SheepIT - An Electronic Shepherd for the Vineyards

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Abstract. This paper presents a new and innovative Internet of Things based solution for controlling grazing sheep in vineyards. The SheepIT solution includes a postural control mechanism that prevents animals from eating grapes and the lower branches of the vines, but allows them feeding from the unwanted weeds, thus taking advantage of the animal's biologic need to feed themselves to have an ecological vineyard weed control solution. Additionally, a radio-based virtual fence mechanism is used to contain the flock inside the desired grazing areas, allowing simultaneously to monitor animal's activity and to transfer the gathered data to a cloud application, for logging and analysis purposes. This paper identifies the main requirements and presents the system architecture. Moreover, the functional blocks that compose the developed solution are detailed, with special focus on the collar to be carried by the sheep. The implementation of the solution is also addressed in the paper, and some preliminary experimental results, concerning the virtual fence mechanism, are presented.

Keywords: Autonomous herd management, IoT, posture control, virtual fence, cloud application

1 Introduction

The constant growth of unwanted and undesirable weeds in vineyards, which compete for soil nutrients, forces the producers to repeatedly remove them through the use of mechanical and chemical methods (Monteiro and Moreira, 2004). These methods include machinery usage as plows and brushcutters to remove the weeds between plant rows, and herbicides on the line between plant feet, in order to kill or prevent the growth of weeds. Nonetheless, such methods are considered very aggressive for vines, as well as harmful for the public health, since chemicals may remain in the environment and hence contaminate water lines. Moreover, such processes have to be repeated over the year, which entails a significant economic impact, representing in the case of vineyards, 20 to 35% of total working time, with costs per hectare ranging from 80€/ha up to 380€/ha (Carlos, 2014).

The use of animals to weed vineyards (Dastgheib and Frampton, 2000)(Bekkers, 2011), usually ovines, is an ancient practice used around the world. Animals grazing in vineyards, feed from the unwanted weeds and fertilize the soil, in an inexpensive,

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ecological and sustainable way. However, as depicted in the Little Prince story[1], sheep may be dangerous to vines since they tend to feed on grapes and on the lower branches of the vines, which causes enormous production losses. To overcome that issue, sheep were traditionally used to weed vineyards only before the beginning of the growth cycle of grapevines, requiring the use of mechanical and/or chemical methods during the remainder of the production cycle.

The SheepIT project (*SheepIT Project*, 2017) aims at developing an autonomous mechanism to control sheep's posture and location during vineyard grazing periods. The project includes an Internet of Things (IoT) based solution to monitor and control the animals. Data concerning the behavior and physical condition of each one of the animals are sent, in real-time, to a cloud platform. This cloud platform allows the human operator to oversee, in an easy and efficient way, the flock, namely browsing the collected data about animals and equipment. It also permits deploying algorithms to process the data and detect abnormal situations, such as health conditions, lost animals or attacks from predators, generating automatically alarms when one of such events occurs.

The system architecture was designed in order to provide a flexible and adaptable solution regardless of vineyard's size and shape. Moreover, the human intervention is maintained at a low level, being only indispensable for setting up the devices. The system incorporates: a portable electronic collar, carried by the sheep, responsible for monitoring and controlling its behavior; fixed devices called beacons, installed in vineyards, responsible for interconnecting the network devices, define the virtual fence placement and carrying out collar's relative localization; a gateway device, that aggregates data from all the beacons and uploads it to the cloud; and a cloud application, responsible for gathering all the data collected and make them available to the user.

This paper presents an overview of the SheepIT project, with special emphasis on the global system architecture, functional blocks and their interactions. Moreover, and due to its relevance, a special attention is given to the collars design. This paper continues in Section 2 with a review of the related work in monitoring and controlling animals. Section 3 describes the SheepIT architecture and the IoT network. Section 4 describes the solution implementation and Section 5 presents some preliminary results concerning the virtual fence, which is a key element of this solution. Section 6 concludes the paper and presents future work.

