Chapter 7

Experiences of developing an innovative application of sensors to monitor the health and activity of the *peri-partum* sow

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Abstract

Bringing innovations and novel technical applications into livestock production requires a series of development steps and approaches. A first step is to analyse benefits for the end-user from use of the technology. In a use case within the IoF2020 project, we addressed ways to give pig farmers more control of vulnerable production processes, which can improve competitiveness. The sow is the most important component of piglet production, so we focused particularly on sow health and farrowing. We assessed whether automatic and continuous monitoring would provide benefits to the farmer, since careful manual monitoring of sow health around farrowing is impractical. The major health issue in sows is *post-partum* dysgalactia syndrome (PPDS), a complex of diseases with vague symptoms that leads to reduced milk production, which has serious consequences for new-born piglets. Another issue is that prolonged farrowing can reduce the future fertility of the sow. Establishing a starting point for farrowing is important, as it can provide information on the progression of farrowing and indicate the need for extra assistance. We developed an ear tag with an inbuilt photoplethysmograph (PPG) and an accelerometer to monitor physiological parameters of the sow (level of activity, resting heart rate), since changes in resting heart rate are linked to health issues (e.g. fever) and the level of activity of the sow changes around farrowing. The system is intended for capture of reliable data under practical conditions from the sensors to a gateway. Technical testing included optimisation of battery life with respect to data collection and determining intervals for data transfer. Future development steps will include data analysis, information management and applications where the processed information is provided to farmers in near real-time.

Keywords: precision livestock farming, plethysmography, accelerometer, health, farrowing

10.3920/978-90-8686-934-3_7,

7.1 Introduction

Current challenges in pig production involve improving competitiveness by better efficiency and monitoring processes in different production stages. A high degree of rationalisation and efficient routines has reduced working hours and human presence in the pig house (Martel *et al.*, 2008). However, this has made careful monitoring of individual pigs more difficult, which means that subtle, early disease symptoms can often be missed. Improved monitoring using sensors can help animal handlers identify animals in need of attention and care. Sensors may also indicate symptoms and can thus be useful in making the correct diagnosis and thus applying the correct treatment. This would allow a greater focus on the individual animal and on case-specific treatment, which could lead to lower use of antibiotics. Introducing automatic monitoring of critical production processes could help animal handlers make correct judgements and decisions.

In this paper, we describe development work aimed at enabling the use of sensors to monitor reproducing sows. The work was part of use case UC5.6 (Interoperable pig production or FITpig) in the IoF2020 project (IoF2020.eu).

The aims of the work were to:
- Identify critical points in pig production that would benefit from continuous monitoring of physiological (resting heart rate) and behavioural parameters (as detected by an ear-mounted accelerometer).
- Develop and apply a sensor that captures the resting heart rate of pigs, in order to automatically identify pigs with health problems, in this case sows in the *peri-partum* period.
- Make use of activity data captured from an ear-mounted sensor to identify the nest-building behaviour which precedes the start of the farrowing, and thus establish a time-point for the start of farrowing.
- Develop a system for connecting ear-mounted devices for transfer of data.
- Provide the end-user with a useful system that adds information and decision support in pig production.

Specific technological goals were to:
- Develop a functioning unit, comprising a photoplethysmograph (PPG) sensor and an accelerometer, to be mounted on an ear tag.
- Develop functioning connectivity of the ear tag unit to a gateway, including data storage.
- Develop an optimised energy supply with battery.
- Develop a housing for the unit that is resistant to the challenging environment and the wear, tear and bites that can be anticipated.
- The process leading to a prototype sensor is described below, followed by a discussion on its further development into a functional system for end-users.

7.2 Background

There are several critical points in piglet production in terms of the sow. The challenge in successful in piglet production is to ensure that the reproductive sow stays healthy, ensuring the birth of live piglets and weaning as many piglets as possible. Careful monitoring of the reproductive sow in the *peri-partum* period is particularly important, as the sow displays distinctive changes in behaviour related to impending farrowing and is at risk of developing health issues that can severely affect the new-born piglets. Precision livestock farming technology has been successfully developed for individual monitoring of cattle, with various devices that can capture early signs of disease, lameness, heat/oestrus, rumination, feed intake, etc. of individual animals and accumulate the information (reviewed by Herlin *et al.*, 2021; Rutten *et al.*, 2013). For pigs, a major focus in research to date has been on monitoring animals at group level. There are some commercial systems for fattening pigs that use sound analysis to detect coughing (Exadaktylos *et al.*, 2008), which is linked to illness, and aggressions on group level (Oczak *et al.*, 2013) in the pen. There are also systems for weight estimation using top-down images (e.g. Wang *et al.*, 2008). However, there are few commercial technologies for monitoring individual pigs, although there have been some advances in this area. Examples include a system for monitoring water intake using a combination of animal identity at the drinker and data on the timing and amount of water flow (Domun *et al.*, 2019) and a video camera for use during farrowing that is programmed to count the newly born piglets and alert the handler (Porcovision, Odense, Denmark). However, its use is restricted to fixed sows in crates, where the camera is always pointing towards the back part of the sow so the new-born piglets can be detected during the farrowing process.

In general, development of commercial technologies for monitoring individual pigs is hampered by difficulties in the use of wearables, since pigs can be very harsh and destructive of equipment compared with cattle. Using neck collars or a leg-mounted collars seems very risky, as they can be destroyed by the pig itself or by other pigs in the same pen. However, use of an ear tag device with inbuilt technology for capturing several physiological and behavioural states and events has been useful in cattle. Research on this technology for pigs has achieved successful inclusion of thermometer, accelerometer and electronic identification sensors (see Benjamin and Yik, 2019; Ringgenberg *et al.*, 2010) and some commercial products have been developed (e.g. Chapa *et al.*, 2020; Kapun *et al.*, 2020).

