UNIVERSIDADE DA BEIRA INTERIOR
Engenharia

Real-time vital signs monitoring system for livestock

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Dissertação para obtenção do Grau de Mestre em

Engenharia Eletrotécnica e de Computadores

(2º ciclo de estudos)

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Covilhã, junho de 2019

Acknowledgments

This dissertation is the final accomplishment of all the past academic years. It depended on the orientation, advice and support from people with whom it was possible to count in all moments.

To Professor Pedro Dinis Gaspar, for his guidance, availability, support and advice transmitted to me during this work, without which it would not have been possible to carry it out.

To Professors Nuno Garcia and Virginie Felizardo, for their readiness and willingness to help and advice when necessary.

To the Professional Agricultural School Quinta da Lageosa, where it was possible to perform the necessary practical tests, and to all those who helped, for their availability and advice.

To André, for the support, motivation and help, always.

To my parents and to my brother, for the unconditional support.

Resumo

O foco na aplicação de tecnologias de informação e comunicação e eletrónica (TICE) na agricultura provou ser muito eficiente e revolucionário de várias maneiras. Com a adoção de tecnologias cada vez mais eficientes e modernas, a agricultura em geral melhora sua competitividade e a produção é realizada de forma mais sustentável. O uso intensivo de TICE neste setor tem por objetivo criar soluções integradas que gerem ganhos efetivos em produtividade, sustentabilidade e qualidade económica, social e ambiental.

Este tipo de tecnologias, quando destinadas à monitoração de gado, têm algumas características em comum. Posicionamento preciso e geolocalização de GPS, mapeamento geográfico, sensores e sistemas de comunicação são algumas das ferramentas que permitirão o desenvolvimento de um sistema completo e preciso para monitorar sinais vitais de animais.

Esta proposta para um sistema de monitorização de gado ou equinos, baseado em TICE, é desenvolvido como um cinto. Este contém um dispositivo microcontrolador que é usado para avaliar a frequência cardíaca do animal e detetar mobilidade anormal. A avaliação correta desses dois parâmetros mostra-se muito útil para a deteção de muitas das patologias e anomalias que constituem perdas económicas para os produtores. Com uma monitorização precisa, é possível contornar estes eventos prejudiciais a uma produção animal.

Palavras-chave

Agricultura 4.0, Produção, Eficiência, Produtividade, Acelerometria, Frequência Cardíaca.

Abstract

The focus on the application of information and communication technologies & electronics (ICTE) in agriculture has proved to be very efficient and revolutionary in several ways. With the adoption of increasingly efficient and modern technologies, agriculture, in general, improves its competitiveness and production is carried out in a more sustainable way. The intensive use of ICTE in this sector has been aimed at creating integrated solutions that generate efficiency gains in productivity, sustainability and economic, social and environmental quality.

This type of technologies, when aimed at monitoring livestock, have some characteristics in common. Precise positioning and geolocation from GPS, geographic mapping, sensors and communication systems are some of the tools that will allow the development of a complete and extremely accurate system for monitoring vital signs.

This proposal for a cattle or equine ICTE-based monitoring system is developed as a belt. It contains a microcontroller that is used to evaluate the animal's heart rate and detect abnormal mobility. The correct evaluation of these two parameters proves very useful for the detection of many of the pathologies and anomalies that constitute economic losses for the producers. With accurate monitoring, it is possible to circumvent these events that are detrimental to animal production.

Keywords

Agriculture 4.0, Production, Efficiency, Productivity, Accelerometry, Heart Rate.

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Nomenclature

General:

BPM	Beats per minute;
LCT	Lower critical temperature, [ºC];
UCT	Upper critical temperature, [ºC];
VCC	Voltage in the common collector, [V];
GND	Ground, [V];
Φ	Roll angle in the *X*-axis, [º];
θ	Pitch angle in the *Y*-axis, [º];
φ	Yaw angle, on the *Z*-axis [º];
ECG	ECG value, [mV];
g	Acceleration, [m/s^2]

Acronyms:

FAO	Food and Agriculture Organization of the United Nations;
PLF	Precision Livestock Farming;
GHG	Greenhouse gases;
IoT	Internet of Things;
GPS	Global Positioning System;
USB	Universal Serial Bus;
PC	Personal Computer;
RFID	Radio Frequency Identification;
FDX	Full-Duplex Communication;
HDX	Half-Duplex Communication;
ISO	International organization for standardization;
UBI	Universidade da Beira Interior;
TVWS	Television White Space;
RF	Radio Frequency;
LED	Light Emitting Diode;

VHF	Very High Frequency;
UHF	Ultra High Frequency;
FM	Frequency Modulation;
OS	Operating System;
ECG	Electrocardiogram;
EMG	Electromyogram;
ACC	Accelerometry;
AMD	Advanced Micro Devices;
VB.NET	Visual Basic.NET;
SQL	Structured Query Language;
MCU	Microcontroller Unit;
GPRS	General Packet Radio Service;
ARM	Advanced RISC Machine;
RISC	Reduced Instruction Set Computer;
SMS	Short Message Service;
PID	Proportional–Integral–Derivative;
SVM	Support Vector Machine;
A2	Analog 2;
Ref	Reference;
SMTP	Simple Mail Transfer Protocol;

1. Introduction

1.1. Thematic framework

The agricultural sector is very important for the economy and sustainability of a country, and on a larger scale, the world, since livestock systems occupy about 30% of the planet's ice-free terrestrial surface area and are a significant global asset with an estimated value of over 1.4 trillion dollars [1]. With increasing population growth, the task of providing quality food to all is becoming more and more difficult. Over the next 15 years, global meat consumption is expected to increase by 40%, precisely due to the increase in population, since in the year 2025 8 billion people are expected worldwide, and in 2050, 9.6 thousand million [2], [3], [4], [5]. In Figures 1 and 2 it is possible to conclude that although there are differences between developed and developing countries, milk and meat consumption are growing [6].

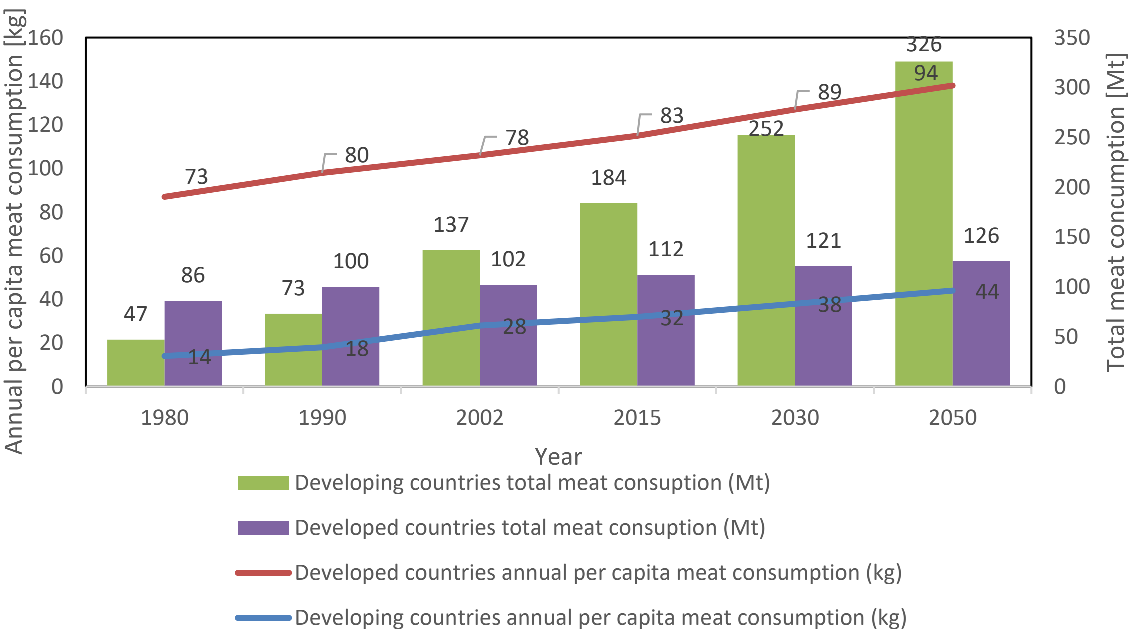


Fig. 1 – Past and projected trends in meat consumption 1980 to 2050 [6].

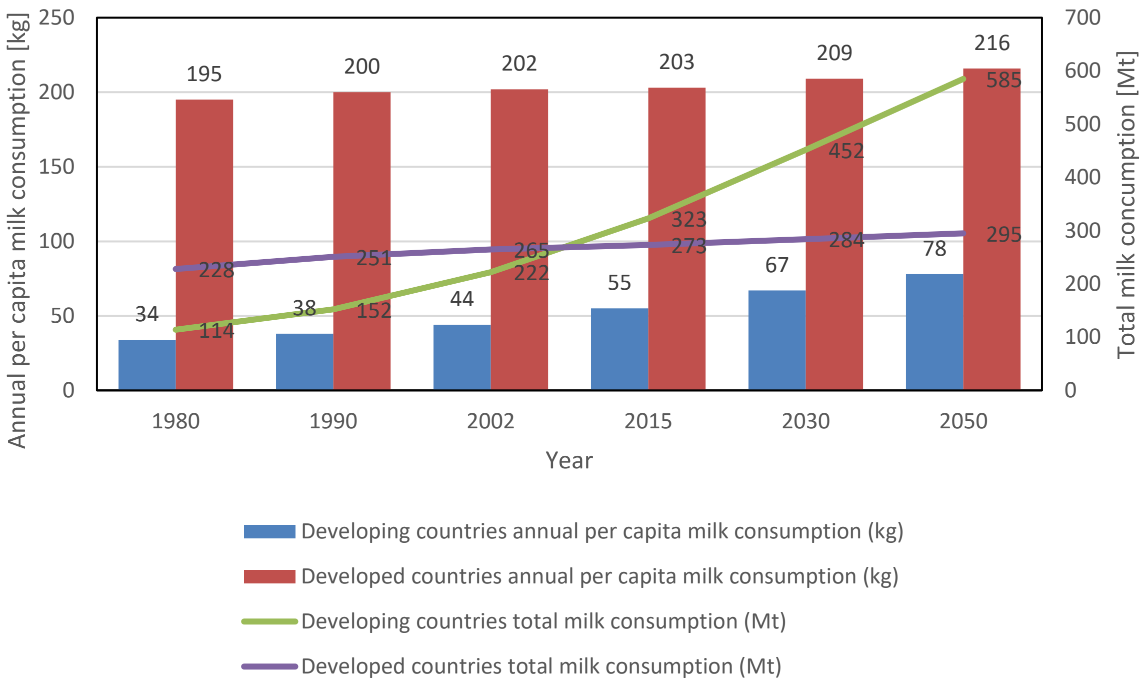


Fig. 2 – Past and projected trends in milk consumption 1980 to 2050 [6].

Livestock sector contributes with up to 50% of the global agricultural gross domestic product and supports the livelihoods and food security of almost 1.3 billion people in developing countries [7], [8].

According to FAO [7], the global demand for livestock products will increase by 70% by 2050. Approximately 1 billion people considered poor depend on livestock raising for food and income. It has been estimated that two-thirds of the individuals living on less than $2/day own or keep livestock [9]. Increasing productivity in developing countries is crucial for production optimization and efficiency, as well as for improving the quality and safety of food produced [7].

This demand is the result of human dietary evolution that, as the income increases, the more animal products are consumed. Regarding meat production, about 65 billion chickens, 1.5 billion pigs, 1 billion goats and sheep, and around 330 million cattle and buffaloes are breed worldwide for human consumption [6], [10]. As for milk and egg production, there are an estimated 234 million cows producing milk and 7.6 billion laying hens for egg production [8].

1.2. Problem and its relevance

This project is in the area of precision agriculture, precisely in animal raising and livestock. Precision farming enables producers to meet current and future demand more efficiently and effectively, while at the same time improving quality, as they will be able to manage more animals with less human resources [9], [11].

In the context of this project, it is intended that the producers obtain the evaluations of the physiological and mobility parameters of the animals whenever they want, thus saving time and money since veterinary support will only be necessary in case of deviation from the normal values. Additionally, the need for animals' isolation can be fast predicted, reducing the possibility of disease spread. While reducing the number of affected animals by a disease, higher will be the income of selling healthy animals or derived products. This type of monitoring is not confined to cattle, it is reprogrammable and adaptable to various species.

Currently, the difficulty in monitoring cattle is already felt, and with population growth, this difficulty will increase greatly. The usual monitoring techniques are insufficient for a constant and accurate update of the health status of the animals since they require a lot of investment in human resources and veterinary knowledge, all for only sporadic information [2], [6].

A system with all these characteristics, that is, capable of monitoring whenever the user wishes to, will be very useful and hereafter essential for the sustainability of production.

The term Agriculture 4.0 refers to the modernization of agriculture in general. This evolution has already achieved positive results, both in time and resource management, and it is increasingly being applied. For instance, by using GPS technology on animal collar, it is possible to monitor certain grazing and walking patterns. With this, conclusions about health status and behavioral information can be assessed and analyzed [2], [12].

Although the results describe a high potential when compared to the traditional method, there are still some setbacks, such as the initial investment in the automation of production, since it tends to be high, and the adaptation of the new technologies by the producers is another obstacle. On the other hand, placing these types of system in animals is not easy, since they consider it as a strange object and they will try to take it out.

Environmentally speaking, it is also of everyone interest the implementation of precision livestock farming (PLF) systems, since the agricultural sector is one of the sectors most responsible for the emission of greenhouse gases and water and soil pollution [8], [13]. As for air impact, agriculture is responsible for 94% of all anthropogenic ammonia emission and 75% of these originate from livestock manure only. Regarding greenhouse gases (GHG), livestock is responsible for about 15% of global emissions. About 44% occur because of the eructation in ruminants, that releases methane (CH_4), 27% is CO_2 related to transportation and 29% are N_2O related to manure and fertilizer [8].

The livestock sector waste contains a great quantity of organic matter, which is composed of nutrients, antibiotics, and other chemicals that will be absorbed by the soils and consequently the water. The result is devastating for the water quality and results in the spread of antibiotic-resistant bacteria, and a high concentration of nitrates and phosphorus [8].

By ensuring animal welfare, production is improved, and environmental impact is reduced as well as health hazards [2], [6], [7], [8].

1.3. Objectives and contribution of the dissertation

This work complements the studies carried out so far on this subject, and with continuous research and technological development, it is possible to optimize existing systems. In this way, it is possible to create an optimal method, without disadvantages for any of the parties involved.

By incorporating sensors, wireless technology, communication tools, and large data storage capacity, it is possible to create an extremely useful, accurate system, as well as low cost, intuitive, user-friendly and non-invasive. The goal of a monitoring system is to collect and evaluate data continuously, accurately and in real-time for user decision-making, while lowering operating costs and minimizing the ecological footprint [2].

For the specific case of this dissertation, the main goal is to create a system that is capable of acquiring data from sensors, process it and evaluate if the values are in the healthy and normal range or not. This system will rely on a microcontroller board that will have an accelerometer and ECG sensor, which will allow the obtaining of the heart rate. With this information, the farmer can always monitor if the animal is healthy or if it needs medical attention.

In terms of economic influence, since thermal stress limits metabolic efficiency, annual economic losses are around 802 and 330 million euros for dairy and field cows, respectively [14].

Regarding the economic influence of mastitis[1], Canadian dairy producers lose about 300 million dollars/year. This illness also affects milk production [15].

Agriculture 4.0 is a very actual topic with a high economic and environmental importance, as a conscious use of resources is crucial. The term refers to the fourth evolution of agriculture, i.e. the development and implementation of IoT technologies, GPS and sensors, with the goal to create a precision agriculture system. Systems like this can add value to a whole production. Both environmentally and humanly, good resources management is required to maintain the environmental and economic sustainability of the area where production exists and also globally [2], [16].

1.4. Overview and organization of the dissertation

This work is divided into six chapters. The first chapter is introductory, and it highlights the various needs currently present and the relevance of this work. The development of the theme is presented in the second, third and fourth chapters, which will present the various stages that form the entire research process and all the constituents of the project structure. The fifth chapter contains the results of the experimental tests carried out after the completion of the prototype, and the sixth chapter serves as conclusion and future prospects.

This first chapter presents a general introduction which summarizes the objectives and highlights the benefits of this work to the environment, producers, consumers, and animals. The objective

[1] Bovine mastitis is the persistent, inflammatory reaction of the udder tissue due to physical trauma or microorganisms infections. Mastitis, a potentially fatal mammary gland infection, is the most common disease in dairy cattle in the United States and worldwide.

is the analysis of our reality. There is a growing awareness of people concerning the need for sustainability to improve food, environment, the agriculture sector and producers, and animal welfare.

The second chapter consists of the basis and foundation of the work. Firstly, it is explored a great deal of veterinary health, including the most common diseases and anomalies, and the causes of this recurrence in livestock and equines. Environmental, physical and physiological factors that lead to changes in biosynthesis, and consequently the health status of individuals, will be enumerated. It is also acknowledged the impact that late disease detection and lack of monitoring, can have on an entire production, in a region and on the consumers, who receive the final product when it comes to livestock. As for equines, their reproduction is also explored. This first part of the chapter serves to understand the need for constant monitoring for rapid preventive veterinary action in order to avoid contagion and proceed to the immediate treatment of an anomaly. Later in the second chapter there is an analysis of the existing applications already on the market, the patents and prototypes, and the most relevant academic works related to this topic. All the approaches under study in this chapter form a great basis for reflection on which are the best methods, as well as those most relevant, to the goals to achieve. By analyzing the state of the art, it is possible to predict and find out the best ways forward in research and what can be improved or conceived.

