Real-Time Vital Signs Monitoring System Towards Livestock Health Furtherance

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Abstract— **The application of information and communication technologies & electronics (ICTE) in agriculture has proved to be very efficient and revolutionary. With the adoption of increasingly efficient and modern technologies, the competitiveness and production in agriculture activities is carried out in a more sustainable way. Precise positioning and geolocation, geographic mapping, sensors and communication systems are tools that help the development of a complete and accurate system for livestock monitoring. This paper includes the proposal for a cattle or equine ICTE-based monitoring system 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.**

Index Terms—**Agriculture 4.0, Production, Efficiency, Productivity, Accelerometry, Heart Rate.**

I. INTRODUCTION

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].

According to FAO [6], 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 [7]. Increasing productivity in developing countries is crucial for production optimization and efficiency, as well as for improving the quality and safety of food produced [6].

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], [8]. This paper describes an application 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 [7], [9].

Agriculture is now facing the 4th revolution (Agriculture 4.0), integrating information and communication technologies & electronics (ICTE) into traditional agricultural practices. Technologies such as Remote Sensing, Internet of Things (IoT), Unmanned Aerial Vehicles (UAVs), Big Data Analytics (BDA) and Machine Learning (ML) are particularly promising and can offer innovative solutions in agricultural practices. A wide range of agricultural parameters can be monitored in smart farming applications to improve productivity, reduce costs and optimize processes. IoT sensors and technologies such as wireless sensor networks, cloud computing, big data, security protocols and architectures, communication protocols, have a large potential in the field of agriculture [10], [11], [12]. Several applications in this sense can be highlighted, such as devoted to real time monitoring using IoT [13], to enhance smart and sustainable agriculture [14], its recent advances and future challenges [15], precision farming and food manufacturing [16], and sensors mesh for monitorization of intrinsic and extrinsic parameters in large-scale orchard [17]. In terms of livestock, precision livestock farming has been used to improve the economic, social and environmental sustainability of livestock practices through the animal monitoring and control [18]. The real-time vital signs monitoring of livestock is then relevant to their health furtherance. As example, thermal stress limits the metabolic efficiency. This condition leads to annual economic losses around 802 and 330 M€ for dairy and field cows, respectively [19]. Regarding the economic influence of mastitis, Canadian dairy producers lose about 300 M€/year. This illness also affects milk production [20]. Some diseases can be notices through the evaluation of the heartrate of an individual. Table I shows the resting heart beats per minute on some species [21]. Accelerometry (ACC) has to be further studied in this work, on how each pattern can be a symptom of a disease or the beginning of it. Still, the alarm that will be discussed later, contains the accelerometry history in it. Table II shows the most suitable sensors, Accelerometer (ACC), Temperature or Electrocardiogram (ECG) for each of the common diseases, such as mastitis and laminitis, based on the anomalous behavior or physiological changes [22].

TABLE I
NORMAL RANGE OF RESTING HEARTBEAT PER MINUTE IN SOME SPECIES [21].

Species	**Heartbeats per minute (BPM)**
Dairy cow	48–84
Horse	25-60
Goats	70–80
Sheep	70-80
Pigs	70–120

TABLE II
SUITABLE SENSORS FOR EACH TYPE OF ABNORMALITY [22].

	Abnormality	**Anomalous Behaviors / Physiological Changes**	**Sensor**
Bovine cattle	**Thermal stress**	Less activity/Discomfort	ACC
		Abnormal body temperature	Temp
	Laminitis	Changes in locomotion	ACC
		Abnormal heart rate	ECG
	Mastitis	Less production	ACC
	Hypocalcemia	Movement alterations	ACC
		Increase in heart rate (approx. 100 BPM)	ECG
Equine cattle	**Colic**	Increase in heart rate (approx. 60 BPM)	ECG
		Movement alterations	ACC
	Laminitis	Movement alterations	ACC
	Fertility	Movement alterations	ACC

II. PROTOTYPE DEVELOPMENT AND TESTING

The prototype development and testing of a vital signs monitoring device for livestock (bovine and equine) followed the block diagram shown in Figure 1. Before setting the device specifications, an analysis of the state of the art allow defining the common technological base between different patents, prototypes and products on market. Table III shows the crossed information regarding monitoring systems. It was possible to conclude, among other requisites, that GPS is important in various areas to prevent theft, and that the ear tag is largely used. The expected specification for the system to be developed are also included in Table III.

