Research platform for cattle virtual fences

Néstor Acosta*, Nicolás Barreto*, *Student Member, IEEE*, Pablo Caitano*, Raúl Marichal†,
Martín Pedemonte†, *Member, IEEE*, and Julián Oreggioni*, *Senior Member, IEEE*
*Instituto de Ingeniería Eléctrica.
†Instituto de Computación.
Facultad de Ingeniería, Universidad de la República. Montevideo, Uruguay.

***Abstract*—Prior work in virtual fences has proposed different schemes to keep cattle confined within a remotely configured perimeter. These techniques share a common pattern that consists in placing an electronic device in the animal capable of applying a stimulation when it approaches the pre-established limits. The method of stimulation most widely used is electric shocks. This work proposes a solution compatible with animal welfare, which avoids electric shocks, based only on sound and tactile stimuli (using a buzzer and a vibrating motor, respectively). For this, a system was developed consisting in an electronic device that is placed on the animal's neck, and has the capacity to stimulate and send information wirelessly; a central server that is able to receive, process and store that information; and a graphical user interface, where the animal's location can be visualized and several parameters can be configured to evaluate different virtual confinement techniques. Preliminary tests performed on animals suggest that the stimuli used is aversive, so it is inferred that they could achieve their goal after a period of training. The research on the effectiveness of the proposed confinement techniques using our platform should be carried out in a next stage.**

***Index Terms*—animal confinement, cattle tracking, animal welfare.**

I. INTRODUCTION

Virtual fences (VF) have been studied for several decades to replace physical barriers used for animal confinement since they can produce great benefits for the livestock industry [1]. VFs typically are implemented with an electronic device carried by an animal, with GPS and means to deliver a sensorial stimulus (typically an electrical shock) to the animal to discourage it from approaching pre-established limits. These systems, which usually incorporate wireless data transmission, can be applied to animal monitoring or to study animal behavior [2], [3], as well as they may enable the relocation of animals allowing the usage of precision grazing techniques [4]–[7]. At the same time, since they can continuously provide the location of the animals, they help to reduce cattle theft and loss, as well as, early detection of diseases (e.g., studying movement patterns). They can also generate a significant reduction in maintenance costs and minimize losses in the event of emergencies, such as wildfires or floods, since physical obstacles are no longer used for retaining the animals in places with potential danger.

The effectiveness of VFs is showing promissory results [8], [9]. However, the use of electric shock stimuli generates controversy, and it has been banned in some countries [10]. In this context, the study of alternatives compatible with animal welfare provides new opportunities for the development and application of this technology.

The goal of this work is to generate a research platform for assessing different virtual confinement techniques, especially considering devices that produce stimuli compatible with animal welfare, such as sound and tactile (vibrational) stimuli.

II. PROPOSED SOLUTION

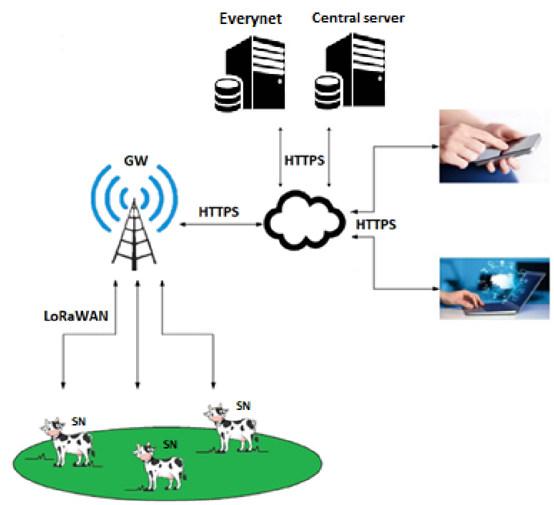

Fig. 1. Architecture of the proposed solution.

Fig. 1 shows a scheme of the proposed platform. The core of our virtual fence platform is an animal-borne electronic device (called sensor node or SN). SN is based on a low power microcontroller, with the following design requirements:

- The stimulation generated by the SN should be compatible with animal welfare (e.g., sound and tactile/vibrational stimuli).
- It must be able to determine its geographical location in real-time with an accuracy of 5 m.
- It must communicate wirelessly with a central server using a long-range and low power consumption protocol. Since the virtual perimeter should be configurable from the central server, the communication must be bidirectional and have a minimum range of 5 km.
- The SN is expected to have an area smaller than 225 cm^2, a minimum autonomy of 7 days, and a sampling frequency of the location of at least 1 Hz.