Prior to this study, we held discussions with experienced pig farmers, researchers and veterinarians and applied our own knowledge in physiology and animal behaviour to assess what could be done using the available technology. We decided at an early stage to focus on the *peri-partum* sow and to seek to detect changes in behaviour and signs of health issues that could affect the piglets. In further discussions with pig farmers and experts, we decided that automated monitoring would be a useful tool for managing sows during the vulnerable *peri-partum* period.

7.2.1 Sow health and health monitoring

Sow health is important, as disturbances will affect the growth and survival of piglets (review by Gerjets and Kemper, 2009). The most common health problem in the sow is *post-partum* dysgalactia syndrome (PPDS or PDS), a complex of diseases with vague symptoms leading to reduced milk production as well as colostrum, which has serious consequences for the new-born piglets, less growth and higher mortality. Several disease conditions in PDS refers to infections of the uterus or udder which results in severely reduced milk production. The condition is usually named mastitis, metritis and agalactia (MMA) or any combinations of thereof (reviewed by Gerjets and Kemper, 2009). However, MMA is nowadays considered as a subtype of PDS as inflammation symptoms including fever are seen in affected sows in *pre-partum* sows which is linked to more stillborn pigs. Signs of PDS include elevated rectal temperature, loss of appetite, inflamed udder, decreased activity, and milk-searching behaviour among piglets; are used in combination with rectal temperatures. It has been suggested to be a failed transition of the sow from pregnancy to lactating (Martineau *et al.*, 2013). Incidence of PPDS/PDS is estimated to differ between 0.5 and 60% on the farm level (Hirsch *et al.*, 2004). The economic consequences can be immense. Niemi *et al.* (2017) estimated that the losses of PPDS affected sows were in the magnitude of €300-470.

Indicators of health can be captured, e.g. by accelerometers as changes in activity patterns (Chapa *et al.,* 2020). There is also scope for measuring physiological parameters such as resting heart rate (RHR), changes in which can indicate fever and infection (Schmidt *et al.*, 2013; Zhang *et al.,* 2019). Devices for measuring RHR have been developed within human medicine and it has recently been suggested that the one such device, the PPG, can also be a cost-effective sensor for monitoring heart rate in animals and as an indicator of fever (Davies and Maconochie, 2009; Nie *et al.,* 2020).

Against this background, we set out to develop a novel sensor that incorporates a PPG and an accelerometer, but integrated into an ear tag. The aim was to enable monitoring of level of activity and RHR in the *peri-partum* sow as indicators of health issues and pre-farrowing activity. The functionality of the PPG sensor is described later in this paper.

7.2.2 Monitoring of farrowing

Farrowing is the most crucial phase in pig production, as the new pigs are produced. In modern pig production, sows are managed group-wise within all in-all out systems, where sows are moved into a cleaned farrowing unit a few days prior to the expected date of farrowing. There are some variations in breeding dates and length of pregnancy, so the date of farrowing in a group of sows moved together into the farrowing unit can vary by up to a week from first to last farrowing.

Before farrowing, the sow starts to express nest-building behaviour, by seeking to collect material and build a nest for the piglets. This behaviour starts around 12-24 h before farrowing and peaks at about 12-6 h before the first piglet emerges. Absence or scarcity of nest-building material does not eliminate this hormone-driven behaviour but alters it, with a reduction in the frequency of pawing and the duration of rooting (Burne *et al.*, 2000). As parturition approaches, the sow calms down, lies on her side and generally remains immobile during and after parturition. It is important for the farmer to know the duration of farrowing, as prolonged farrowing can reduce the future fertility of the sow. In this study, we examined whether detecting the start and end of nest building can be a suitable indicator of imminent farrowing and give an approximate time for the start of farrowing.

7.3 Development of the FITpig system

The interoperable pig production (FITpig) system developed, consists of a unit containing devices for measurement of heart rate and animal activity, attached to an ear tag. During the work described in this paper, various considerations regarding the housing of the devices and its robustness and connectivity were analysed. A farm trial was performed following development of the system.

7.3.1 Heart rate measurement

The PPG device is an optical technology that measures the change in light absorption by tissues during a cardiac cycle. Its most popular application is monitoring of oxygen saturation (SpO_2) in human patients (pulse oximetry), where two forms of light with different wavelengths are used to estimate the difference in absorbance of arterial blood of these two colours. This difference is then related to the oxygen level in arterial blood. In the context of heart rate (HR) monitoring, dilation of arteries due to the pulsatile nature of blood flow is measured, using light of a single wavelength. This technology is now widely used in the smartwatches that monitor HR at the wrist in humans. Figure 7.1 illustrates the two different PPG techniques. In both, a light-emitting diode (LED) injects light into the living tissues, and a photodiode captures either the light that is transmitted through