Hardware (HW) and software (SW) specifications were set. Then, it was defined how to hold and position the device on the animal. The holding system as well as the position of the device were set to reduce the discomfort of the animal as well as to be able to ensure reliable measurements. The experimental tests measured the value of ACC and ECG, which can be related to anomalous behaviors or physiological changes and consequently attributed to some of the illnesses shown in Table II. This prediction capability is the main novelty of this device.

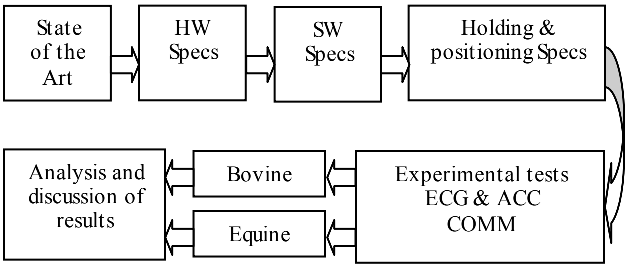


Fig. 1. Work flow diagram of the prototype development and testing.

A. Hardware specifications

First, the microcontroller (MCU) must be selected. There is a large number of choices regarding MCU boards. Based on the HW requisites for the system, the MCU selected for this prototype was the BITalino R-IoT [35], [36]. This specific model has Wi-Fi, simplifying and extending the communication part of the system. This model includes a Triaxial Accelerometer (ACC), a Triaxial Gyroscope (GYR) and a Triaxial Magnetometer (MAG). However, it does not include by default an ECG sensor, which is crucial for animals' heartrate to assessment. An ECG sensor with electrodes was then added to the system [37].

TABLE III
OVERALL CHARACTERISTICS OF PRODUCTS, PATENTS AND ACADEMIC PROJECTS.

	Collar/ Bracelet	**Ear tag**	**Heart rate assessment**	**Temperature assessment**	**Heat detection**	**GPS**	**Accelerometer**	**Animal identification**	**Alerts**	**Real-time information**	**Application on other species**
Allflex [23]	No	Yes	No	No	No	No	No	Yes	No	No	Yes
IceRobotics [24]	Yes	No	No	No	No	No	Yes	No	No	No	No
MooMonitor+ [25]	Yes	No	*	No	Yes	No	Yes	Yes	Yes	Yes	No
Nkwari *et al.* [26]	*	*	No	No	No	Yes	*	*	Yes	Yes	*
Arbel [27]	Yes	Yes	*	*	*	Yes	Yes	Yes	Yes	Yes	Yes
Mobley [28]	No	Yes	*	*	*	*	*	*	Yes	Yes	*
Yaden [29]	No	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	*
Smith *et al.* [30]	No	Yes	Yes	Yes	No	Yes	Yes	*	Yes	Yes	Yes
Wang *et al.* [31]	No	No	No	No	No	No	No	Yes	No	Yes	*
Umega and Raja [32]	No	Yes	Yes	Yes	*	No	Yes	Yes	No	*	*
Bouazza *et al.* [33]	No	Yes	No	Yes	No	*	*	Yes	Yes	Yes	No
Guo *et al.* [34]	*	*	*	Yes	*	Yes	Yes	*	*	Yes	*
This project	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Unkown/Not clear.

A sketch of the proposed system is shown in Figure 2.