After analyzing all the existing products, patents, prototypes and academic contributions relevant to this theme, it was possible to select the best options to take into account when choosing the components of the prototype to be developed. The microcontroller used for the measurement, acquisition, and transmission of data is explored in the third chapter. This device encompasses sufficient peripherals and is capable of being the executor of a great part of the necessary steps. It will be introduced with the reasons for the use of BITalino [17], as well as its characteristics and potentialities. The remaining constitution of the device and prototype will also be explored, as well as the device positioning and ideal conditions to access the data.

The experimental tests will be explored in the fourth chapter, and results will be discussed in chapter five. This section will include the results and their analysis.

As a concluding chapter, the sixth of this work, contains the general conclusions of this dissertation and the suggestions for future work.

2. State of the art

2.1. Livestock health

2.1.1. Bovines

Bovines are mainly divided into two categories, dairy and beef cattle. They have similar physiological characteristics, but for instance, in terms of heart rate, while determining if a cow is sick or not, the records of beef cattle may not be so helpful. This happens because they are usually outdoors, and the heart rate is propitious to suffer abrupt changes.

In the following sections, the most relevant vital signs are presented when trying to ascertain the health status of a bovine, such as normal temperature, heart rate, and respiratory rate range values.

2.1.1.1. Thermal stress

Thermal stress occurs when the ambient temperature is not in a zone of thermal comfort for the animals, that is, the animals suffer stress due to cold or heat. The zone of thermal comfort differs in relation to race and species. The ideal body temperature in cattle is 38.6ºC, and normal physiological processes are not changed if the temperature stays between 37.8ºC and 40.0ºC [18]. Outside this range, the animals suffer thermal stress, either by low or high temperatures. Table 1 lists the various normal rectal temperature ranges for various species.

Table 2 contains the normal ranges regarding resting heartbeats per minute, in various species. As mentioned before, heart rate is a very reliable indicator in assessing the health status of an animal [19]. Additionally, Table 3 presents the normal ranges of resting respiratory rates in various species.

Table 1. Normal ranges of rectal temperature in various species [20].

Species	**Rectal temperature (°C)**
Cow	36.7–39.1
Dairy cow	38.0–39.3
Goats	38.5–39.7
Sheep	38.3–39.9
Pigs	38.7–39.8

Table 2. Normal ranges of resting heartbeats per minute in various species [21].

Species	Heartbeats per minute (BPM)
Dairy cow	48–84
Goats	70–80
Sheep	70-80
Pigs	70–120

Table 3. Normal ranges of resting respiratory rates in various species [22], [23].

Species	Breaths per minute (range)
Dairy Cattle	26-50
Sheep	16-34
Pigs	32-58
Horses	10-14

The comfort zone is limited by lower critical (LCT) and upper critical (UCT) temperatures. When the animals are in the comfort zone, the physiological cost is minimal, they retain the maximum energy, there is no sweating and the respiratory rate is normal, the appetite of which is also normal and optimal production.

When animals are at temperatures below LCT and above UCT, physiological reactions occur due to hypothermia or hyperthermia that can lead to death [24].

In order of event, the first physiological response of the animals, in this case, is vasodilation, followed by sweating. Then the breathing changes, increasing the respiratory rate. The animal will be in severe heat stress due to the heat when it exceeds 100 breaths per minute.

With this, it can be concluded that thermal stress consists in the attempt of the animals to try to regulate their body temperature [24].

As for the influence of thermal stress, in addition to the financial losses referred to in Chapter 1.3, milk production is compromised under very high temperatures, as food consumption decreases and there will be less blood flow in the mammary gland, which will consequently lead to a lack of nutrients and energy for milk production [25].

In addition, the homoeothermic process takes precedence over the production of milk, thus reducing production in case of attempting to regulate body heat.

Thermal stress also influences reproductive capacities, as it compromises the functioning of various tissues, such as the embryo, which affects implantation. Embryonic mortality is the major responsible factor in the failure rate at gestation [26].

In calves, growth is affected by excessive heat [26].

2.1.1.2. Laminitis

This disease is observable through abnormal locomotion, usually in a paw. In Table 4 the various classifications of lameness level are represented.

Laminitis is the third cause of economic loss of a farm (only surpassed by mastitis and infertility) and the main cause of animal welfare problems [27]. The main consequence is the production decrease [28], [29].

Table 4. Lameness level classification [30], [31], [32].

Lameness level	Observations/Symptoms
1 - Normal (not lame)	Normal walking and standing; Ability to take long strides.
2 - Mildly lame	Slightly abnormal standing and gait; Walk with a slight arch.
3 - Moderately lame	Loss of ability to take long strides in one or more legs; Standing and walking with an arched back.
4 - Lame	Standing and walking with an arched back; Weight transfer to non-affected limbs; Leaning on one or more limbs.
5 - Severely lame	Distinct arching of back; Unwillingness to move; Complete weight transfer away from the affected limbs.

2.1.1.3. Mastitis

This disease consists of acute or chronic inflammation and reveals symptoms such as swelling of the mammary glands and surrounding tissue. It can be a consequence of chemical, mechanical or thermal injuries and is one of the most recurrent diseases in cattle that produce milk. There is an immune response when bacteria enter the breast canal.

In a cattle breeding, there are many sources of bacterial spread, the most common being E. coli. This disease does not present relevant or very notable behavioral differences, but rather a decrease in milk production and in its pH. Usually, the pH of the milk is 6.6 and with this pathology, it increases to 6.8 and 6.9. There is an increase in temperature in the mammary area when the animal suffers from mastitis. Fever may also occur, that is, a temperature of 39.5°C or more [33].

Mastitis is the most economically damaging and common disease in dairy cows. It causes lower revenues due to lower sales of milk, worse conception rate, losses by culling, and costs in animal recovery and milk sample analysis, among others. There are other factors that are affected and represent higher losses than the average [27].

2.1.1.4. Hypocalcemia (Milk fever)

It is a metabolic disease characterized by the loss of calcium in the blood resulting in diminished productivity in the next three years.

Normally this disease is contracted within 72 hours after newborn delivery, due to the excessive quantity of calcium spent in milk production, and some animals cannot replenish calcium fast enough to avoid contraction. Older and larger dairy cows are more likely to get this fever.

This pathology can be divided into 3 states, based on the symptoms in each. The first state may go unnoticed as it lasts less than an hour, and the most notable symptoms are a loss of appetite and increased sensitivity and muscle weakness. The second stage can last from one to twelve hours and features cold ears and dry nose, incoordination, and muscle tremors. At this stage there is a decrease in body temperature, up to 35ºC-37ºC and an increase in heart rate per minute, exceeding 100 BPM. Finally, the third condition is characterized by a lack of ability on the part of the animal to stand, and progressively leads to severe disorientation and coma [34].

2.1.1.5. Estrous cycle and fertility

Estrus is the first day of the estrous cycle. It is the period in which the animal demonstrates sexual receptivity, and then ovulation occurs. If fertilization does not occur, the mean interval between two estruses is 21 days. The duration of estrus varies from 10 to 30 hours, with younger animals tending to have shorter estrus.

Females should be observed twice a day for determination of the esters cycle by measuring the temperature. Precise estrus detection is essential for optimal calving intervals in order to optimize the reproductive efficiency of cattle. If estrus is detected optimally, there will be more animals in the gestation phase and consequently more lactating animals. The goal is to optimize production, as a major problem of production, in general, is the failure of the identification of estrus. Table 1 shows the range of normal temperature values with the differentiation of dairy and beef cattle [35].

Like humans and other mammals, in order to produce milk, a cow needs to give birth. Dairy cows are pregnant for about 9.5 months, and in the U.S., cows give birth for the first time when they are about two years old. Although twins are possible, it is not the norm, and most cows will give birth to a single calf at a time, either a heifer (female) or bull (male) calf. After giving birth, cows are bred again a couple months later, they milk for just over 300 days, and then they are dried off (they no longer produce milk). The dry period usually lasts 45-60 days, allowing the cow some time to rest before giving birth again. It usually works out that cows are giving birth every 12-14 months. With the lifespan of U.S. dairy cows averaging 4-6 years, most cows have 2-4 calves in a lifetime [8].

During domestication, breeds have been developed to express certain desired characteristics such as high milk production, resulting in the dairy cows we see today in commercial farming. In the 1800s, each cow produced an average of 1000 liters of milk annually; in many countries around the world today, the average annual milk yield is over 10,000 liters per cow. A cow can live for around 20 years old, but in commercial systems, she will be culled at 6 years old on average, usually because of lameness, mastitis and poor fertility [36].

Regarding fertility management, and relevant to this work, there is an abnormal behavior that can be noticed with an ACC analysis. Cows during this time tend to be restless and move around much more than usual [37]. If there is a known pattern of normal movement, it is possible to know when the animal is less time lying down or just standing.

2.1.2. Equines

Horses and other equines have a great variety of breeds, and from racing to breeding they are raised for a great number of purposes. In this section regarding equine health, the main causes of horse casualties and most common diseases are explored. In order to determine if a horse is healthy, it is important to know it vital signs range and usual behaviors, which is also all presented in this section. By knowing these factors, the assessment of the animal's health status becomes easier to evaluate.

Table 5 shows the normal ranges of rectal temperature in horses, while Table 6 the resting heart rate in horses also depends on their age. Table 6 and Table 7 contain the relation between a horse's activity, its speed and heartbeats per minute and the normal resting heartbeat values by age, respectively. As shown, the resting heart rate in horses also depends on their age.

Table 5. Normal ranges of rectal temperature in horses [20].

Horse	Rectal temperature (°C)
Female	37.3–38.2
Male	37.2–38.1

Table 6. A relation between a horse's activity, its speed and heartbeats per minute [38], [39].

Activity	Speed (km/h)	Heartbeats per minute (BPM)
Standing	0	25-60
Walking	7.5	50-90
Jogging	15	80-130
Trotting	18	100-150
Cantering/Loping	21	120-160
Galloping	30	150-200

Table 7. Normal resting heart rates in horses by age [23].

Horse's age	Heartbeats per minute (BPM)
Foal (male or female horse up to one-year-old)	70-120
Yearlings (male or female horse between one and two years old)	45-60
Male or female 2-year-olds	40-50

If the heart rate is above 60 BPM while standing, it is very probable that the cause is colic, since it is the more common cause of elevated heart rate. The severity of colic can be determined by the heart rate, since the higher, the more severe it is.

The measurement of a single vital sign is usually insufficient to accurately assess the horse's health. However, it is a good indicator and helpful decision-making aid on how to proceed. A horse's heart rate can be measured in a number of different ways, and the most common one is under the jawbone [23], [40].

There are several other vital signs to pay attention to. Besides temperature and heart rate, there is respiration rate, gut sounds, etc. [23].

2.1.2.1. Colic

Colic is a digestive disorder that causes abdominal pain, and it is very common in horses. It is not a disease, but a term used to refer to the combination of signs that indicates abdominal pain [41]. The range of colic goes from mild, which and be resolved with medication, to very severe, even to the point of euthanization, when surgery does not solve the problem.

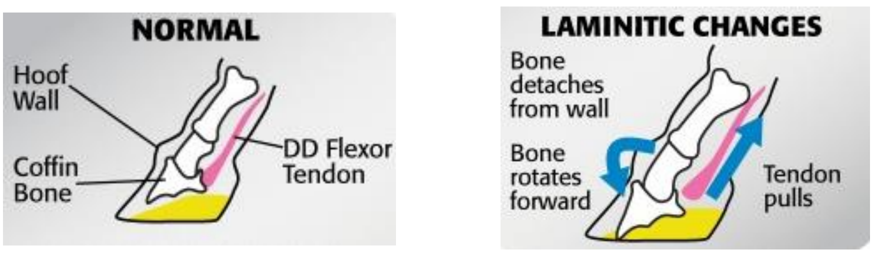
There are visible symptoms like include pawing, rolling or lying down, and sometimes the inability to defecate. Other symptoms include lack of appetite, abnormal gut noises, and excessive sweating.

There are two types of colic, spasmodic and impaction. The first one is caused by excessive gas accumulation in the colon, while the second has various causes such as internal parasitism, excessive ingestion of sand and dehydration. Although some of the symptoms differ, heart rate is a good vital signal to use in order to evaluate if the horse has colic. While resting, if the heart rate is above 60 BPM, it can be a sign of colic, and the veterinary should be warned right away [42].

2.1.2.2. Laminitis

Although laminitis can occur in both equines and bovines, the disease is different in both species. In this case, it is an inflammation of the laminae in a horse's hooves. It is a very serious condition that can result in lameness in horses and may even lead to its eventual euthanasia, depending on the detection timing and severity. Typically, the condition affects the front hooves, but it can affect all four. The condition progresses through four stages, which include the developmental stage, acute, subacute, and chronic. Obesity, high fevers, and working on hard surfaces, are risk factors. Figure 3 shows the comparison between a normal and a laminitic hoof.

In either case, it can be caused by grain overload, but in the equine case, it can occur due to the equine laminae, which is the lamellar surface of the hoof. This surface of the equine hoof is more extensive than that of the bovine, so it can be concluded that the main difference is anatomical [43].



a) Normal horse hoof.
b) Laminitic horse hoof.

Fig. 3 – Normal and laminitic hoofs illustrations [44].

The symptoms of laminitis depend on the damage to the lamella and the duration of the episode, if it lasts hours or a few days it is considered acute, and if it goes on for more than a week it is considered chronic. It most commonly occurs in the forelimbs and both forelimbs but can also occur in all four hooves.

As referred to before, lameness results from laminitis. It starts with odd but small head movements, like a nod, and it can be even almost imperceptible just by looking but it is noticeable when riding. This is the mild lameness in terms of severity. It can evolve into severe lameness, which translates to the inability to stand up, bear weight on one leg, and abnormal walking (like walking on eggshells).

An increase in digital pulse pressure in the arteries that supply the affected foot referred to as "bounding digital pulse" and/or the hoof wall feels warm/hot to the touch can also be a common finding as well, although not specific for laminitis [45].

2.1.2.3. Fertility

Puberty in horses is reached between 12 and 18 months of age, and although young horses can reproduce, it not advisable. Thus, it is recommended to separate colts and fillies once they have reached 1 year of age. Mares that are bred prior to maturity will require extra care and nutrition, especially during the period of lactation and last 3 months of pregnancy (due to the risk of dystocia), so that she and her foal will grow to their genetic potential. Handle mares and performance test them prior to being bred, to assess their quality. If they perform well, the value of their foals increases. The estrous cycle in most mares starts to normalize in late April or early May until August, the normal breeding season for horses. During this time, the mare will have an estrous cycle of 21 days (±3 days). The estrous cycle is composed of two phases: the estrous phase (in heat) and the diestrous phase (out of heat). Estrus usually lasts for 6 days, but can be 4-10 days, depending on the mare. Diestrus is normally 15 days but may vary from 12-18 days. Older mares have longer estrous cycles [46]. From September through March, very few mares will cycle normally, so conception is more difficult to achieve during these months As for detection, like the bovines there are some movement alterations, since the mare also tends to move more frequently than usually around a stallion [47], [48].

Although stallions undergo seasonal cycles with regard to how fertile they are too, there are differences. Stallions are ready and able to breed whenever there is a receptive mare but they are much easier to lose the sexual appetite [48].

The optimization of the breeding process can be immensely profitable, since in some breeds, an individual can be bought for up to $100,000, for example the Arabian breed. Some breeds that are especially good for races or other purposes are very expensive. By correctly assessing heat time, chances of successful pregnancies are higher.

This type of control is also useful regarding the conservation of some horse breeds, and to prevent their extinction. There are some horse breeds with very few individuals left. For instance, there are under 100 American Cream horses left worldwide (Figure 4), less than 850 Suffolk, under 1100 Cleveland Bay, and so on [49], [50].

Fig. 4 – American Cream horse [50].

2.2. General view over abnormalities and suitable sensors

Table 8 gathers all relevant information concerning the evaluation of abnormalities, diseases and fertility assessment, both for bovine and equine individuals, that was covered in the previous chapters. There it is possible to connect each symptom with a sensor and then use it in order to determine if the animal is, in fact, healthy or not.

Table 8. Suitable sensors for each type of abnormality [31].

	Abnormality	Anomalous Behaviors / Physiological Changes	Suitable sensor
Bovine cattle	Thermal stress	Less activity/Discomfort	Accelerometer
		Abnormal body temperature	Temperature
	Laminitis	Changes in locomotion	Accelerometer
		Abnormal heart rate	ECG
	Mastitis	Less production	Accelerometer
	Hypocalcemia	Movement alterations	Accelerometer
		Increase in heart rate (approximately 100 BPM)	ECG
Equine	Colic	Increase in heart rate (approximately 60 BPM)	ECG
		Movement alterations	Accelerometer
	Laminitis	Movement alterations	Accelerometer
	Fertility	Movement alterations	Accelerometer

2.3. Current research and market

2.3.1. Available products currently on the market

As for existing companies with similar products, Allflex [51] stands out worldwide. This company sells electronic ear tags, subcutaneous implants, and readers for these devices. The products developed by this company are shown in Figure 5 to Figure 8.

