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# Livestock Monitoring: Approaches, Challenges and Opportunities

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***Abstract*: *This survey presents approaches and technologies for livestock identification, vital signs monitoring and location tracking. It first introduces the related concepts. Then, provides an analysis of existing solutions and highlights their strengths and limitations. Finally, it presents key challenges in the field, and discusses recent trends that must be factored in by researchers, implementers, and manufacturers towards future developments in the area.***

***Keywords*: *Livestock, Cattle, Farm Animals, Monitoring, Internet of Things, Survey, Tutorial.***

## I. INTRODUCTION

In 2019, Food and Agriculture Organization (FAO) of the United Nations in Sustainable Development Goals stated that half of the population will live in urban areas and by 2050 it is expected that this value will rise to over 2.5 billion [1]. Since most of the activities related to agriculture take place in rural areas, the rural abandonment will have a great impact on agricultural production. On the other hand, the consumption of products sourced from farms has been increasing. For example, in 2020, International Dairy Foods Association (IDFA) stated that the consumption of dairy products per capita has increased 21% since 1975 [2]. With the increase in consumption of agricultural products and decrease in labor force, this will be unsustainable in the long term if nothing is done. To minimize the impact, it is necessary to implement a sustainable strategy that can answer the high demand. To keep up with the consumption growth it is essential to produce more and avoid waste by optimizing production. The method of animal monitoring traditionally requires diagnosing each animal individually for health, welfare, and production, which is feasible on small farms, however on medium and large farms it becomes cumbersome and costly [3].

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In the last years, technology has been used with livestock to help identifying animals uniquely, using electronic ear tags or ruminal boluses. Furthermore, Internet of Things (IoT) [4] devices can also be used to monitor animal vital signals, behavior, location, and movement. These devices have the advantage of being modular, allowing multiple sensors to be added [5]. Sensing livestock helps farmers reducing manual work and saving labor time. It improves animal health, increases profits and lowers the environmental footprint.

This paper surveys publications and projects dealing with livestock identification and monitoring, as well as challenges and opportunities that remain to be implemented. It is organized as follows: Section 2 presents the methods used for livestock identification. Section 3 presents the approaches used for livestock vital signs monitoring and location tracking. Section 4 discusses the challenges and opportunities and provides a vision for future developments and research directions in the area. Finally, Section 5 presents the conclusions.

## II. LIVESTOCK IDENTIFICATION

Livestock identification enables producers to maintain records on an animal's birth date, weight, health history, parentage, production records, and other information. It facilitates individual or herd management and disease control [6]. There are two ways to identify cattle: non-electronic; or electronic identification.

The most common methods of non-electronic identification are thru branding, tagging, notched ear, nose tattooing, paint branding, and biometrics [7]. Branding consists in the application of a heated iron directly into the animal's skin, burning hair and skin, making a permanent mark, usually with a number [8]. Ear tags have a number that identifies the animal and are the cheapest alternative [9]. Ear notching is commonly used to identify piglets, by making cuts in their ears.

Tattooing the animal's nose is a permanent form of identification, however the animal must be immobilized during the process. Paint branding is a painless method of identification, where a number is painted on the animal's fur, nevertheless it is not permanent and will come off as the coat falls out. Biometric identification is painless for the animal and is a unique way of identification, since DNA, iris, and retinal patterns are unique to each animal. However, the animal must be immobilized to perform this task. Fig. 1 shows the most common methods of non-electronic identification.


**Fig. 1. Non-electronic animal identification: (A) Branding; (B) Ear tag; (C) Ear notching; (D) Nose tattooing; (E) Paint branding. Source: Adapted from [7], [10]–[13].**