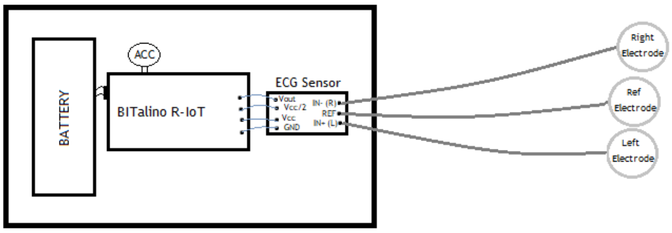


Fig. 2. Sketch of the prototype: MCU, ACC, ECG, electrodes and battery.

The ECG sensor (1) with electrodes (2) was welded to the BITalino R-IoT (3) to assess movement alterations and BPM, as shown in Figure 3. The device is powered by a Li-Po Battery with 700 mAh (4). Considerations concerning the energy management for wireless sensor networks can be found in [38].

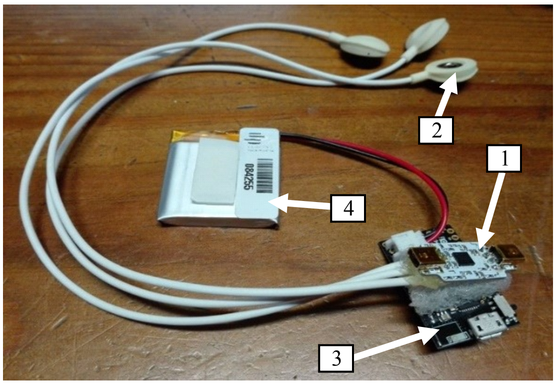
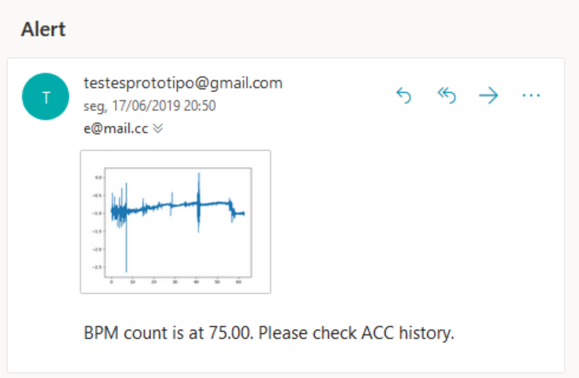


Fig. 3. Welded cables and ECG sensor to BITalino R-IoT.

B. *Software specifications*

The software used was OpenSignals [39], also developed available by Plux, in order to ensure compatibility. The system will send an alert to the livestock producer if the measured values are not expected for a healthy animal. A test was performed generating an abnormal value for horses (75 BPM). Figure 4 shows the result of test where an email is sent to the producer. That email includes the BPM count that set the alarm and a picture of the ACC history.



Alert

testesprototipo@gmail.com
seg, 17/06/2019 20:50
e@mail.cc

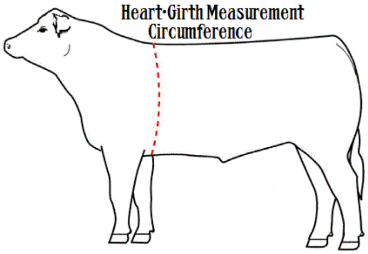
BPM count is at 75.00. Please check ACC history.

Fig. 4. Received email after testing.

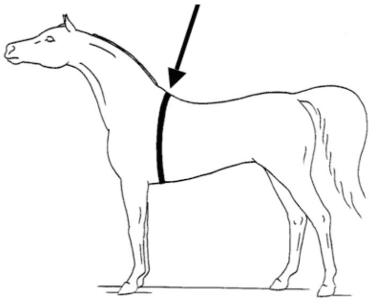
The overall operation of the system consists firstly in acquiring the signal by software OpenSignals, then the file is saved both in a cloud and in a local folder. After processing, the file is automatically deleted from the local folder. If the values are considered normal, the system waits for another acquisition, if not, an email is sent.

C. *Holding and positioning system specifications*

The area near the heart-girth circumference of the animals shown in Figure 5 is the best spot to assess heart rate according [24], [25], [26]. The prototype is hold onto the animal through a belt in this site. This spot is also useful to estimate the weight of some species, since values relating heart-girth and weight are tabulated for horses and bulls. In fact, the horse that was tested in this work had 183 cm of heart-girth, which means that the animal weights roughly 500 kg [40].



