Development of a measuring system for monitoring transport of boar semen from artificial insemination centers to sow farms

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Abstract: During transport of boar semen for artificial insemination of pigs, there is currently no mobile measuring system available for recording all relevant impact factors systematically. Based on a survey of artificial insemination centers, this paper describes the requirements for a systematic approach to record all relevant environmental impact factors during the transport of artificial insemination doses. The developed system architecture as well as the implementation to fulfil the derived requirements is presented. An Arduino Nano 33 BLE Sense with an external temperature sensor and an external luminance sensor is used as the measuring device. This device sends measurement data to a smartphone app using Bluetooth Low Energy (BLE). The app persists the measurement data on a local storage on the smartphone. With the presented mobile measuring system, a comprehensive monitoring for transport of artificial insemination doses becomes available.

Keywords: Data acquisition, data logger, system architecture, measurement system, sperm transport, boar

1 Introduction

Boar semen is a highly sensitive product, which requires special demands to maintain quality [Ms17]. Previous studies shows an influence of transport on sperm quality [Sc18]. In today's pig reproduction liquid preserved boar semen is delivered from artificial insemination centers to downstream sow farms using standard passenger cars or small trucks. Relevant vibrations occur during transport of artificial insemination doses, which might have a negative impact on semen quality [Ht22]. There are other impact factors which occur during transport as well e.g., temperature fluctuations. With existing systems (data loggers, etc.) both factors can only be recorded insufficient. The literature shows contributions where mobile measuring systems are used to record vibrations [FSA17, SDW18,

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SLS19]. However, the solutions presented here have been developed only for specific applications. There is no system for a mobile recording of the impact factors during the transport of boar semen available. Therefore, the development of an adapted measuring system is necessary.

The aim of this paper is to show development, implementation and evaluation of a mobile measuring system for the systematically recording of impact factors during the transport of artificial insemination doses. The mobile measuring system will be integrated as a component in a real-time monitoring system for the transport of boar semen.

This paper is structured as followed: Systematic approach and methods used are presented in section 2. Relevant factors which have an impact on transport stress of boar semen and which should be recorded by our proposed system are shown in section 3. This is followed by a requirements analysis for the planned measurement system. Based on these results a general architecture and then a technical concept for the measurement system are presented. Section 4 describes implementation of the measurement system. In section 0 results are discussed. The paper closes with a summary and an outlook in section 6.

2 Methodical approach

A literature review was done to determine all relevant impact factors on transport stress of boar semen, which affect quality during transport. Furthermore, a qualitative survey of six selected breeding companies (production companies for insemination doses of boar semen) with a total of about 10,000 boars in Brazil, Germany and the USA was performed as part of the research project "IQ-TranS"[6]. The aim of the survey was to analyse the current state of transport process as well as supply chains. For this purpose, an interview guide was developed that takes into account the current situation in delivery process of artificial insemination doses. Then a stakeholder analysis was done to identify relevant stakeholder for the mobile measurement system. As a result of the survey requirements for a measurement system were determined and a system architecture was designed that fulfil these requirements. Based on this concept, the mobile measuring system was implemented. Finally, the mobile measuring system was validated in a field test.

3 Concept

In the following, the concept of the measurement system is presented. For this purpose, the results of the literature review and the expert interviews are summarized. Furthermore, requirements for the measurement system are determined. The general architecture and the technical concept for the implementation of these requirements are presented afterwards.

[6] Website: www.iqtrans-projekt.de

3.1 Relevant impact factors on transport stress of boar semen

The nature of boar semen demands high standards for transport of this perishable product. Numerous influencing factors are known, such as the dilution technique, storage, **tem perature**, **light**, etc., which affect the quality (negatively) [HGK16, Ms17]. Besides these factors, rotation of the semen doses as well as the transport itself can have a negative influence on quality of boar semen as well. Recent studies shows that **vibrations** during transport can have a negative influence on the quality of boar semen too [Ht22, Sc18]. Reduction in quality of semen doses leads to a reduction in economic value. [FBS18, SRW15]. The Literature review shows that boar sperm is a highly sensitive product that requires very specific demands during transport (constant cold chain at 16 °C and low-emission transport) in order to maintain its condition and quality.

