A 5µA Wireless Platform for Cattle Heat Detection.

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Abstract*— Cattle heat (oestrus) detection has become an important problem to solve at dairy farms. Tracking the animal's physical activity is known to be a very effective way to check heat, sometimes requiring expensive electronics and large batteries for the task. In this work, several state of the art technologies are combined in an ultra low power platform with wireless long range communication, for activity data collection for oestrus detection. A modern micro-power accelerometer, FRAM-microcontroller, and a LoRa transceiver are utilized to develop the activity tracker. The device reaches a measured ultra low power consumption of 2 uA while collecting data, and a very large (> 10 km) communication distance using a star topology and LoRaWAN protocol at countryside areas.

Keywords*—IoT; LoRa; Heat Detection; Accelerometer; Low-power.

I. Introduction

The reproductive efficiency of dairy industry has increased over the last ten years due mainly to an intensification of the management techniques of the herd [1]. A main objective of worldwide dairy farms is to ensure that dairy cows, produce as much milk as possible. A cow produces milk while it has a calf to breastfeed, therefore, the less time passes between births, more "productive" the cow is. This is the principal reason why the precise heat (oestrus) detection has became so important, a task traditionally assigned to veterinary and expert people examining and watching the cattle behavior, and in recent years to electronic devices monitoring the cow's physical activity. Tracking the animal's physical activity by means of a portable device strapped to each animal, is known to be a very effective way to determine heat, but sometimes requires expensive hardware and large batteries. In this work, a micro-power wireless system able to automatically detect oestrus period of cattle is presented, designed at BQN [2], a company developing technology for the agribusiness industry in Uruguay. The system seizes the recent availability of micro-power accelerometers, long range transceivers and FRAM microcontrollers, to achieve a coin cell battery powered paradigm.

A. Current solutions on market

There are several studies and publications referring to the study of cows behaviour and heat detection from activity measurement, implemented using a 3-D accelerometer and wireless communication, using different techniques, methods, and algorithms. Bikker et al. (2014) [3] evaluated a 3-dimensional accelerometer device from Agis Automatisering, the CowManager SensOor, which can be attached to ear identification tags (Fig. 1 (a)) for monitoring cow welfare. A 3-dimensional accelerometer continuously registers the movements of the cow's ear. Data is sent through a wireless connection, via routers and coordinators, to a host computer [4]. Jonsson et al. (2010) [5] introduce a lying balance to estimate dairy cows motivation to lie down that can be correlated to heat. The new approach involves measuring steps and lying/standing behavior recorded by the commercially available activity monitor IceTag3D. The sensor is attached to the dairy cow's leg and assesses its activity in terms of the variables lying, standing, motion index, and step count using accelerometer technology. Vanrell et al. (2014) [6] proposed an oestrus detection method, where a recording device (collar) is attached to the cow, and acceleration records are filtered and segmented. After that, simple statistical attributes are extracted from each segment. The latter approach, the collar, is the most common method used and at the present there are some solutions in the market like [13][14] that include collars, apps, and software to help farmers to detect heat in a cattle herd. While the hardware and algorithms change for each example, the mentioned devices use a 3-axis accelerometer, a local low-power data processing to avoid huge amounts of samples to be transmitted, and a medium to long range but wireless link.

Fig. 1. Different methods used to measure activity: a) CowManager SensOor, b) IceTag3D, c) A collar is the most common and implemented solution.

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II. The Proposed Solution

A. Overview

Since there is a narrow time window for the heat detection, all the proposed solutions include a wireless link to track and alert the veterinary/farmer, using different communication protocols and network topologies. One of the main goals of this project was to procure a simple, low-power but long range solution (because in Uruguay cattle are raised in the open, in relatively large farms), and in order to meet these requisites LoRa technology [12] was selected. LoRaWAN (Long Range) protocol allows star network topology, supporting up to ten thousand nodes connected to only one gateway, and each transceiver can reach a few kms range at very low-power consumption in low data rates. Fig. 2 shows an explanatory scheme of the proposed solution. Each cow has a collar or eartag, which includes an accelerometer and LoRa wireless connectivity (class A node type), connected to a LoRa gateway. Meanwhile, the LoRa gateway is connected to internet and sends the information to a server with a software application where data is processed and analyzed.