However, these types of markings, except the biometric method, are highly error prone as animals are only identified based on the herd they are in, which means that in other herds/flocks owned by other producers, there may be an animal with the same identification. Thus, the identification is not universal. On the other hand, animal identification can be done electronically, through ear tag buttons, microchip implant, ruminal boluses, and neck collars. All of them work with Radio Frequency Identification (RFID) [14]. RFID is a non-contact identification technology using sensors and radio waves or microwave energy to conduct contactless communication, identification, and data exchange grounded on electromagnetic theory. An RFID system consists of three components: tag, antenna, and reader. A tag is made of a chip and has built-in antennas to communicate with the radio antenna [14]. Tags are programmed with an identifier code that can be read/transmitted under an external force called an active device [15]. The antenna is responsible for transmitting and receiving information between the tag and the reader. The reader is used for receiving the information from the tag, parsing the information, and sending it to the host system (i.e., computer). As illustrated in Fig. 2, the reader (active device) sends electromagnetic waves (radio waves) through the antenna to the tag (passive device), then the tag produces induced current and activates itself, sending back an electromagnetic wave that contains the identifier number. After that, the receiver translates the electromagnetic wave back to a number to display to the end-user [15]. RFID unique identifier number and ease of reading through portable readers, improves data accuracy and availability, and facilitates tracking animals and managing livestock.

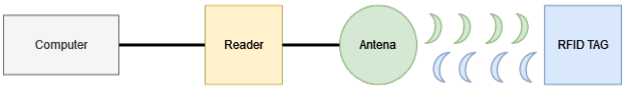


**Fig. 2. How RFID technology works.**

Ear tags are the most common form of identification in livestock [16]. It allows two forms of identification, tagging and RFID, and allow permanent identification. An applicator gun is needed to put an ear tag. The tag shown in Fig. 3 is both a visible and an electronic identification method.

**Fig. 3. Sheep with an ear tag button. Source: Adapted from [17].**

Microchips are the most common form of permanent identification for domestic animals. It consists in a chip (with a radio transponder), a device (with RFID technology), and an antenna (passive device) implanted under the skin of the animal. The microchip is typically implanted in the neck of the animal between the shoulder blades or near the base of the ear [18]. Fig. 4 shows the material used to implant the microchip.

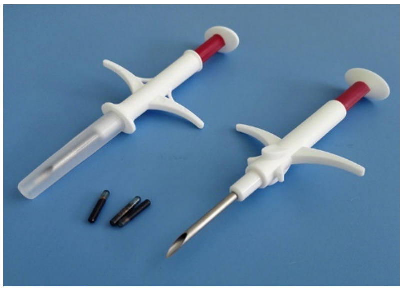

**Fig. 4. Microchip and syringe for implantation. Source: Adapted from [19].**

Ruminal boluses are used in cows and small ruminants. They are composed of a cylindrical ceramic capsule that has a transponder, which is a read-only device [15], [20]. A ruminal bolus is applied using a bolus applicator, which is a pistol-shaped mechanical device shown in Fig. 5. The tip of the bolus applicator is introduced in the animal's mouth, placing the reticular bolus at the beginning of the digestive tract.

Then it is ingested, and it will deposit itself by the force of gravity in the reticulum, where it will remain until the end of the animal's life [20]. Ruminal boluses don't cause physical pain to the animal, which can occur when implanting microchips or piercing ears [18].

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**Fig. 5. Bolus applicator and ruminal bolus. Source: Adapted from [20].**

Neck chains are a painless method of identification often used with dairy cattle as shown in Fig. 6. It consists of a chain with an attached tag having an identifier code that can be read by a scanner. They are easy to use and are painless to the animal. The neck collar should be placed tight enough in the animal's neck so it doesn't slip, but the animal's growth should be considered to avoid choking [18].

**Fig. 6. Cow with a neck chain. Source: Adapted from [18].**

Non-electronic identification often requires the immobilization of the animal and does not provide a unique identification in comparison with electronic identification. On the other hand, electronic identification has a higher cost than the non-electronic identification methods. Table I summarizes the advantages and disadvantages of each identification method.

## III. LIVESTOCK MONITORING

This section surveys approaches and technologies to vital signs monitoring and location tracking of livestock.

### A. Vital Signs Monitoring

Several proposals have been introduced to allow monitoring animals' vital signs so that diseases and injuries can be detected earlier, prevented, or better treated, contributing to the animal health and profitability of livestock. Some examples are presented below.

