Distributed Sensing System for an Old Vineyard in the Douro Demarcated Region - North Portugal

Sérgio Silva[*†**], Salviano Soares[*¶], Filipe Cabral Pinto[§]
[*]Engineering Department School of Sciences and
Technology, UTAD, Vila Real, Portugal
[**]Globaltronic, Aveiro, Portugal
[†]INESC TEC -INESC Technology and Science
Porto, Portugal
Email: sergio.s.silva@ inescporto.pt

Diogo Duarte[‡], João Barroso[*†] and Justino Soares[‖]
[‡]Department of Electronics, Telecommunications
and Informatics, UA, Aveiro, Portugal
[§]Altice Labs, Aveiro, Portugal
[¶]IEETA - UA, Aveiro, Portugal
[‖]Quinta do Crasto, Vila Real, Portugal

***Abstract*—Two-thirds of the world's population currently lives in areas that experience water scarcity for at least one month every year. And like humans, plants, and especially grapes in vineyards, need the correct amount of water in order to grow healthy. Therefore, to assist the irrigation process, we do not only need to use reliable measuring systems to gauge the water amount per plant, but also to estimate the kg of chemical agents per hectare, like fertilisers, that contribute to the growing of the plants, as well as the pollution of rivers and water supplies. The implemented monitoring station is part of a Distributed Sensing System Model (DSS) that allows continuous measurements over time, and is based on an autonomous wireless sensor network capable of measuring the parameters of interest and storing all this information. The implemented station is fully autonomous, receiving energy from a solar panel that charges the two main batteries, even if there is no direct sunlight available. The station communicates to the remote sensors by RF and can be remotely accessed using 3G and Narrow Band IoT (NB-IoT). Besides the RF sensors, the station allows multiple interfaces to connect other sensors, as is the case of the developed sensor board that measures different gases like Nitrogen Dioxide (NO2) and Carbon Monoxide (CO) using I2C calibrated sensors for easy replacement and station adaptation. Traditional wind and rain sensors are supported, allowing new sensor value comparison and validation.**

Keywords*–Weather Station; Sensors: Humidity, Temperature, CO, NO, CO2, O3, Dust, Pressure, Light, Anemometer; RF; LoRa; NB-IoT; GatewayFE; Old Vineyards; Quinta do Crasto.

I. INTRODUCTION

Agriculture is one of the most ancient activities of man, and a place where it is difficult to introduce innovation and technology due to the lack of investment and the difficulty to show the benefits of this introduction into productivity and profitability while minimizing unintended impacts on wildlife and the environment. Nevertheless, the use of information from the environment, especially when we speak about precision agriculture, has demonstrated that it is possible to maximize crop production while minimizing watering and fertilization schemes [1].

One of the biggest issues, when installing monitoring weather systems is the need of maintenance and station cost. An unattended wireless sensors network able to measure the parameters of interest like the amount of water in the soils, the Electrical Conductivity (EC - as a measure of total nutrients), soil thermal properties (temperature, thermal conductivity, heat capacity, and thermal diffusivity – as a measure of how energy is partitioned in the soil profile), water flux, and environmental temperature at the surface is one of the most promising technics developed by Valente in 2018 [2].

The developed sensor uses RF to connect to a main station that is fully energy autonomous, gathering energy from a solar panel that is stored into two main batteries, even if no direct Sun is available. Figure 1 shows the implementation of the data acquisition network.

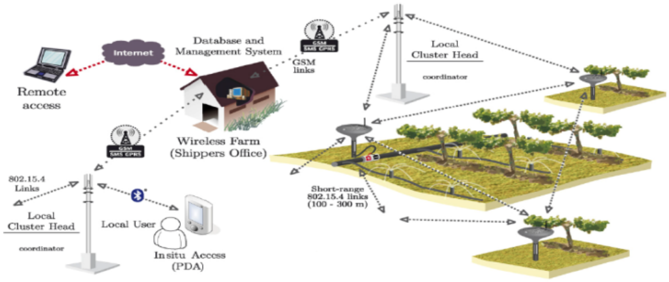

Figure 1. In-field data acquisition network.