Fig. 5 – Electronic ear tag Allflex [51].

Fig. 6 – Electronic ear tag Allflex on bovine [51].

Fig. 7 – Subcutaneous implant [51].

Fig. 8 – Allflex manual reader [51].

The ear tags shown in Figure 6 are composed of two parts (male and female). In the female part, there is an electronic chip programmed with ISO 11784 and ISO 11785 standards. ISO 11784 specifies the identification code so that there is no equal code, while ISO 11785 specifies how the data is stored, transferred and how the identifier is activated, being, in this case, a chip. They also regulate RFID communication in animals. RFID is the method of identifying animals and needs a transmitter that in this case is the ear tag and a receiver that is the data reader.

This reader will identify the chip number and record the desired information. The frequency for the identification of animals is 134.3 kHz. Allflex uses two protocols for the communication of these chips and readers: HDX and FDX, outlined in Figure 9. Duplex technology consists of the communication between a transmitter and a receiver. When HDX is the transmission is bidirectional, that is, both can send and receive but not simultaneously, that is, there is always a receiver and a data transmitter and can change their functions, as long as both do. In the case of FDX technology the communication is continuous, being the transmission bidirectional and can transmit data simultaneously.

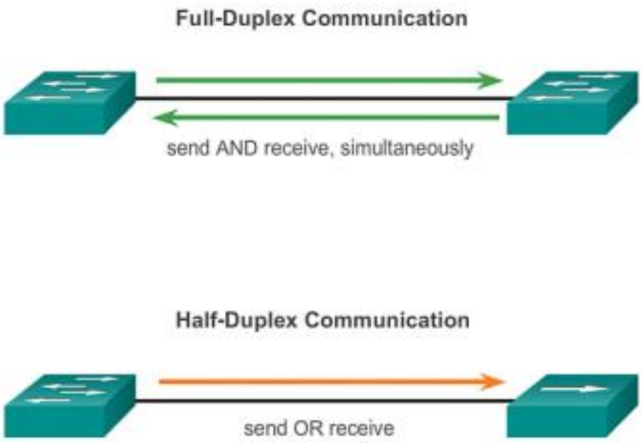


Fig. 9 – Full and Half Duplex communication scheme [52].

The subcutaneous implant that is shown in Figure 7 is used for horses. At the level of communication and RFID identification is equal to electronic ear tags, as it also contains a microchip. However, its application is quite different because it is an invasive device. The implants are produced with BIOVIDRO 8625 since this material has been widely used in many species, including humans and in a very popular application, the identification of domestic animals, namely dogs.

This glass is soda-lime, that is, it is not inert which causes a layer of tissue to grow around the implant. This growth results in the maintenance of the implant where it was initially placed, rather than migrating to another part of the body.

Figure 10 shows where the microchip should be implanted in the horse. Prior to implantation, safety and hygiene rules such as proper waxing and disinfection of the part where it should be placed should be taken. It is very important the correct application to avoid migration of the implant, because otherwise adverse reactions may occur [51].


Fig. 10 – Deployment location [51].

IceRobotics [53] is the world leader in data acquisition and analysis for dairy cow monitoring. This company has several products for monitoring the pose behavior of these animals. Among these products are the sensors, which are characterized by being able to do several readings per second. They are placed on the legs for greater accuracy because they are like a bracelet, as shown in Figure 11. They have a tri-axial accelerometer, which is used to evaluate the acceleration of a body.

The IceQube sensor [53] is used for data acquisition in large groups of animals. It has memory up to 9 days, and the data is aggregated in blocks of 15 minutes. The user can download this data through IceReader, which is another IceRobotics appliance or automatically download through a wireless infrastructure at the production site.

Fig. 11 – IceCube [53].

The IceTag that is shown in Figure 12 was developed for smaller groups of animals and has a memory of 60 days. The data can be viewed and even analyzed in seconds and the user can download it through IceReader when connected to the computer.

Fig. 12 – IceTag [53].

IceReader is IceRobotics' solution for wireless data download and it only requires a USB connection to the computer. The system is shown in Figure 13.

Fig. 13 – IceReader [53].

IceManager [53] is the tool used in the computer to manage sensor data. This allows the user to enable and disable sensors, manipulate data in charts, convert to more accessible formats and create statistical reports with the data obtained.

MooMonitor+ [54], shown in Figure 14, is a wireless sensor that allows the detection of changes in the health status of animals. This system distinguishes various types of behaviors, such as feeding, rumination and different levels of activity. With these characteristics, the sensor helps the farmer detecting (fertile period) and evaluate the health status, among other useful information. The farmer receives SMS, email or other forms of communication desired, that serves as an alert. As mentioned before, one of the main goals of monitoring livestock is improving an animal's health and also fertility, i.e. cows can get pregnant faster and reduce calving intervals.

Other advantages are reduced labor costs, more calves, therefore more milk, better conception timing rates and fewer farm injuries due to less direct interaction with the animals.

The sensor’s range exceeds 1000 m, and it is possible to manage more than 1000 cows (both pasture and housed) wearing the sensor. Its battery lasts up to 10 years and the data is collected in 15 minutes intervals.

Fig. 14 – Cows wearing a collar containing MooMonitor+ sensor [54].

Figure 15 illustrates the entire MooMonitor+ system, which includes the sensors that collect the data, the communication component with the base, the data processing program and the application, compatible with tablet, smartphone and PC.

Fig. 15 – Daily Cattle Watch information on Smartphone or PC [54].

There are more systems like the ones mentioned before. Some examples are DeLaval HerdNavigator™ [55], Cowlar [56], Afimilk® [57] and CowManager® [58].

2.3.2. Patents and prototypes

About patents and academic studies, there are several approaches currently. In the work developed by Nkwari *et al.* [59], the objective was a standard model of the movement of livestock using wireless sensor networks in order to extract as much information as possible. There are several types of sensors in every network, from mechanical, chemical, optical, even magnetic, and systems have GPS. With this data, by calculating the standard model it is possible to predict at a statistical level the supposed position of an individual. From the normal model, if an anomaly occurs, the producer is notified. For the communication of the sensors, an Xbee transmitter was used that operates with a frequency of 2.4 GHz. In this study, a network of sensors is developed that analyzes the position of the cattle every second.

For each individual, a statistical tool called Continuous Time Markov Process is used, which consists of a stochastic process [59]. A stochastic process is a sequence of random variables, which in this case indicate the random motion of an animal. With this tool it is possible to predict the random movement of the individuals, thus looking for anomalies due to theft or disorientation.

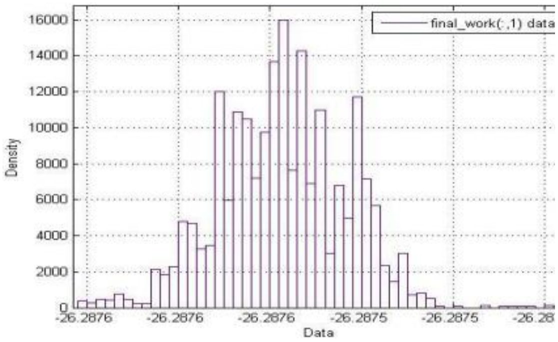
As for the Markov chain and the process, this is a statistical case in which it can be concluded that the probability of a state is only dependent on the immediately previous one, that is, previous states (in this case applicable to the state of the cattle position), are irrelevant for the probability distribution of the next state.

An algorithm was used, and the data were analyzed with the Matlab program after its acquisition. The main parameters at the location level were the longitude and latitude, which were then analyzed in order to find the probabilistic density function for each of them. After all the analysis it was concluded that the functions that best fit the latitude and longitude are the normal distribution and the Gaussian distribution. Figure 16 below are the graphs for the normal distribution.

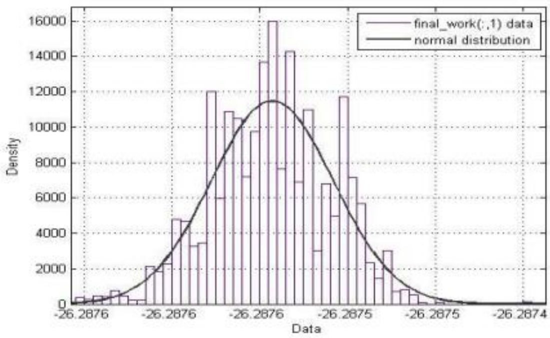
During the experiment, cow speed data were constantly acquired and after statistical analysis, the authors concluded that on average cows move at 0.5 km/h and rarely move at more than 2.5 km/h. With this data, they used 2.5 km/h as basal value to detect some agitation.

The system and method proposed by Arbel [60] are for the remote monitoring of animals. This system is used to analyze physical parameters in order to evaluate the behavior of the animal, both in large areas of grazing and surrounded areas (geofences). It is applicable to various types of animals, such as cattle, horses, and goats. The devices can be collars or ear tags and include identification and sensors that measure parameters such as speed, posture, neck angle and back angle relative to the ground. This system can distinguish when the animal is lying, standing, grazing, mating, thermal stress, pregnancy, among others.

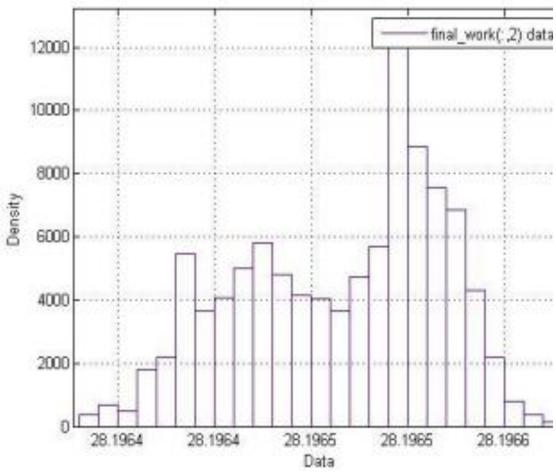
These factors are detected through sensors in measuring and data acquisition devices such as accelerometer and tri-axial gyroscope. The factors are then determined by mathematical algorithms capable of identifying and distinguishing the pose of the animal.



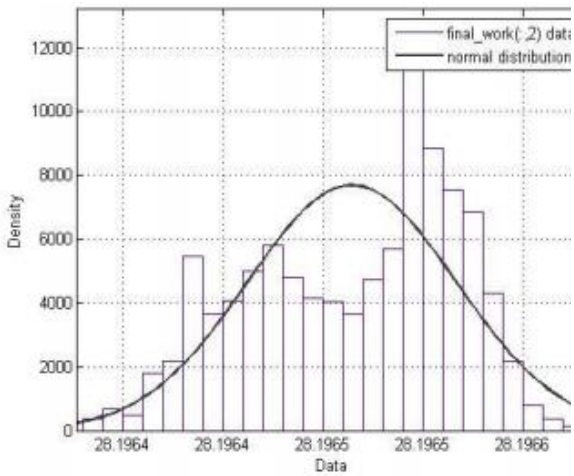
a) Distribution of latitude data.



b) Normal distribution of latitude data.



c) Distribution of longitude data.



d) Normal distribution of longitude data.

Fig. 16 – Longitude and latitude location distribution [59].

The Direction Cosine Matrix is used to calculate positions. Directional cosines are an analogous extension of the usual slope to larger dimensions. Generally, a directional cosine refers to the cosine of the angle between two vectors. They are useful for creating a matrix of directional cosines that express a vector known in different bases. The matrix of directional cosines is shown in Equation 1. The angle Φ represents the roll in the *X*-axis, the angle θ represents the pitch in the *Y*-axis and the angle φ represents the yaw, on the *Z*-axis [60] as shown in Figure 17.

$$[C] \equiv \begin{bmatrix} l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \\ l_3 & m_3 & n_3 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\theta\ \cos\phi & \cos\theta\sin\phi & -\sin\theta \\ \sin\phi\sin\theta\cos\phi - \cos\phi\sin\phi & \sin\phi\sin\theta\sin\phi + \cos\phi\cos\phi & \sin\phi\cos\theta \\ \cos\phi\sin\theta\cos\phi + \sin\phi\sin\phi & \cos\phi\sin\theta\sin\phi - \sin\phi\cos\phi & \cos\phi\cos\theta \end{bmatrix}$$

Equation 1 - Direction Cosine Matrix [60].

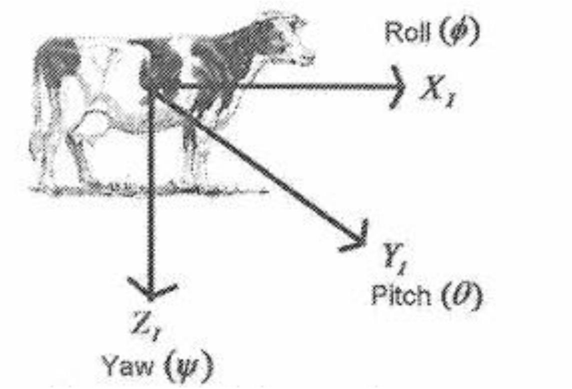


Fig. 17 – Cartesian axes for the directional cosines array [60].

The authors describe for each type of bovine the states that the system can analyze. For an ox, the system can analyze normal locomotion, breaking bones in the leg, grazing, mating, standing, lying down, ingestion, and panic or hostility.

For a cow, the factors are similar to those of the ox with some additions: breastfeeding, thermal stress, childbirth, pregnancy, and abortion.

Regarding calf analysis, the factors are normal locomotion, grazing, bone breakage, standing, lying down, panic, hostility and water intake and milk or other food intakes.

Each unit, despite having a low range (frequency transmitter between 600-900 m), can transmit data via satellite or GPRS and the server in return sends data to the user's personal computer or mobile phone.

If the sensors measure something that might be considered an anomaly, the user can send a drone to the location where those animals are located. This drone is automatically addressed and includes a camera for transmitting images or video to the user's phone or computer, and may also include a thermal camera or visible spectrum camera for night use.

In all, this complete system includes: a remote server for data storage, which in turn includes a processor for the stored data and a non-volatile memory (there is no loss in case of power failure); a data acquisition apparatus in contact with the animal so that it is monitored, that is, it has to contain a sensor to measure the necessary physical parameters; a two-way FDX network for configuring and accessing the data analyzed in real-time, and with this feature being real-time, includes alarms for the remote communication device. A scheme of the system is shown in Figure 18.

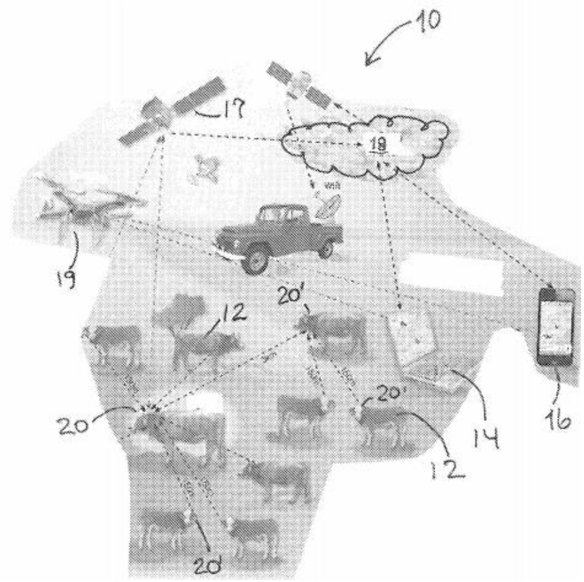


Fig. 18 – Monitoring system sketch [61].

As for energy supply, the authors suggest a long battery life, such as a non-rechargeable lithium battery or solar panel. The purpose of this energy supply solution lies in proportional energy independence of at least one year so that frequent replacement of batteries is not necessary.

This invention also includes methods for monitoring animals for the time intervals in which they are monitored and for when the data is acquired and transmitted.

The objective of the system developed by Mobley [62] is once again centered on evaluating the position of animals by combining wireless technology with a geo-location fence in order to prevent theft.

The system consists of a base station, intelligent sensors for livestock, positioned on an ear tag for animals, and a mobile device. The sensors communicate with each other and subsequently with the base.

The advantage of ear tags with smart sensors is that as the sensors are in a network they communicate with each other, not having to communicate individually with the base.

The analysis consists of placing sensors in the individuals and evaluating them in clusters, that is, in groups and then the animal with the main sensor communicates with the base, which is where all the information is concentrated. This communication is carried out via radiofrequency and other wireless mechanisms so that there is not great energy consumption, being able to send signals at long distances. This system may include TV White Space (TVWS) wireless communication technology.

This technology basically consists of the use of unused television channels between those that are actually being used in Very High Frequency (VHF) and UHF (Ultra High Frequency) spectrum. VHFs are between 88 and 108 MHz for FM radio transmission and UHFs are between 300 MHz and 3 GHz. The use of this technology has the advantage that its frequencies correspond to long wavelengths. In this way, certain signals of low power can propagate at greater distances.

TVWS frequencies allow you to optimize the ratio between frequency, power, and broadband. A schematic of the described system is shown in Figure 19, while Figure 20 is provided with an illustration of the sensor network.