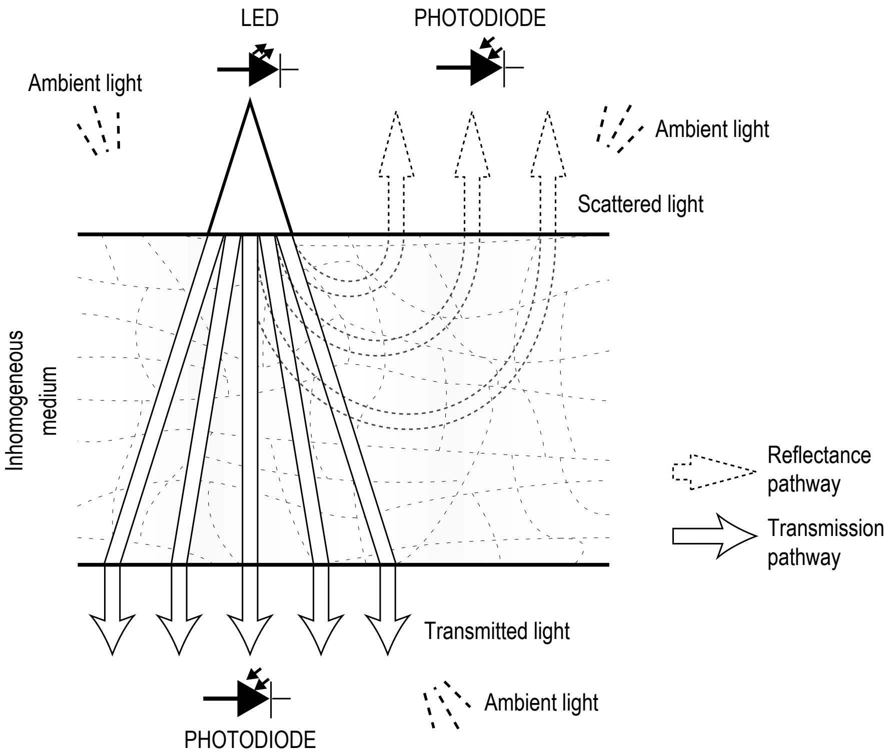

Figure 7.1. Illustration of the optical path of transmission in photoplethysmograph (PPG) technology and reflectance-based technology.

the tissues or the light that is scattered back. The choice of option depends on the placement of the sensor, e.g. for an SpO_2 finger clip the transmission mode is used, whereas the scattering mode is used for a HR-monitoring smartwatch.

Figure 7.2 illustrates light absorption in the tissues. Following the Beer-Lambert law, the sum of the absorbed and transmitted light corresponds to the emitted light. Each absorber contributes to the total absorbance, as the sum of each individual absorbance, although this is a simplification it assumes that the light travels through a homogenous layer and biological tissues, especially blood, are non-homogenous materials exhibiting non-linear absorbance of light.

This simplified view nevertheless helps understand the principle of the PPG technology. Assuming that at least one of the tissues in the light path is an artery, each time the heart beats a blood pressure pulse is generated and propagates through the blood vessels. When the pressure wave reaches the illuminated spot, it modifies both the geometry of the blood vessel (due to volume change) and the blood properties (due to changes in blood composition and concentration). This results in an increase in light absorption and an attenuation of the transmitted light, which are detected as light changes by the measuring photodiode. The resulting signal is split into two components, commonly referred to as AC (from the electrical engineering nomenclature alternating current) and DC (direct current). The AC component illustrates the pulsatile arterial blood, with its systolic and diastolic waves, while the DC component illustrates 'constant' light absorption, although in fact it is not constant, but varies slowly due to respiratory and vasomotor activities and to thermoregulation.

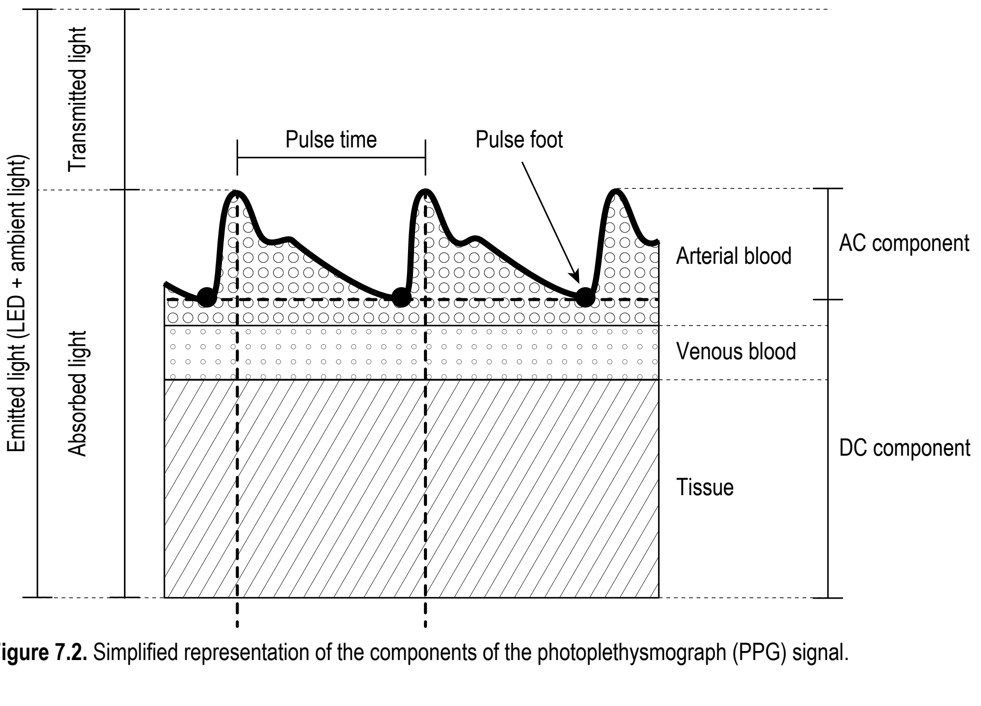

Figure 7.2. Simplified representation of the components of the photoplethysmograph (PPG) signal.