This work presents a precision viticulture environment of "Quinta do Crasto", located in a prime spot in the Douro Demarcated Region in Northern Portugal. This region is characterized by the extreme weather condition and its own peculiar combination of topography, geology and water resources, all of which come together to form the unparalleled theatre of global winemaking. Quinta do Crasto soils are composed of schist complex types, and have been worked into steep slopes near the river in a remarkably awe-inspiring work of human ingenuity. The traditional "socalcos" (terraces with stone retaining walls) house the oldest vines, some dating more than one hundread years. An average of 5,000 plants/hectare of younger vines are planted vertically on slopes of less than 35%. On the slopes greater than 40%, "patamares" (more recent terraces) carry either one or two rows of vine, with a density of between 3,000 to 3,500 plants/hectare.

The excellent sun exposure with primarily eastern and southern aspects, in conjunction with the dry conditions of the Cima Corgo sub-region and the ability of schist soils to absorb and retain heat, come together to force the roots of these vines to grow dozens of meters deep in search of water. This also provides competition between the plants and contributes to the complexity and intensity of the wines produced.

The quality of these wines and this *terroir* also requires closely monitoring every step in the grape growing and winemaking process from pruning to harvest. Safeguarding the identity of vineyards is a fundamental prerequisite for the preservation of a unique genetic heritage and the only way to ensure the continuity of the old Douro vineyard, *Vinha Maria Teresa*, that give rise to internationally recognized wines [3].

In this complex scenario, a Distributed Sensing System can gather information that can help in understanding vineyard variability and therefore how it might be managed, thus improving the quantity and quality of the wines, not to mention ensuring the consistent production of the highest quality wines, year after year, in a matchless wine in their character and uniqueness.

Figure 2 shows the *terroir* of Quinta do Crasto.

Figure 2. *Vinha Maria Teresa*, Quinta do Crasto

In Section II, the objectives of the system are described, from the hardware and software perspective, to costs. The communication systems that were used are presented in Section III. In Section IV, the hardware implementation is exposed. In contrast, Section V presents the software implementation and the system web interface. Finally, Section VI presents the main conclusions and future work.

II. OBJECTIVE

The primary objective of this work is to implement the hardware and firmware that will allow the Distributed Sensing System Model described in [4]. As stated, the system must be able to implement a Wireless Aboveground Sensor Network (WASN) capable of sensing and transporting data towards the central monitoring station [4], but with capacity to use different bands like 433 MHz and 868 MHz. The system should also be fully energetically autonomous, i.e., capable of harvesting energy from the nature.

The DSS platform must incorporate information from remote sensing, as well as *in situ* weather conditions, such as water source levels and soil history, and was stated that needed to be cost-effective, as less intrusive as possible, and include a reliable data communication system that allows data collection from sensors monitoring the crops, land, and environment. Towards these goals, a primary Gateway was developed using the latest technology available for communication and sensing. The hardware used for this implementation will be described in detail in the next chapter.

III. COMUNICATION SYSTEMS

IoT services require connectivity to link objects to the Internet. Sensors and actuators require communication paths to allow exchanging information with cloud-based services, making possible the extraction of useful insights and also enabling the control of different connected infrastructures. Depending on the scenario, several options may be taken, from fixed to mobile, from ad-hoc to more structured networks. The “best” solution is always the one that fits to the customer needs and constrains. The application of IoT technology to an agricultural use case presupposes the existence of some requirements. It will be necessary to ensure wireless communications, at great distance and without waste of energy. These requirements map directly to the characteristics of Low Power Wide Area Networks (LPWAN).

There are already several commercial offers that make available similar solutions, that are able to cope with the diversity of applications requiring long range communications and reduced power consumption at lower costs. This variety of LPWAN systems can be roughly grouped in two major distinct sets: solutions using unlicensed radio bands and standardized systems operating under licensed spectrum.

The LoRa Alliance is an open association of companies targeting the specification of LPWAN for IoT applications. The members have detailed the open standard LoRaWan protocol in order to allow long range wireless IoT services for battery constrained devices [5] . It provides a secure bi-directional channel for communication between devices and applications supporting bit rates ranging from 0.3 kbps to 50 kbps, being the rate deeply dependent on the distance and the type of data to be sent. LoRaWan is built on top of the proprietary LoRa radio modulation technology from Semtech Corporation, which, however, relies on shared spectrum for radio communication.