3.2 Requirements analysis

The evaluation of the expert survey with focus on the transport process showed, that there is a need for documentation and tracking of supply chains. Semen doses are transported from artificial insemination center to the customer by land over distances of up to 500 km and for up to 12 h. The transport process is very heterogeneous among the companies surveyed and is summarized below. Tubes or blisters are usually used as transport packaging for boar semen doses. Packaged semen doses are transported in actively temperature-controlled boxes, insulated polystyrene boxes with warm or cold packs, or without special insulating packaging within a temperature-controlled cargo hold. Logging of the temperature of the transported goods takes place irregularly. Standard passenger cars or small trucks are used as transport vehicles. Shipment is usually carried out by instructed employees or commissioned subcontractors. In-house employees were trained in handling of vulnerable semen doses. Interviewed breeding companies have a high interest that all relevant impact factors on transport stress of boar semen are recorded with an automatic system and stored for later analysis.

For the planned mobile measurement system, the following stakeholders were identified: the artificial insemination center and the delivery persons. The artificial insemination center needs measurement data, which are collected during transports. These transports are carried out by the delivering persons. The aim of the planned mobile measuring system is to automatically record all relevant impact factors which have an influence on transport stress of boar semen. The mobile measuring system is part of a real-time monitoring system in prospect for the digitalization of boar semen transport (see: [Sp22]).

In order to fulfil the requirements of the artificial insemination centers surveyed, the planned measurement system must be embedded into the existing delivery process. The requirements and use cases for the measuring system are described below:

- All relevant impact factors on transport stress of boar semen during the entire transport process have to be recorded. These are temperature inside the transport box used or temperature of the cargo hold of the vehicle, light intensity to which the sperm doses are being exposed and vibrations applied to semen doses during the transport process.
- For documentation and tracking of the transport chain, the location should be continuously recorded during the entire transport process.
- The measuring system is planned to be used in delivery vehicles. It should be possible to install it into or upgrade existing transport boxes. For this purpose, sufficient miniaturization, battery operation and wireless data transmission have to be taken into account.
- All measurement data have to be stored for analysis and evaluation after measurement. For this purpose, a standardized, memory-saving and human-readable data format has to be used.
- Quality requirements have to be fulfilled, too. This includes fault tolerance of the measuring system: No failure of the measuring system in case of a failure of individual components as well as the interchangeability of components used.

3.3 General architecture

Due to the required hardware, the general architecture of the planned measurement system cannot be considered separately from the hardware. Therefore, the planned hardware is described below in abstract form as far as possible and specified in the following section 3.4. below.

Sensors are required to measure environmental parameters as well as fulfil performance requirements. The following sensors types are required to measure the environmental parameters: accelerometer, thermometer, luxmeter, GNSS receiver. The measurement of acceleration should take place with at least 50 Hz (see: [FBS18]). All other environmental parameters must be measured at least every 5 s. The runtime of a single recording is at least 12 h.

To fulfil the identified requirements a general architecture was developed. The measuring system is divided into several parts. A **programmable datalogger** is used to query and control the **sensors** used as well as to transmit the measured environment parameters. An **app** is used to control the data logger. The measured values are received from the data logger by the app and persisted in the **data storage** of the smartphone used. Additionally, the app is used to determinate the current **location** using a GNSS receiver in the smartphone. Figure 1 shows the general architecture of the measurement system.

Commands and measured values are as transmitted via a text-based (non-binary) key-value data model. The advantages of a key-value data model are very good scalability, high performance and easy modification [SK20]. This leads to easier data transfer between the subsystems and a faster implementation. [BA20].