The PPG technology has been validated for humans and is now widely used in medical environments (e.g. hospitals) and in sport applications (Mendes *et al.,* 2016). It is also used in veterinary medicine, for monitoring heart rate during anaesthesia (Cugmas *et al.*, 2019), but the proposed application in the present study is unique. However, the cardiovascular system of pigs is not expected to be different from the human system.

In humans, the most common sites to measure PPG in transmission mode are the fingertip, the earlobe, while the tongue is commonly used in veterinary medicine. These sites are known for their high density of microvasculature close to the skin, which helps to ensure that an artery meets the light path of the PPG sensor. For pigs, we chose the ear as the best place to monitor these signals, primarily because of the necessary vascularisation, but also because pigs already wear some identification ear tags. Integration of the sensor into an ear tag avoids the need for farmers to place an additional device on their animals.

Due to the measurement principle, PPG signals are very sensitive to motion artefacts. In fact, body movements produce changes in the mass distribution of the tissues, e.g. motion of muscles and tendons results in compression or dilation of tissues. Gravity also affects the distribution of some tissues (e.g. fat) and changes the distribution of fluids in the tissues due to inertial movements. Light absorption changes due to these modifications of tissue composition along the light path and the signal received is strongly affected. Another consideration is that fixation of the sensor is never a perfectly rigid link and movement of the sensing area may cause displacement of the sensor relative to the skin surface. These displacements will also induce changes in the light path and artefacts visible on the raw optical signal.

To minimise these effects, the opto-mechanical interface must be carefully designed. In particular, the optical sensor must not slide on the skin, but it must also not pinch the ear too strongly, to avoid blocking the blood vascularisation. In addition, the analogue front-end (AFE), i.e. the analogue signal conditioning circuitry, must be tuned to regulate the light intensity of the emitted signal so that it covers the whole dynamic range of the observed signal, to optimise the signal-to-noise ratio (SNR), minimise energy (battery) consumption and avoid signal saturation. Commercial off-the-shelf components are available (such as the AFE4410 from Texas Instruments used in FITpig), but their fine-tuning to optimise the performance of the sensor to the use case requires good knowledge of the particular technology. An advanced signal-processing algorithm can further improve the overall performance of the sensor. Different algorithms based on temporal or spectral analysis can allow tracking of the useful signal (the pulsatile component due to heartbeats) out of the noisy environment arising due to motion artefacts.

One goal of the sensor developed within the IoF2020 project was to monitor RHR of the animal. Heart rate at rest is known to be correlated to body temperature. In human children, an increase in temperature of one degree centigrade raises the HR by 10 beats per minute (BPM) (Davies and Maconochie, 2009), whereas in buffalo it leads to a rise in HR of 15 BPM (Kumar *et al.*, 2015). The effect of an increase of body temperature on the heart rate of pigs is not yet known, but there is no reason to suspect that there is no correlation.

To assess the performance of the HR sensor, three pigs under anaesthesia were monitored by reference electrocardiography (ECG) and the PPG-based ear tag sensor, and the results were compared (Figure 7.3). For a total of 2,846 heartbeats, the mean absolute error (MAE) of inter-beat intervals (IBIs) from the ear tag sensor compared with the ECG was 4.99 ms, which corresponds to about 1 BPM. As mentioned, motion artefacts would reduce the overall performance of the sensor, but the present use case did not require monitoring the HR of a pig in motion, as RHR was the target for health monitoring in the *peri-partum* sow. Use of the sensor for monitoring HR of a pig in motion would require the development of a dedicated algorithm modelling the influence of typical movements of the animal on the optical signals.

7.3.2 Activity measuring and data processing

The sensor also includes an inbuilt 3D motion sensor (accelerometer), which serves two goals: (1) it allows detection of when the pig is at rest, so that HR measurements are made only during rest (an active animal will anyway have an increase in HR, which is not relevant to motion as body temperature changes); and (2) it monitors the level of activity of the animal, as a higher level of activity can indicate when the sow starts its nest building before farrowing and a low level of activity can be a symptom of sickness or injury. For estimation of the level of activity, the three axes of the accelerometer are used to calculate the energy of the signal. The norm of the acceleration vector is first calculated as:

$$E(n) = \sqrt{acc_x(n)^2 + acc_y(n)^2 + acc_z(n)^2}$$

where:

$E(n)$: norm of the acceleration vector at instant n

$acc_x(n)$: acceleration sample in the x axis at instant n

$acc_y(n)$: acceleration sample in the y axis at instant n

$acc_z(n)$: acceleration sample in the z axis at instant n

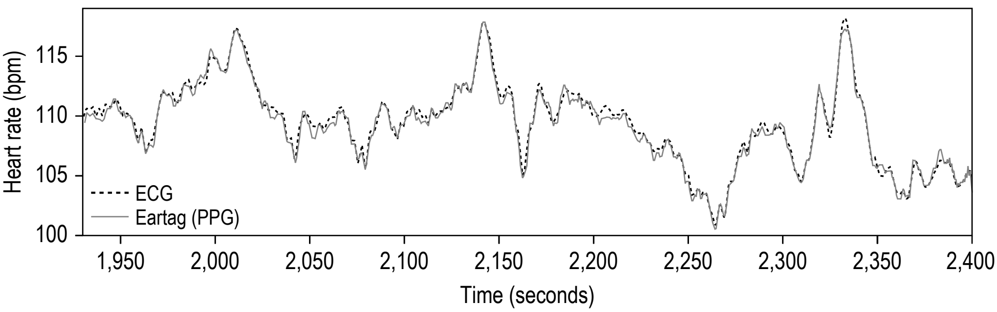

Figure 7.3. Comparison of heart rate between an electrocardiogram (ECG) and the photoplethysmograph (PPG) based ear tag sensor.