3GPP has also developed efforts in the network specification for IoT, but operating under licensed spectrum. The systems were particularly simplified and new mechanisms were created to meet the specific needs of constrained devices. These efforts were particularly noticeable in the NB-IoT technology, which does not operate in the Long-Term Evolution (LTE) construct. NB-IoT was the main 4G solution to support ultra-low bit rate applications for limited devices communicating in large geographical areas. It is a cellular-based low power technology developed to support the link of low-cost devices to web-based applications [6]. It intends to reduce terminal costs and support extended coverage, while ensuring a long battery life. It supports communications up to 250 kbps on both directions with half-duplex operation using 180 kHz bands. The usage of licensed spectrum enables the full control of the communication channel making easier the availability of quality of service for IoT communications.

IV. HARDWARE

The sensors hardware is based on the Multi-Functional Probe (MFP), which is schematically represented in Figure 3. The MFP consists of one central heater needle and four surrounding thermistors, as reported by Mori et al. [8]. The needles are made from stainless steel tubing, $0.912\,\mathrm{m}$ min diameter, protruding $40\,\mathrm{mm}$ beyond the edge of the PVC mounting. Spacing between the heater and temperature sensors is about $8.5\,\mathrm{mm}$. The heater was made from enameled Stablohm $800\,\mathrm{A}$ wire ($0.062\,\mathrm{mm}$ in diameter and $440.8\,\Omega\,\mathrm{m}^{-1}$

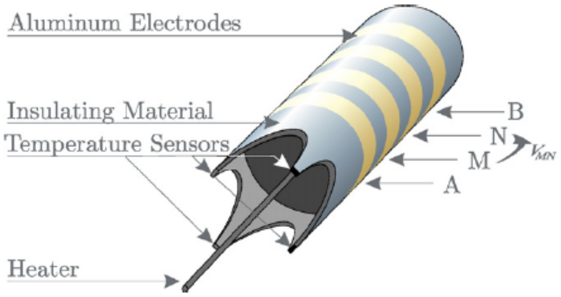

Figure 3. Multi-functional probe [7]

of resistivity) [9], which was inserted in the heater needle. The heater resistance was $100\,\Omega$ (heater resistivity of $2010\,\Omega\,\mathrm{m}^{-1}$). The needle is then filled with high thermal-conductivity epoxy glue, making it water-resistant, thus causing the heater to be electrically insulated.

The Wenner array is formed by four aluminum ring electrodes equally spaced with $3\,\mathrm{mm}$ separation [10]. The outer electrodes (denoted as A and B in Figure 3) provide for an alternated current source ($1\,\mathrm{mA}$ peak-to-peak and $100\,\mathrm{Hz}$ frequency), whereas the potential difference is measured across the two inner electrodes (M and N). The overall system, including battery, fits in a cylinder with $21.4\,\mathrm{mm}$ in diameter and approximately $50\,\mathrm{mm}$ long [4].

The developed Gateway, Figure 4, is based on WIIPIIDO, a powerful high-performance single-board computer equipped with a Quad-core ARM Cortex-A53 Processor@1.2 GHz and 2GB DDR3 memory RAM. The system offers four 16 Bit Analog to Digital Converter (ADC), an internal 8 GB INAND eMMC Flash Drive and four USB ports for expansion. The Real Time Clock Calendar (RTCC) and GPS provide the users with off the grid time and location keeping.

Figure 4. Gateway FE Plus

For connectivity, the Gateway offers several communication possibilities like Wi-Fi, Bluetooth, RF, GPRS and NB-IoT. The two RF Serial Peripherical Interface (SPI) modules implemented allow the Gateway to communicate on multiple bands and different protocols. A solar panel and the battery system allow energy harvesting with up to 3 days autonomy. The RTCC and Linux based system provide the database collection and system sensor monitoring.

There are also two relay Outputs and four digital inputs available. Figure 5 shows the schematics of the relay Outputs. The LED D9 is used to monitor the state of the output and it connects showing the user the relay activity. The output is used to automatically control the irrigation.