2 Related work

In the scope of the SheepIT project, there are mainly two issues of interest that must be explored, namely *i)* how to control animal's posture and *ii)* how to monitor its behavior, actions and location. For the latter case, many studies and applications can be found in the literature (Umstatter, 2011), especially concerning monitoring the location, pastures and welfare. On this, GPS (Global Positioning System), sometimes combined with accelerometers, is the most portrayed technology found in the

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[1] Little prince

literature, being evaluated to be used for locating cattle (Augustine and Derner, 2013) (Kjellqvist, 2008) (Turner *et al.*, 2000), white-tailed deers (Bowman *et al.*, 2000), griffons (Nathan *et al.*, 2012), crocodiles ((Hunter *et al.*, 2013) and sheep (Rutter, Beresford and Roberts, 1997). In the last case, a GPS, together with a jaw and lying/standing sensors, are used to monitor the grazing areas of domestic sheep. However, this solution weights almost 2kg, needs to be transported in the back of the sheep and has an estimated autonomy of 7 days. The relatively short autonomy highlights one of the GPS limitations, which is its high-energy consumption, that together with its high cost and usual loss of satellites connection (Nadimi *et al.*, 2008) makes it unsuitable for animal's localization, particularly small to medium size ones.

To mitigate GPS device limitations, new alternatives started to arise, namely through the use of algorithms to estimate the relative position between nodes. Within those, and due to its simplicity, the Received Signal Strength Indicator (RSSI) is the most popular (Umstatter, 2011). In fact, as the RSSI is a common parameter available in most of the wireless interfaces and many wireless technologies are designed to exhibit low energy consumption, this method becomes very appealing for carrying out relative localization in energy-constrained scenarios. Therefore, several solutions employing that technique come up, particularly using Zigbee Wireless Sensor Networks (Nadimi et al., 2008) (Huircán et al., 2010). A solution using UHF radio tags, able to communicate with network terminals equipped with GPS and GPRS devices, was presented in (Thorstensen et al., 2004). The denominated e-shepherd solution, aimed at developing a system capable of monitoring the location of grazing sheep in mountains. However, this solution only allowed a rough estimation of the flock location and presented many communication problems.

The control and conditioning of animal's location is typically made using physical ground-based fences. However, its cost and lack of flexibility, prompted the use of virtual fences, in which electronic systems control the animal's behavior (Anderson, 2007). These systems emit cues/stimulus to animals when they adopt undesirable behaviors (e.g. approaching the defined boundary of the fence). These cues are mostly constituted by a pair of stimuli, namely a warning tone or vibration, followed by an electrostatic discharge, if the animal persists on the unwanted behavior (Tiedemann, A.R.; Quigley, T.M.; White, 1999). Using a warning cue, allows animals to associate it with an electrostatic stimulation and consequently revert its behavior. The success of this process depends on a training process in which not all breeds and animals react in the same way. It is important to stress that the use of electrostatic cues raises ethical issues, but it is proven (Lee *et al.*, 2008) that the effects of using low energy electrostatic cues on animals are similar to weighing or treatment processes, and hence can be considered suitable and safe to be used on animals. Among the solutions described in the literature to constrain animals, the ones tested in goats ((Fay, McElligott and Havstad, 1989) and sheep (Jouven *et al.*, 2012) are the most closely related with the SheepIT project. Both use training collars for dogs with audio and electrostatic cues. Although both studies show that both animals are able to be trained with those cues, they are not enlightening in what concerns to the characterization of the stimuli (e.g. duration, intensity).

Table 1 compares the SheepIT requirements with the most relevant solutions found in the literature and introduced before. The SheepIT system shall implement a virtual fence, confining the sheep grazing inside a predefined area defined by shepherds/farmers as well as it shall allow to know the localization of each sheep. Moreover, the system comprises a device, integrated on the animal's collar, that shall include a posture control mechanism, in which the neck and head position are monitored, in order to detect possible undesired behaviors. Additionally, the collar device shall have small dimensions, similar to the available solutions for training dogs, in order to be comfortably carried by sheep. The autonomy of collars shall be at least 4 months, in order to avoid too often battery replacements, thus reducing the maintenance time and costs. These last two requirements require a highly energy-efficient system, in which communications, localization, sensing, actuation and processing activities must be properly synchronized and scheduled, to attain the desired functionality, while, at the same time, keeping the collars in low-power consumption modes as long as possible. The data gathered shall then be delivered to a cloud service, to be analyzed and presented to the user, using a simple and user-friendly interface. Finally, as the solution is intended to be used in vineyards to remove weeds, it is expected to have thousands of sheep in few hectares, resulting in the need of a high scalable network.