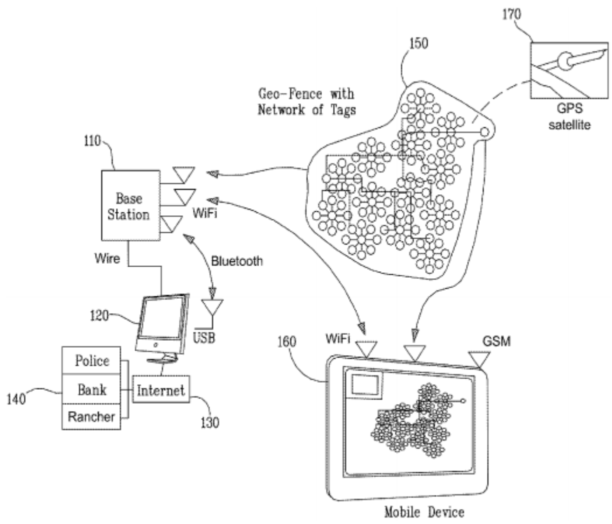


Fig. 19 – Schematic of the whole system and its components [62].

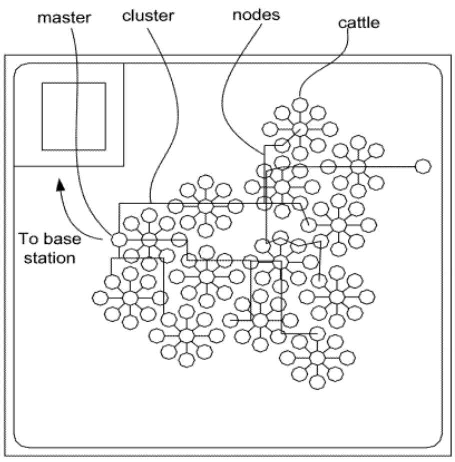


Fig. 20 – Illustration of the Sensor network [62].

In the patent document are explained various parts of the process of acquisition and processing of data through flowcharts. In the first flowchart (shown in Figure 21) the method of data acquisition is illustrated. First, a sensor is selected and then a signal is transmitted to it. When the sensor receives the signal, in response it transmits another signal with data, which is received by the base. After the transmission to the base, the system analyzes if there are still sensors that have not yet received a signal and select another one for the same process. If they do not exist, all information is processed.

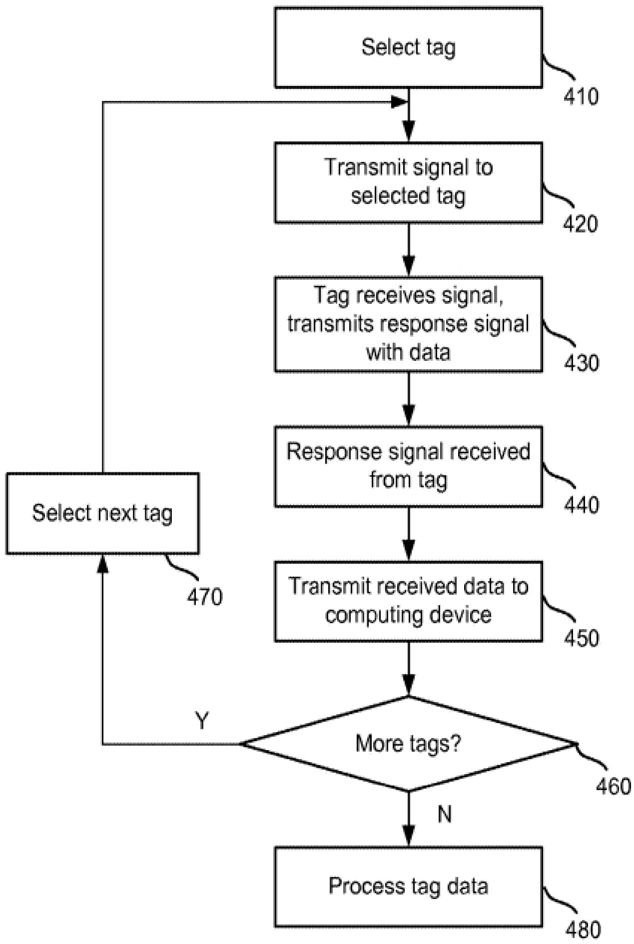


Fig. 21 – Illustration of the data acquisition method for each sensor [62].

For the processing, the position of each sensor, that is, of each animal, is determined and the area of the fence where the animals are analyzed. Then, if some of the sensors are not within that area, an alarm is issued to the user and the authorities in case of theft. If all sensors are within the area, the system analyzes the next step, which is if any sensors are not emitting or receiving data. If so, an alarm is issued again. If not, that is, if everything is within the normal range the cycle ends, without alarms. This process is shown in the flowchart of Figure 22.

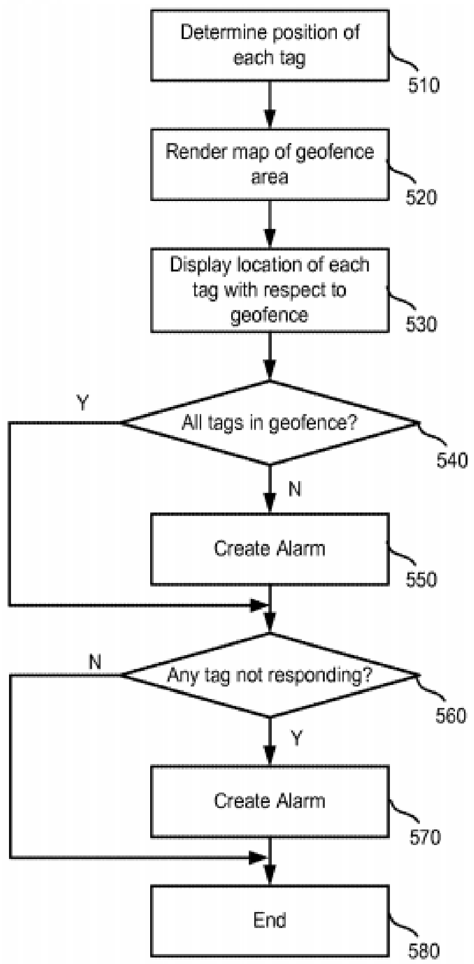


Fig. 22 – Illustration of the data processing method [62].

The system presented by Yaden [63] is intended for the monitoring of physiological factors in order to evaluate if the animal has any disease. The data acquisition and operation mechanism of this system has two essential components: Basic Tag and Smart Tag. Animals can be divided into groups or not, depending on the amount of animals in production, and depending on the producer's choice, Basic Tag is placed on all animals in a group except one that has the Smart Tag. Basic Tags are less complex and send data to Smart Tags. These have the function of sending information to a mobile unit and this to the base, where the whole system is controlled.

All sensors have an identification and Basic Tags send Smart Tags all the data along with their identification so that they can send the data of all Tags with which they are paired to the mobile unit and to the computer on the base (Figure 23).

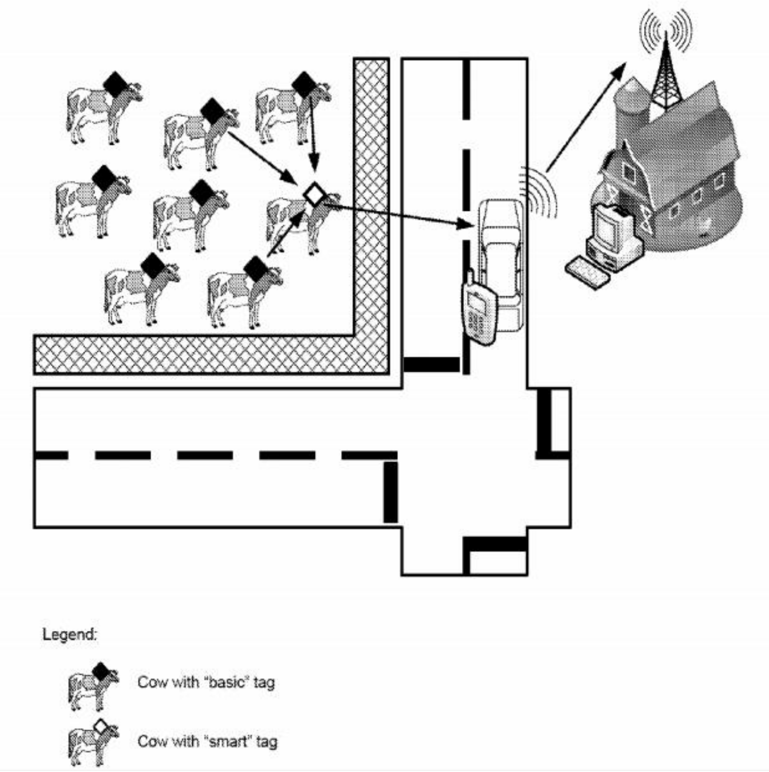


Fig. 23 – Illustration of the Basic and Smart Tags system and its communication [63].

Tags are placed in the ear, or other places that the producer or veterinarian finds appropriate. After the distribution of sensors by all the animals proceed to the development of a database that contains all the Tags, and Smart Tags have a receiver for the Basic Tags.

The system can include or not, once again it is at the discretion of the producer, a memory unit that contains the database of all Smart Tags and Basic Tags linked to Smart Tags. Finally, you need a computer that contains the database of all Smart Tags in a specific section and the Basic Tags related to their respective Smart Tag.

If the production is large, there may be multiple memories, and in turn multiple databases. Data transmission occurs by RF. The big distinction between Basic and Smart Tags is that Smart Tags have not only a transmitter but also a receiver to receive the data of all that the producer chooses.

The schematic of a Tag (1600) is shown in Figure 24. It contains a temperature and motion sensor, an LED that emits light in the case of an alarm, a buzzer that emits sound also in the case of an alarm and a data transmitter/receiver. These alarms are triggered if the system acknowledges that any animal is ill or has abnormal behaviors.

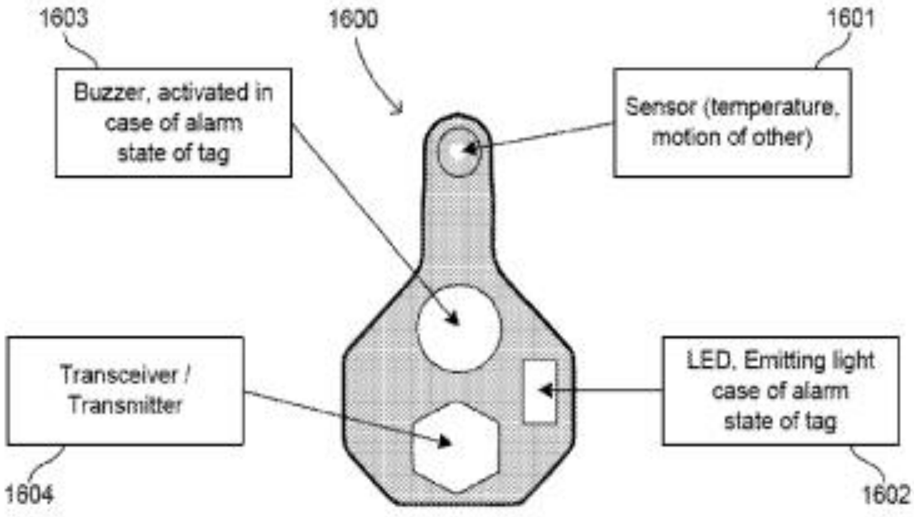


Fig. 24 – Illustration of Basic and Smart Tags and their components [63].

The type of sensor is not limited to temperature and movement as it can be changed according to the preferences and objectives of each producer. The authors suggest accelerometers, proximity sensors, piezoelectric, ambient temperature, GPS or others.

This belt contains electrodes for the measurement and is not usable in the long term, because for the measurement the electrodes require conductive gel, that with the passage of time, in a matter of hours, dries and the electrodes can leave the original and correct site. Although there is this disadvantage, the authors point out that in the short term this belt is the best option.

2.3.3. Scientific and technological research

The system proposed by Smith *et al.* [64] is a mechanism that measures body temperature, heart rate and respiratory rate in real-time. The information of each animal is analyzed by an offline processor and the anomalies will be detected. The state of each animal is characterized as discrete states as normal, suspected anomaly and anomaly. Whenever some measurement does not correspond to normal within what is a daily average and taking into account external factors such as humidity and ambient temperature and its circadian cycle, the producer is warned. From the consideration of the standard environmental and physiological factors, it is possible to distinguish through the system whether animals have any disease immediately.

The authors intend to join the observation of the movement of the head of the animals as improvement of the method because they believe that it brings advantages. They do not want anything invasive, just a sensor in an ear tag or halter, easy to change in case of malfunction or other reasons.

By optimizing the time in which the producer or veterinarian is slow to notice that anomalies may exist, they can act more quickly by preventing the spread of a disease if this is the case, as they can put the affected individuals in quarantine or, for example, if an animal suffers from thermal stress, an injury or other problem, can treat it immediately. Data from each production are collected and aggregated so that veterinarians, producers and other individuals involved in maintaining the health of production can have access to data at a regional or national level in order to detect a general anomaly or trends.

This work provides ZigBee-compatible download stations, where there are always a large number of animals, such as shelters, drinking fountains and places where they usually feed. In this way, if the animal leaves the reach of the wireless receiver, the data will be sent to the base where it will be analyzed and stored. Likewise, when the animal enters the reach of the ZigBee wireless receiver, the monitoring system that the animal has, senses and establishes a connection with the network. Another system it has is GPS, which in this case is for when the animal leaves the area where it should be, the data collected until then go immediately to the base for storage, analysis and notification.

The prototype of the system in development has an AMD 186 processor in a Tern microcontroller and a custom code runs in real-time on the hardware. In this way, the coordination and time of the sensor data samples are more efficient and saves energy. Compact flash memory is used during measurements in case of database failure or wireless errors.

In order to measure internal body temperature, the authors used the CorTemp sensor, as shown in Figure 25, which is placed in the first part of the bovine stomach and travels through the digestive system. This sensor transmits wireless data to a reader that records this data for later analysis (see Figure 26).

Fig. 25 – CorTemp internal temperature sensor [65].

Fig. 26 – Data reader compatible with CorTemp sensor [65].

Another internal sensor similar to CorTemp is in development, but with the peculiarity of having a microphone. The function of this is to pick up the heart sounds and turn them into heart rate. For heart rate measurement, the authors' choice was a Polar brand belt (see Figure 27), commonly used to measure this parameter in horses (see Figure 28).

In conclusion, the authors state that their final intention is to join several physiological and environmental factors such as internal temperature, heart rate, exact location (GPS), ambient temperature and humidity and movement (tri-axial Accelerometer).

Fig. 27 – Polar Belt for heart rate measurement [66].


Fig. 28 – Illustration of the location of the Polar belt [66].

Wang *et al.* [67] propose a monitoring and management system that monitors livestock production, with a great component of feeding control. It is also capable of RFID identification, growth and farming environment monitoring.

This system is composed of various modules and equipment, but the main components are the intelligent environment control module, the intelligent feed delivery module, and the RFID e-label. The first one measures various indicators and environmental factors, such as temperature, humidity, and CO_2. The system can also control all these factors, for instance, adjusting automatically using a PID controller for temperature (Figure 29), which allows optimal conditions in order to promote growth. Regarding the temperature curve in Figure 29, it is visible the signal overshoot and then the stabilization of the temperature.

The intelligent feeding system uses real-time status of an animal to assess the necessary food amount, with the growth rate consideration. Feed delivery is stopped when it gets to the maximum level (determined by the real-time analysis). As for identification, the RFID e-label identifies each animal and the corresponding data in the database can be accessed after it is transmitted to the control computer through an RFID wireless transmitter and synchronized with the cloud database.

This system has shown a prediction accuracy of 86.67%, which means that the used algorithm (SVM) can be used to conclude about the health and physiological status of the animal and the process of breeding [67].

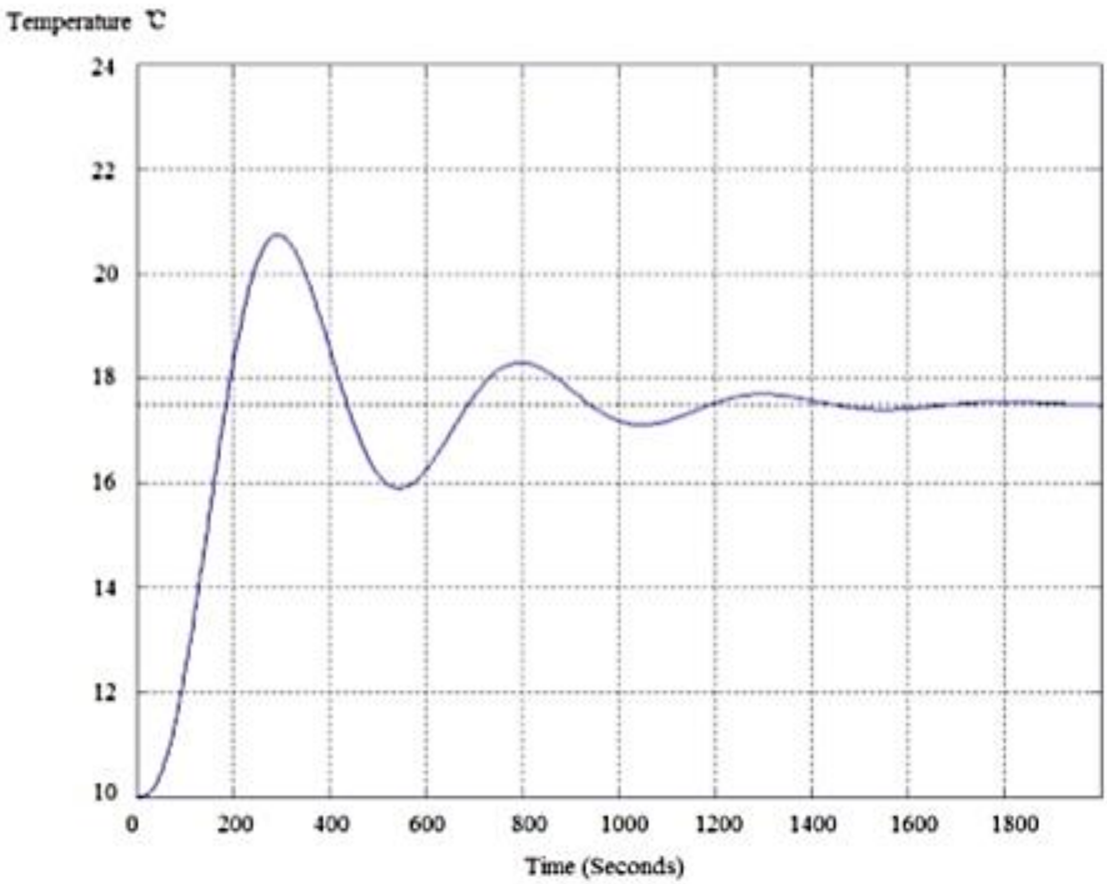


Fig. 29 – Temperature control curve [67].