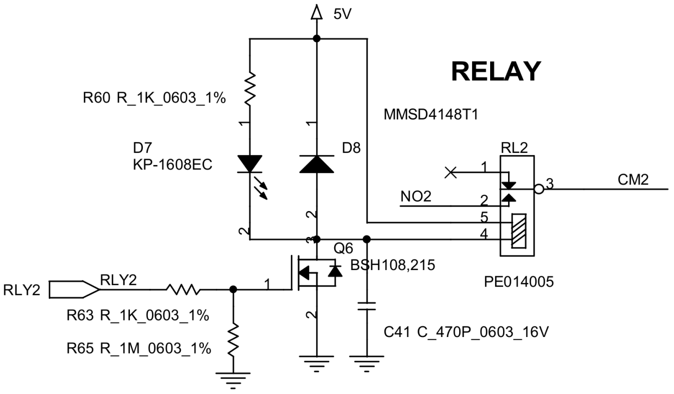

Figure 5. Schematic of the relay output

As for the inputs, they all are optically isolated as can been seen in Figure 6. For simplicity sake, only one of the Outputs and one of the Inputs were presented in the schematics. The inputs are used to allow manual control of the irrigation, as well as the detection of the pump activation, and the full level of the water tank.

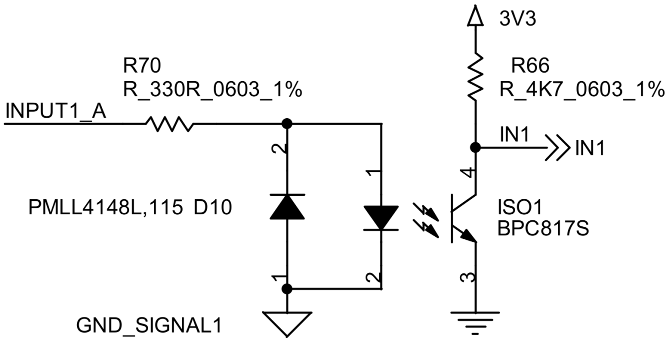

Figure 6. Schematic of the digital input

Due to the Douro Valley location, communication tends to be very difficult, so the Gateway allows remote communication through multiple backup systems like GPRS and Narrow Band IoT, with the latest being developed to enable efficient communication for wide geographical footprints. This module is based on the Sara N2.

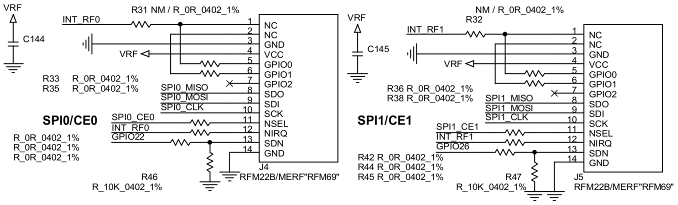

Figure 7. Schematic of RF module

The system communicates with the sensors using RF, and the schematic in Figure 7 shows one of the several RF modules implemented and supported by the Gateway. Up to two different modules can be used at the same time in the Gateway, allowing us to test different RF modules and their performance under the hillside vineyards in the Douro Region that is strongly conditioned by the original slope and relief of the parcels of vines.

To achieve maximum flexibility, the system should recharge its batteries using energy harvested from the surrounding environment, avoiding maintenance and human interference. Therefore, a solar panel and battery system were chosen for the task and they must be managed. The solar charger board was implemented using a PIC16F1938, as can be seen in the schematic represented in Figure 8. This board presents features such as battery charging, temperature control, battery discharging, light sensor, among others.

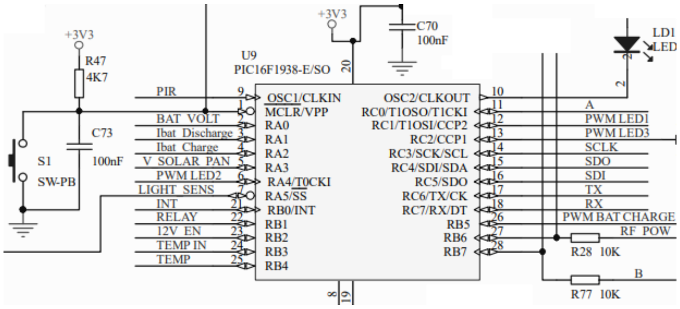

Figure 8. Schematic of Solar Charger

Besides the Gateway, the system also as a sensor board that allows the user to connect different sensors, from gas to the traditional weather station sensors like wind, rain, temperature and humidity. The board responsible to control the sensors communicates using RS-485 with the Gateway, and was implemented using the schematic in Figure 9.