(a) Bovines.



(b) Equines.

Fig. 5. Heart-girth measurement circumference in equines [40].

The box that contains the MCU and that it is attached to the belt is illustrated in Figure 6.

Fig. 6. Sketch of the microcontroller box with belt holder.

III. EXPERIMENTAL TESTS

The experimental tests were performed on two animals, one from each species, bovine and equine. The bovine was in a milking station and the equine was not confined to any space. Figure 7 show both animals.

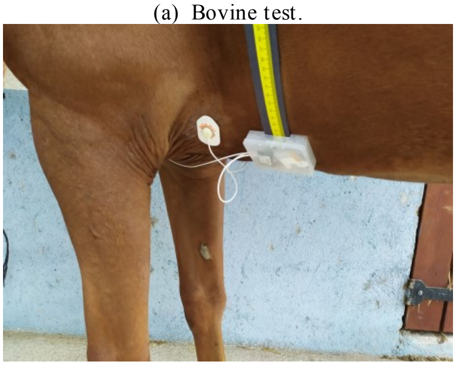
(a) Bovine individual.

(b) Equine individual.

Fig. 7. Test animals.

The belt was placed in the heart-girth area as mentioned before, but the three electrodes have a specific position. The electrodes position in the animal consists of the positive one in the left side behind the hand, the neutral in the chest area, and the negative in the right side. Figure 8 show the animals with the belt. Figure 8(a) shows also the electrode position in the bovine, before the belt was tightened. Figure 8(b) shows clearly one of the electrodes placed in the equine.

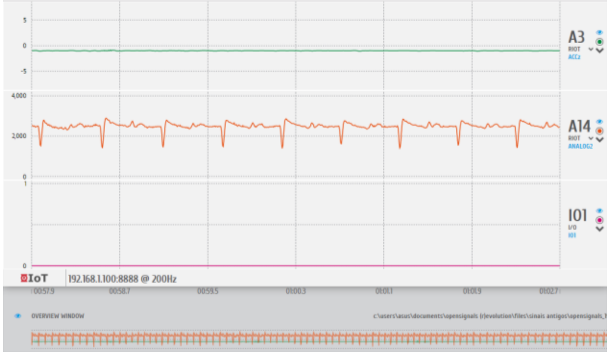
(a) Bovine test.



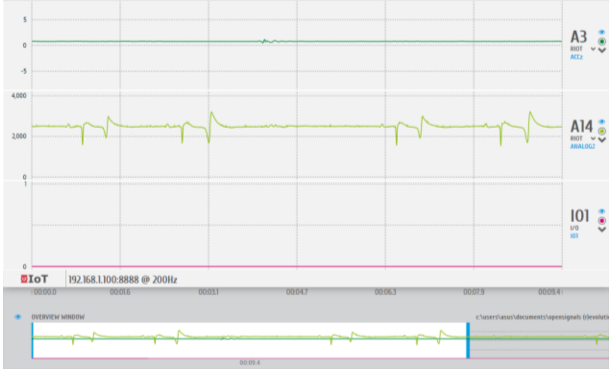
(b) Equine test.

Fig. 8. Belt and electrodes positioning.

It was noticed during the signal processing task that the equines measurement values were not correct. The difference in the results is due to the differences between QRS complexes in horses, humans and cows. For humans and cows, even though they are quite different, it does not interfere. It was necessary to have some adaptations in the developed algorithm, so that it could work for both species, bovines and equines. Figure 9 show the different ECG signals, acquired with OpenSignals for bovines and equines, respectively.



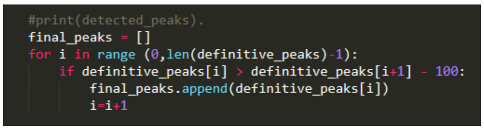
(a) Bovine.



(b) Equine.