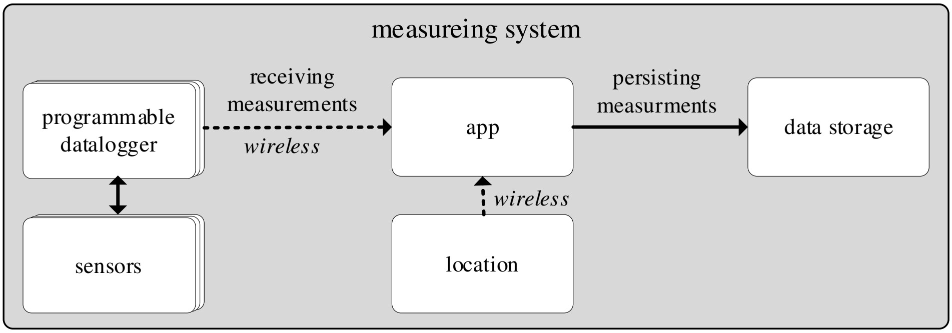

Figure 1: General architecture of the measurement system

To meet the quality requirements of fault tolerance and interchangeability, only hardware components with standardized interfaces should be used. Furthermore, the data transfer between the subsystems should be realized with existing and stable interfaces.

3.4 Technical concept

Based on the general architecture and the requirements analysis, the required hardware components for the measurement system are determined and described below. The following standards can be used for wireless data transmission: Bluetooth, Bluetooth Low Energy (BLE), WiFi and WiFi Direct [CGS13, GOP12]. Radio technologies such as LoraWAN and ZigBee are not suitable due to their limited data rate [JSM22].

Numerous programmable microcontrollers are available that can be used as data loggers [JSM22]. For intended use the "Arduino Nano 33 BLE Sense" is suitable. This microcontroller has built-in sensors such as: accelerometer, thermometer, barometer, luxmeter and more. The board has a size of approx. 45 mm x 18 mm. With the decision to use this microcontroller, the radio interface was set to BLE or WiFi by hardware [Ar22]. Compared to WiFi BLE has the advantage that no access point is required inside the vehicle and the overhead for data transmission is lower, which enables a faster implementation [JSM22]. For this reason, BLE is used to transmit the measured values from the microcontroller to the app. By using existing interfaces (like I²C, SPI, ...) additional sensors and peripheral devices can be connected to and operated by the microcontroller as well [Ar22].

Own examinations showed that the integrated temperature sensor of the Arduino Nano 33 board is influenced by the other components on this board and has a temperature offset of at least 5 °C. Therefore, an external 10 kΩ thermistors (temperature dependent resistor) is used to measure the temperature of insemination doses.

The external luminance sensor "Seeed Studio Grove APDS9002" is used to measure light intensity. All sensors read out by the microcontroller are directly connected to it or already integrated on the board. To determine the location by GNSS, a smartphone running the data logger app is used. All Measured data is persisted on the file storage of the smartphone used. The microcontroller is powered by an integrated battery circuit with a Li-Ion battery and can also be charged via this circuit.

The selected components are common and well available standard components with a sufficient degree of miniaturization. All components of the measuring system fitted together fit well in one "hand". Figure 2 shows the component diagram of the measuring system with the sensors and modules used.

4 Implementation

The implementation of the measurement system is described below. Firmware was written in C for the microcontroller (data logger), which queries all sensors with adjustable sampling rates and then transmits the measured values via BLE. The measuring rate for the acceleration sensor was set to 50 Hz and for the other sensors to 0.2 Hz. The microcontroller publishes a GATT service as a server for data transmission and registers a “characteristic” for each environmental parameter. These characteristics are used to published the measured environmental parameters. Each microcontroller can be uniquely identified via its MAC address. The GATT characteristics are uniquely assigned using previously defined UUIDs. Figure 3 shows the definition of the GATT service for data transmission via BLE. Due to the GATT protocol, each measured parameter is sent in a separate message. Data transmission is based on the push principle i.e., the receiver (client, the app) registers for the characteristics to be received. Transmission of the measured values takes place in "notify" mode and is therefore independent of the receiver i.e., there is no delay in receiving an acknowledgement of receipt [HP20]. The data logger stores the measured values temporarily until transmission. Persistence is not implemented on the data logger.