Given the power consumption and range requirements, LoRa technology for data transmission and LoRaWAN for network protocol were chosen. This protocol uses a star network topology, defining three classes of devices (A, B and C) to establish a communication between multiple nodes and a gateway (GW). Class A devices support bidirectional communication. They can send messages at any time, while reception can only occur after sending a message. Classes B and C are extensions of Class A, that offer longer reception periods, increasing energy consumption. For this reason, and considering the needs of the application, we decided to use class A devices. We implemented the LoRaWAN protocol using the IBM LMiC library [11], which is described in Section II-B. This requires that the SN microcontroller must have a program memory greater than 32 kB.

The architecture of our solution contemplates that the system is used simultaneously in several animals. Therefore, the SNs network communicates with the central server through one or several gateways. The gateways communicate with the central server using the Everynet platform. The central server provides the backend services for storing information in databases and managing the communication with the SNs. It also provides a graphical user interface (frontend) for visualizing the SNs on a map and configuring the different parameters of the platform.

A. Hardware

The embedded system was designed using the Arduino-based Moteino development board. This board includes an Atmega 1284p microcontroller and an RFM95 radio for communication. Besides, we incorporated to the board a GPS module, a buzzer, a vibrating DC motor, and a power management system. Fig. 2 presents the block diagram of the SN.

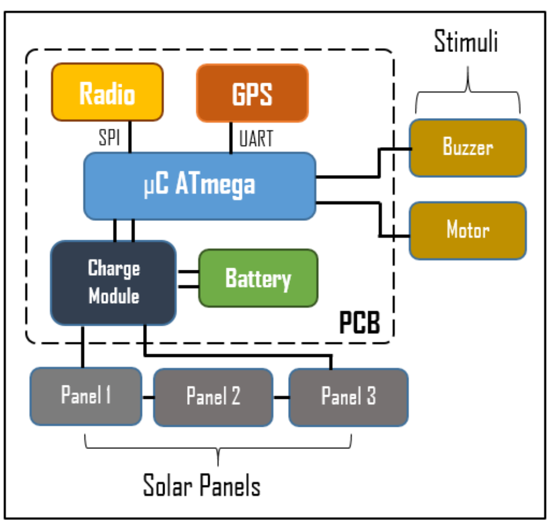

Fig. 2. Block diagram of Sensor Node (SN).

The ATmega 1284p chip is a Microchip microcontroller of the AVR family, which consumes 400 μA in active mode at 1 MHz and 0.1 μA in power-down mode. It has an 8-bit data bus, 128 kB of Flash memory, 4 kB of EEPROM and 16 kB of SRAM memory. It also includes up to 32 input/output pins.

For determining the geographical location of the SNs, we use a NEO-M8N GPS module from u-blox. It has an accuracy of 2.5 m under optimal conditions and a maximum sampling frequency of 10 Hz.

The communication module is an RFM95 radio based on the SX1276 chip from Semtech. This model uses LoRa modulation and supports the 915 MHz band that is used in this work. The module consumes 10 mA and 120 mA in reception and transmission, respectively. It has a sensitivity of up to -148 dBm using a low-cost crystal.

Two different stimulation mechanisms, based on sound and vibrations, are part of the embedded system. The sound stimulus is implemented using a passive buzzer. The microcontroller can modify the buzzer frequency varying the frequency of an auxiliary signal (up to 10 kHz). In addition, a PWM signal is used to generate different voltage levels in its power supply to modify the volume (which may exceed 100 dBA). On the oher hand, the vibrational stimulus is generated with an R260 dc motor featuring a speed of up to 3000 rpm and a weight of 30 grams.

The power system is composed of one rigid solar panel of 4.5 V and 0.5 W connected in series with two flexible 2 V 0.5 W solar panels, a Li-Ion 18650 battery of 3400 mAh and 3.7 V, and a TP4056 linear Li-Ion battery charger with a maximum current of 500 mA.