Umega and Raja [18] propose a Monitoring System composed by an Arduino Uno microcontroller, to which are connected a 3-axis accelerometer, temperature, humidity and heart rate sensors. The communication is done by a Wi-Fi network. In order to identify tags, it is used RFID technology. Figure 30 illustrates the whole system and its modules.

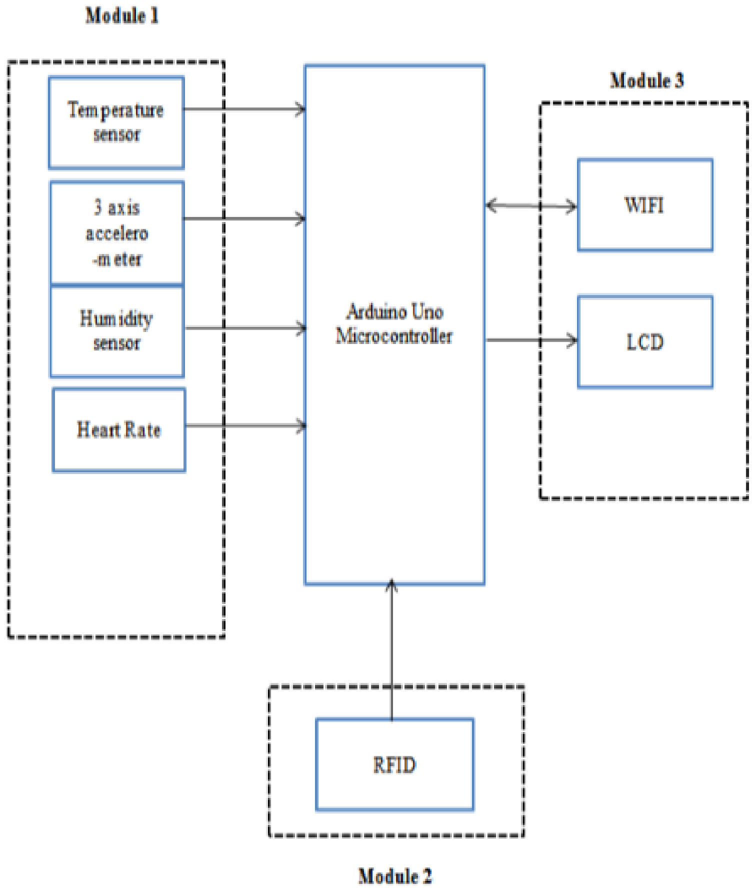


Fig. 30 – Diagram of the proposed “Livestock Barn Monitoring” system [18].

The normal and abnormal conditions are tabulated so that it is possible to assess if the values that the system is measuring are within the ideal intervals. For instance, if an animal’s body temperature is greater than 38.6°C, it is considered abnormal temperature, while if it is 38.6°C, it is normal.

As shown in Figure 30, the system contains a temperature sensor, MLX90614. This sensor is an infrared thermometer, and it measures a great amplitude of temperatures, from -40°C to 125°C. The 3-axis accelerometer (ADXL335) is used to measure the head movement of the cattle, and it is low power and of small dimension.

Bouazza *et al*. [68] present a Novel RFID System for Monitoring Livestock Health State. Their goal is to lower labor costs, enhance profits and improve productivity and animal health. Thus, they presented a health state monitoring system that makes use of telemetry and RFID. That system is constituted by an ear tag that has an integrated temperature sensor. This tag communicates with a local computer which has a RFID reader. They also developed dedicated software using VB.NET/SQL Server programming languages. A LED is used as a visual indicator, for instance, to identify a specific animal or health status. There are three possible states/colors, red (Alert), orange (In process of treatment) and green (normal state). Figure 31 shows a scheme of the system.

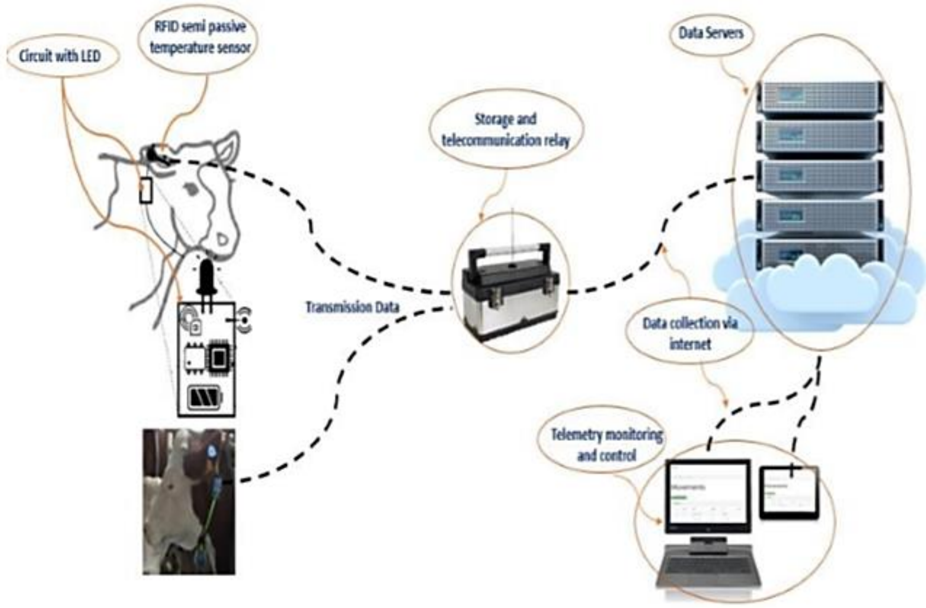


Fig. 31 – Illustration of the proposed "A Novel RFID System for Monitoring Livestock Health State" system [68].

Guo *et al.* [69] developed a research work devoted to animal behavior understanding using Wireless Sensor Networks. Their approach involves the development of wireless sensor networks in order to better understand and collect information about animal behavior so that they can ascertain the hypothesis that livestock can be controllable. They use various sensors that can assess information such as moving speed, location, temperature, and 3-axis acceleration and magnetometer values and a Fleck2 board. There is a diagram in Figure 32 that shows how the investigators classified animal's activities. It is divided into two main activities, barely moving (stationary state) and the existence of significant movement (Travelling state). One activity is shared between the two main ones because it is possible for an animal to be grazing while standing and walking.

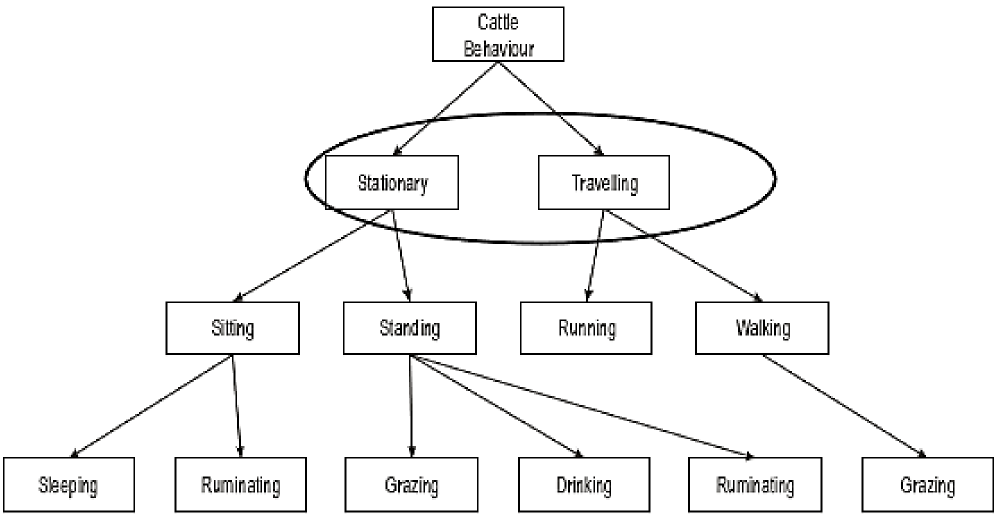


Fig. 32 – Diagram of the various livestock possible activities [69].

As shown in Figure 17 [8], regarding the angle definition of an animal possible movements, used to define body status, but instead of *Yaw*, they use the term "Heading" when referring to the *Z*-axis [69].

In order to determine the three angles during a Fleck2 rotation, it would be ideal to have two axes in parallel with the ground and the other downward, so they exemplify with the *X*-axis being downward, and *Y*-axis and *Z*-axis in parallel with the ground. When an animal uses the collar with Fleck2, the position isn't ideal, so in order to obtain the ideal orientation, the researchers applied a transformation so that it would rotate to the ideal position. For calculating ideal angles, it was assumed that the accelerometer value was [1 0 0] (x=1, y=0, z=0), and rotated to the average measurement of the current accelerometer value. After assessing the rotation angles, the rotation can be inverted so that the ideal position is discovered. The researchers conclude that it is better to use technology rather than individually analyze animal behaviour, since the proposed system is adjustable according to real-time data and it adapts to each animal [69].

2.3.4. Concluding notes

This section serves as a conclusion to observe how monitoring and control, i.e. the development of agriculture 4.0, can prevent the emergence of diseases and common anomalies, and warn the producer or farmer for timely diagnosis and treatment. As seen in Table 8, chapter 2.2, there are sensors for the various diseases, symptoms or observable signs. It can be concluded that a single sensor has several applications, namely the same sensor can help in the prevention or early treatment of disease because it is usually the first warning.

All these products, patents and academic projects have in common the objective of optimizing production, preventing diseases or harmful behaviors, thus improving animal and therefore human living quality. Table 9 gathers all the information and characteristics of systems and devices mentioned in sections 2.3.1, 2.3.2 and 2.3.3.

After exploring and studying in detail all the state of the art, it is clear that most projects do not make use of temperature sensors, and the application on other animals is not a priority. The majority uses accelerometers, GPS and identification. GPS has proven to be important not only in terms of behavior study but also because of a very common problem, that is animal theft [70]. While investigating, it also became clear that the reason behind temperature sensors not being used is the lack of accuracy due to the positioning difficulty of that type of sensor. The only reliable location in terms of accuracy is the animal rectum, so it is not comfortable for the animal to have its temperature measured in real-time and it is also an easy place for some movements to damage the sensor. Although thermal stress is a prevalent disease, temperature sensors will not be used in this dissertation's prototype since it is possible to rightly assess an animal's condition just by using heart rate and accelerometer, which are more accurate and provide more reliable information. Also, if one animal shows signs of disease, the temperature can be quickly measured directly by a person.

Some of those assumptions are mostly theoretical, since it would be very difficult to develop such systems for numerous reasons. For certain systems would become very expensive, and that is why in this dissertation the BITalino R-ioT board will be used, since it is a low-cost, yet tremendously reliable system. In chapter 3.2., the details on this board will be explored.

Table 9. Products, patents and academic projects overall characteristics.

	Collar/Bracelet	Ear tag	Heart rate assessment	Temperature assessment	Heat detection	GPS	Accelerometer	Animal identification	Alerts	Real-time information	Application on other species
Allflex [51]	No	Yes	No	No	No	No	No	Yes	No	No	Yes
IceRobotics [53]	Yes	No	No	No	No	No	Yes	No	No	No	No
MooMonitor+ [54]	Yes	No	*	No	Yes	No	Yes	Yes	Yes	Yes	No
Nkwari *et al*. [59]	*	*	No	No	No	Yes	*	*	Yes	Yes	*
Arbel [60]	Yes	Yes	*	*	*	Yes	Yes	Yes	Yes	Yes	Yes
Mobley [61]	No	Yes	*	*	*	*	*	*	Yes	Yes	*
Yaden [63]	No	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	*
Smith *et al*. [64]	No	Yes	Yes	Yes	No	Yes	Yes	*	Yes	Yes	Yes
Wang *et al*. [67]	No	No	No	No	No	No	No	Yes	No	Yes	*
Umega and Raja [18]	No	Yes	Yes	Yes	*	No	Yes	Yes	No	*	*
Bouazza *et al*. [68]	No	Yes	No	Yes	No	*	*	Yes	Yes	Yes	No
Guo *et al*. [69]	*	*	*	Yes	*	Yes	Yes	*	*	Yes	*

* Unkown/Not clear.

3. Prototype developing process

3.1. Introduction

In this chapter, all prototype components and its elaboration will be discussed. Some boards that were also capable of serving for this prototype will be mentioned, as well as the justifications for all the choices of software and hardware for this work. Although the electrical and electronical parts are extremely important, and the BITalino boards have emphasis, one cannot bypass the physical and biometric data. This chapter also includes the measures of animals, and how the belt and respective system will be placed.

3.2. Commercial hardware

There are many examples of available hardware, which could be chosen as part of the prototype.

3.2.1. Microcontroller boards

There is a large number of choices regarding microcontroller boards. For instance, Arduino boards only, have an extensive and diverse offer of boards, shields and also modules. Boards and modules differ in size, as modules are a smaller version of classic boards, and shields are elements that can be plugged onto a board in order to provide extra features. Figure 33 shows Arduino UNO, one of the best and most used boards in education since it is a very good board to begin learning and experiencing with electronics [71].

Fig. 33 – Arduino UNO board [71].

RaspberryPi [72] also provides suitable boards in terms of education. RaspberryPi 3 Model B+ (Figure 34) is the most recent board, and there are a lot of tutorials and other learning material available.

Fig. 34 – RaspberryPi 3 Model B+ board [72].

3.3. BITalino microcontrollers

BITalino provides low-cost options for researchers, or even just amateurs in the electrical and microelectronics area, to experiment and create prototypes. It possible to create wearable prototypes and perform several different tests with them. This is possible because there are various models of BITalino [17] microcontroller boards, with sensors capable of performing electrocardiogram (ECG), Electromyography (EMG), measure airflow, accelerometry, among others. Their advantages and disadvantages will be addressed in relation to the other microcontrollers that could be used in this project. Figure 35 shows an example of one of the available boards in the BITalino store.

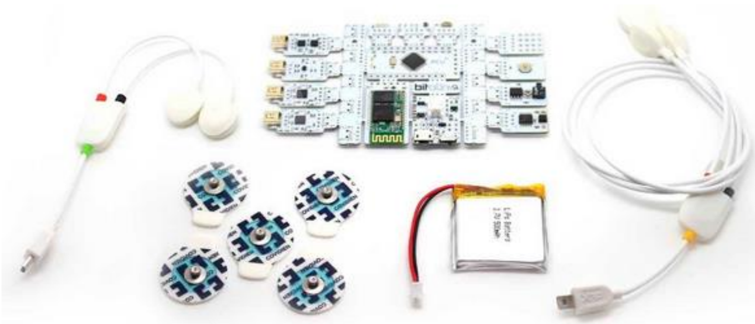


Fig. 35 – BITalino (r)evolution Board Kit BT [17].

The main objective of this work is to gather knowledge and tools to program a BITalino [17] to measure heart rate and accelerometry parameters of certain animals. As seen before in chapter 2.1., each species has its different normal parameters. Due to the real-time measuring characteristic of this device, it is possible to rapidly assess if an animal is healthy or not.

Heart rate (obtained with the ECG) and the accelerometry values, are the main parameters for the monitoring of animals in this work, and for the early diagnosis of possible physiological anomalies. This work required a thorough analysis and research in veterinary health vital signs in order to accurately predict and evaluate their condition.

After discussing with veterinarians, other important information and perspectives about the differences between individuals of the same species were obtained, providing insights that help selecting the components, such as sensors and actuators to be incorporated in BITalino [17]. As previously mentioned, this scientific area has a lot of interest and demand, so there are already some devices and creations that are similar to the objective of this work.

As was reported in chapter 2, monitoring vital signs for the early and timely evaluation of the presence of disease or other anomalies is crucial to the prosperity of a production. All monitoring systems focus on a system that brings together various components in order to obtain data on the most relevant physiological parameters.