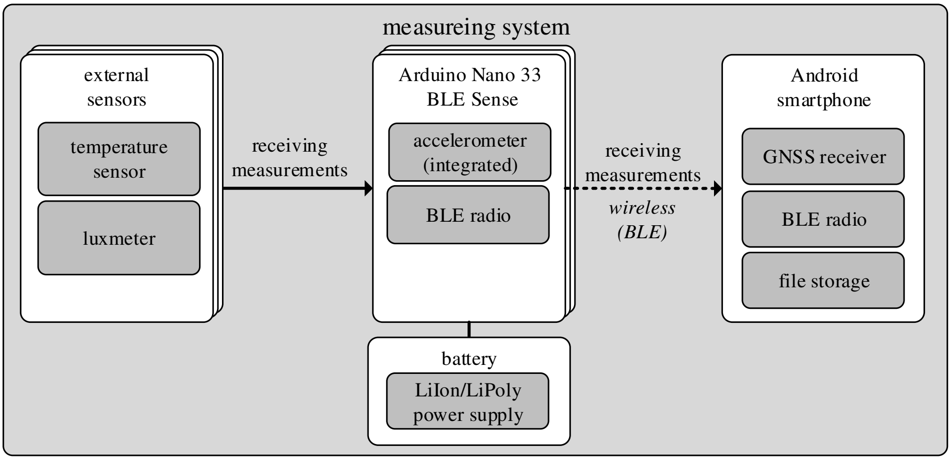

Figure 2: Component diagram of the measuring system with the sensors and modules used

An Android app was written in Java as receiver. The app searches for BLE devices in the surrounding area and can connect to several data loggers simultaneously to receive measurement data from these devices at the same time. After initiating the connection, the latest measurement data is transmitted directly to the app. Due to the use of Bluetooth Low-Energy, it is possible to establish several connections between measuring devices and the smartphone at the same time. A simultaneous transmission of measurement data from several measuring devices was successfully accomplished. However, it should be noted that wireless radio is always a shared medium which leads to a limitation of data transmission. Especially at high measurement rates, as our system has, upscaling is limited. To eliminate this bottleneck, in the future measurement values for acceleration will be calculated on the microcontroller (Arduino Nano) and summarized to a displacement index. The displacement represents the average vector length between two sampling points per second (see equation 1 in [Ht22]). This reduces our transmitted data rate for acceleration to 1 Hz. Therefore, a sufficient scaling is possible to connect all transport boxes of a vehicle to the smartphone.

The app receives the measured values and persist them as a text-based (non-binary) data format on the smartphones integrated file store system. Thereby the measured values are stored in a key-value based data format. For each key-value pair the measurement time (Unixtime in millisecond) and an ID of the measuring device are stored as well. This allows each measurement to be uniquely assigned.

A suitable case was produced for the data logger prototype using a 3D printing process. This case protects the hardware components from moisture and dust and allows an easy handling. To increase the durability of the measuring device further, it is planned to protect the electronic components with epoxy resin. We expect a sufficient protection for the rough environment in the field. In Figure 4 the prototype is shown.

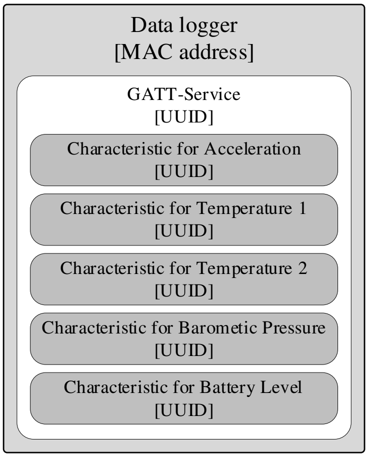

Figure 3: Definition of the GATT service and the included GATT characteristics for publication of the measured values from the data logger via Bluetooth Low Energy (BLE).