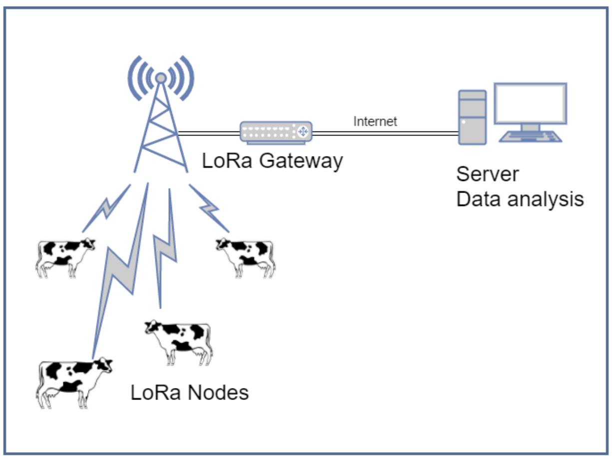

Fig. 2. Proposed system topology.

B. The developed hardware

In Fig. 3 a block diagram of the nodes (collar) hardware is shown. It includes:

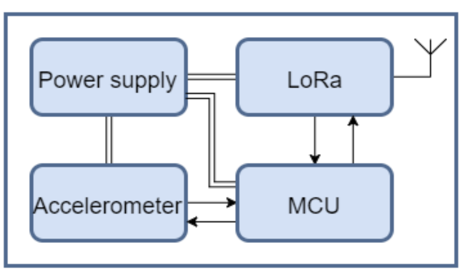

Fig. 3. A block diagram of the heat detection node (collar).

Accelerometer: In order to measure the physical activity of the cows, an ADXL362 3-axis MEMS accelerometer was employed. Particularly, it has a very small current consumption for battery powered applications consuming less than 2 μA at a 100 Hz output data rate and 270 nA when in motion triggered wake-up mode. In addition it has many features to enable true system level power reduction including a deep multi-mode output FIFO, a built-in micro-power temperature sensor, and several activity detection modes. Communication interface is SPI as slave [7].

MCU: For configuration, control, and data processing the MSP430FR5969 microcontroller from Texas Instruments was chosen. It was selected among the vast universe of microcontrollers available for its ultra low power characteristic due to its Ferroelectric memory (FRAM). FRAM technology combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash at a much lower power budget. MSP430 ULP FRAM portfolio includes a plenty set of peripherals and the processor architecture has seven low-power modes, optimized to extend battery life [8].

LoRa: The SX1276 transceiver from Semtech was selected. It incorporates a LoRa chirp spread spectrum modem which is capable of achieving significantly longer range than other options available based on FSK/OOK modulation. At the maximum data rates of LoRa, sensitivity is 8 dB better than FSK, and receiver sensitivity more than 20 dB compared to FSK. In LoRa the user may decide on the spread spectrum modulation bandwidth (BW), spreading factor (SF) and error correction rate (CR), to optimize each application. Another benefit of the spread modulation is that each spreading factor is orthogonal, thus multiple transmitted signals can occupy the same channel without interfering. This also permits simple coexistence with existing FSK based systems. The SX1276 offers bandwidth options ranging from 7.8 kHz to 500 kHz with spreading factors ranging from 6 to 12, and covering all available frequency bands [10]. While there is still a discussion about the performance of LoRa in the presence of interference, in the case of farms away from the city (a less polluted RF spectrum) it promises to be an ideal solution: thousand nodes (cattle heads) can be tracked in several kms around.

Power Supply (battery): The system is intended to be used on collar for cows in an aggressive environment, with a battery duration of a couple of months to ideally several years. The major limitation is not power consumption but current peaks only present during transmission (a few milliseconds every each hour) but estimated to be about 125mA in a worst case. A Polymer Lithium Manganese Dioxide battery with enough maximum pulse current rating was chosen. Its principal features are listed below:

- Nominal capacity: 400 mAh (typical).
- Nominal voltage: 3.0 V (mean voltage at a discharge current of 1 mA).
- Operating temperature range: -20 to +60.
- Max. pulse current: 150 mA for 15 s.
- Dimensions: 30.0 mm x 39.0 mm x 2.3 mm.

Final PCB: The heat detection node prototype is shown in Fig. 4 in a 74.0 mm x 34 mm x 1.6 mm, 4 layer PCB. Special care was taken for RF wireless communication front-end, placing a distributed power plane between 2 ground plane layers enabling an evenly distributed RF decoupling capacitance between the supply and ground. In addition, the power plane provides a very low impedance trace at radio frequencies. The power plane is surrounded by a ground trace with vias that connect the two ground traces together, thus preventing any radiated emissions at the board edge. The power plane is suppressed at the final stage of the TX matching network to prevent any parasitic coupling caused by radiated and reflected energy at this stage.