Table 1. Comparison between the SheepIT requirements and the similar solutions available

Requirements/Solution	SheepIT	E-Shepherd	Nadimi et al	Huircan et al	Jouven et al	Rutter et al
Small Dimensions (0,5Kg-1Kg)	✔	✔	✔	✔	✔	✘
Localization (relative or absolute)	✔	✔	✔	✔	✘	✔
Data Collection	✔	✔	✔	✔	✘	✔
Communication Infrastructure	✔	✔	✔	✔	✘	✘
High Autonomy (~ 4 months)	✔	✘	**NA**	✘	**NA**	✘
Virtual Fence	✔	✘	✘	✘	✔	✘
Posture Control	✔	✘	✘	✘	✘	✘
Pasture geographic delimitation	✔	✘	✘	✘	✘	✘
User interface	✔	✘	✘	✘	✘	✘
Network Scalability	✔	**NA**	**NA**	**NA**	**NA**	**NA**
Year	**2017**	**2016**	**2008**	**2010**	**2012**	**1997**

3 System architecture

As depicted in Fig. 1, SheepIT follows a typical IoT architecture, with a Wireless Sensor Network (WSN) layer, a cloud computing layer and an application layer. On the WSN layer, mobiles nodes, named collars, are carried by sheep and are composed of a set of sensors and actuators, a microprocessor, a radio link and a battery. Sensors detect animal's posture, while actuators apply stimulus when sheep adopt undesirable behaviours. The radio link reports data sensed by collars and provides support to relative localization, through the measurement of the link's RSSI. Carrying out the localization using the same radio infrastructure used for data collection contributes significantly to reduce the power consumption, as it can be obtained with minimum energy expenditure, because it requires only processing the RSSI after regular radio data exchanges. Collars move within the range of one or more fixed beacons, which are nodes that are installed by shepherds in the areas to be grazed, enabling the implementation of a virtual fence mechanism and the gathering of data transmitted by collars. The system also contains a gateway node, which collects the data gathered by the beacons and sends it to a cloud platform. Finally, a web application processes the data received and makes them available to the user.

The following subsections present in more detail the system, with special focus on the wireless sensor network layer, collar device, communication infrastructure and cloud platform.

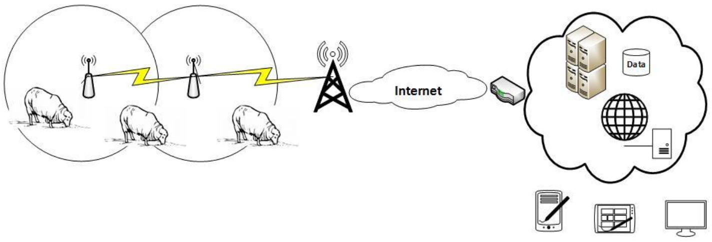

Fig. 1. Overall system architecture

3.1 Wireless Sensor Network

Confining animals inside the vineyards without continuous human supervision requires a fence mechanism. In order to allow an easy and flexible definition of weeding areas, it is adopted a virtual fence approach, supported by an RSSI-based relative localization mechanism. This one uses the measurement of the RSSI of the communication between beacons and collars, which are carried out at regular intervals, to determine an estimate of the distance between them. Moreover, this relative localization can be converted in an absolute one, as the beacons, which do not have particular size and weight limitations, shall incorporate a GPS device. To enable this mechanism, periodic messages are transmitted between beacons and collars, allowing regular updates of their location as well as providing synchronization of the network. Moreover, to enhance the localization process, beacons are installed close to each other to guarantee overlapping of individual areas of coverage, which in turn allows merging multiple localization data, thus contributing to improve the accuracy of the relative localization process.

In the general case, beacons have to relay information of other beacons, since it may be necessary to cover relatively large areas with arbitrary topologies, therefore it is not possible to ensure that the gateway device can communicate directly with all bacons. Therefore, the system integrates a routing mechanism to ensure that the data sent by collars and collected by beacons, are relayed until reaching the gateway and consequently the cloud application.