Patil *et al.* [21] proposed a system whose main objective is to prevent widespread diseases, whether it's from a natural cause or a biological cause. To achieve regular monitorization of vital signals it uses four types of sensors: temperature, humidity, heart rate and rumination. The system uses a ZigBee module, a microcontroller, and a computer. The temperature sensor is used for measuring the animal's body temperature. If this temperature is higher or lower than normal, this indicates that the animal is ill. The humidity sensor indicates the humidity in the environment. If it is too high or too low, then it can impact the cooling capacity of plants and animals. In addition, heart rate is an indicator if the animal is under stress or agitation. The Zigbee protocol [22] is a wireless networking protocol that has low power consumption, low data rate and is a low-cost solution. Additionally, a ZigBee network can achieve a range of 10-75 meters between devices.

**Table I: Advantages and Disadvantages of Livestock Identification Methods. Source [7].**

| Method | Advantages | Disadvantages |
|---|---|---|
| Branding | Permanent mark | Painful method, applying heated iron directly on skin |
| Tagging | Tags are cheap and easy to read | The head of the animal must be restrained |
| Notched ear | Easy to identify | The animal must be restrained, only used with piglets |
| Nose tattooing | Permanent | The animal must be restrained |
| Paint branding | Painless to the animal and can be done quickly | Not permanent, because it's painted on the animal fur |
| Biometric | Painless to the animal and unique identification method because DNA, iris and retinal patterns are exclusive | The animal must be restrained to read the identification |
| Ear tag buttons | Permanent, allows the animal to be identified in two ways visible and technological | Animal head must be restrained |
| Microchip implant | Permanent | Must be done by a professional |
| Ruminal boluses | Lifetime identification | Animal head must be restrained for the application, and it can be regurgitated |
| Neck chain | Painless to the animal | Risk of falling off or choking the animal |

Reigones *et al.* [23] designed a system that had the objective to monitor farm animals like dairy cow, horse, goats, sheep, and pigs with the intention of detecting abnormalities using various sensors. Monitoring cattle enables the detection of physiological changes like predicting the estrous cycle and fertility or the detection of pathologies like thermal stress and milk fever. This helps detecting early diseases that may lead to economic losses. The proposed system includes a microcontroller unit (MCU), more specifically the BITalino R-IoT [24], which has Wi-Fi to extend the communication of the system, a triaxial accelerometer, a triaxial gyroscope and a triaxial magnetometer to monitor the animal movement. Later an ECG sensor was added to monitor the animal's heartrate, as seen in Fig. 7. If the system measures values that are not in the normal range for a healthy animal, then an alert is sent via email to the producer. Results show some success monitoring cows and horses.

However, some abnormalities were observed with the bovine's heart rate that was above the normal range. This situation could be explained by the animal being under stress during the tests.


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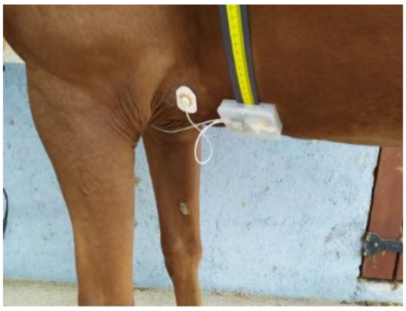

**Fig. 7. Equine with the system proposed by Reigones *et al.* Source: Adapted from [23].**

The company Cowlar [25] created a commercial solution to monitor cows, that allows early disease detection, operation efficiency, feeding optimization, stress management and contributes to increase the reproduction rate. It enables the measurement of the animal's temperature, activity meter, and behavior, which shows whether the cow was eating or sleeping. The functioning of Cowlar requires the use of a non-evasive collar placed around the cow's neck, as seen in Fig. 8. The collar is composed of a box that is located at the back of the cow's neck with a strap to hold it in place. A solar-powered router allows the establishment of a connection to the collars up to three kilometers. The router sends the data collected via a mobile network to the company's cloud. All gathered information can be accessed through a dashboard that allows the user to see all the data generated, graphs, and tips on actions to take. In addition, it has a functionality to send messages with alerts, such as when a cow has an excessive temperature.

