Web based monitoring and irrigation system with energy autonomous wireless sensor network for Precision Agriculture

Georgios Mitralexis and Christos Goumopoulos

School of Science and Technology, Hellenic Open University, Patras, Greece
{mitralexis.georgios@mfa.gr, goumop@aegean.gr}

Abstract. The use of Precision Agriculture systems is in its infancy in Greece, because of the high fragmented land and the adherence of farmers to traditional farming methods. This paper presents the design, implementation and performance evaluation of an integrated agricultural monitoring and irrigation system using energy-autonomous wireless sensors and actuators. Monitoring and irrigation of the field are carried out through a web application that collects data from a Wireless Sensor Network deployed in a cultivation and displays relative information in real time. Furthermore, the system can operate proactively based on user-defined rules that can decide when the farm should be irrigated. The system is easy to use by farmers who look for a first contact with Precision Agriculture applications. Our results have revealed the possibility to develop a robust, fully-automated, solar powered, and low cost monitoring and irrigation system that suits to the socio-economic conditions of small scale farms in countries like Greece.

Keywords: Wireless Sensor/Actuator Network, Precision Agriculture, Rule Based Irrigation, Outdoor Deployment, Energy Harvesting.

1 Introduction

In the last decades in Greece, but also worldwide, has been observed a reduction and ageing of the rural population, while the climate change and the destructions that will cause, are expected to endanger global agriculture production. Farmers, in order to meet future challenges, must improve the efficiency and the quality of agricultural production, with the growth of "Precision Agriculture" (PA) [1]. Despite the possibilities offered by the current technological progress in the manufacture and development of wireless sensor networks, Greek farmers do not embrace with proportional rhythms innovative applications in the production process. The majority of Greek farmers have small scale cultivations, low educative level and deficit of technological skills, so they hesitate to invest in modern agricultural production methods.

In this paper we present the design, implementation and performance evaluation of an energy autonomous monitoring and culture irrigation system via Internet. Our system, because of its low cost and user-friendly interface of the web application, can be easily adopted by small farmers who want to use PA practices at an introductory level without having to invest in new technologies. The system developed is based exclusively on open source tools (programming languages, software and hardware) so that a low-cost but efficient and relatively simple to install system can be implemented. The system by exploiting a wireless sensor/actuator network, can provide multiple benefits both in terms of crop yield and in terms of better management and protection of natural resources.

The rest of the paper is organized as follows. Section 2 discusses related work. The design choices of our system are explained in Section 3. The implementation of the system in terms of the wireless sensor network, the irrigation system and the web application are discussed in Section 4. Section 5 presents a real deployment of our system followed by the experimental results collected and our conclusions.

2 Related Work

In recent years, a wide diversity of applications that follow PA practices in cultures, using WSNs have been presented. Four indicative examples of using WSNs for crop cultivation are in vineyard farms in Galicia [2], in potato plantation in India [3], in cotton crop in USA [4] and in potato cultivation in Egypt [5]. The approach followed in by the example systems in Galicia and Egypt include the use of a WSN and the creation of decision tools in order the farmer to better plan the irrigation and fertilization of the crop in addition to the ability to forecast the occurrence of diseases as demonstrated in [2]. In both implementations the remote monitoring of the crop via Internet was possible, but there was not a subsystem that controlled irrigation of the fields, which continued to be performed in a traditional way. On the other side, the example systems in India and USA have used the WSN technology to gather the required information needed by an irrigation system to determine and implement the automated watering strategy. In both cases, an application for remote monitoring and control of systems was missing.

The system presented in this paper, combines all the individual features demonstrated by the above examples, with the addition of more advanced features, as the exploitation of solar panels to achieve the energy autonomy of the WSN nodes and the browser-based access to the system from any device, anywhere.

3 System Design

The aim of the system is to monitor in "real-time" via Internet selected plant and environmental conditions in the field and irrigate it when it is necessary. The system architecture consists of three subsystems (Fig. 1). The first one is a *wireless sensor network* which is installed in the field, collects sensor measurements and then uploads the data in the Cloud Database. The components of the WSN include a coordinator node and two sensor nodes that communicate in a star topology with protocol ZigBee Pro (v.2007). The sensor nodes include temperature, relative humidity, soil moisture and leaf wetness sensors. The second subsystem manages irrigation using an *irrigation controller* that is being administered by the web application. The irrigation controller controls two solenoid valves that are connected in two respective irrigation lines. The system configuration is completed by the presence of a *web application* which stores sensors measurements in a database, presents them to the user in various forms and controls the irrigation subsystem of the field.