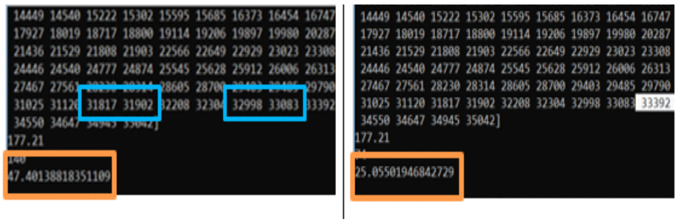
Fig. 9. Normal ECG signal.

Figure 10 contains the MCU code for the system work for both species. In the bovine (and human case, there was only necessary the "definitive_peaks" array. For equines, the system counts two R-peaks instead of one, because of the shape of the signal. Since the second peak (the one that it is not real) is less than 100 samples away from the first, the algorithm in Figure 10 creates the array "final_peaks" and saves only the first peak. Figure 11(a) shows the BPM count before the peak selecting (47.40) and Figure 11(b) shows it after (25.05). The rectangles in blue show the sample pairs that duplicate R-peaks. Only the first R-peak is counted with this algorithm.



```
#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. 10. Peak selecting code.



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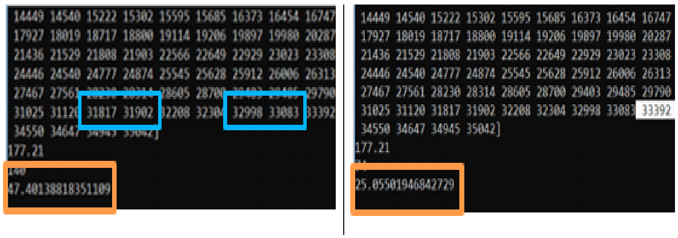
14449 14540 15222 15302 15595 15685 16373 16454 16747
17927 18019 18717 18800 19114 19206 19897 19980 20287
21436 21529 21808 21903 22566 22649 22929 23023 23308
24446 24540 24777 24874 25545 25628 25912 26006 26313
27467 27561             28605 28700             29790
31025 31120 31817 31902 32208 32304 32998 33083 33392
34550 34647 34945 35042]
177.21
140
47.40138818351109
```

```
14449 14540 15222 15302 15595 15685 16373 16454 16747
17927 18019 18717 18800 19114 19206 19897 19980 20287
21436 21529 21808 21903 22566 22649 22929 23023 23308
24446 24540 24777 24874 25545 25628 25912 26006 26313
27467 27561 28230 28314 28605 28700 29403 29485 29790
31025 31120 31817 31902 32208 32304 32998 33083 33392
34550 34647 34945 35042]
177.21
25.05501946842729
```

(a) Before peak selection.