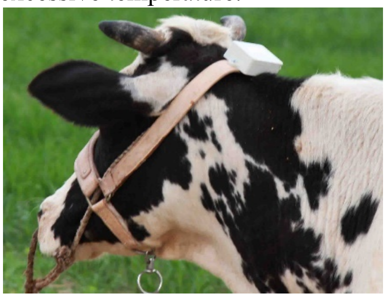

**Fig. 8. Cow with Cowlar's device. Source: Adapted from [25].**

EnviraIoT also developed a system [26] for monitoring farm animals, consisting of a remote module with sensors for data collection, and a central station to receive the sensor data. Sensors are used to measure animal welfare indicators such as humidity, temperature, ammonia concentration and hydrogen sulphide. Each remote module can have up to 8 sensors and stores the data locally. Since these systems have low power consumption they can be powered by solar energy. The data collected by the modules can be sent to a central module placed on the farm, through the mobile network to EnviraIoT's cloud or to third-party companies using technologies such as 3G [27], 4G [28] and LoRa [29]. Wide area networks like LoRaWAN, 3G and 4G have the advantage of long-rage communication between the device and the service, which allows only a single hop between the devices and the gateway. The company uses the data collected to provide a calendar with daily carbon dioxide concentration, ammonia aggregation and an alert system through SMS or e-mail. IceRobotics [30] developed a solution called CowAlert [31] to increase the performance of dairy herds. It uses a wristband called an IceQubes placed on the back of the cow's leg, which contains an accelerometer that measures the orientation and acceleration in three axes, several times per second. Based on the data collected, the system sends an alert when the cow is in heat, resting or when it detects lameness. The company Moocall has two systems for monitoring herds, the Moocall Heat [32] and the Calving Sensor [33], shown in Fig. 9. Moocall Heat is a device that detects heat in cows. The system consists of a collar that is placed on the bull's neck and ear tags with RFID tags that are placed on the cow's ears. When the collar detects movement between the bull and the cow, it 'tags' the cow with the ear tag, so the producer knows which cows will breed. The Calving Sensor is a sensor placed in the cow's tail that detects certain movements of the tail, these movements are indicators of contractions that announce the beginning of the calving process. This helps the farmer to know when assistance is needed for the cow to calve.


A B

**Fig. 9. (A) Moocal Heat; (B) Moocal Calving Sensor. Source: Adapted from [32] [33].**

ActiveHerd [34] is a bolus designed by NFCGROUP [35] to monitor cow temperature on a large scale. The ruminal bolus is placed using an applicator. After being ingested by the cow it will remain in the rumen until the end of the animal's life. However, the autonomy of the device is only five years. The ActiveHerd bolus transmits the data via Wi-Fi to a locally installed gateway receiver. Then, the data is sent to the cloud and the user can access information through a smartphone or a computer. ChickenBoy [36] is a ceiling-hung robot developed by Faromatics [37] shown in Fig. 10. The robot is used in poultry houses, to automatically monitor the well-being of the chickens, measuring the air quality, thermal comfort, health, and well-being of the animals, as well as ensuring the functioning of the rest of the equipment. It moves throughout the poultry house and collects data through a camera. Using artificial intelligence, it is possible to identify droppings, deceased birds, and defective drinkers. The data is then displayed in graphical form on a dashboard to the user, where it is possible to view a map of the temperature and $CO_2$ in the poultry house. This is useful for farmers, because in a poultry house with thousands of birds it is difficult for one person to analyze and keep track of all this information.

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**Fig. 10. Chicken Boy Robot. Source: Adapted from [38].**

The projects presented in this section can be divided into two groups, those that analyse animals' vital signs (such as heartrate, temperature, and movement) and those that analyse the quality of the environment. The devices that collect data about the animals' vital signs are placed on animals as wearables to collect information. They operate using batteries, making autonomy a concern. On the other hand, the devices responsible for monitoring the environment do not need to be in constant contact with the animal.

In all projects, the data collected by the devices is sent to a central device that is responsible for data gathering and to send it to a local or remote server for processing, reporting, and alerting. Table II summarizes some of the main characteristics of each solution in terms of:

- Animal: animal or group of animals to which the project was targeted.
- Vital Signs Read: which vital signs are measured/read.
- Communication Network: network used to establish communication between the device that reads the vital signs and the device that gathers the data.