The chosen gateway was an Everynet Network Gateway v2.0, which is compatible with LoRaWAN. This gateway has an integrated GPS and it can be connected to the Internet using 3G cellular data network or Ethernet. It is powered by the Ethernet port (PoE, Power over Ethernet), and it has an integrated backup battery. The gateway has a nominal range of more than 15 km with line of sight and 2 km in dense urban environments.

B. Embedded Software

The embedded software of the SN was developed in `C++` using Arduino functions. The implementation is strongly based on the LMiC [11] library. LMiC is a `C`-language implementation of the medium access control layer specification of the LoRa protocol. The library uses an event-based programming model, where the application code is executed by tasks, which are triggered by events and are managed using functions of the library. LMiC includes drivers for the Semtech SX1276 radio but it also includes a hardware abstraction layer, which helps to use it with other radio modules. In particular, we have used the library implemented by M. Kooijman [12] to incorporate the RFM95 radio with the LMiC library in an Arduino environment.

Fig. 3 presents a simplified flowchart of the embedded software. Initially, location data (latitude and longitude), date, and time are acquired. Then, the distance to each side of the virtual perimeter is calculated and it is determined whether the device is inside or outside of the VF. This calculation is computed using the well-known Ray Casting algorithm. Based

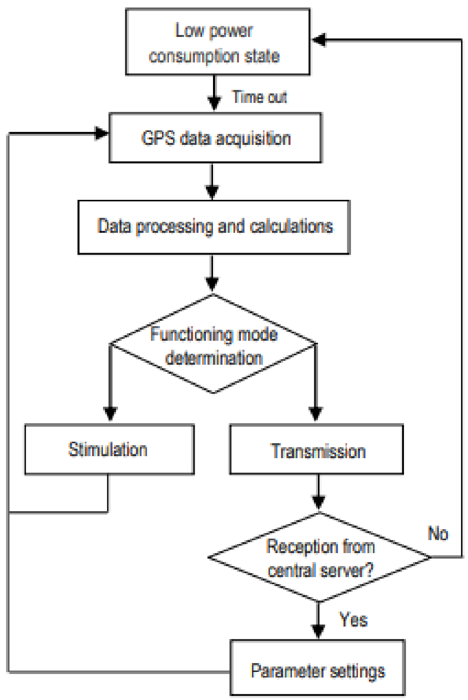

Fig. 3. Simplified flowchart of the SN embedded software.

on this information, the system selects one of the two operation modes: Stimulation Mode and Data Transmission Mode (low power consumption).

When the SN is far from the virtual perimeter, the device operates in Data Transmission Mode. In this mode, after a message is transmitted, and according to LoRa class A protocol, two time-windows are opened (one and two seconds after the transmission) to enable the reception of messages from the central server. If no data is received by the SN, the microcontroller, radio, and GPS are placed in a low power consumption state during a configurable time.

The virtual fence scheme consists of two different stimulation zones with a configurable width: F1 zone, where only the buzzer is running, and F2 zone, where the buzzer and vibrator are activated (see Fig. 4). When the SN is close to the virtual perimeter, the device enters the Stimulation Mode and the animal is stimulated using one or both mechanisms depending on the zone. In this mode, GPS data is acquired with the maximum possible frequency and communications are disabled, in order to increase the speed response of the device to the movements of the animal.

C. Cattle virtual fences software

To simplify the interaction between the user and the devices, we developed a web application to be hosted on the cloud. The system follows the architecture suggested by EveryNet (see Fig. 1), and is divided into three main parts: frontend, backend, and database (see Fig. 5). SNs periodically send information to the gateway, which is then uploaded to the Everynet platform

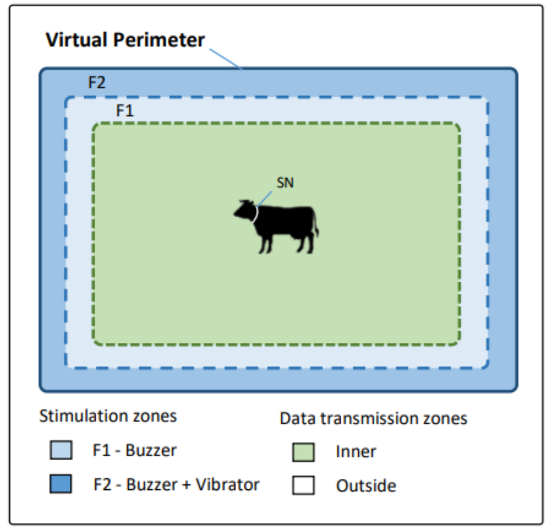

Fig. 4. Virtual perimeter zones.

via HTTPS. This platform has an API that can be accessed via web service.