This norm is then low-pass filtered (averaged) to obtain a smoothed energy value that can be correlated to the actual energy expenditure of the animal. From this energy signal, three features are calculated: the mean value, the variance of the signal and the root mean square. The mean energy provides an indication of the average activity of the animal, the variance indicates whether the activity of the animal changes greatly (e.g. head shaking for a few seconds while resting) and the root mean square is similar to the average, but gives higher emphasis on the peaks in animal activity. Figure 7.4 shows the raw signals of the accelerometer and the calculated energy of an animal at rest and an animal in motion. In the field trial it was decided that, in order to save battery, the accelerometer would sample data for 30 s every 5 min.

7.3.3 Housing and battery considerations

The device is powered by a rechargeable lithium-ion battery. Pigs are curious and playful animals and tend to explore their world by biting anything new in their environment. To avoid the animals biting through the battery, which could lead to food poisoning or ignition of the device, it was decided that the printed circuit board (PCB, the board hosting all the electronics) and especially the battery would protected by a housing made out of titanium. This material was chosen due to its solidity and low weight, making it adequate for the prototypes developed in the FITpig project, although its cost would not be acceptable in a commercial product. To commercialise the sensor, its power consumption would need to be reduced to allow use of a less dangerous energy source, such as a nickel metal hydride (NiMH) battery. It could also be modified to use wireless battery-charging technology, which would allow the housing to be dispensed with, making the device lighter and cheaper.

We investigated the energy consumption in order to predict battery lifetime. The current consumption of the device while not measuring anything (sleeping mode) is of about 0.05 mA. When measuring the activity, the current consumption is of 0.8 mA. When the HR is measured, the current consumption rises to 4 mA. It is obvious that the optical sensor is the part of the system which costs the most energy. For this reason, the HR is measured at a maximum rate of once per

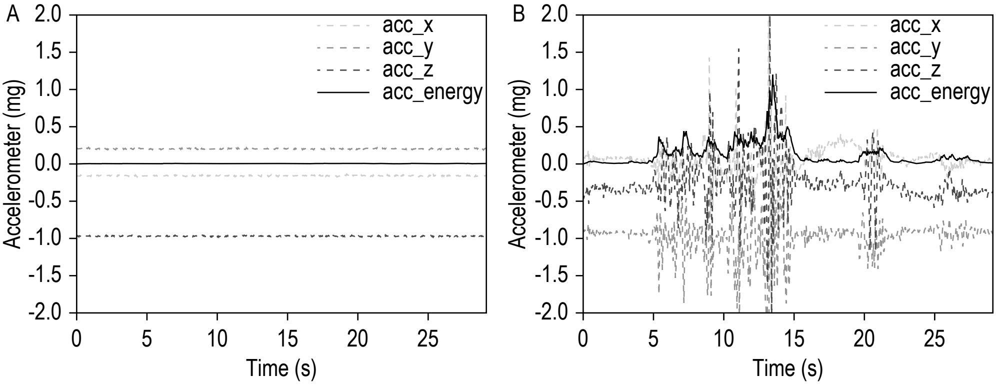

Figure 7.4. Raw X-axis, Y-axis and Z-axis signals and calculated energy (solid line) from the accelerometer on a pig at rest (A) and in motion (B).

hour, and only if the pig is at rest. HR measurement is skipped if the animal is moving. Activity, on the other hand, is measured once every 5 min. To process a robust estimation, for activity or for HR, the raw signals, accelerometer signals or optical ones, need to be acquired during 1 min. The battery integrated into the device has a storage capacity of 200 mAh. Therefore, the system has an autonomy of 36.8 days if the HR is measured every hour (which is not the case in practice due to the activity of the animal).

The energy management is a key factor for the design of physiological monitoring of animal devices. The consumption could be improved by fine-tuning the parameters of the analogue frontend of the optical sensor. It could also be increased if we reduce the HR measurement rate. However, the improvement that would provide the highest flexibility for this kind of device is remote recharging capability.

Figure 7.5 illustrates the sensor in its current form, where the housing is open at the bottom to allow the Bluetooth antenna to stream the data. The PCB is sealed into the housing with silicone and all openings are filled with silicone, protecting the device from dust and water. The housing is riveted onto a commercial off-the-shelf identification ear tag. In the current form, the HR sensor can be used for scientific investigations.

7.3.4 Experiences of connectivity development for data transfer

Initially, there were several options for communication of the ear tags to a gateway and further to a remote server. It was decided early on that the data collected by the pig's ear-tag sensors would be sent by Bluetooth, through the gateways designed by the project partner HOPU (HOP UBIQUITOUS S.L., Murcia, Spain). We started early testing of the communication between the ear tags and the gateway using some sensors from CSEM (Swiss Center for Electronics and Microtechnology, Neuchâtel, Switzerland).

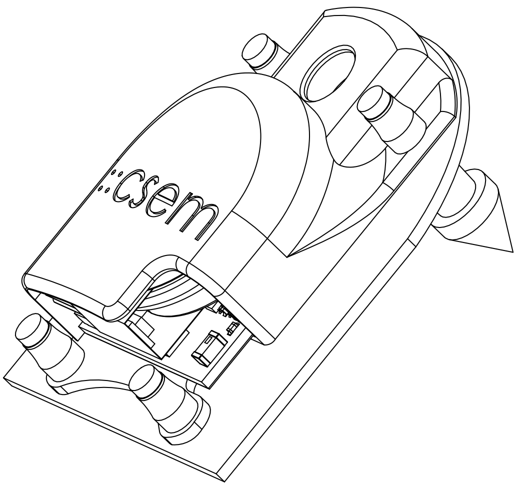

Figure 7.5. Overview of the embedded heart rate sensor.