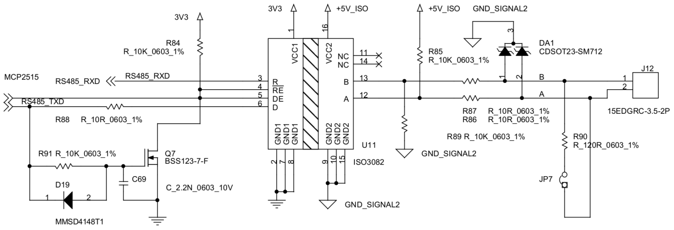

Figure 9. Schematic of RS-485

The ISO3082 transceiver was used since we need a good isolation, because it is expected that the I/O can be subjected to electrical noise transients from various sources, especially on the hillside where thunder storms tend to be more intense.

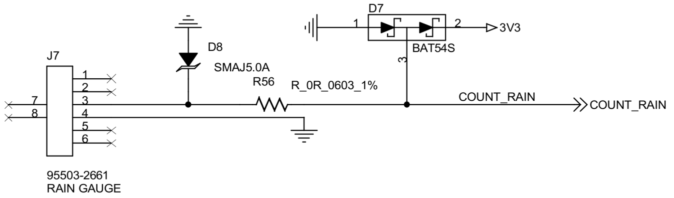

Figure 10. Schematic of the rain sensor

On the sensor board several traditional sensors can be connected, allowing the user to compare its values with the ones obtained from the new implemented sensors. The schematic in Figure 10 shows the rain sensor connection. In the case of the wind sensor, the board implements the connection to an anemometer wind vane. Figure 11 shows this schematic implementation, which allows the user to detect not only the wind speed but also the wind direction.

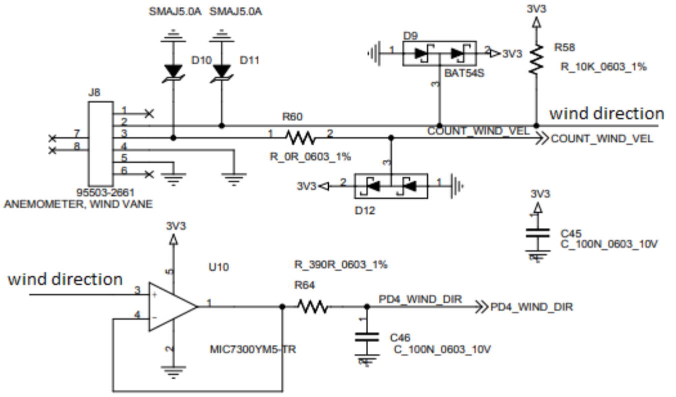

Figure 11. Schematic of the wind sensor

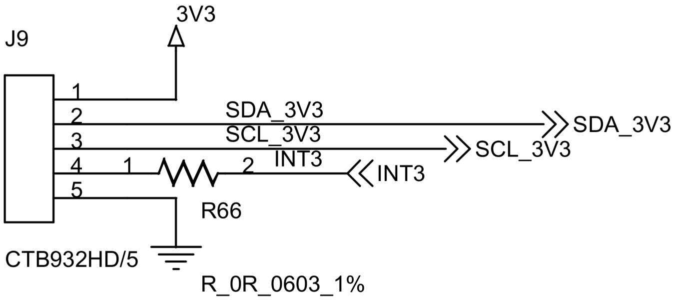

Figure 12. Schematic of the light and UV connector

The board allows light and UV measurements by using an Inter-Integrated Circuit (I2C) sensor. The connector schematic is showed in Figure 12. The sensor used is the Si1133, with a high accuracy UV Index Sensor and Ambient Light Sensor. In the schematic represented in Figure 13 we can see the sensor itself. The presence of the light diffuser allows the sensor to be inside a weather protection cover.