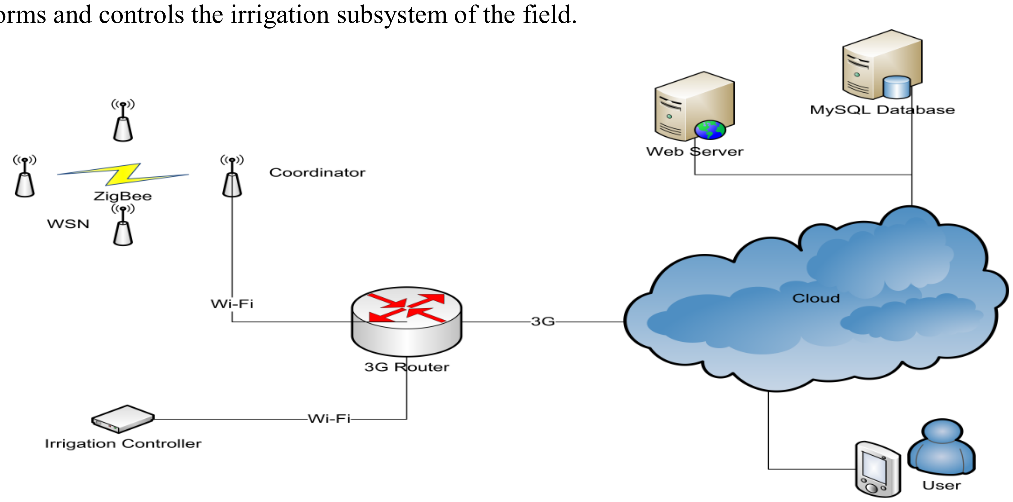

Fig. 1. System Architecture

Irrigation can be performed either manually or automatically by the system, based on rules activated when the soil moisture values exceeds a specific threshold. More advanced rules can be specified based on crop expert advisement. The role of the coordinator node is to receive sensor data from end devices, process and send them to the database with HTTP via the 3G router, which is the Gateway of the system to the Internet via the mobile telephony network. The coordinator is connected to the 3G router with Wi-Fi and the irrigation controller with Ethernet or Wi-Fi, respectively (Fig. 1). In automatic mode, when the system receives a measurement by a soil moisture sensor, it calculates the mean from the last ten measurements of the node. A mean filter is implemented in order to avoid random noise that it would trigger the irrigation accidentally. If the average of the last 10 measurements of the soil moisture sensor exceeds the threshold, the system activates the irrigation line for a predetermined period of time.

4 System Implementation

4.1 Wireless Sensor Network

Nodes wireless communication is based on ZigBee Pro protocol which is characterized by very low power consumption and wide-range coverage. ZigBee Pro emits in 2,4 GHz band with 250kbps data transfer speed. A star network topology is used along with the CSMA-CA access method in order to avoid collisions when the sensor nodes send packets to the coordinator. The WSN nodes used are based on the Waspmote by Libelium which are characterized by their very low energy consumption and modular architecture. In the decreased energy consumption contribute the embedded Real Time Clock (RTC), which allows Waspmote to enter in low power mode (Deep Sleep and Hibernate) and to wake up in a scheduled time. All nodes have ZigBee modules to communicate with each other and are powered by battery Li-Ion 6600mAh. For recharging the batteries each node is connected to a solar panel 7V-500mA. An Expansion Radio Board and a Wi-Fi module are installed on the Coordinator node (Fig. 2) in order to communicate with the 3G router.

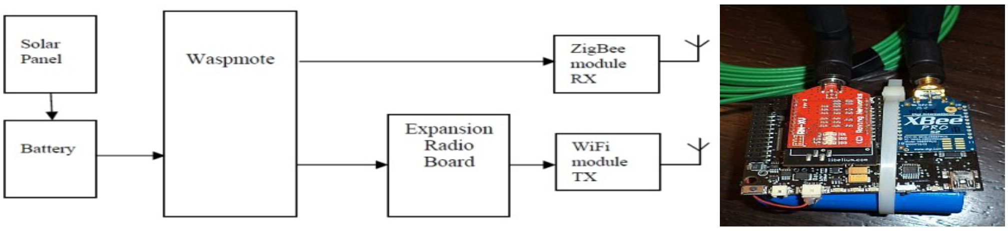

Fig. 2. Coordinator Architecture

The WSN terminal nodes (Fig. 3) have an Agriculture Sensor Board that mount the sensors of the system. The sensors used in each node are Temperature (MCP9700A), Humidity (808H5V5), Soil Moisture (Watermark 200SS) and Leaf Wetness.