As the collars are mobile and beacon’s coverage areas overlap, a collar can, in a short period of time, be in the range of different beacons or set of beacons. Hence, the data from a collar can be received by multiple beacons. Relaying replicated data would consume bandwidth unnecessarily, therefore beacons follow a data centric approach (Ghaffari, Jafari and Shahraki, 2013), merging the information received locally and the information relayed by other beacons.

The existence of multiple nodes competing for the transmission medium, allied to the system energy constraints, requires an efficient Medium Access Control (MAC) mechanism. The system incorporates different types of traffic, with different purposes and specifications, namely: periodic sensor data sent from collars to beacons, periodic localization messages sent beacons to collars, periodic relay traffic between beacons and sporadic traffic to allow nodes to register dynamically in the network. As the overall bandwidth utilization can be relatively high (the system shall allow the presence of several hundreds or even thousands of animals over regions of a few square kilometers) and it is important minimize the energy expended by collars, it is adopted a temporal multiplexing approach combined with a cyclic structure. This cyclic structure is composed of different micro-cycles (uC), on which different traffic is transmitted, forming a macro-cycle (MC) that is repeated in a cyclic way (Kopetz, 2011). A uC starts with a message from beacons to collars that is used to perform localization, to synchronize collars with the remaining nodes and to identify the type of uC. Depending on the uC type, the remaining time is used for different purposes, eventually employing different access control methods. Collars registered on the network send sensor data periodically to the beacons. To minimize the number of collisions and the amount of time that the radios have to be active, this kind of uC adopts a Time Division Multiplexing Access (TDMA) scheme, in which each node has a non-overlapping individual communication slot. Communication between beacons is also periodic, and uCs dedicated to this kind of communication adopt a similar TDMA scheme. On the other hand, there are communications that are not periodic. For example, when a sheep enters in a protected area for the first time or after being absent for a long time, its collar must register on the system to get a periodic communication slot. For this purpose, there is one uC type that has an arbitration scheme based on Carrier Sense Multiple Access, which allows the transmission of unscheduled communications such as the one related with registration.

3.2 Posture control

The posture control mechanism is crucial for the SheepIT solution, since it enables animals to be used inside the vineyard, without threatening the vine grapes and lower branches. This mechanism is enabled by collars applied on animals and it is based on the three main blocks shown in Fig. 3: a set of sensors, to monitor the animal posture and movements; an algorithm executed by a microprocessor that analyzes the data gathered by sensors, applies sensor fusion and decides about the necessity of applying stimuli; and a set of actuators that apply the actual stimulation to the animal, when commanded to do so.

At this stage the animal's posture is monitored by two kinds of sensors: an ultrasound sensor, to measure the distance between the neck of the animal and the ground; and an accelerometer to monitor the neck tilt. These sensors are periodically read and their inputs are fused, in order to detect incorrect animal postures. The need for using more than one kind of sensor and fuse their readings arises from the fact that the terrain has irregularities (e.g. obstacles and holes in the ground) and animals may adopt different postures (e.g. laying on the ground or walking), together with the need for having a reliable detection of undesirable behaviors, as the success of the animal's learning process depends on this and it is considered essential for animal's comfort. The combination of sound and electrostatic stimuli (Umstatter et al., 2013) are the most effective, and hence used as the posture control actuators.

3.3 Cloud platform

A cloud platform is proposed with a triple purpose: (*i*) to store sensor data streams and perform continuously data mining to extract relevant information about the location, activity and behavior of animals, as well as about device's state and operation; (*ii)* to provide a user interface through a web interface, allowing shepherds and/or farmers to use a mobile device to access to the collected data; (*iii*) to autonomously generate alarms when problems occur on animals or equipment.
The IoT gateway periodically streams the device monitoring information to the cloud platform through a broker (Fig. 2). This broker delivers the information within the cloud platform to entities, on a subscription basis. This allows several entities to subscribe specific subjects of the stream and carry out data mining of specific subjects. Moreover, the subscriber entities identify critical values and trigger alarms (*e.g.* animal out of bounds, animal's panic, equipment failure), storing this information on a database.