The BITalino R-Iot [73], is a microcontroller that has all the characteristics for the feasibility of the experimental tests to be performed. With the accelerometer (ACC) sensor that is included in BITalino R-Iot, and by adding an ECG sensor (Figure 36), it is possible to obtain the movement values and patterns, and heart rate. Table 10 contains BITalino R-Iot's main characteristics [73]. By measuring the heart rate, it becomes possible to sketch a wide range of conclusions about the health state of the animal. This board also includes Wi-Fi communications capabilities, which allows for a superior range, which is an extremely useful feature. The other boards available in the BITalino store only have Bluetooth as a form of communication, which restricts the range. Figure 37 shows the BITalino R-Iot kit, which includes the board, a battery and a cable [73].

Fig. 36 – ECG Sensor [74].

Fig. 37 – BITalino R-Iot kit [73].

Table 10. BITalino R-Iot specifications [73].

BITalino R-Iot specifications	
Sampling rate	200 Hz
Communication	2.4 GHz WiFi
MCU	CC3200 80 MHz 36-bit ARM
Size	34x23x7 mm
Battery life	6 hours of runtime (minimum)

3.3.1. OpenSignals (r)evolution

OpenSignals (r)evolution is a software that has direct interaction with BITalino boards and allows the user to visualize signals in real-time. It is possible to acquire data from multiple channels and devices, record it and then load pre-recorded signals. The fact that it is possible to acquire data from multiple channels is a great, since it is important to analyze ECG and Accelerometry (ACC) data simultaneously. It is available for Windows, Mac OS X, Linux, and Android [17]. Figure 38 shows a window of this software.

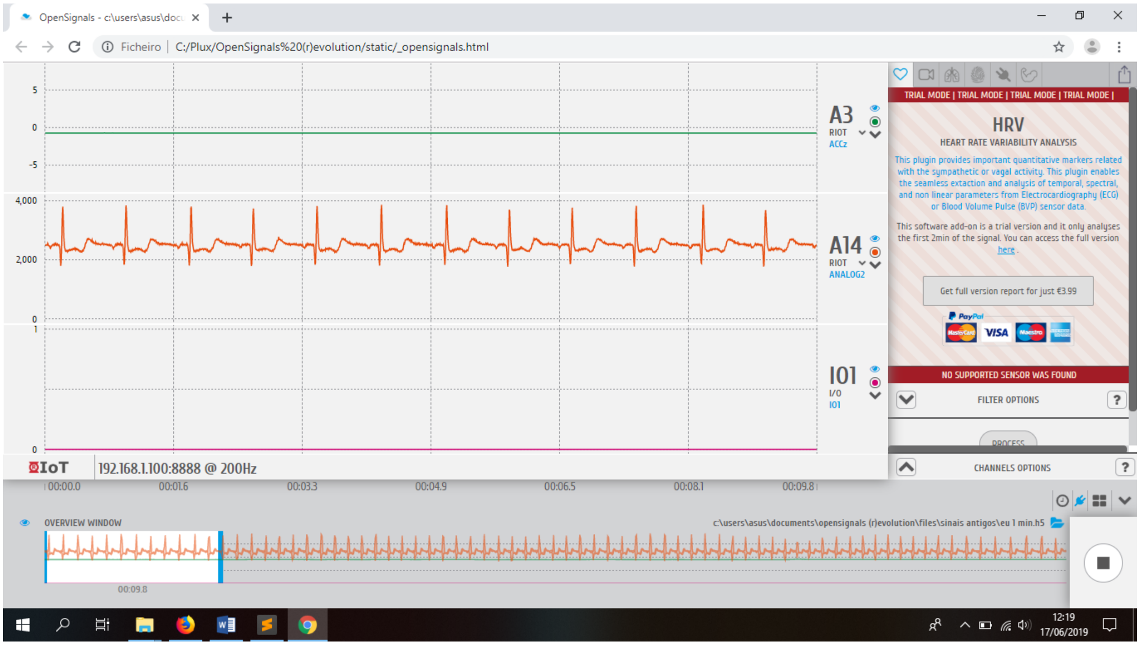


Fig. 38 - OpenSignals software with 2 acquisition channels for ECG and ACC [17].

3.3.2. ECG sensor

This sensor translates the heart's electrical signals that trigger heartbeats, into numerical values. After processing this signal, it is possible to know the animal's heart rate. As seen before, this is information is extremely useful. In Figure 39 there is an image of the sensor's physical dimensions. Some of its characteristics are explored In Table 11 [74].

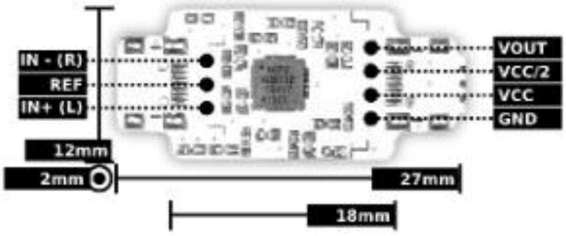


Fig. 39 – Physical dimensions of the ECG sensor [75].

Table 11. ECG sensor specifications [75].

ECG sensor specifications	
Gain	1100
Range	±1.5 mV (VCC = 3.3 V)
Bandwidth	0.5-40 Hz
Consumption	~0.17 mA
Input Voltage Range	2.0-3.5 V

3.3.3. Accelerometer sensor

One of the onboard sensors of the BITalino R-Iot is the triaxial Accelerometer. Although not being used in this work, it is also available one gyroscope and one magnetometer. When something moves, and in this case, it will be an animal, that motion can be translated into numerical values. By default, only the Z-axis on the Accelerometer (ACC) sensor is connected, but it is possible to connect the other axis. In this work, X and Y-axis will not be necessary, because only the Z-axis movement is relevant. This sensor is useful for many applications, such as biomechanics, tilt detection, monitoring activities, prototyping. Figure 40 shows the physical dimensions of this sensor and Table 12 its specifications [76].

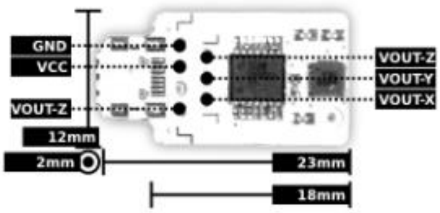


Fig. 40 – Physical dimensions of the ACC sensor [76].

Table 12. ECG sensor specifications [76].

ACC sensor specifications	
Range	±3 g
Bandwidth	0-50 Hz
Consumption	~0.35 mA
Input Voltage Range	1.8-3.6 V

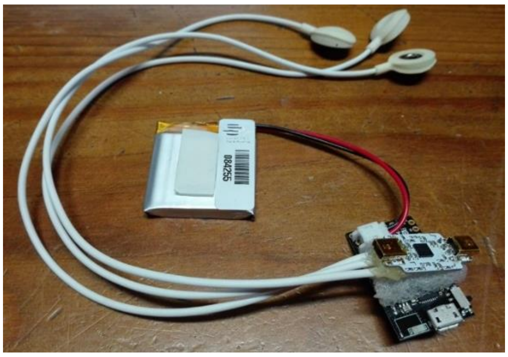
3.4. Microcontroller plus sensor

Since the microcontroller BITalino R-Iot does not include an onboard ECG sensor, it was necessary to include one in the system. That sensor can be bought separately to add to any other compatible microcontroller board. This sub-chapter contains the practical procedure of implementing the ECG sensor to the microcontroller, and also the necessary cables to connect the board with the electrodes. Figure 41 shows the sequence of the procedure.

a) Electrode cables, board and battery, and solding cables (from left to right).

b) Connection by welding of cables, of the A2, Ref, AVCC and GND in both the board and the ECG sensor.

c) Cable modification in order to correctly connect to the ECG sensor, also by welding.



d) All the components are connected and functional.

Fig. 41 – Assembling of the board, sensor and cables.

In Figure 41 a) it is possible to see several wires (on the right), but only four of those were used in the welding of both the board and sensor. As seen in Figure 41 c), it was necessary to modify the cables in order to make them open wired, so they could connect to the IN-, IN+ and Ref pins of the ECG sensor. Since they were multi-stringer cables, they required further treatment. Because they were coated with varnish and had to be welded so that they could lose their coating. Also in that figure, it is possible to see a piece of foam between the sensor and the board, which was added to protect against short-circuits. Finally, in Figure 41 d), all the components are welded, and the cables connected to the sensor were reinforced with glue, to protect against rupture caused by sudden movements and overall disturbances.

3.5. Belt positioning

According to veterinarians and researches [65], [76], [78], one of the best spots to assess both species heart rate is in the area near the animal's hearth-girth circumference. This is close to the heart, and therefore that is where the microcontroller box and sensors will be placed.

Figure 42 illustrates the heart-girth circumference in bovines and Figure 43 in equines. It is necessary to know each species range of heart-girth, i.e., the measurement that mostly matters to the prototype placement.

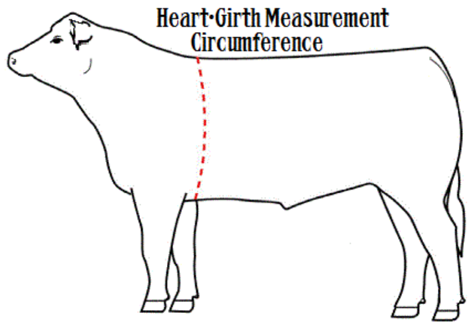


Fig. 42 – Illustration of heart-girth measurement circumference in bovines [79].

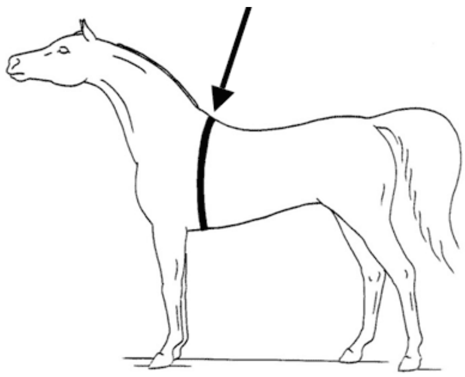


Fig. 43 – Illustration of heart-girth measurement circumference in equines [80].

This measurement is not only important for the prototype positioning but also to gauge the animal's weight, since the values of heart-girth/weight (estimated) are tabulated for bovines and equines. For dairy cattle there are no agreed upon tabulated values, but there is a large quantity of heart-girth/weight values for bulls. The tabulated range for bulls goes from 68 to 277 cm, and the weight from 30 to 1405 kg, respectively. In the equines' case, it goes from 76 to 197 cm, and the weight from 45.5 kg to 591 kg, respectively. In the equine case, the tabulated values are not as thorough as for bulls, still, it gives the owner a hint on the horse's weight. For dairy cattle it has to be calculated according to another measurement. Table 13 shows all the values for bulls [79], [81], [82] and Table 14 for equine [80], [83].

Table 13. Estimated heart-girth measurement/bull weight [79], [81], [82].

(cm)	(kg)	(cm)	(kg)	(cm)	(kg)	(cm)	(kg)	(cm)	(kg)	(cm)	(kg)	(cm)	(kg)	(cm)	(kg)
68	30	95	79	122	161	149	280	176	456	203	676	230	949	257	1211
69	31	96	82	123	164	150	285	177	463	204	685	231	959	258	1221
70	32	97	84	124	168	151	290	178	471	205	694	232	968	259	1231
71	34	98	87	125	172	152	295	179	478	206	703	233	978	260	1240
72	35	99	90	126	176	153	300	180	485	207	712	234	988	261	1250
73	36	100	93	127	180	154	305	181	492	208	722	235	998	262	1260
74	37	101	96	128	184	155	310	182	500	209	732	236	1007	263	1270
75	38	102	98	129	188	156	316	183	508	210	742	237	1017	264	1279
76	40	103	101	130	192	157	321	184	516	211	752	238	1027	265	1289
77	42	104	103	131	196	158	327	185	524	212	762	239	1036	266	1299
78	43	105	106	132	201	159	332	186	532	213	772	240	1046	267	1308
79	45	106	109	133	205	160	338	187	540	214	782	241	1056	268	1318
80	46	107	112	134	210	161	344	188	548	215	792	242	1066	269	1328
81	48	108	115	135	214	162	351	189	556	216	803	243	1075	270	1338
82	50	109	118	136	219	163	358	190	564	217	814	244	1085	271	1347
83	52	110	121	137	223	164	366	191	572	218	825	245	1095	272	1357
84	54	111	124	138	228	165	373	192	580	219	836	246	1104	273	1367
85	56	112	127	139	232	166	381	193	588	220	847	247	1114	274	1376
86	58	113	130	140	236	167	388	194	596	221	858	248	1124	275	1386
87	60	114	133	141	241	168	396	195	604	222	869	249	1134	276	1396
88	62	115	136	142	246	169	403	196	613	223	880	250	1143	277	1405
89	65	116	140	143	250	170	410	197	622	224	891	251	1153		
90	67	117	143	144	255	171	418	198	631	225	900	252	1163		
91	69	118	147	145	260	172	426	199	640	226	910	253	1172		
92	72	119	150	146	265	173	433	200	649	227	920	254	1182		
93	74	120	153	147	270	174	441	201	658	228	930	255	1192		
94	77	121	157	148	275	175	448	202	667	229	939	256	1202		

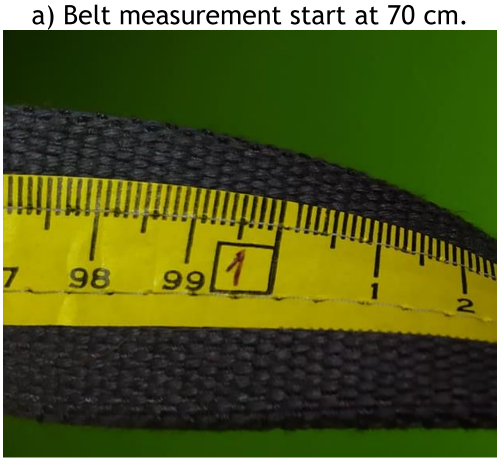
Table 14. Estimated heart-girth measurement/equine weight [83], [80].

(cm)	(kg)
76	45.5
102	91
116	136.5
128	182
140	227
148	273
156	318
164	364
171	409
178	455
185	500
192	545
197	591

The belt measurement starts at 70 cm, and the buckle that marks the measure is already accounted for in the total length. Since there were only available one-meter sticker measuring tapes, the belt is composed by three, and they were stitched together so there would be a greater adherence and resistance. In the beginning of the second and third tapes, there are the numbers 1 and 2, respectively, so that it is easier to assess the heart-girth.

Figure 44 shows the 70 cm start and the beginning of the second tape (a) and b) respectively), in which it is written the first meter of the whole belt. Figure 45 shows the heart-girth measurement of the horse from the experimental tests, and the green arrow indicates where to assess. As it is possible to see in the image, it has a heart-girth of approximately 183 cm.

a) Belt measurement start at 70 cm.

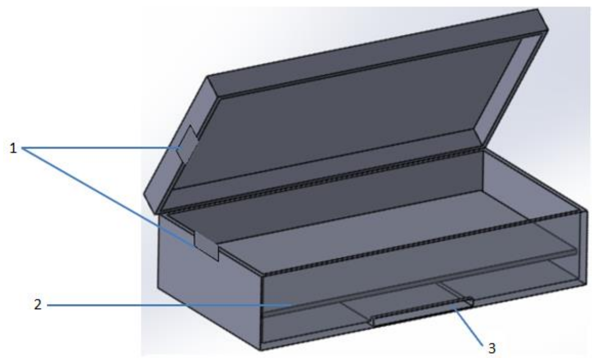


b) Mark of the first meter.
Fig. 44 – Belt marks.

Fig. 45 – Measurement of heart-girth measurement circumference in equine with prototype belt.

3.6. Microcontroller box

Figure 46 a) is a sketch of the box used for the prototype, with labels regarding each important detail. Label number (1) represents the two openings that make possible for the electrode cables to pass to the outside of the box. Number (2) is regarding the partition that does not let the microcontroller touch the bottom of the box. Lastly, number (3) consists of the opening that lets the belt go through, and because of number (2), there is no contact between the belt and the microcontroller, ensuring that it will not be damaged easily due to the belt positioning and oscillations, since it is better confined in the top division. Figure 46 b) shows the box, which is made of a resistant and flexible plastic. As it is possible to assess from the figure, the microcontroller stays on top, not touching the belt, and the cables pass through.



a) Sketch of the microcontroller box. b) Microcontroller box.

Fig. 46 – Microcontroller box.

3.7. Alert system

An email alert system is extremely helpful for the user. By using email as an alert, the user can receive it in various devices, such as smartphone, tablet or PC, and it is a reliable and fast form of communication.

This operation is possible because of a protocol, SMTP (Simple Mail Transfer Protocol). This is a transportation protocol, and it is used by all email servers, to send emails from one server to another. SMTP is a client/server procedure. One of the occasions in which it starts is when a client in a local network wants to send an email, using the local email server, to an address outside that local network [84].

SMTP is also a Python library, so it is possible to send emails automatically when there is an anomaly. Figure 47 illustrates the SMTP protocol procedure.