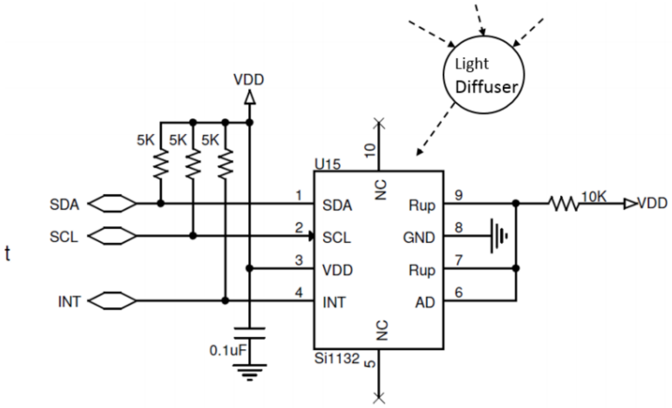

Figure 13. Schematic of the light and UV sensor

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Besides the traditional sensors, the sensor board allows the connection of the following sensors, through I2C.

- CO - Carbon Monoxide: 2112B0052400 + 212B019900;
- NO - Nitric Oxide: 2112B0522400 + 212B019900;
- CO2 - Carbon Dioxide : MG-811;
- O3 - Ozone: MiCS-2614;
- DUST - Particulate Matter level : PPD42NS;
- PRESSURE - absolute pressure : LPS25HB;
- TEMP_HUM - Relative Humidity and temperature: Si7021-A20.

After connecting the sensors, the firmware automatically detects the type of sensor that was connected and starts sending the correspondent sensor data to the Gateway, which can be access using the available Wi-Fi connection. All data received from the sensors is stored in a database.

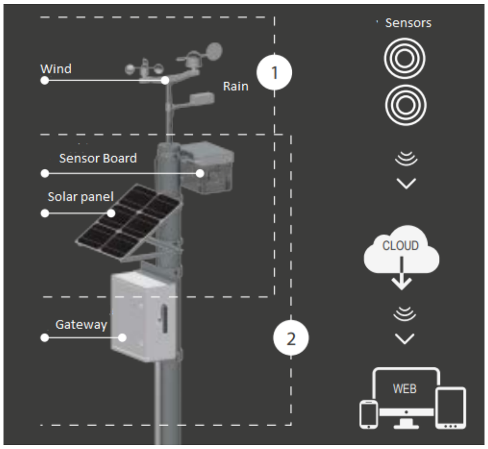


Figure 14. Main Pole configuration

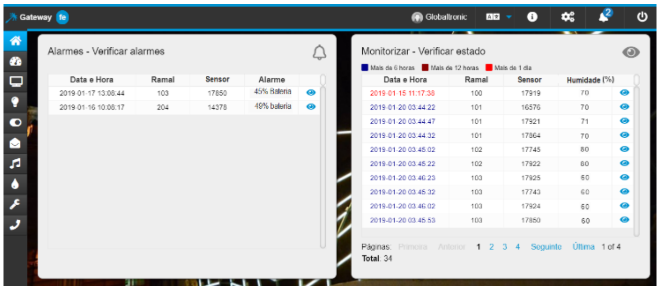
Figure 14 shows the pole layout for the Gateway, Sensor Board, Solar Panel and traditional wind and rain sensors.

V. SOFTWARE

The software platform install was developed in JavaScript, under the NodeJS application platform over the Linux operating system. This makes the software platform independent, i.e., able to run under any device with a web browser install, thus highly scalable since the NodeJS is an asynchronous event driven JavaScript meaning that every network call creates a parallel process that handles the call without blocking the event-loop. This also implies that every callback function will work in parallel, but in a single thread.

Although at a first glanced the above does not seems important, the fact that there can be several users, and even sensors that will require access to the system and to the database at the same time can, on a networking environment, be problematic. The selected environment provides asynchronous operations avoiding blocking operation.

Figure 15 shows the opening page of the developed platform. On its left side, the sensors that have alarms, (for example battery below 50%) and on the right side the last time a sensor has communicated with the platform, along side some meta-data, as well as the soil humidity % at the time of the message. All sensor data can be seen by pressing the correspondent sensor line. Figure 16 shows the sensor screen.