Using a low-power Bluetooth module, which is perfect for embedded systems, we applied a solution that facilitated incorporation of low-power, simple connectivity, giving a highly integrated, scalable and reliable solution. The Bluetooth module was integrated into the CPU of the Smart Spot system (ESP32 Tensilica Xtensa LX6 microprocessor 240 Hz), with the SmartSpot system serving the ear-tag units).

Initially, passage of information from the tag to the SmartSpot (gateway) was carried out through an 'Active Scan' mechanism, in which the responses issued (scan response) to the scan requests contained the information. However, owing to difficulties in communication due to the physical coverage limitations of the device (its metallic encapsulation) and the complex process of data extraction, data were sometimes lost. Instead, information was sent via broadcast and passive reading from the gateway/SmartSpot, which removed the information extraction barrier. Even so, the coverage or emission radius of the tags was still quite limited due to the metallic encapsulation, an issue which was resolved by placing the gateway closest to the tags. A further development would be to make a compact version of the gateway with a possible extension with antennas or strategically placed the gateway centrally could cover an area of 300 m^2. The strong value of Bluetooth Low Energy (BLE) to transmit information as part of the advertisement (beacon), thereby making it able to transmit data without requiring a connection, makes it totally scalable and feasible for massive communications.

Another important problem that occurred was loss of data due to limited memory capacity of the gateway. This problem arose because data collection via Bluetooth was performed through the Blueroid stack (Bluetooth communication protocol), which was used for BLE communication management. It was solved through internal adjustments in the firmware by modifying the processes and the Blueroid stack. At the same time, the collection data platform based on FIWARE facilitated integration of near real-time data, reducing the requirement for large memory (The FIWARE Community is an independent open community which develops implementation-driven software platform standards that will ease the development of new smart applications in multiple sectors). In the field, another problem with the ear tags was the coverage. Because of the connectivity problems, sensor data were lost and thus some animals did not fulfil the inclusion criteria for further work on annotation of sensor data from behaviour studies to produce detector algorithms. Nevertheless, the identified problems led to improvements in ear tags, software and the gateway, which improved the quality of data and collection through the gateway.

Connectivity within the farm was improved when the solution was integrated with Wi-Fi for sending data from the gateway to the cloud. As the farm trials were conducted in two separate building sections, an extra access point was installed to improve connectivity to the router. The different components were modified to obtain a robust and suitable solution for on-farm use. Data collection and processing were integrated into a full system with an app using the FIWARE platform for data presentation, including the data from the HR sensor and activity of the sows. With further development, these data can give indications of sow health and the farrowing process.

7.4 Farm trial

7.4.1 Animals and housing

The on-farm trial of the device was performed at a commercial pig farm in southern Sweden with a total of 400 sows in production. Two separate sections of 52 farrowing pens were alternately used, with identical design of all farrowing pens. Each pen measured 6 m^2 (2×3 m), with bar barriers at the sides, a piglet section separated from the sow by a diagonal gate and, above the piglet area, a heating lamp. The sows were not restrained in the pen at any time. The floor of the pens consisted of solid concrete at the front and solid cast iron at the back. Straw was provided daily.

The sows were hybrid Swedish Landrace × Yorkshire. For the studies, 10 multiparous sows in each farrowing batch were randomly selected to be equipped with the test ear tag device. The ear tag devices were attached on the day of arrival at the farrowing pen, except for a few occasions due to delays in postal delivery.

The selected sows were kept in a section of 10 pens within the 52-pen house section, to ensure adequate data transfer by Bluetooth from the ear tags to the gateway. The indoor climate was controlled by forced ventilation steered based on the environmental temperature. The studies were conducted during June to December 2020. With the use of the two house sections and with farrowing taking place every three to four weeks, alternating between the sections, a total of seven batches (70 sows) were put through during the test period.

The sows moved to the farrowing pens a few days before the expected day of farrowing. In practice, this meant that some sows farrowed one or two days after being moved and all sows farrowed within a week of being moved. The sows stayed in the pens for five weeks, until weaning of the piglets. Normal feeding routines included feeding twice a day (semi-automatic feeders) and *ad libitum* water via a nipple.

Observations by the handler were recorded on the animal cards positioned above each pen and in protocols. The handler recorded the day of farrowing, occasionally the number of piglets born at certain times during daytime, the number of piglets born alive and the number of still-borns. In addition, specific events for the sows and piglets were noted. In terms of health, diagnosis, treatment and, on a few occasions, body temperature was recorded on a protocol in each section. Treatment records included medication (mainly antibiotics and analgesics), the commercial names, doses and number of treatment days. In hindsight, additional ways to detect symptoms and to make as correct a diagnosis as possible would have been desirable, but were not possible due to the high workload of the handler. In future testing, we suggest that daily body temperature be recorded, so it can be connected with the heart rate data and relationships with disease can be established in a timeline.

7.4.2 Video recording

The behaviour of the sows was video recorded for 10 days from their introduction to the farrowing pens, using 2D cameras in order to produce annotated data. Each camera (HIKVision, iVMS-4200) covered two pens and was mounted 2.50 m above the pens, giving 45 degree angled images from the back end of the pen toward the front. The cameras recorded with 1,680×1,050-pixel resolution, in MPEG-4 format, in 1 fps in order to minimise the size of the data files.