**Table II: Comparison Between Animal Vital Signs Monitoring Projects.**

| Name | Animal | Vital Signs Measured | Communication Network |
|---|---|---|---|
| Patil *et al*. [21] | Cattle | Body temperature, heart rate and humidity | ZigBee |
| Reigones *et al*. [23] | Dairy cow, horse, goats, sheep and pigs | Heart rate, body movement | Wi-Fi |
| Cowlar [25] | Cows | Temperature, activity meter, and behaviour | Mobile network (through the router and cowlar's services) |
| EnviraIoT [26] | Farm animals | Humidity (exterior), temperature (exterior), ammonia concentration and hydrogen sulphide (exterior) | LoRaWAN/Mobile network (3G and 4G) |
| CowAlert [31] | Cows | Movement | N/A |
| Moocall Heat [32] | Cows and bulls | Contact between the cow and the bull | RFID (between the cow and the bull) |
| Moocal Calving Sensor [33] | Cows | Tail movement (indicator of contractions) | N/A |
| ActiveHerd [34] | Cows | Body temperature | Wi-Fi |
| ChickenBoy [36] | Chicken | Air quality, thermal comfort, health and well-being of the animals | Cable |

## B. Location Tracking

Grazing animals require large areas of open land to find grass. Due to the difficulty to keep track of each animal and to keep the cattle in the same place, fences are used to keep animals within a certain area, but in large areas they become very costly or impossible to deploy. Alternatives like virtual fencing are being explored to reduce the costs of fencing and to monitor each animal individually [39]. Some recent projects related with location tracking and virtual fences are presented below. In [40], the objective was to develop a low-cost solution to monitor the location of the animals in a herd. As seen in Fig. 11, the system is composed of Global Positioning System (GPS) collars connected to a Low Power Wide Area network, and low-cost Bluetooth Low Energy (BLE) tags connected to the collars. The GPS [41], [42] is a positioning service that allows the devices to get the precise location by using a set of satellites that are constantly sending their location and time. Bluetooth Low Energy [43] is a low-power radio communication technology that provides indoor positioning technology. Some animals use GPS collars, while the others use BLE Tags. While the GPS collars provide the exact location of an animal, the BLE tags provide an approximate position. The GPS collar has a GPS unit, a BLE module, a microcontroller, a battery, and a long-range communication module using Sigfox [44]. The BLE tags use Bluetooth 4.2, a microcontroller, and a coin battery. This tag sends advertisement messages which includes the device ID and the code referring to the owner. The data collected by the GPS collars and nearby BLE tags is sent to a cloud service, thus enabling an app that sends alerts. GPS collars have an autonomy of more than 365 days, while the BLE tags only last 280 days.

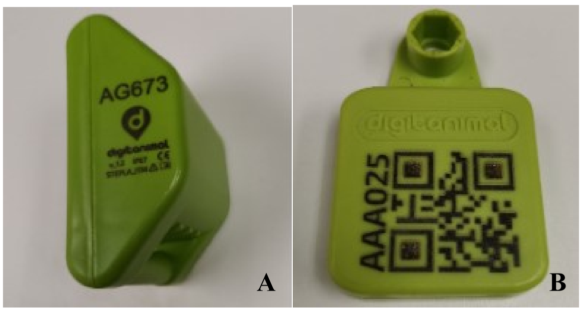


**Fig. 11. Devices used to track animal location: (A) GPS device; (B) BLE Tag. Source: Adapted from [40].**

Park *et al*. [45] designed a system for collecting real-time location of cattle using Wireless Sensor Networks (WSN) [46], cloud services to store data and a website to display a map with the location of each cow. Cows are known to graze large areas of pasture and when they do not move for an extended period this indicates they are unwell.


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Tracking the location of cattle can help detect cows that need to be physically inspected. As seen in Fig. 12, the collars contain a WSN module, a GPS module, and a 3G communication module. The GPS module is responsible for obtaining the location of the animal, while the short-range radio module allows the node to send the collected data to another node. In each herd, a leader was chosen by the livestock manager that carries the gateway node. In other words, all the information collected in that herd is sent to that exit node, which uses a 3G network to send that data to cloud services. Animals in farms can be divided into several groups and this can cause loss of connection with the exit node. But since each collar has a 3G module, if the connection to the exit node is lost, then a new temporary leader and thus an exit node is defined.