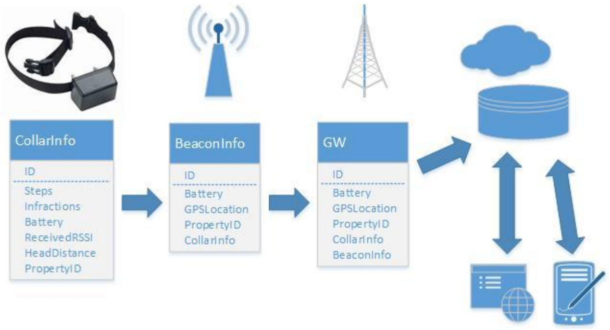

Fig. 2 – Cloud platform organization

The alarms are sent by the system to the human operator, notifying him about the occurrence of critical events, so that he can intervene in the system, correcting the anomalies as soon as possible, preventing undesirable consequences (*e.g.* loss of animals, network failures, damages in the cultures).
Together with the dynamic information generated by the system (*e.g.* animal activity, battery state), the system database also contains static information about animals (*e.g.* gender, birthdate, vaccines) and equipment (*e.g.* model, firmware version) that can be inserted by the system operator. This introduces additional value to the solution, allowing farmers to correlate information gathered on-line by collars installed on the sheep with specific information of each animal, as veterinary data.

4 Implementation

SheepIT collars are a crucial element due to their requirements and features. Its implementation is based on Texas CC1110 SoC, which includes a microcontroller with several IO Ports and timers, allowing diverse power saving modes. Moreover, this SoC also includes a radio module operating at the 433 MHz ISM band. This SoC was selected because it has a low-cost and low power consumption and the 433MHz band radio is suitable to be the used on vineyards, considering the radio environment constraints (*e.g.* trees, posts, metallic strings and vine relief). In addition to the CC1110, the collar, whose architecture is illustrated in Fig 3, contains an accelerometer, an ultrasound-based distance measurement circuit (using a transceiver similar to the ones used on cars), a buzzer, and a high voltage stimulator.

The first prototype of the collar, shown in Fig. 4, includes all the signal conditioning circuitry necessary to integrate sensors and actuators, as well as the firmware to control the circuit peripherals, allowing the complete parametrization of measurements and actions.

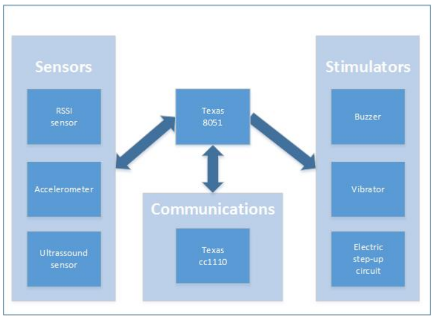

Fig. 3. Collar modules

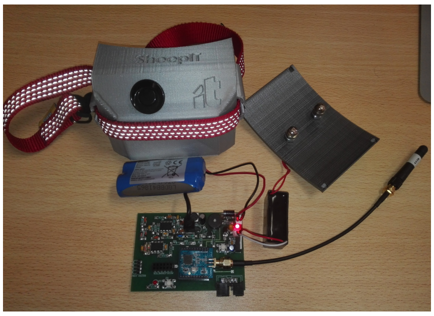

Fig. 4. Collar prototype

SheepIT beacons are also based on the Texas CC1110 SoC. Regarding communications, no additional components are required, as the same radio used for collar-beacon communication is also used for *beacon*-beacon and beacon-gateway communication. In the future, a GPS module will be added to the beacon hardware platform, to enable the deployment of the absolute localization services.

5 Results

The project is still at a very early development stage and, so far, it was only possible to make preliminary tests of the communications and virtual fence operation. As such, a scenario test, depicted in Fig. 5, composed of two beacons directly connected to Linux-based PCs, and a collar, was set up. The collar node moves between the two beacons, which receive the data from the collar, and computes the RSSI of each link. The PCs are connected, via a serial link, to the beacons, displaying and storing the received data. Beacons are placed at a higher position (2m) than collars (50 cm).

Measured values were captured during 3 minutes, from both beacons, with 5 meters' intervals.