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14449 14540 15222 15302 15595 15685 16373 16454 16747
17927 18019 18717 18800 19114 19206 19897 19980 20287
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24446 24540 24777 24874 25545 25628 25912 26006 26313
27467 27561             28605 28700             29790
31025 31120 31817 31902 32208 32304 32998 33083 33392
34550 34647 34945 35042]
177.21
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14449 14540 15222 15302 15595 15685 16373 16454 16747
17927 18019 18717 18800 19114 19206 19897 19980 20287
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27467 27561 28230 28314 28605 28700 29403 29485 29790
31025 31120 31817 31902 32208 32304 32998 33083 33392
34550 34647 34945 35042]
177.21
25.05501946842729
```
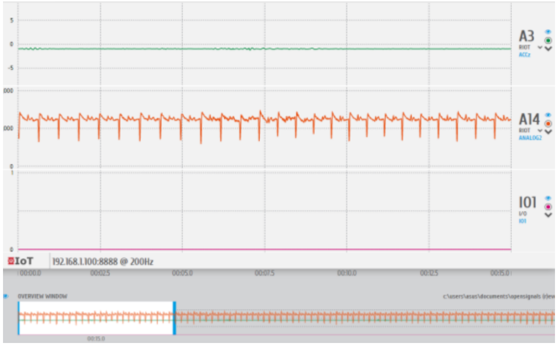
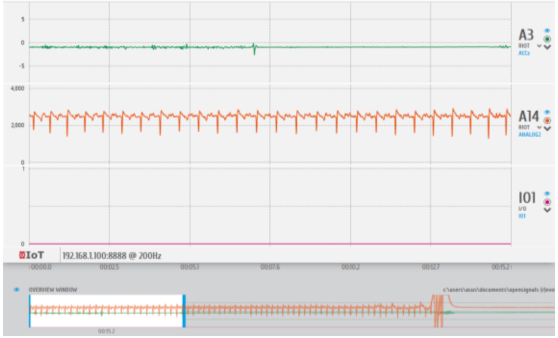

(b) After peak selection.
Fig. 11. BPM count.

Ten tests with 2 minutes of duration were performed to the bovine individual, and the most conclusive ones are illustrated in Figure 12. The signal duration was cut in some situations because of the animal agitation and consequent fall of the electrodes, which resulted in loss of signal and the acquisition was stopped. The minimum raw (Y-axis) value of detected R-peaks was 2305, and the maximum was 4095. The average value was 2515. It is possible to conclude that although the animal was in stress, the ACC acquisitions in real-time were almost stable. The acquisition in Figure 12(a) resulted in a BPM count of 102, and in Figure 12(b) was 103. Although the values are not normal, they are plausible since the animal was in stress and the resulting acquisition visualization is expected and typical for the QRS complex form of this species.

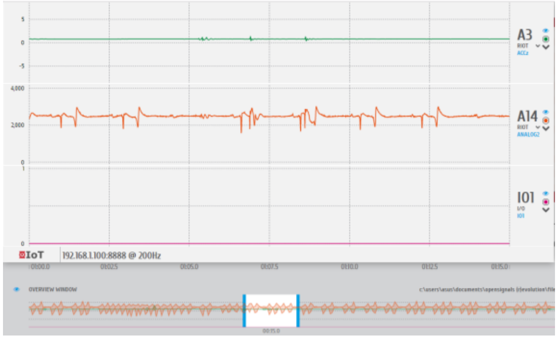


(a) Example #1.



(b) Example #2.
Fig. 12. Bovine ACC and ECG acquisitions.

For equines, 16 tests with the duration of 2 minutes were performed, and the values were closer to the normal range of values for BPM when compared to the bovines. Figure 13 shows two acquisitions. As in bovines, the signal duration had to be cut in order to disregard the perturbances. The ACC result does not show signs of agitation. The BPM result in Figure 13(a) was 25, which is very plausible and within the normal range. The manual assessment recorded was 30 BPM, so the obtained results are precise. The same situation happened for the second example, since the manual assessment was 30 BPM and the result was 24. Regarding the R-peaks raw values, the minimum, maximum and average values were 1817, 2732 and 2210, respectively. In the equine case, the acquired waves were also as expected and corresponded to what it the typical for this species.



(a) Example #1.

(b) Example #2.
Fig. 13. Equine ECG and ACC acquisitions.

IV. CONCLUSIONS

A belt-based cattle or equine ICT-based monitoring system was developed. It contains a microcontroller that is used to evaluate the animal's heart rate (ECG signal) and detect abnormal mobility (ACC signal). The correct evaluation of these two parameters is very useful for the detection several pathologies and anomalies that may lead to economic losses for the livestock owners. The most common pathologies for bovines are thermal stress, laminitis, mastitis and hypocalcemia (milk fever). Physiological changes of the animal can be used to predict the estric cycle and fertility. Colic and laminitis are the most frequent anomalies for equines. The fertility prediction is also extremely important for this species. Thus, this kind of monitoring systems becomes a long-term advantage for any livestock production. With an intuitive and accurate application such as the proposed system, animal losses may be prevented through early and preventive assessment.

The system can be improved with the inclusion of GPS and temperature monitoring features. Additionally, a detailed study of ACC values and movement alterations is extremely valuable for a full assessment of an animal's state. All these parameters will be crucial for an accurate assessment of the overall picture of a production.

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