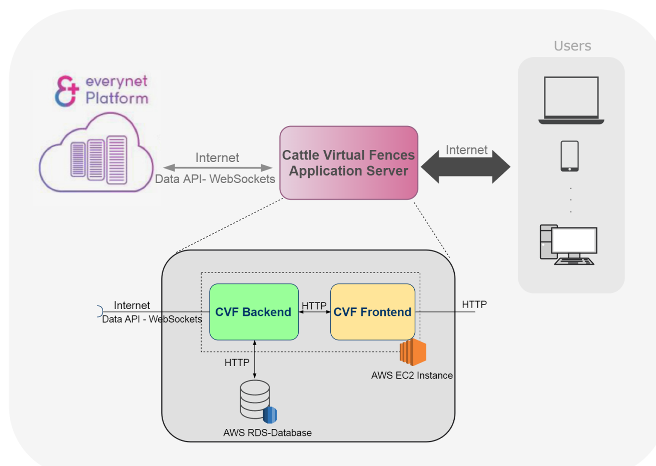

Fig. 5. Application server architecture.

Our backend consumes the Data API exposed by Everynet using a bidirectional streaming interface based on WebSockets, designed for message exchange between EveryNet Server and our Application Server. In this way, the backend periodically receives data from the SNs (uplink) and stores it into the database (DB). The backend is also able to send, to the EveryNet Server, device configuration commands that were previously received from the frontend (downlink).

The frontend provides a user interface to trace and configure each SN. It communicates with the backend to get devices information (location, configuration, etc.) and send new configurations. It also consumes the Google Maps API to show current locations, create perimeters (fences), and history traces on a map. The user interface is shown in Fig. 6.

The main features of the cattle virtual fences software are:

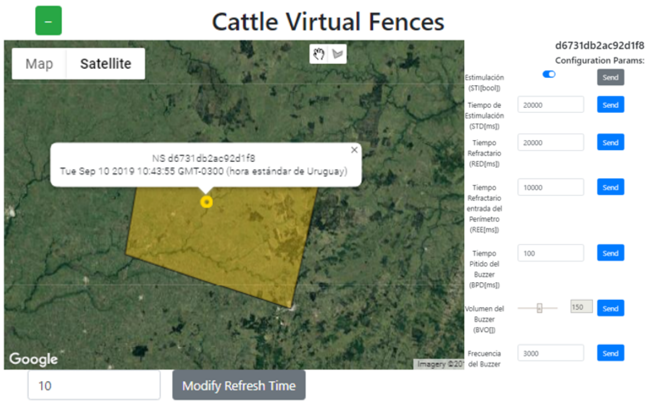

Fig. 6. SN location and virtual fence configured in the user interface.

- Create and delete virtual fences for each SN.
- Parameter configuration for each SN: virtual perimeter, stimulation zones width, sampling period in Data Transmission Mode, stimulation time, frequency and volume of buzzer stimulus, etc.
- Show current location of each SN.
- Show the historical location of each SN.

D. Manufacturing of the SNs

The SNs must be fastened to the animal body to be able to report the location continuously. We have especially considered in the design of the device some aspects such as size, weight and fasten method, in order to not cause harm to the animals. For this reason, we manufactured a necklace with webbing tape and plastic buckles, which can be adjusted using a velcro, as can be seen in Fig. 7. The adjustment range is from 70 to 90 cm. The webbing tape is flexible enough to fasten to the animal's neck but can also be easily pierced, which simplified its sewing.

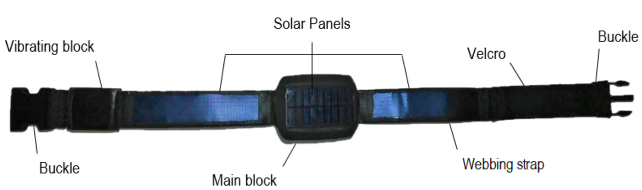

Fig. 7. Final prototype of SN.