Alarmes - Verificar alarmes

Data e Hora	Ramal	Sensor	Alarme
2019-01-17 13:08:44	103	17850	45% Bateria
2019-01-16 10:08:17	204	14378	49% bateria

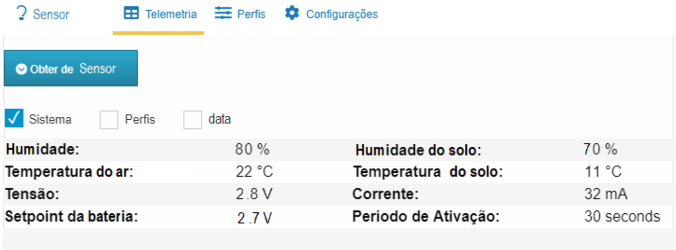
Monitorizar - Verificar estado

🟦 Mais de 6 horas 🟥 Mais de 12 horas 🟥 Mais de 1 dia

Data e Hora	Ramal	Sensor	Humidade (%)
2019-01-15 11:17:38	100	17919	70
2019-01-20 03:44:22	101	16576	70
2019-01-20 03:44:47	101	17921	71
2019-01-20 03:44:32	101	17864	70
2019-01-20 03:45:02	102	17745	80
2019-01-20 03:45:22	102	17922	80
2019-01-20 03:46:23	103	17925	60
2019-01-20 03:45:32	103	17743	60
2019-01-20 03:46:02	103	17924	60
2019-01-20 03:45:53	103	17850	60

Páginas: Primeira Anterior 1 2 3 4 Seguinte Última 1 of 4
Total: 34

Figure 15. Main page of the developed platform

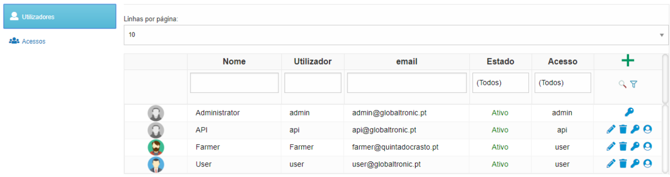


☑ Sistema ☐ Perfis ☐ data

Humidade:	80 %	**Humidade do solo:**	70 %
Temperatura do ar:	22 °C	**Temperatura do solo:**	11 °C
Tensão:	2.8 V	**Corrente:**	32 mA
Setpoint da bateria:	2.7 V	**Periodo de Ativação:**	30 seconds

Figure 16. Sensor screen

The sensor has two additional screens: one for profile *Perfis* and the *Data* screen. The first allows sensor configuration, activation time and the amount of times the sensor activates during each day. The last shows all sensor data besides the one present on the system screen like thermal conductivity, heat capacity, and thermal diffusivity. In this phase, the system is mainly collecting data that will be analyzed and transformed into useful data. Besides sensor analysis and configuration, we can also configure users and their level of permissions or access, as seen in Figure 17.



Linhas por página: 10

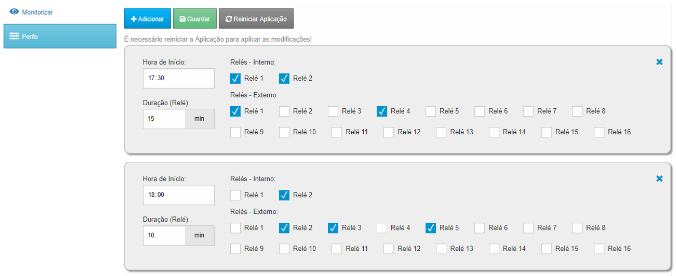
	Nome	Utilizador	email	Estado	Acesso
				(Todos)	(Todos)
	Administrator	admin	admin@globaltronic.pt	Ativo	admin
	API	api	api@globaltronic.pt	Ativo	api
	Farmer	Farmer	farmer@quintadocrasto.pt	Ativo	user
	User	user	user@globaltronic.pt	Ativo	user

Figure 17. User configuration page

In page *Rega*, or Watering, the user can activate the watering system and control up to 18 different watering pumps, as well as configure the running and starting time for one or more pumps at the same time. Figure 18 illustrates this screen.