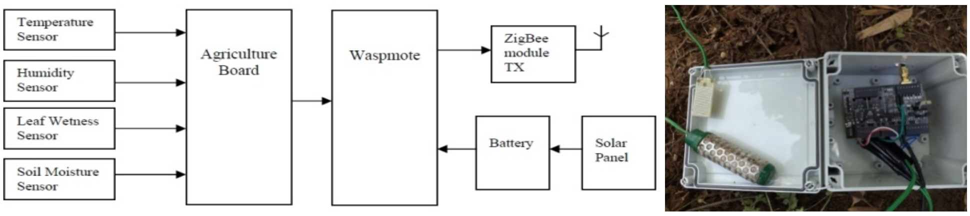

Fig. 3. Sensor Node Architecture

4.2 Irrigation System

The irrigation controller consists of an Arduino board with integrated microcontroller ATmega644, which is running open source software OpenSprinkler. The irrigation controller is able to be connected with up to 8 solenoid valves 24V. Also, there is a built-in Web Server for remote communication and management. The irrigation board is connected to the 3G router via Ethernet or Wi-Fi adapter.

4.3 Web Application

The Web Application has been developed with web technologies such as PHP, HTML, Javascript and jQuery and is compatible with any kind of device (PC, tablet, smartphone etc.). The application presents the sensors data in real-time in numerical and graphical format. Also the user will be able to download a csv file of historical data, to create graphs and to manage the irrigation controller and the irrigation mode (Manual or Automatic). The Web application has a friendly Graphical User Interface that can be used by a simple smartphone user, requiring no previous experience.

5 Experiment

The experimental system deployed in the Social Vegetable Garden of Agioi Anargiroi Municipality for 31 days (17/5 – 16/6/2015). A software program was developed and uploaded into the sensor nodes to allow them to measure temperature, relative humidity, soil moisture, leaf wetness, battery level, and RSSI (Received Signal Strength Indicator) at time intervals of 15 minutes (duty cycle 6,66%) for the 1st node and 30 minutes (duty cycle 3,3%) for the 2nd node. The scope of the experiment was to test the reliability and functionality of the system in real conditions. At the same time, we examined the energy consumption of sensor nodes and various factors that affect the quality of wireless links of the network.

6 Results

6.1 Battery Level

To study the WSN energy behavior, the nodes were connected to solar panels for the first seven days, where the batteries level was steadily between 96% and 97%. The solar panel was disconnected for a period of 21 days and the sensor nodes were powered exclusively by batteries. During this period, the daily discharge rate stood at 0,38% (25,08 mAH per day about) and the level fell from 96% to 88% for both nodes. On the 29th day of experiment, the solar panels were reconnected to the nodes; within 7 hours of plenty sunshine, the batteries covered the energy losses of the previous 21 days. The charging rate fluctuated 528 mAH per day, proving that in a country with high level of sunshine (like Greece), the nodes of the system can operate until battery lifetime is exhausted and the battery is not able to be charged anymore (Figs. 4 and 5).