7.4.3 Animal behaviour

Only limited behaviour studies were performed within the present study to illustrate activity data. In on-going and future work, annotation of behaviour is matched to the accelerometer data scans for 30 s every 5 min, to determine a status or activity performed during this period. A simplified ethogram is used for the annotation in the present case, comprising:

- Standing: standing up and/or walking around the pen, turning, exploring the pen.
- Lying: lying sternally on the belly, front legs under the sow and lying laterally or lying on the side, udder exposed.
- Sitting: sitting with straight front legs, front hooves on the ground.
- Eating/drinking: head in the trough or chewing straw, chewing movements or small head movements.
- Nest building: moving and manipulating straw, moving head forward and backwards on the floor, pawing with front leg, biting or rooting behaviour.
- Farrowing: first piglet born – the time of the first visible piglet and the last-born piglet.

Videos are annotated by an experienced observer to create ground truth data for developing an algorithm for automatic detection of nest-building behaviour, with the end of this behaviour marking the start of farrowing, and general activity pattern, which could be used for health classification. In order to produce a usable dataset, the following inclusion criterion was set, with the time of the start of farrowing, the first piglet visible in the video, used as the deciding time point: If video and sensor data were available for at least 24 h before this time point, behaviour annotation of the signal data was done. Whether annotation of the data is necessary after the birth of the first pig will be explored in future mathematical analysis.

Figure 7.6 shows an example of the activity mean value for one sow at each annotation point during the 24 hours before farrowing. Of 216 accelerometer annotations, 33 annotations were classified as nest-building behaviour by the sow, with the first and last marked in the diagram. However, over 70 accelerometer values were missing (288 were expected), possibly due to poor connectivity. All 33 annotations with nest building for this sow had activity mean values above 50, with a mean value of 135. The mean activity value of the standing sows was 116 and mean activity value when lying was 15.

As found by others (Oczak *et al.*, 2015; Liu *et al.*, 2018), nest building in sows seems to be easily detectable from the data in ear tag-mounted accelerometers. The data collection rate, i.e. 30 s every 5 min, was also sufficient, although we would like to have continuous data collection and then simulate intervals and length of data collection. With nest building detected, it would be very easy to establish an approximate starting time of farrowing, or end of nest building. This time point would then be communicated to the farmer/handler. The usefulness of such information should of course be evaluated by involving the end-users in discussions to develop operational procedures and their sense

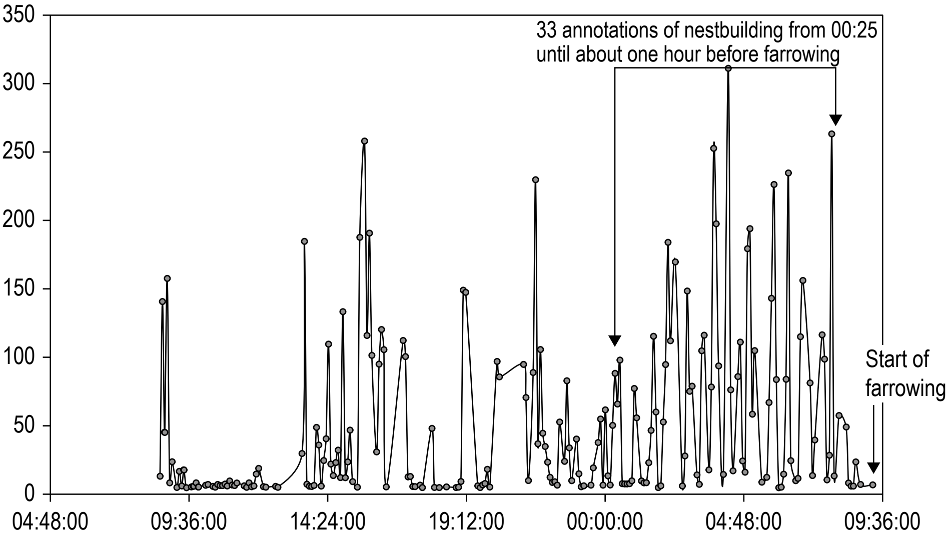

Figure 7.6. Activity mean value in one sow for each annotation point during 24 h before farrowing. The first and the last annotations of the nest building behaviour are indicated.

of control of farrowing sows and intervention when the system indicates dystocia. As suggested by Oczak *et al.* (2020), detection of nest building could be of value for farms that use farrowing crates. The information provided on nest building and start of farrowing could also be used to confine the sow to a crate at the start of farrowing, with the intention of preventing piglets being crushed (Oczak *et al.*, 2020). However, the efficacy of such heavy restriction of sow movement and negative societal opinion on the practice make this a highly questionable application (Baxter *et al.,* 2018).

7.4.4 Animal health and resting heart rate

Eight sows were recorded as having disease (fever or mastitis) of the 40 sows tested (4 batches) that had reliable general connectivity from the sensors to the gateway on group level. However, detecting reliable RHR was somewhat difficult, as non-realistic data were immediately discarded, so more missing data can be expected. In future work we will further analyse heart data, decide inclusion criteria and compare RHR during the *peri-partum* period of sows in healthy and sick animals and in relation to farrowing. Figure 7.7 shows the RHR captured by the PPG sensor in a sow diagnosed with mastitis and treated with antibiotics. In that sow, the RHR was elevated by about 10-20 BPM from before farrowing until one or two days after the start of the antibiotic treatment, when RHR returned to normal.