By the design stage, we decided to separate the vibrating motor from the main package (see Fig. 7). For this reason, it was necessary to design two different containers, one for the main block (which includes the microcontroller, GPS, LoRa radio, buzzer, batteries, and solar panel) and another one for the motor. We also included a counterweight mechanism in the necklace to ensure that the solar panels are always oriented towards the sun.

The containers were designed using Autocad's Tinkercad software and manufactured in Polylactic Acid (PLA) since it is a resistant, economical, and biodegradable material. The pieces were polished to improve its finishing and allow better placement of internal components. The cable entry holes were filled with silicone to prevent liquid entrance.

III. Experimental Analysis

In this section, we experimentally analyze the prototype of the system for cattle virtual fence devised in this work. We will analyze several important features of the platform, including current consumption, autonomy, and communication range.

A. Current consumption

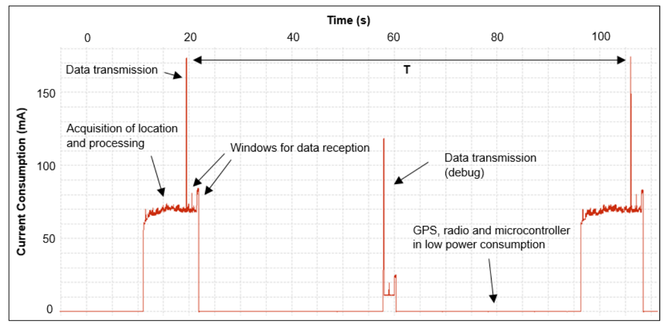

Fig. 8. Device current consumption profile in Data Transmission Mode. There is a transmission for control and debugging between data transmissions that can be ignored.

The individual current consumption of each component was measured with a Qoitech Otii Standard current meter. Fig. 8 shows the current consumption profile in the Data Transmission Mode. From these measurements, the duty cycle (which is the % of the time that the component is active, the rest of the time is off or in a low power consumption state) of each component was estimated, see Table I. Then, the average current consumption of the device can be roughly estimated under the assumption that it operates an 80% of the time in Data Transmission Mode, resulting in 28.1 mA.

TABLE I
AVERAGE CURRENT CONSUMPTION PER COMPONENT

Component	Current consumption	Duty cycle
Atmega 1284p	11 mA	36 %
Radio RFM95 stand-by	2 mA	36 %
Radio RFM95 TX	120 mA	0.09 %
Radio RFM95 RX	10 mA	0.27 %
GPS NEO M8N	57 mA	32.8 %
Buzzer	47 mA	2.5 %
Motor	540 mA	0.625 %

B. Device's autonomy

Let us now consider the autonomy of the device. The average consumption of 28.1 mA determines that 674.4 mAh is required daily. Therefore, the autonomy is approximately 5.1 days using a 3.4 Ah battery in the total absence of sunlight.

The current delivered by the solar panels was measured with a DT9208L Multimeter. The average value was 100 mA, with peaks of up to 120 mA, with a constant voltage of 4.2 V provided by the TP4056 charging module. Therefore, we estimate that the solar panels are capable of harvesting around 100 mAh per peak sun hour (PSH). As a consequence, almost 7 PSH per day are required for proving the 674.4 mAh demanded by the device. This number of PSH is satisfied in Uruguay almost all year, except for winter. If we consider the worst-case scenario of winter, when the PSH per day is 3, the device's autonomy would be up to 10 days.

C. Communication range

Two different tests were conducted to analyze the communication range between the SN and the gateway. Firstly, a line of sight experiment in a urban environment was conducted. The experimental results show that communication has a range of at least 9 km. In the second experiment, the gateway was installed on the roof of a farm shed. In this case, there were obstacles (mainly groups of threes, and constructions) between the SN and the gateway, and the maximum communication distance achieved was 1.6 km. In both cases a spreading factor of 7 was used. Results are presented in Table II.