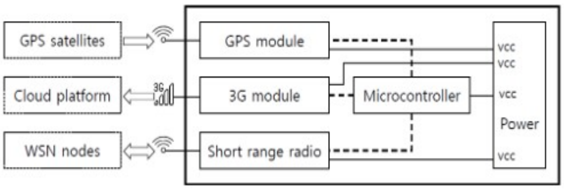


**Fig. 12. Schematic of the node. Source: Adapted from [45].**

Ramesh *et al.* [47] proposed a solution for tracking the location of farm animals using Arduino and a GPS module. The system is designed with the intention of being worn in the form of a collar and placed on the neck of the animals to be tracked. The collar consists of an Arduino Uno (ATmega328p) which is battery powered. The Wi-Fi module (ESP8266) and the GPS module are connected to it. The operation of the collar consists of obtaining the location coordinates through the GPS module, which are sent by Wi-Fi to a device connected wirelessly. This allows to show the position of the animals through a graphical interface.

mOOvement [48] is an ear tag for cattle that allows monitoring the location of each animal. The device uses GPS technology to detect the location together with batteries and solar energy to maintain its operation. The gateway antenna, which operates over a LoRa (Long Range) network, receives the data and sends it to the mOOvement platform. It allows users to receive alerts and have access to the location of each animal in real time. Fig. 13 shows mOOvement's GPS Ear Tag.

**Fig. 13. mO Ovement's GPS Ear Tag. Source: Adapted from [48].**

The SheepIT [49] project has the goal to control animal posture and monitor its behavior, actions, and location. It is based on a WSN with cloud computing and an application layer. This project uses an WSN, so the nodes transfer data collected by the sensors wirelessly between them and handle relative location using the Received Signal Strength Indication (RSSI) value, which helps reducing power consumption. To form the WSN layer, sheep carry collars with a set of sensors, actuators, a microprocessor, a radio antenna, and a battery. The sensors are used to detect and control animal posture and to apply stimulus with the help of actuators when sheep adopt unwanted behaviors. The data sensed by the collars is transmitted by the radio antenna, which also provides relative localization through the RSSI value. The shepherds installed fixed beacons in the grazing area, making possible the implementation of a virtual fence mechanism and the collection of data transmitted by the nodes. Preliminary tests were conducted on the communication method and the virtual fence operation. With help of beacons, it was possible to demonstrate the concept of virtual fence. Virtual fences are structures serving as an enclosure, like a barrier or boundaries without physical barriers [39]. They intend to be an alternative to applying fences in large areas. If a sheep moves away more than 40m from the beacon, then an audible signal is triggered. If the sheep doesn't return, then the collar starts an electrostatic stimulus. Fig. 14 shows the architecture of the SheepIT project.

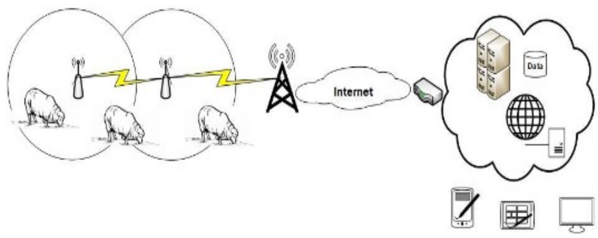


**Fig. 14. Architecture of the Sheep IT project. Source: Adapted from [49].**

Brunberg *et al.* [50] used a system called NoFence [51], shown in Fig. 15, to test the ability of sheep to learn a virtual fencing system. To apply the virtual fencing mechanism, collars with built-in GPS and two electrodes are used. GPS technology is used to obtain the position of the sheep. Electrodes are used so that if a sheep passes the boundary area, then a sound signal and a harmless electric shock and are performed.

The collars are placed around the sheep's neck. For the electrodes to have contact with the skin, trichotomy is performed on the sheep's neck. The virtual boundaries are programmed. The conducted experiments revealed difficulties in applying the virtual fencing mechanism because of various factors such as malfunctioning collars that made sheep not learn the boundaries, some sheep did not have any reaction to the electric shock, others didn't associate the sound signal with the shock, and others crossed the border due to outside attractions like other sheep or grass. The learning algorithm also applied high numbers of electronic stimuli due to technical failures in the No Fence hardware putting the animal's life at risk.

