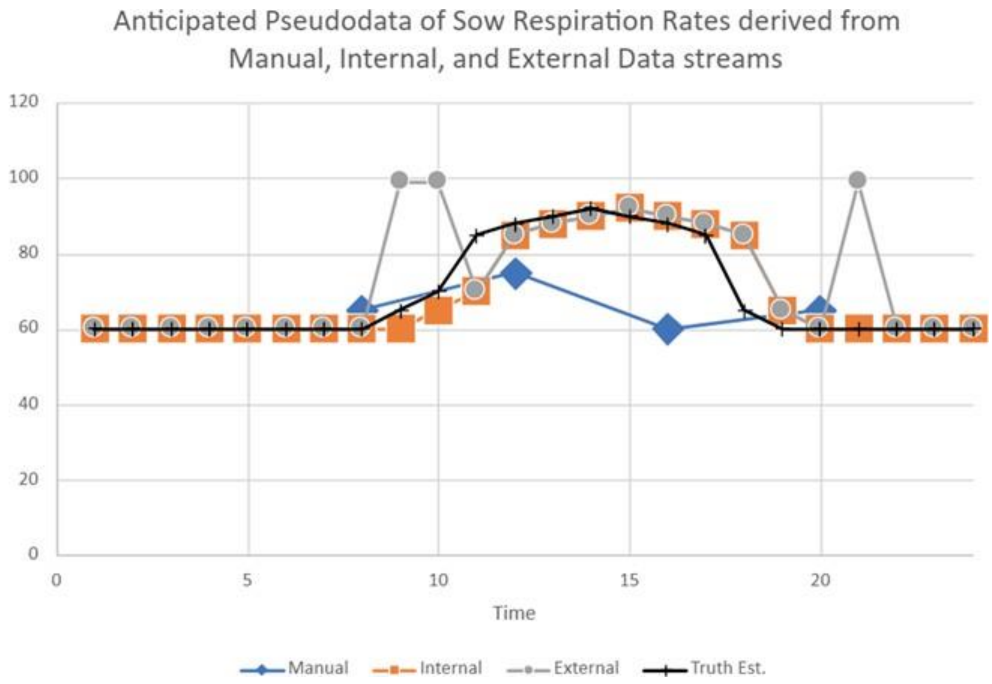

Figure 3: Anticipated comparison of pseudo-data from human measurement vs internal vs external acoustic recording.

During the validation trial, a set of sensors will be deployed to a group of 24 Landrace x Yorkshire sows from post-farrowing through weaning. There will be an even distribution of sows from Parity 3 to Parity 5. Devices will be present during the entire three weeks of lactation, and the current iteration will be expected to accommodate the projected power requirements. Daily manual measurements of respiration rate will be compared to the continuous acoustic data collected from the internal and external devices. The independent variable for the study will be data acquisition method (categorical, 2 levels: internal, manual).

Conclusions

Incorporating a deformable enclosure housing for the microcontroller will be more compatible with the sow as a stakeholder and still enable quality internal acoustic data. The next steps in this instrumentation suite development will include proving protocols and assumptions in a pilot study. This will inform the protocols and procedures used in a validation trial, which will collect internal data on respiration rate. It is hoped that this will be as accurate and robust as the human-collected measurements with higher fidelity. The acoustic data from this new device will have the potential to extract real-time respiration rates in lactating sows for the detection of early heat stress, and potentially, serve as a screening tool for other signs of distress, disease, or injury.

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