TABLE II
RANGE COMMUNICATION TESTS

Area	GW height	Range	Midst
Rural	4 m	1.6 km	with obstacles
Urban	35 m	9 km	line of sight

D. Device's functionality

We continue the analysis with the experiments conducted for testing the behavior of the system for different variables of interest of the virtual perimeter. In these experiments, we selected four points on the map forming a convex quadrilateral, and the coordinates of these points were configured as the virtual perimeter of the SN. Then, the SN was moved throughout the area of the virtual perimeter, recording the relevant data (instantaneous location, date, time, and stimulation triggers). In all the tests conducted, it was corroborated that stimuli were activated according to the location of the SN and the virtual perimeter and the previously configured parameters, verifying the proper functioning of the whole system.

E. Preliminary tests with cattle

Finally, preliminary tests were performed on cattle (see Fig. 9) using different versions of the device at each stage of the development, testing several aspects of the proposed solution. In these experiments, the collar was placed for a few hours in cattle, verifying the ease of installation and checking that all the components held in place.

We also performed a primary functional validation observing the first reactions of the animals. It was found that the used materials do not produce any harm to the animals and they do not cause discomfort that affects their usual behavior.

Even though the behavior showed variations when considering different animals and characteristics of their environment, it was found that a large part of the cattle did not react to

Fig. 9. Cow grazing using our necklace.

the sound stimulus (buzzer). On the other hand, the tactile stimulus (vibrating motor) produced a significant reaction in the animals, causing in some cases the movement of the cattle in the desired direction (towards the interior zone of the virtual perimeter), without any prior training.

F. Summary of characteristics

Table III presents the main features of the designed platform. The location accuracy is taken from the GPS datasheet. The maximum sampling period happens when the SN is within the stimulation zones. On the other hand, the typical sampling period corresponds to a configurable parameter (in the present implementation is equal to 40 seconds). The response time represents the typical delay time between a configuration parameter is changed on our application server and the changes take effect on the SN.

TABLE III
SUMMARY OF CHARACTERISTICS

Feature	Description
Accuracy (in location)	2.5 m
Sampling period	Min: 1 second; Typ: 40 seconds
Range	9 km
Communication protocol	LoRa - Class A (915 MHz)
Current consumption	28.1 mA
Autonomy	5 days without sunlight 10 days with 3 PSH No limitation with 7 PSH
Stimuli	Sound (buzzer) and tactile (vibrator)
Weight	0.8 Kg
Size	Max: 90 x 9.4 x 4.5 cm
Response time	Typical: 1 minute

IV. DISCUSSION

Although the autonomy of the device is appropriate for a research platform, it may be not enough for commercial purposes. In this aspect, it should be considered that both the current consumption and the harvested energy have been conservatively estimated. On the other hand, if the animals are properly trained with the device, it is expected that they would stay for a longer time inside the virtual fence (to avoid stimulation). Since the interior area causes a lower energy consumption, this would produce a reduction in the consumed energy and thus a longer autonomy.

As it can be seen in Fig. 10, the power consumption bottleneck is on the GPS. Increasing the time that the NS is in the low power mode (and therefore the GPS) would not be a solution. This time is set around 32 seconds, which is near the maximum. Therefore, if it were necessary to increase the autonomy, it should be considered to increase the number of solar panels or use a GPS that consumes less.

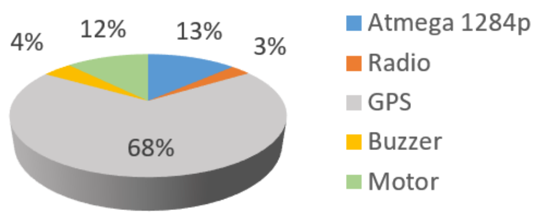

Fig. 10. SN energy consumption profile

Regarding the maximum achievable communication distance between SNs and the gateway, more exhaustive experiments are required. Although the test performed in a rural environment covered only 1.6 km, we believe that this result was conditioned by the height of the placement of the gateway. Since a range of 9 km was achieved in an urban environment, we expect to obtain better results in a rural environment installing the gateway at a higher height.

The platform permits to remotely track each SNs location and to build a record of the movements of the animals. Besides, the platform enables the assessment of different stimulation schemes, and thus allows the researcher to determine the best one. In our preliminary experiments, a significant reaction to the tactile stimulation was observed. We expect that after a learning period the animals could also react to the sound, and move towards the inner zone of the perimeter to avoid the tactile stimulus.