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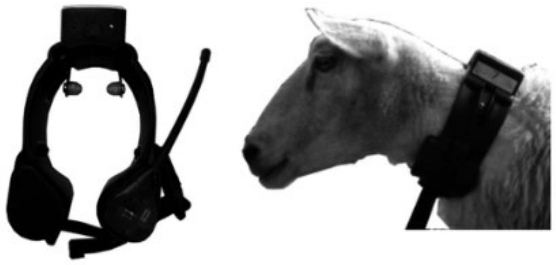

**Fig. 15. No Fence collar on a sheep. Source: Adapted from [50].**

Ilyas *et al.* [52] proposed a system to track cattle and implement the virtual fence concept. The system warns farmers if a cattle animal leaves a predefined grazing area. Each animal has a collar that is composed of an Arduino and a GPS module to detect its location. Arduinos with ultrasonic sensors are placed at the edge of the fence. They indicate how far away an animal is from the sensor. An alert distance is set between the animal and the boundary of the virtual fence. If an animal approaches the virtual fence, the Arduino with the ultrasonic sensor sends a signal to the animal's collar. This signal tells the Arduino with the GPS sensor to activate and get the animal's current location. Then, this location information is sent to a cloud service that will trigger an alert to the farmer, which notifies that an animal is near the fence boundary. Fig. 16 shows the architecture of the system.

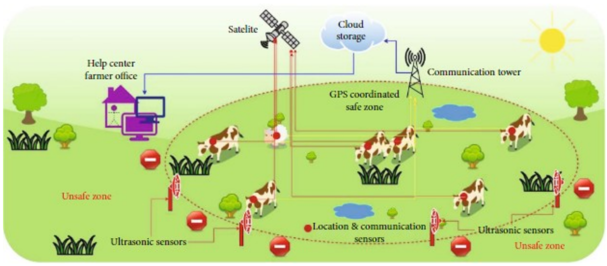


**Fig. 16. Architecture of the system proposed by Ilyas *et al.* Source: Adapted from [52].**

Abeeway [53] is a company that created a device whose main goal is to provide real-time location of cattle in remote agriculture areas where it is difficult to use cellular-based GPS trackers. The device uses the LoRaWAN network to provide connectivity. LoRaWAN is a low-power technology, which allows increased battery life of the device. It also uses LoRa TDoA [54] a location technology that allows getting the approximate location of cattle, while having low-power consumption in comparison with GPS. In addition to obtaining the geolocation of the animal it is possible to define an area that corresponds to the area of the fence called geofencing, which warns the farmer if an animal has left it.

The ZebraNet project [55] aimed to monitor the movements of wild animals and study their relationship with temperature, human and other movement patterns. Monitoring wild animals is quite difficult. Data must be collected frequently to record all the events, and it needs to be obtained without human intervention. The only human intervention should be for the application of the collar that collects the data. The collar consists of a GPS-MS1E board that has GPS, RAM and CPU, a short range, and a long-range radio antenna. It also has batteries, a solar panel, and power management circuitry. The GPS board is responsible for obtaining and storing the zebra's position data. The short-range antenna enables communications between the collars of other zebras. The long-range antenna is used to detect the base station and send the data contained in the collar. One of the main concerns of the project is the energy consumption of the system. It must have an autonomy of five days without charging. Nevertheless, the system includes the ability to charge through solar energy. The GPS data acquisition has a great impact on the battery consumption, so a hibernation strategy is used to minimize the energy consumption. The device will go into a sleep mode over a certain period of time and then turn on again to collect the coordinates of the current location. The long-range antenna is the component of the system that consumes the larger amount of energy, mainly due to the range distance it achieves, which is about 8 kilometers. The experimental results show success in the operation of the collars. However, the authors mention some difficulties, due to limited data storage and constrained bandwidth. The transfer rate is low being bottlenecked at 12kbs. Fig. 17 shows the architecture of the Zebra Net project.