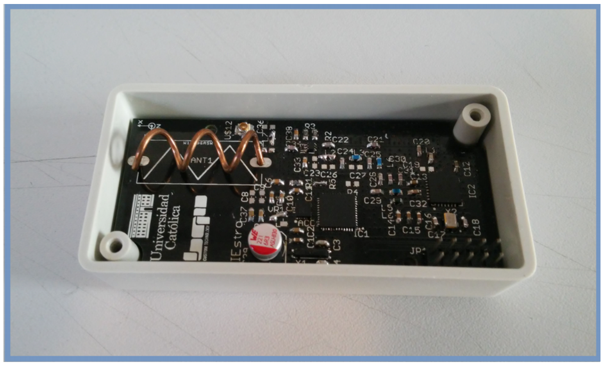

Fig. 4. Assembled final PCB in a plastic case.

C. Firmware

All the firmware - accelerometer drivers, LoRa drivers, data processing logic, etc. - is implemented in C programming language, and developed with Code Composer Studio, an Eclipse based IDE provided by the manufacturer. A round-robing with interrupts architecture was selected, where at start, all the hardware components are initiated and configured and then, a while(1) loop keeps all the program. Inside this loop, most of the time, the MCU and LoRa transceiver are in sleep mode, while the accelerometer gets information and stores it in its FIFO buffer. Once the FIFO is full (each 6 secs – 150 samples for 3 axis and 2 bytes per axis sampled at 25 Hz -), the MCU wakes up, clears the FIFO and process the data. When enough data is collected, each hour, data is processed and transmitted via LoRa wireless protocol. Acceleration samples are low pass filtered by the accelerometer itself at half the sample rate, 12.5 Hz, and then, when the FIFO is full, the MCU calculates a mean value for each axis, and subtract its mean to each value (high pass filter) to avoid offset due mainly to the force of gravity. After that, the square module of acceleration is calculated and stored. Once per hour, all stored samples are averaged giving a mean value of square module accelerations from previous hour, and it is taken as an activity numeric representation. In Fig. 5 and Fig. 6, firmware flowchart and block diagram are shown.

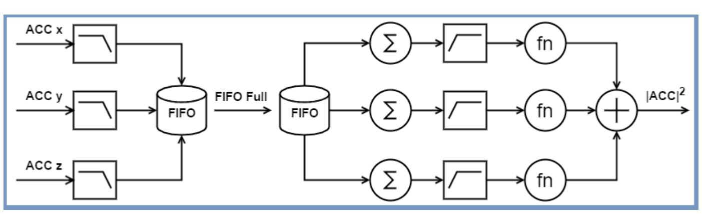

Fig. 5. *Data acquisition and processing block diagram.*

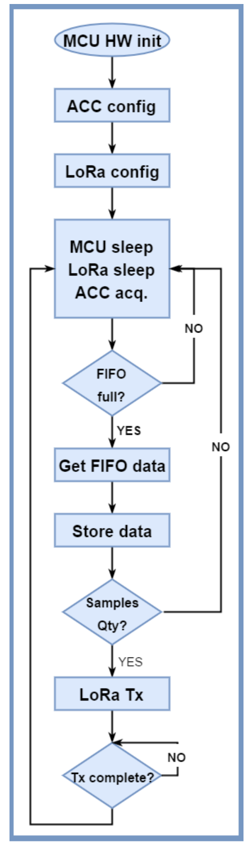

Fig. 6. *Firmware flowchart and data acquisition and processing block diagram.*

III. Measurement Results

The system worked as expected, data was acquired and transmitted to the Server at a maximum distance of 11.4 km. The idea is each collar transmit on an hourly basis (or in the case of abnormal activity) a data block to the server containing several activity samples. A proprietary algorithm can be utilized at both the collar and server to estimate if the physical activity is indicating a probable to heat period. Some measurement results on hardware follows:

Power consumption and battery lifetime: In order to measure power consumption, a known R-C circuit was placed in series with the battery to measure the current consumption using an instrumentation amplifier with a gain G = 76. R-C values change to measure system sleep, active, and transmit current. This measurement circuits and data acquisition were implemented with the aid of an Electronics Explorer board [34]. The results are shown in Table I.