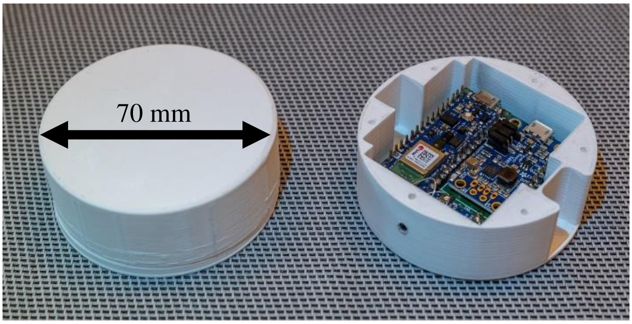

Figure 4: Prototype of a datalogger from the measurement system.

5 Evaluation

For the evaluation of the measuring system, measurement trips from producers (artificial insemination centers) to customers (sow farms) were carried out during a reference delivery with length of about 800 km. The roads covered had different surfaces: smooth asphalt, interrupted asphalt, cobblestone and unpaved dirt road. The measuring system could be successfully tested and validated to determinate vibration immissions during the transport of boar semen (see: [Ht22]). In addition to the vibration immissions, the temperature and the location were successfully recorded during the test trips as well. Our Experience with the system shows that a transport of up to 12 h can be recorded entirely and reliable. For further evaluation of our measurement system, additional test drives are planned with potential users. Handling and reliability will be tested particularly in this field test.

The key-value data format used to store the measurement data, ensured the measurement data can to be easily imported and extended by any other sensors and metadata if required. In the current development state of the mobile measuring system, no efforts have been made to protect the data from manipulation. For a successful deployment under real production conditions, further adjustments are necessary by the development team.

Due to the size of the system components and the integrated power supply our measuring device can either be installed in the transport boxes or it can be placed in a transport box as an external logger (cf. Figure 4) [Ar22]. The use of low-cost common components enables production even in large quantities.

During the measurement trips done, it could be confirmed, that the developed measurement system meets the system quality requirements. Thus, a failure of a sensor does not lead to a complete failure of the measuring system. Even interference in the Bluetooth connection leads only to a temporarily interrupted data transmission. By using the "nofity" mode for data transmission, an interrupted connection is restored as quickly as possible without user interaction. However, data packets that are not received are irreversibly lost and cannot be recovered. Our own tests using "indicate" mode in Bluetooth Low Energy for data transfer have shown, that data transfer rate drops significantly compared to "notifiy" mode.

With the developed and presented mobile measuring system all the requirements from the interviewed artificial insemination centers are fulfilled (cf. section 3.2 Requirements analysis).

6 Summary and Outlook

In this paper a mobile measuring system was designed, which allows a complete recording and storage of all relevant impact factors (see: [HGK16, Ms17].) during transport of boar insemination doses from artificial insemination centers to downstream sow farms. The measurement system consists of an “Arduino Nano 33 BLE Sense” as a microcontroller with integrated sensors such as an accelerometer as well as other integrated sensors. An external 10 kΩ thermistor was connected to the microcontroller board to determine the temperature of the insemination doses and a “Seeed Studio Grove APDS9002 luminance sensor” was connected to determine the luminance in the transport box. The measurement data is transmitted via Bluetooth Low Energy to a smartphone and our developed app persists the data on the smartphone's integrated memory. The location is determined via the GNSS receiver integrated in the smartphone. It is possible for multiple loggers to be connected to the app at the same time and take measurements simultaneously.

With the presented measuring system, a part of the real-time monitoring system for the transport of boar semen could be implemented (see: [Sp22]). Following research will be focused on the determination of tolerable vibrations (threshold values) for the transport for boar semen. The collected measurement data from the transport trips will be analysed later in the app and suitably presented in a user-friendly front end. For this purpose, a driving assistance app is planned. The app carries out an evaluation of influence on transported boar sperm to determined its current condition (e.g.: green, yellow and red transport conditions). As soon as one of the monitored values (temperature and vibrations) exceeds the threshold value, the user will be warned.

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