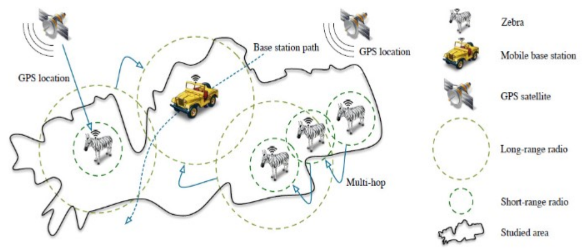


**Fig. 17. Architecture of Zebra Net. Source: Adapted from [45].**

Each of the above-described projects are summarized in Table III in terms of:

- Animal: animal or group of animals to which the project was targeted.
- Type of Wearable: wearable design used in the animal.
- Location Technology: technology used to obtain the geolocation of the animal.
- Geolocation: indicates if it allows to obtain the real time location of the animal.
- Virtual Fencing: indicates if it allows establishing a grazing area.
- Communication Network: network used to establish communication between the device that captures the location of the animal and the device that stores the data.

**Table III: Comparison Between Animal Location Tracking Projects.**

| Name | Animal | Type of Wearable | Location Method | Geolocation | Virtual Fencing | Communication Network |
|---|---|---|---|---|---|---|
| SheepIT [49] | Sheep | Collar | RSSI | No | Yes | Wi-Fi |
| Maroto-Molina *et al.* [40] | Cows or sheep | Collar | GPS, BLE Tags | Yes | No | SigFox |
| NoFence [51] | Sheep | Collar | GPS | Yes, but only for the virtual fencing construction | Yes | N/A |
| ZebraNet [55] | Wild animals | Collar | GPS | Yes | No | Radio |
| Park *et al.* [45] | Cows | Collar | GPS | Yes | No | WSN and 3G |
| Ramesh *et al.* [47] | Cows or sheep | Collar | GPS | Yes | No | Wi-Fi |
| Ilyas *et al.* [52] | Cows | Collar | GPS | Yes | Yes | N/A |
| mOOvement [48] | Cows | Ear tag | GPS | Yes | No | LoRaWAN and 3G/4G |
| Abeeway [53] | Cows or sheep | Collar | LoRa TDoA | Yes | Yes | LoRaWAN |

## IV. CHALLENGES AND OPPORTUNITIES

Reducing the nodes energy consumption and maximizing network lifetime are a main goal for all above-presented projects, to collect data for as long as possible without human operator intervention to recharge nodes batteries. Several communication technologies have been assessed to achieve this goal. Some projects use Wi-Fi networks to collect and send data from the monitored animals to the gateway. However, these networks have a smaller range than the animals' grazing area. For this reason, other projects adopt the use of technologies such as 3G or 4G. Low power wide area networks such as LoRa and Sigfox systems minimize energy consumption. The LoRa technology has emerged as an interesting solution, designed for lightweight IoT devices, that may be used to connect monitored animals to a gateway. The project described in [56] have tested it and concluded that some work remains to be done to control the data flow for it to comply with the LoRa network standards. Furthermore, the tests were conducted assuming just one animal collar. Therefore, the performance of the network should be tested with more than one collar and while handling larger amounts of data traffic generated by the collars (i.e., data collected by sensors). To the best of our knowledge none of the related projects considers the use of a LoRa mesh network topology. Such a topology can be interesting in situations where some animals are not in the antenna range. The animal collar may not be able to contact the LoRA gateway directly, but instead may use another collar on other animal as a relay station. However, this may increase the complexity of the network. Furthermore, the sleep mode has been tested on network nodes to improve power consumption as well as using solar panels to extend the battery life. Regarding animal localization, some projects consider the use of LoRa TDoA, Bluetooth Low Energy or RSSI to reduce the GPS energy consumption although they don't provide the same accuracy [54]. There is still much work to be done to successfully implement the virtual fencing concept that notifies the farmer if an animal leaves the defined grazing area. The surveyed projects still require a human to reroute the animal back to the grazing area.

## V. CONCLUSIONS

Precision agriculture technology solutions and products help farmers to become more efficient. Sensing livestock reduces manual work and saves labor time. It improves animal health, increases profits and lowers the environmental footprint. This survey has presented a comparative analysis of methods for livestock identification and approaches to monitor animal health and welfare parameters as well as behavior, location, or postures, in a continuous and automated way. It introduced the related concepts. Next, an analysis of existing solutions discussing their strengths and limitations was presented. Key challenges and opportunities were identified as well as perspectives on future developments relevant to the area.

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