TABLE I. Current consumptions comparison

State	Current	Time
Sleep	3.07 μA	5988.7 ms
Processing	1.18 mA	11.3 ms
Transmitting	89.4 mA	9.6 ms

Since every 6 seconds the FIFO buffer of the accelerometer must be read and cleared, the sleep-processing periods impose a minimum power consumption (in the case of continuous measurement) and the highest impact in battery lifetime correspond to the transmission strategy (how often data is transmitted to the gateway). Different transmission periods where proposed to compare battery lifetime as shown on Fig. 7. From the picture, a good trade-off is to transmit data every each hour, having a good relation between data acquisition and battery life duration. It should be pointed that ADXL362 accelerometer allows further reducing power consumption using the activity detection modes but this feature has been not tested yet. Current consumption without transmitting is calculated below in equation (1), being I_{sleep}, t_{sleep}, I_{proc}, and t_{proc} extracted from Table I, and t_{total} the sum of t_{sleep} and t_{proc}.

$$I_{tot}=I_{sleep}*\left(\frac{t_{sleep}}{t_{tot}}\right)+I_{proc}*\left(\frac{t_{proc}}{t_{tot}}\right)=5.28\mu A \tag{1}$$

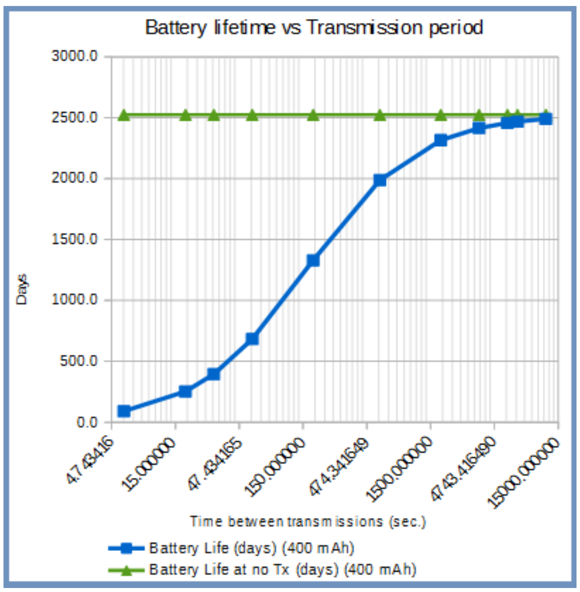

Fig. 7. *Battery lifetime vs Transmission periods. LoRa parameters: SF=7, BW=500 kHz, CR=4/5.*

Also different LoRa configuration parameters combinations were performed to measure the transmission time taxing on the energy autonomy of the platform. A mean battery lifetime of 1695 days was obtained (4.6 years).

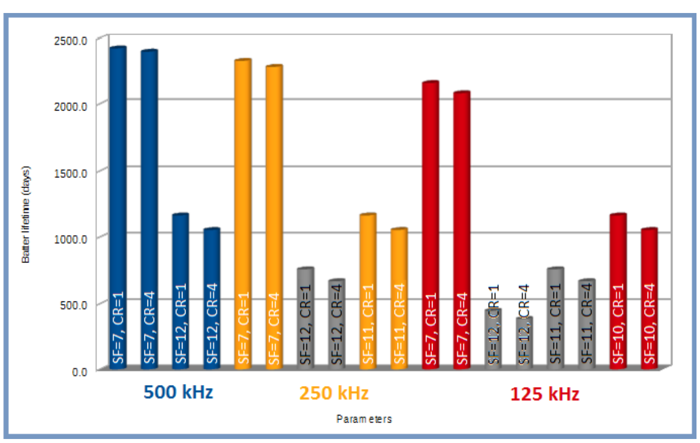

Fig. 8. *Battery lifetime vs LoRa parameters*

IV. Conclusions

The design and measurement results of an ultra low power platform including wireless long range communication aimed at collecting activity data for heat detection on cattle was presented. The solution was developed using state of the art of-the-shelf components, reaching very good power consumption and wireless distance range results. The system consumes an average of only 5 uA current consumption while continuosly capturing acceleration samples, reaching a 5 year battery life for a Polymer Lithium Manganese Dioxide battery of 400 mAh, and transmitting data each hour over more than 10 km distance to the nearest gateway. Hardware cost is under 25 dollars for 100 units, it will drastically drop for thousands units, and also with time since LoRa and micropower accelerometer are not yet mature technologies. Future work may include further power reductions by means of hardware activity detection modes, investigating the development of geolocalization using LoRa gateways that may have an enormous impact in the industry.

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