7.4.5 Missing data

In total, 70 FITpig ear tags were used, with 10 at a time in the seven batches of 10 sows examined over the six-month testing period. In practice, however, only about 20 FITpig ear tags were manufactured and thus they were reused several times, following checks and recharging. Functionality was tested

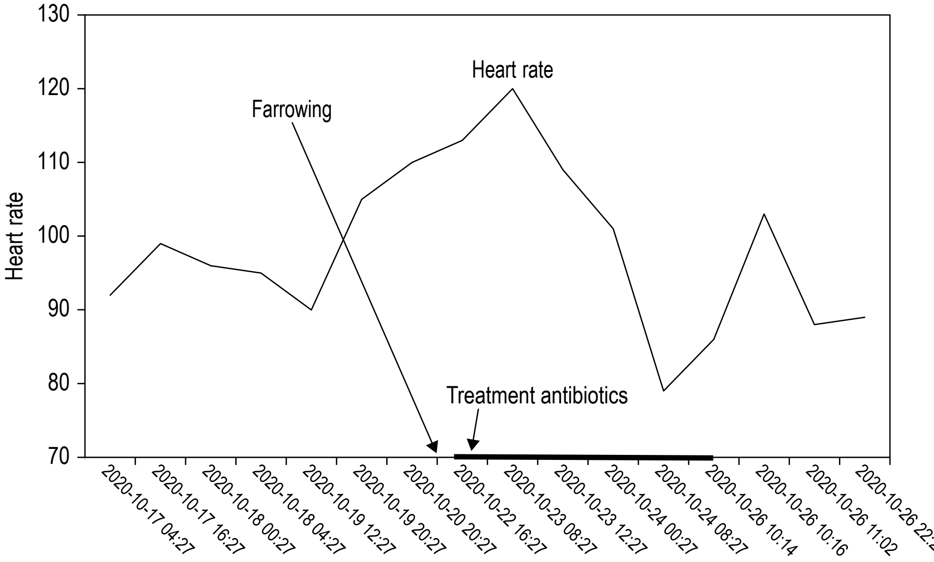

Figure 7.7. Resting heart rate detected by the photoplethysmograph (PPG) sensor in relation to farrowing and treatment of antibiotics in a sow diagnosed with mastitis.

in the laboratory at CSEM before the devices were sent to the test farm in Sweden. The first batch failed due to a change in the connectivity system and there were also problems with the gateway in the second and third batches, where the data could not be retrieved from the cloud dashboard. In the last four batches, data were collected successfully, but data from three sows in batches four and five did not meet the inclusion criteria because the period between activation of the ear tags and the start of farrowing was less than 24 h. In batch seven, a failed system update was discovered and fixed after three days, but data from three sows were lost. In batch seven, data from five sows were included as intended. Despite this last issue, there was a successful progression of development in response to problems that emerged over the testing period. In total, data were collected as planned from 24 FITpig units. During batches four to seven, each lasting 10 days, four of the 40 FITpig ear tags dropped off (all after farrowing).

7.4.6 Future development

Future development work will involve analysis of data and further processing, and formulation of rules for inclusion criteria. As mentioned above, there were unfortunate technical failures in connectivity, but also occasional missing sensor data during fully functional connectivity protocols. The final dataset will be used for algorithm development, to achieve our goals of detecting sows with disease and nest building with an approximate time for the start of farrowing. We will also validate the sensor data on part of the annotated data, to give some indication of the system's sensitivity and specificity. However, the lack of annotated data can prevent the system from being fully validated.

The solution includes an end-user application for the farmer. Nowadays, use of mobile applications for farm management of commercial pig herds is very common. The main demand from the farmers is that the system should follow an open design that can integrate all IoT sensors on the farm. This was specifically catered for in the present work, as all the features provided follow data standards from the FIWARE open data protocols. In this sense, the app must include both functionalities – for the animal data and environmental data on the farm, complemented with historical values in their visual representation.

The FIWARE platform is developed for android phones and once the farmer accesses the app, they can find a global view and a list of individual animals is then shown, indicating the activity of each animal and overall temperature, and the user can navigate for individual animals, showing activity mean, battery level, heart rate and temperature.

7.4.7 Animal testing permit

Ethical approval for the Swedish animal research part was given by the Malmö/Lund Ethics Committee on Animal Testing at Lund District Court (Dnr 5.818-04497/2019). The experiment on anaesthetised pigs was approved by the Swiss Cantonal Veterinary Office, under application number 31921.

7.5 Conclusions

This use case in the IoF2020 project accomplished several steps in development of sensor-based technology for use by pig farmers. The technology was targeted at some critical points in piglet production by continuous monitoring of physiological and behavioural parameters. We were able to capture the sensor data with ear tag-mounted devices and found that the data were transferred to a gateway and to a server. We also achieved promising results in capturing resting heart rate of sows, which could help farmers to monitor sow health in the *peri-partum* period. The activity data captured are likely to reflect nest-building behaviour by the sow, providing an estimate of the starting point of farrowing. With a fully functional system in place, the information produced and communicated to end-users can be evaluated and transformed into a form for use by farmers in decision support and by the industry for the development of standard operating procedures in pig production.

Acknowledgements

The project received funding from the European Union's Horizon 2020 research and innovation programme within the IoF2020 project under grant agreement no. 731884. The project was partly co-funded. The field trial in Sweden was hosted at the farm of Elsie, Jos and Frank Botermans, which we sincerely acknowledge. Valuable input was given by the extension organisation 'Gård&Djurhälsan' in Sweden on practical pig farming. Authors had no conflicts of interest in the project.

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