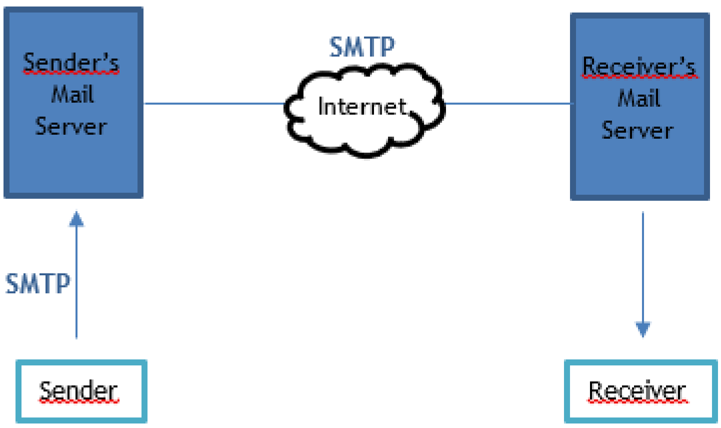


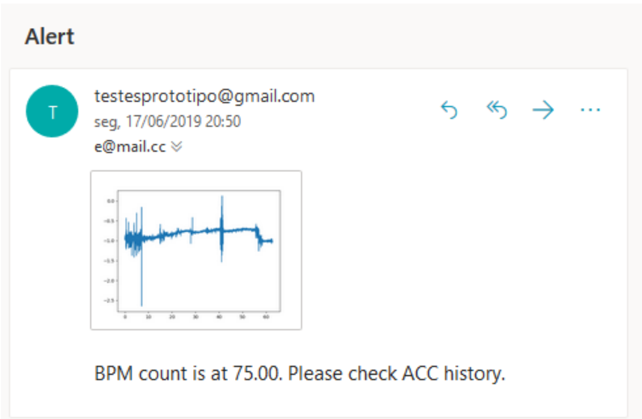
Fig. 47 – Illustration of the SMTP protocol procedure [85].

This section of the system is inserted in the part of the code that corresponds to the abnormality of values. As mentioned before, if the ECG values are not regular, an email will be sent with those and the ACC plot.

A new address was created for the prototype purpose, “testesprototipo@gmail.com”. This email address sends emails automatically to a predefined address that the owner/producer choses. For example, an email was sent to a personal account with the subject “Alert” and the content “BPM count is at 75.00. Please check ACC history.” in order to test the email alert system. It was given a value of to the variable “total_bat” just to test the alert content and functionality. Figure 48 shows the necessary code (the password is hidden), and the received email in each account mentioned earlier, a) and b), respectively.

```
plt.savefig('acc.png')

total_bat = 75

img_data = open('acc.png', 'rb').read()
msg = MIMEMultipart()
msg['Subject'] = 'subject'
msg['From'] = 'e@mail.cc'
msg['To'] = 'e@mail.cc'

text = MIMEText('BPM count is at %.2f. Please check ACC history. ' % total_bat)
msg.attach(text)
image = MIMEImage(img_data, name=os.path.basename('acc.png'))
msg.attach(image)

s = smtplib.SMTP("smtp.gmail.com", 587)
s.ehlo()
s.starttls()
s.ehlo()
s.login('testesprototipo@gmail.com', '[redacted]')
s.sendmail('testesprototipo@gmail.com','ritareigones@hotmail.com', msg.as_string())
s.quit()
```

a) Email sending code with SMTP [86].



b) Received email.

Fig. 48 - Email testing.

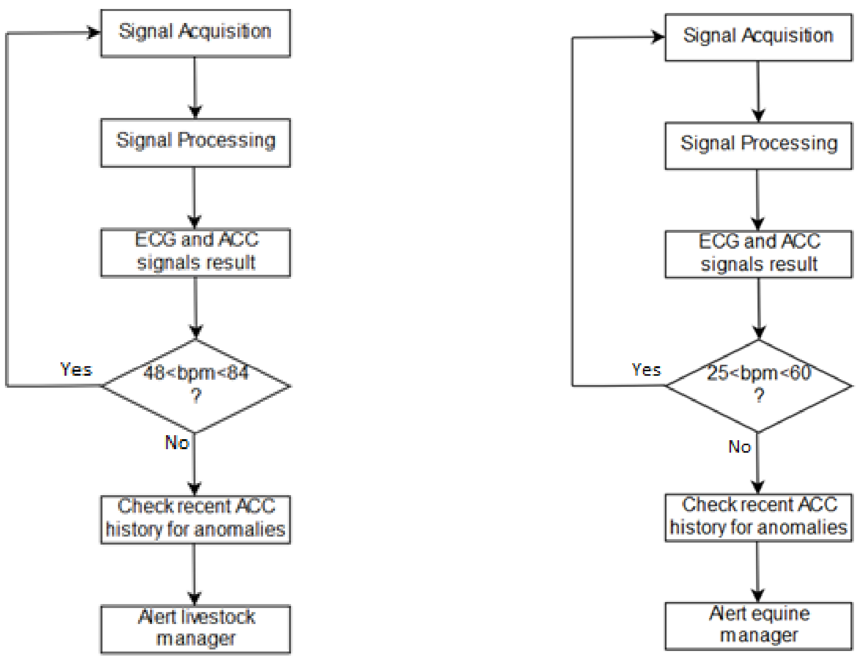
3.8. General operation

Overall, this system will function according to Figure 49. The difference between Figure 49 a) and b) is the BPM count, because the healthy values for bovines are different from the equine values.

As illustrated in Figure 49, the acquired signals are processed. When the signal is finally in the desired form, there is an R-peak count, which corresponds to the peaks in the QRS complex (part of the result of the ECG), and by that we have the heartbeat count. The processed signal can be programmed to assess the animal's condition whenever the owner desires, and in the duration that one finds appropriate. This is possible due to a functionality in the OpenSignals software, that allows a scheduling.

Regarding the ACC results, a graphic will be attached in the email with the past minutes of activity in case of abnormal heartbeat, since the ECG results are more illustrative of a possible problem then the ACC changes.

As seen in Figure 49, in case of anomalies, an alarm is sent via email to the bovine or equine manager, warning them of the specific case. For instance, if there is an equine with a higher heart rate than what is considered normal, the manager will receive the following email: "BPM count is at X. Please check ACC history.".



a) System for bovine parameters (while standing).

b) System for equine parameters (while standing).

Fig. 49 – Schemes for both species.

The operation represented in Figure 49 is extremely simplified. Inside each step there is a great quantity of operations considered specifically for this function. After the signal acquisition, the file is saved in a local folder and Google Drive. The saving in two different platforms is useful to storage an animal's history to check later if needed. In the local storage, after processing, the signal is automatically deleted so that there is no conflict between files. In order to save the information, all samples are saved in Google Drive so that no information is lost. The utilized code is available in Annex A.

4. Experimental Tests

The experimental tests of this project were performed on two animals, one from each species, bovine and equine. The bovine in this experiment is a female that was lactating at the time, and the equine is an active healthy male (Figure 50 and Figure 51, respectively). While the equine was not confined to any space, the bovine was in a milking station.

Fig. 50 –Bovine individual.

Fig. 51 – Equine individual.

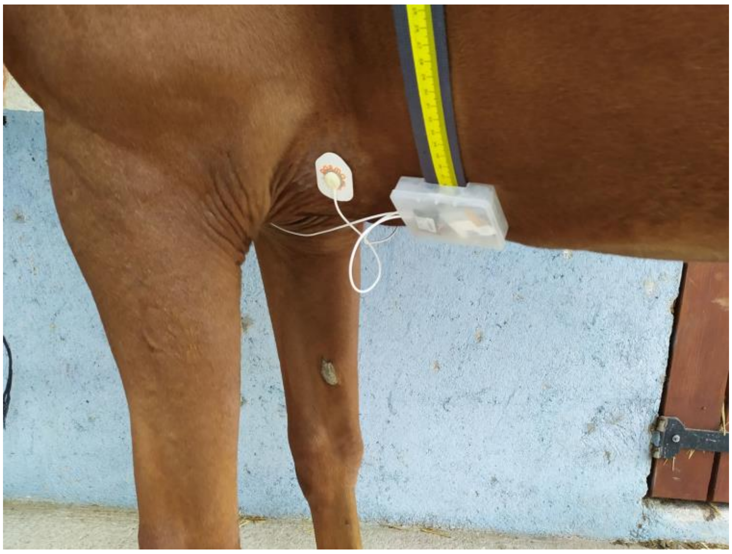
As previously mentioned in sub chapter 3.5, both species had similar positioning regarding the belt and electrodes [78]. Tricotomy was performed in both, and then that area was cleaned before placing the electrodes.

Regarding electrode placing, it was similar in both species, as seen in Figures 52 and 53. The positive electrode was on the left side of the animal and the negative one on the right side, both at the same height as the elbows. The Ref was placed on the animals' chest.

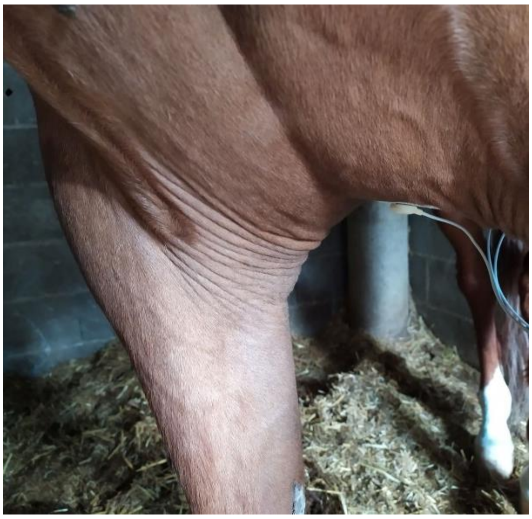
a) Electrode positioning before the belt adjustment.

b) Adjusted prototype. The heart-girth measure was 2.20 m.

Fig. 52 – Belt and electrode positioning for bovines.



a) Positive electrode on the left side.



b) Ref electrode on the chest.

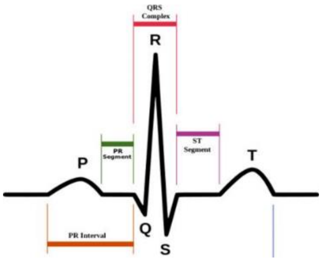
c) Negative electrode on the right.

Fig. 53 – Belt and electrode positioning for equines.

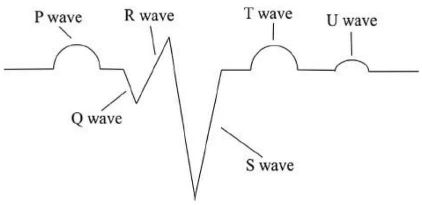
It is possible to see in Figure 53 a), a clearer part on the horse's skin, where the tricotomy was performed before the experimental tests. The bovine also had tricotomy performed but due to its stress and available space, pictures do not describe it so well as at the horse.

The belt measured 183 cm, as it shows in Figure 45 from sub-chapter 3.5, so the horse weights a little under 500 kg according to Table 14 from the same chapter.

In the case of horses and cows, ECG signals are quite different from human signals. In Figure 54 the three types are represented, and it is possible to notice that their QRS complex is different. In humans, under ideal signal conditions, the R wave is undoubtedly the most salient upwards. With this it is possible to count the BPM through algorithms that are generally used, including in this project. In the case of the animals under study, their QRS complex is different because this R wave does not take similar values as the R wave of humans. Due to the obvious differences, it is necessary to make some adjustments to the mechanism used to count valid peaks in equines. In bovines after several tests, results were equal with this selection and other so there is no need to apply it to them. Since there is a further peak of similar value after the highest and most relevant peak for equines, it is necessary to increase change the parameters of counting, so that only one is taken into account. In essence, most non-relevant ones can be ignored. This method is not infallible, but it proves to be useful and yields good results. In figure 55 are three examples of humans, cows, and horses, taken with OpenSignals [87]. The different QRS complexes are noticeable.



a) Normal human QRS complex [88].



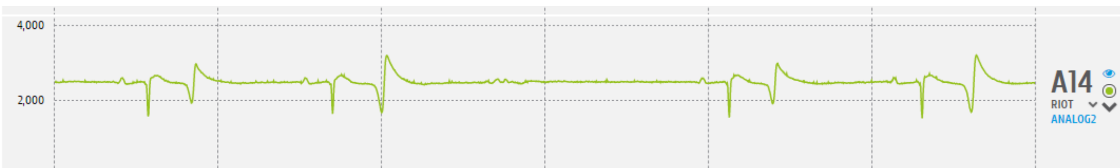
b) Normal bovine QRS complex [89].

c) Normal equine QRS complex [90].

Fig. 54 – Human, bovine, and equine QRS complexes.

a) Human ECG signal.

b) Bovine ECG signal.



c) Equine ECG signal.

Fig. 55 – Human, bovine, and equine (15 seconds) ECG signals acquired with OpenSignals.

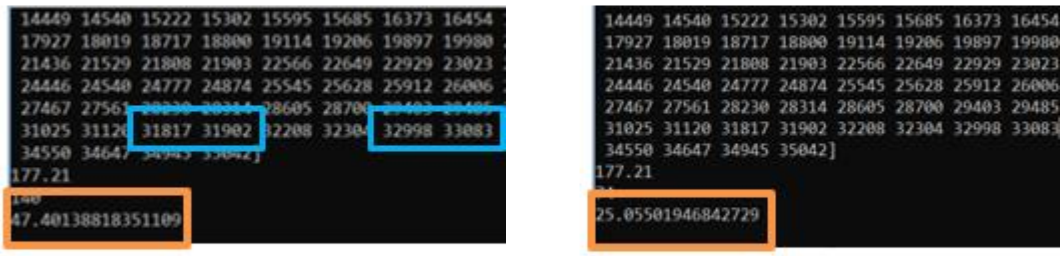
Figures 56 shows the process of changing the parameters of counting peaks. For bovines, this is not relevant since the peak selection works correctly. After filtering and processing signals with the standard algorithms, the array “definitive_peaks” is generated. There are all the distinguishable upward peaks that it is possible to see, as for example, in Figure 55 c). With the code in Figure 56, the “definitive_peaks” array is searched and the first sample containing a peak is saved in a new array called “final_peaks”. After the first peak, only if the next detected is at least 100 samples after the previous, it goes in the “final_peaks” array, and so on. The BPM count is produced with this last array.

This mechanism is necessary, and evidence shows that with it, BPM count is more accurate. In Figure 57 there is the BPM count difference, indicated in orange, from 47 to 25 BPM. The manual assessment of BPM was 30.

Part of the array “definitive_peaks” is above this result. That one is not changed, but it is noticeable that overall there is a difference of less than 100 samples in between each peak represented in that array. Indicated in blue color there are two pairs to serve as example of consecutive samples that prove that. There are less than 100 samples between the pairs 31817 and 31902, and 32998 and 33083.

```
#print(detected_peaks).
final_peaks = []
for i in range (0,len(definitive_peaks)-1):
    if definitive_peaks[i] > definitive_peaks[i+1] - 100:
        final_peaks.append(definitive_peaks[i])
        i=i+1
```

Fig. 56 – Peak selecting code.



a) BPM count before peak selecting. b) BPM count after peak selecting.

Fig. 57 – Peak selecting difference in final BPM count.

4.1. Bovines

On every experiment, the bovine was alone in a milking station, and showed obvious signs of stress. The manual assessments of heartrate were not always conclusive, but the bovine had higher heart rate than expected for a standing stance. As seen in Figure 53, the belt is correctly positioned in the heart-girth, and it marks 2.20 m.

In Figure 55 b), there is one of the extracted signals from the experiment, by the OpenSignals software. The signal is very clear and does not show noise, but as mentioned before the value of BPM with it is not usual. The most probable cause is the stress evidenced by the animal.

In Figure 58 is one of the extracted signals during the experiments. The ACC signal, represented by the A3 division, does not show evidences of relevant disturbance because, as mentioned before the animal was in the milking station so there was no chance for a great movement, noticeable by the ACC sensor. The abscises axis representing time shows a maximum of 15 seconds. Regarding the ECG signal, it is visible that the animal's heartrate was faster than what is usual. The manual assessment was not possible but the OpenSignals total acquisition showed 107 peaks in a 62 second acquisition. The BPM count was 102, so it was accurate.

Fig. 58 – ACC and ECG acquisition.

In Figure 59 is another acquisition, and the BPM count was 103. Regarding ACC activity, this experiment had more activity than the previous.

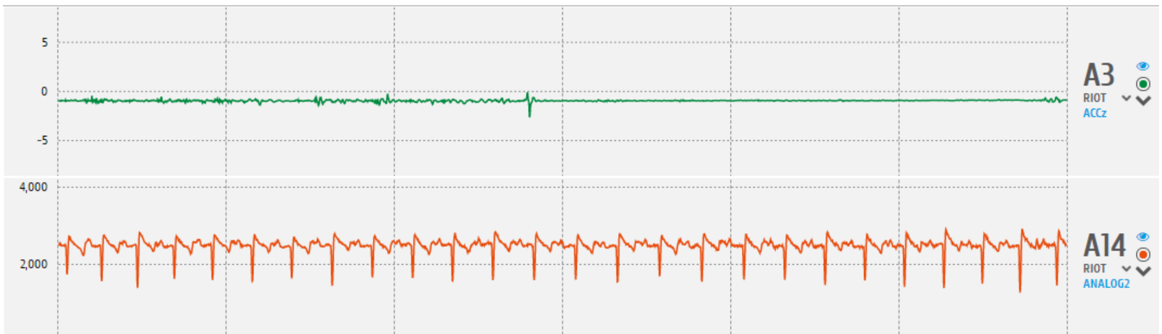


Fig. 59 – ACC and ECG acquisition.