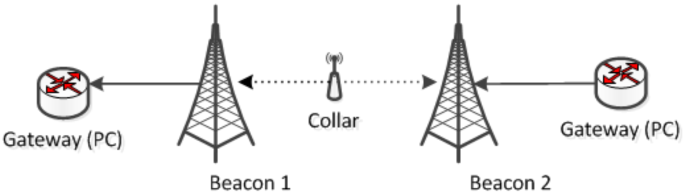

Fig. 5. Topology of the test

The initial data capture analysis (see Fig 6) allows us to conclude that the RSSI value decreases polynomially with the distance between the collar and the beacon. Also, a huge variation of the RSSI can be observed for the same distance. On this basis, it was implemented a virtual fence mechanism establishing a minimum RSSI value of -55 dBm, which in our case corresponds to a distance around 40 m. A communication received by the collar with this RSSI, means the detection of a fence infraction which in turn triggers an audible warning signal. If during the subsequent communications the RSSI value doesn't return to values greater than -55 dBm, the system responds with an electrostatic stimuli.

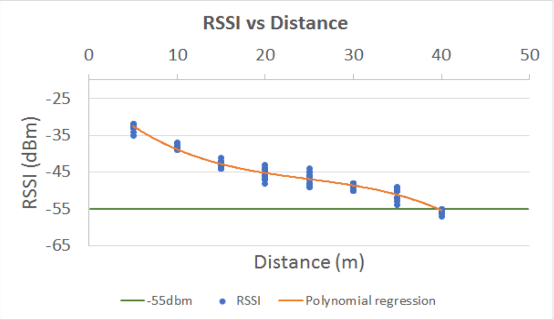

Fig. 6. RSSI measured versus the distance between nodes

In order to enable the computation of an estimation of the distance of a collar according to the RSSI measured, the variables from the graphic represented in Fig. 6 were inverted and a polynomial regression executed (Fig.7). As the virtual fence mechanism is especially crucial at the border of the fence, we evaluated the behavior of the polynomial for values measured close to the border of the fence (40m). Hence, for all the values of the RSSI measured at distance equal to 40m, we calculated the respective distance estimation using the polynomial. Fig. 8 shows that the error associated to the polynomial regression and RSSI measurements result in situations on which the stimulators are triggered even if the collar is still in the border if the fence (red line). However, this limitation can be minimized if the warning sound are triggered before the collar reaches areas close to the border.

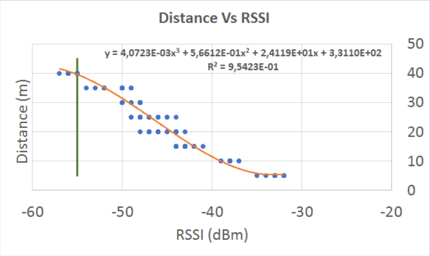

Fig. 7. RSSI measured versus the distance between nodes

Fig. 8. Distance estimated using the polynomial

6 Conclusions

The SheepIT project aims at taking advantage of sheep grazing behavior, to weed vineyards in a economical and ecological approach, fertilizing the soil and thus optimizing the wine production. However, sheep presence within the vineyards creates several challenges, especially the ones related with preserving the integrity of vines and grapes, to not jeopardize the wine production, and with keeping sheep herd within a designated region, all of this without direct human supervision. As such, posture control and virtual fence mechanism are sought in the scope of the project.

Although in the past, sheep have been used to graze in vineyards, nowadays, thanks to the specialization that the vines suffered, the flock is a foreign element. In order to facilitate the animal management process by vineyard staff, the project includes collars and beacons which, combined with a communication infrastructure, feed a cloud platform with animal data, following IoT-like design principles.

The project still is in its initial period and its development in a very embryonic stage. This paper presents the project requirements and goals, as well as the proposed system architecture and a preliminary assessment of the RSSI-based virtual fence mechanism. Tests have been carried out on a test scenario containing two beacons and a collar, with a very rudimentary algorithm to control sheep position.

The obtained results show that the relative localization mechanism, despite basic, offers a precision of around 2m at a 40m distance. This value is of the order of magnitude of the required one, and can still be improved, thus indicating that this localization method is suitable for supporting the virtual fence mechanism. It is, however, important to improve the precision of the localization, namely by combining the RSSI values of several beacons, eventually adding also dead reckoning, and evaluate it in a real scenario to check if the mechanism promotes animal learning.

Beyond assessing the fence mechanism in a real scenario, tests have to be performed to gather real data in order to learn how to recognize animal posture from the collar sensory information, and thus to enhance the definition of a suitable posture control algorithm. Moreover, further work has to be performed in the communication infrastructure, in order to validate and adapt its operation to the Douro vineyards orography.

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