Our platform opens a new set of possibilities for interdisciplinary research in order to validate the effectiveness of different confinement techniques. Validation tests should not neglect either animal welfare or productivity. In particular, it is essential to consider and measure the stress caused to the animals by the stimulation and its eventual impact in milk or meat production. The proposed platform is aligned with the global concern about animal welfare avoiding electric shocks, which distinguishes it from other solutions already available in the market.

V. Conclusions

In this work, we have presented the design and manufacture of a platform for the virtual confinement of animals that is based on sound and tactile stimuli, which makes it compatible with animal welfare.

The main contribution of this work is the creation of a platform for the research of virtual animal confinement techniques. The platform allows the researcher to study the impact of several parameters of interest, including size and location for the virtual perimeter and stimulation zones, and the main parameters of the stimuli generator.

Regarding the experimental validation of the platform, functional tests were carried out that verify that the whole system works properly. The experiments performed with animals suggest that they are reactive to the tactile stimulus. We have confidence that after a training period, the conjunction of both sound and tactile stimuli can cause that the cattle remains confined within the virtual fence. An interdisciplinary team of researchers, including engineers, veterinarians, and agronomists, should address an in-depth study on the effectiveness of confinement methodologies based on this platform as future work.

Our platform could help to find effective methods for virtual livestock confinement without neglecting their welfare, which would benefit rural producers in several ways. These benefits include precision grazing, reduction in the costs of traditional fencing, and the potential to transport livestock without direct human intervention.

Acknowledgment

This project was supported by the Agencia Nacional de Innovación e Investigación (ANII), Fundación Julio Ricaldoni, the Uruguayan chapter of IEEE Circuits and Systems, and PEDECIBA Informática. The authors would like to thank TeLIoT for technical support and loan of a gateway, to Facultad de Veterinaria (Udelar) and Dayanara Bonilla, for allowing the use of their facilities and cattle, and offer assistance in carrying out the experimental work.

References

[1] C. Umstatter, “Review: The evolution of virtual fences: A review,” *Comput. Electron. Agric.*, vol. 75, no. 1, pp. 10–22, Jan. 2011.

[2] R. E. Marsh, “Fenceless animal control system using GPS location information,” Feb. 9 1999, US Patent 5,868,100.

[3] A. Llaria, G. Terrasson, H. Arregui, and A. Hacala, “Geolocation and monitoring platform for extensive farming in mountain pastures,” in *IEEE Intl. Conf. on Industrial Technology (ICIT)*, Mar 2015, pp. 2420–2425.

[4] S. J. Giunta, “Wireless fencing system,” Dec. 28 2010, US Patent 7,856,947.

[5] Z. Butler, P. Corke, R. Peterson, and D. Rus, “Virtual fences for controlling cows,” in *IEEE Intl. Conf. on Robotics and Automation*, vol. 2004, no. 5, 2004, pp. 4429–4436.

[6] ——, “From robots to animals: Virtual fences for controlling cattle,” *Intl. Journal of Robotics Research*, vol. 25, no. 5-6, pp. 485–508, 2006.

[7] G. Bishop-Hurley, D. Swain, D. Anderson, P. Sikka, C. Crossman, and P. Corke, “Virtual fencing applications: Implementing and testing an automated cattle control system,” *Comput. Electron. Agric.*, vol. 56, no. 1, pp. 14–22, 2007.

[8] D. Campbell, J. Lea, W. Farrer, S. Haynes, and C. Lee, “Tech-savvy beef cattle? how heifers respond to moving virtual fence lines,” *Animals*, vol. 7, no. 9, 2017.

[9] D. Campbell, J. Lea, S. Haynes, W. Farrer, C. Leigh-Lancaster, and C. Lee, “Virtual fencing of cattle using an automated collar in a feed attractant trial,” *App. Animal Behaviour Sc.*, vol. 200, pp. 71–77, 2018.

[10] I. Ferrer, “Holanda prohíbe el uso de collares eléctricos para perros (in spanish),” *El País*, 04-06-2019, last access: 09-20-2019. [Online]. Available: https://elpais.com/elpais/2019/04/06/mundo_animal/1554560388_687751.html

[11] IBM, *LoRaWAN in C (LMiC) Technical Specification v 1.5*, May 2015.

[12] M. Kooijman, “Arduino-lmic library,” https://github.com/matthijskooijman/arduino-lmic, 2017.