4.2. Equines

The experimental tests on the horse were performed outside his stall. In the measurement shown in Figure 60, the manual assessment of the heartrate was 30 BPM. The individual was neither stressed nor agitated, so the ACC signal was very steady, as shown in channel A3. The ACC signal shows little alterations, and it is not relevant in this case because it was acquired in a controlled environment. The signal excerpt in Figure 60 corresponds to 15 seconds of a 3-minute total test, and the excerpt in Figure 61 is also 15 seconds and has 1 minute in total. The first one had a BPM count of 25, which is not accurate but close, regarding the manual assessment. In the second example, the manual assessment was also 30 BPM and the result was 24 BPM. All experiments were similar to these two examples.

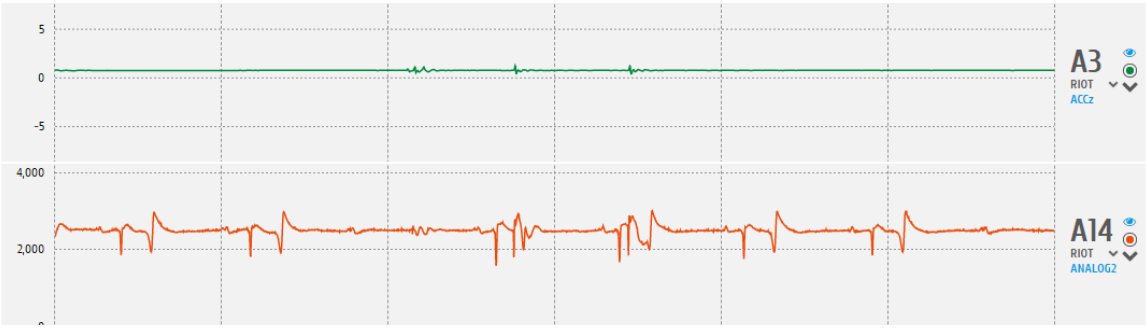


Fig. 60 – Equine ECG and ACC acquisition.

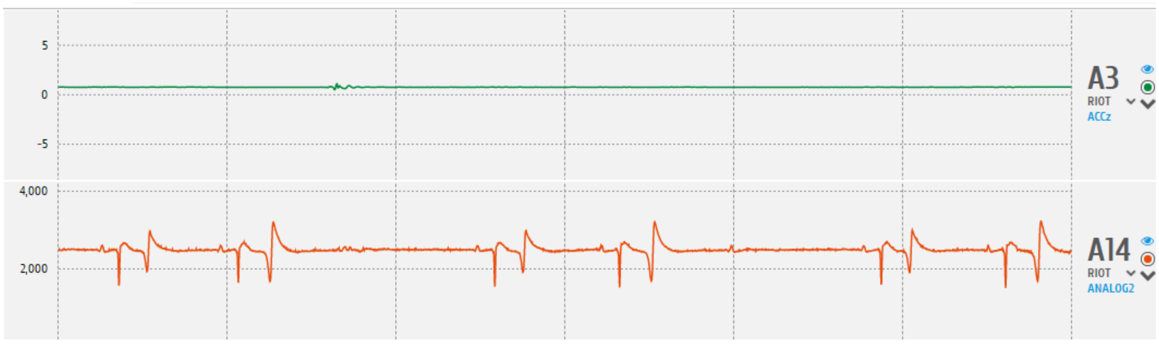


Fig. 61 – Equine ECG and ACC acquisition.

5. Final Results

The first trial in each species was taken without performing tricotomy, in order to have some comparison and prove that this is an advisable procedure. The conclusion was that it is recommended since the obtained values did not correspond to the expectation of normal results. Usually the values were different to what was expected in both species, especially bovines. Figure 62 shows an example of what was one of the acquired equine signals without tricotomy. The resulting BPM was 5.

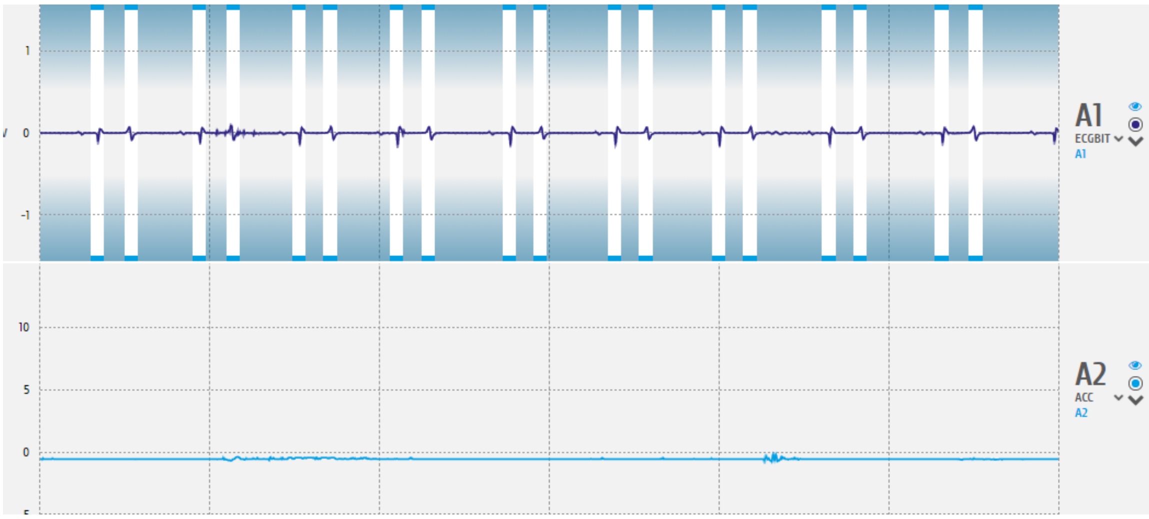


Fig. 62 – ECG and ACC acquisition without tricotomy in an equine.

10 tests were performed in bovines, and 16 on equines. With these tests it is only possible to state that there are some deviations of values when measured manually. Most of the values, if they were to correspond to manual assessment, it would not be worrying. Thus, the upper and lower limit values are marked with a value suitable for possible deviations, since this system assesses lower values than reality. In this case for cattle, the low and high ECG limits are 40 and 90, and in equines, 20 and 65, respectively.

The ideal conditions for improving the algorithm and its adjustment require further experiment in more animals of both species. That was not possible, and especially on bovines, the environment should be adjusted to a calmer situation.

The email alert works correctly, as well as the ability of the system to send ACC results with the alert issuing. Figure 63 shows an example of an ACC plot result, from the experiment presented in Figure 61. In Figure 64 there is an example of this functionality, with the experiment from Figure 59.

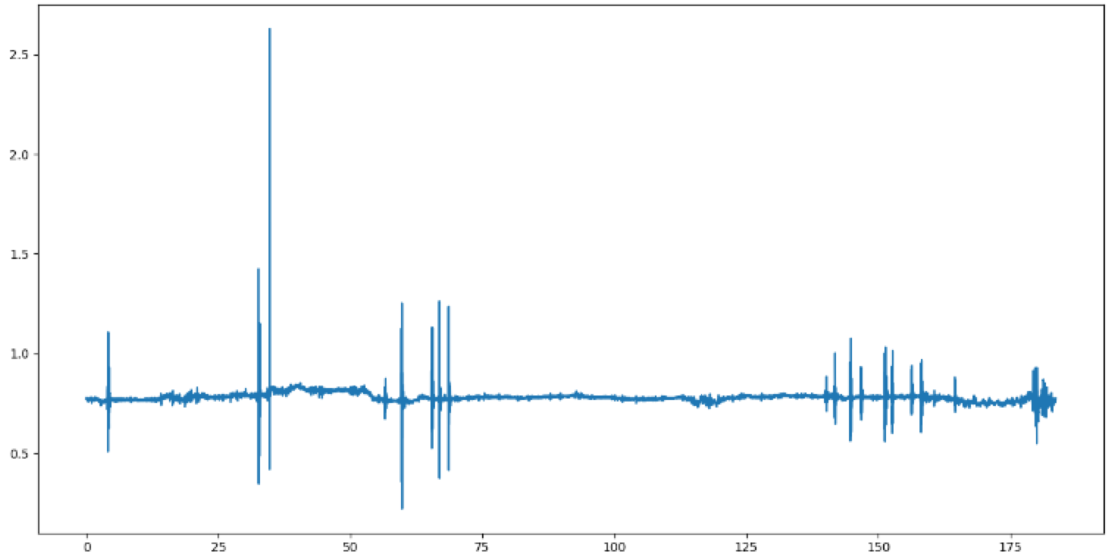


Fig. 63 – ACC plot, X-axis corresponds to time in seconds and Y-axis to acceleration in gravity (g).

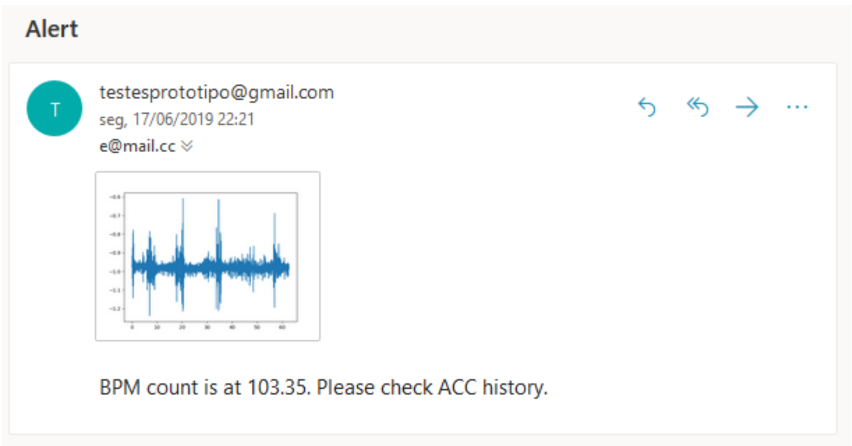


Fig. 64 – Example of alert sent when running the acquisition from Figure 59.

5.1. Concluding note

The adjustment and algorithm that collects and stores the ECG signal and performs BPM count needs some regulation. Further tests must be performed in more individuals so that an average value or a threshold can be traced, in order to obtain more accurate results. Once that calibration is improved, the system will be more precise.

Everything else in the proposed system is working correctly and meets the project expectations.

6. Conclusions

6.1. General Conclusion

Implementing a monitoring system becomes a long-term advantage for any production. Diseases such as hypocalcemia result in loss of profit, because even before the animal begins to produce, it contracts this disease. With the possibility of predicting and preventing the pathologies that take the most profit and animal lives, producers feel the need to adhere to such a system. With an intuitive and accurate application such as the proposed system, many losses will be prevented, through an early and preventive evaluation.

If the proposed system does not require expensive upgrades or other details that require investment apart from the initial cost, producers will more easily use these systems. With the research needed for this project, a pattern of concern has arisen for users to acquire a system that needs recurrent updates because it is not only inconvenient for individuals who do not dominate the technology area, but often adds costs. On several occasions, producers and veterinarians have become aware of this particular system, and the general reaction is of interest and willingness to purchase for their production id it had a reasonable value. Since the aim is not to use all of the production simultaneously, but rather to those whose contraction of disease is most likely to be recognized, it is recognized that it would not be too costly.

As discussed in the first chapter, agriculture 4.0 is the approach to follow as it is comprehensive in both environmental and economic advantages. The adoption of these methods is useful and beneficial to all. The losses recorded per year at global level could be closed and production will be optimized through monitoring.

6.2. Future work suggestions

The adding of a GPS and temperature assessing features, are factors that should still be studied in depth for a follow-up of this project. Also, a profound study of ACC parameters and alterations is extremely valuable to a full assessment of an animal's state. All these will be crucial parameters for an accurate assessment of the overall picture of a production. Several producers have shown interest in this kind of system, since most of their economic losses come from theft or disease. By adding a positioning characteristic to this prototype, most producers' problems would be solved.

Ideally, as system of this kind is in form of a belt or collar, non-invasive, that provides information in real time and alerts the producer of the state of health and location of his animals. Most of those parameters are fulfilled, so the main objective is to improve this system until it becomes an optimal and marketable product.

Adding to the board's components the ability to measure body temperature and a tracking system such as GPS, there is a system that checks the most important factors for an early diagnosis and for a correct prevention of theft.

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Annex A

Most of the utilized code was made available by Biosignals Notebooks, from Biosignals Plux [91].

This first program is used for equines, since it has the peak selection, and the alarming values are over 65 or under 20.

```
from pylab import *
from biosppy.signals import ecg
import numpy as np
from scipy import signal
import biosignalsnotebooks as bsnb
import heartpy as hp
from ast import literal_eval
import warnings
from numpy import loadtxt, linspace
import smtplib
from email.mime.multipart import MIMEMultipart
from email.mime.text import MIMEText
from email.mime.image import MIMEImage
import glob
import os

while True:
       if len(os.listdir('/Users/Asus/Desktop/saved') ) != 0:
              input()
              list_of_files = glob.glob('/Users/Asus/Desktop/saved/*') # * means all if
need specific format then *.csv
              latest_file = max(list_of_files, key=os.path.getctime)
              #print (latest_file)


              #input()
              sr=200  #sample rate
              data = loadtxt(latest_file)[:,-1]
              out = ecg.ecg(signal=data, sampling_rate=sr, show=True)
              show()

              # Step 1 of Pan-Tompkins Algorithm
              filtered_signal = bsnb.detect._ecg_band_pass_filter(data, sr)
              # Step 2 of Pan-Tompkins Algorithm
              differentiated_signal = diff(filtered_signal)
              # Step 3 of Pan-Tompkins Algorithm
              squared_signal = differentiated_signal * differentiated_signal

              time = bsnb.generate_time(squared_signal, sr)
              plot(time, squared_signal)
              out = ecg.ecg(signal = squared_signal, sampling_rate=sr, show=True)
```

```
                nbr_sampls_int_wind = int(0.080 * sr)

                integrated_signal = zeros_like(squared_signal)

                cumulative_sum = squared_signal.cumsum()

                integrated_signal[nbr_sampls_int_wind:] =
(cumulative_sum[nbr_sampls_int_wind:] - cumulative_sum[:-nbr_sampls_int_wind]) /
nbr_sampls_int_wind
                integrated_signal[:nbr_sampls_int_wind] =
cumulative_sum[:nbr_sampls_int_wind] / arange(1, nbr_sampls_int_wind + 1)

                rr_buffer, signal_peak_1, noise_peak_1, threshold =
bsnb.detect._buffer_ini(integrated_signal, sr)
```

```
                probable_peaks, possible_peaks=
bsnb.detect._detects_peaks(integrated_signal, sr)
                definitive_peaks = bsnb.detect._checkup(probable_peaks,
integrated_signal, sr, rr_buffer, signal_peak_1, noise_peak_1, threshold)
                # Conversion to integer type.
                definitive_peaks = array(list(map(int, definitive_peaks)))

                map_integers = definitive_peaks - 40 * (sr / 1000)
                definitive_peaks_reph = array(list(map(int, map_integers)))

                detected_peaks = bsnb.detect_r_peaks(data, sr, time_units=True,
plot_result=True)


                print(detected_peaks)
                final_peaks = []
                for i in range (0,len(definitive_peaks)-1):
                        if definitive_peaks[i] > definitive_peaks[i+1]-100:
                                final_peaks.append(definitive_peaks[i])
                                i=i+1


                time = bsnb.generate_time(data, sr)
                ultimo=time[-1]
                print(ultimo)
                minutos=ultimo/60
                numero_bat=len(final_peaks)
                print(numero_bat)

                total_bat=numero_bat/minutos

                print(total_bat)

                if (20 > total_bat or total_bat > 65):
                        dataacc = loadtxt(latest_file)[:,2]
                        time2 = bsnb.generate_time(dataacc, sr)

                        plot(time2,dataacc)

                        plt.savefig('acc.png')

                        img_data = open('acc.png', 'rb').read()
                        msg = MIMEMultipart()
                        msg['Subject'] = 'Alert'
                        msg['From'] = 'e@mail.cc'
                        msg['To'] = 'e@mail.cc'

                        text = MIMEText('BPM count is at %.2f. Please check ACC history. '
% total_bat)
                        msg.attach(text)
                        image = MIMEImage(img_data, name=os.path.basename('acc.png'))
                        msg.attach(image)

                        s = smtplib.SMTP("smtp.gmail.com", 587)
                        s.ehlo()
                        s.starttls()
                        s.ehlo()
                        s.login('testesprototipo@gmail.com', 'teste1232!')
                        s.sendmail('testesprototipo@gmail.com','ritareigones@hotmail.com',
msg.as_string())
                        s.quit()


                os.remove(latest_file)
```

The code utilized for bovines is very similar, except the alarming values are 40 and 90, and it does not need the peak selection code, which is the following:

```
print(detected_peaks)
final_peaks = []
for i in range (0,len(definitive_peaks)-1):
        if definitive_peaks[i] > definitive_peaks[i+1]-100:
                final_peaks.append(definitive_peaks[i])
                i=i+1
```

Since for bovines the array “final_peaks” is not necessary, the array later used to count BPM is “definitive_peaks”.