Finally, Figure 19 depicts the RF configuration, where it is possible to configure up to two different RF modules working simultaneously, allowing the user to test different bands, distances and protocols.

Another interesting screen refer is the Macro, since it grants users' the possibility to define sets of conditions that when realized, trigger an custom action. For example, if a sensor is below a certain Humidity %, then the correspondent pump

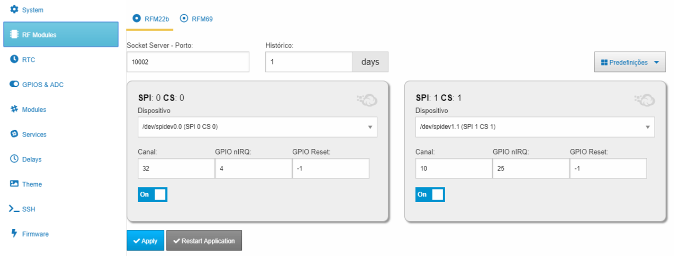


É necessário reiniciar a Aplicação para aplicar as modificações!

Hora de Início: 17:30
Duração (Relé): 15 min
Relés - Interno: ☑ Relé 1 ☑ Relé 2
Relés - Externo: ☑ Relé 1 ☐ Relé 2 ☐ Relé 3 ☑ Relé 4 ☐ Relé 5 ☐ Relé 6 ☐ Relé 7 ☐ Relé 8 ☐ Relé 9 ☐ Relé 10 ☐ Relé 11 ☐ Relé 12 ☐ Relé 13 ☐ Relé 14 ☐ Relé 15 ☐ Relé 16

Hora de Início: 18:00
Duração (Relé): 10 min
Relés - Interno: ☐ Relé 1 ☑ Relé 2
Relés - Externo: ☐ Relé 1 ☑ Relé 2 ☑ Relé 3 ☐ Relé 4 ☑ Relé 5 ☐ Relé 6 ☐ Relé 7 ☐ Relé 8 ☐ Relé 9 ☐ Relé 10 ☐ Relé 11 ☐ Relé 12 ☐ Relé 13 ☐ Relé 14 ☐ Relé 15 ☐ Relé 16

Figure 18. Watering configuration page



● RFM22b ○ RFM69

Socket Server - Porto: 10002
Histórico: 1 days

SPI: 0 **CS**: 0
Dispositivo: /dev/spidev0.0 (SPI 0 CS 0)
Canal: 32
GPIO nIRQ: 4
GPIO Reset: -1
On

SPI: 1 **CS**: 1
Dispositivo: /dev/spidev1.1 (SPI 1 CS 1)
Canal: 10
GPIO nIRQ: 25
GPIO Reset: -1
On

Figure 19. RF configuration page

will be triggered during a certain amount of time, or an email can be sent to the Farmer.

VI. CONCLUSION AND FUTURE WORK

In this paper we have described the DSS system implemented at Quinta do Crasto. The described hardware and software provide the means to accomplish the objectives proposed by the author on his paper [4]. A state of art Gateway was implemented and described in detail, being fully autonomous and able to harvest energy from the nature.

The system can connect to the network using several methods, from Ethernet, 3G/4G, NB-IoT and Wi-Fi. On the other hand, users can connect to it using direct access point or through Bluetooth. Regarding sensors connectivity, besides the newly developed sensors, there is also the possibility to connect several traditional weather sensors, permitting comparison of values between both.

The DSS also implements several RF modules at the same time, allowing band comparison and protocol comparison in terms of reliability and message lost. Furthermore, through the implemented software and hardware, it is possible to use internal and external relays to control watering pumps. So, from the above, it is concluded that the system fully supports the defined requirements, with the next phase being real time, in-field testing.

Future works will pass through the implementation of the new sensors for wind, using ultrasounds, and rain, using sound. The data collected using the existing sensors will be analyzed and used for the DSS model implementation.

ACKNOWLEDGMENT

This work is financed by the ERDF European Regional Development Fund through the COMPETE Programme (operational programme for competitiveness) within project ref. POCI-01-0145-FEDER-006961 and by National Funds through the FCT Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within project ref. UID/EEA/50014/2013.

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