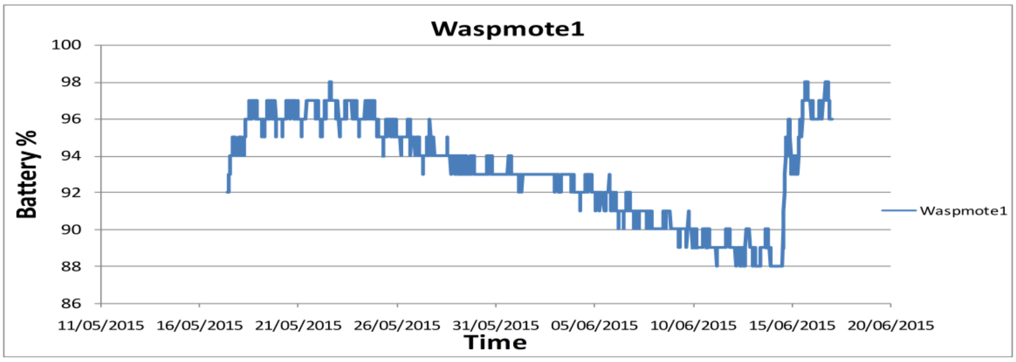

Fig. 4. Battery Level Timeline of 1st sensor node

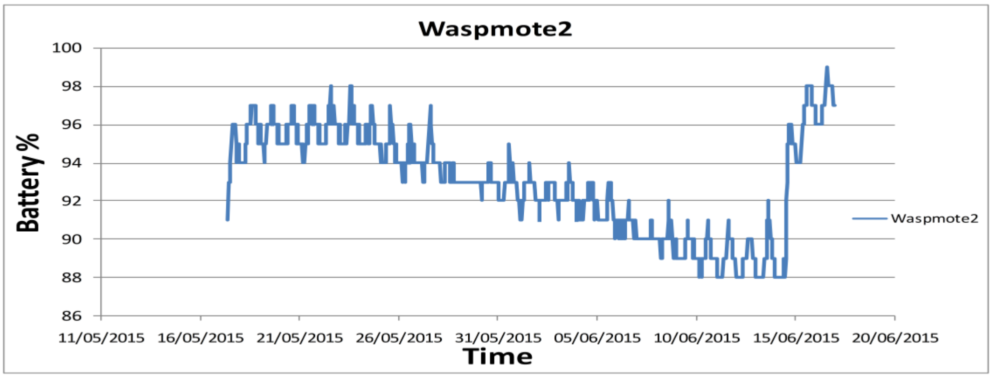

Fig. 5. Battery Level Timeline of 2nd sensor node

6.2 RSSI and Battery Level

Throughout the duration of the experiment, RSSI measurements were collected by the two nodes and then the correlation between battery level and temperature was studied (Figs. 6 and 7). As shown in Fig. 6, the RSSI level of the 1st node remains stable between -45dbm and -55dbm as long as the battery level is above 90%. When it reaches at 90%, we see a visible drop in signal strength levels between -55dbm and -80dbm. With the beginning of battery charge from the solar panel, we observe that the signal strength increases gradually until it stabilizes at the previous levels between -45 and -55dbm.

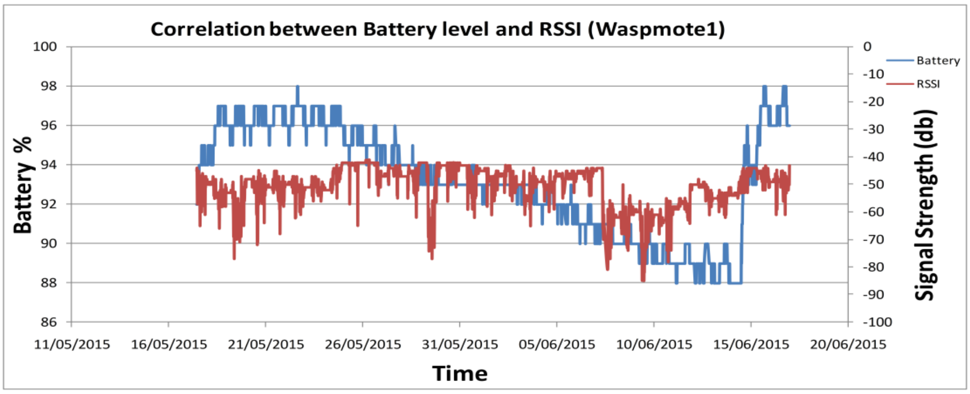

Fig. 6. Correlation between Battery Level and RSSI in 1st node

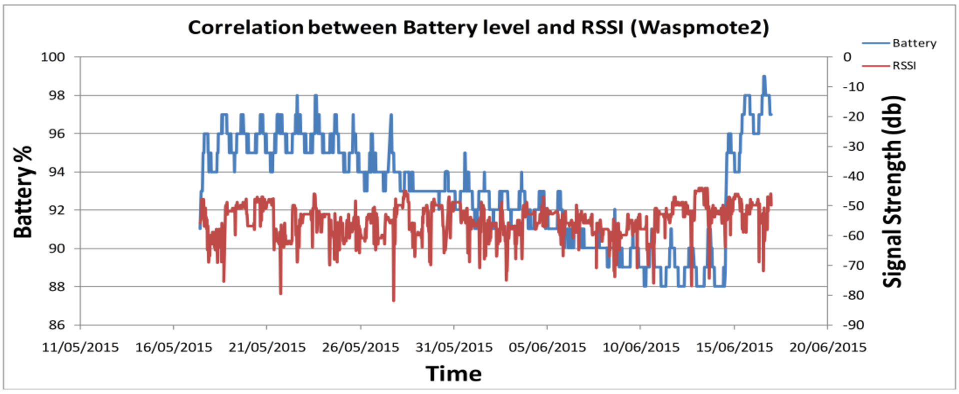

Fig. 7. Correlation between Battery Level and RSSI in 2nd node

Finally, there is a significant correlation between battery level and the quality of the wireless links of the network. A fully charged battery helps nodes to have better and more constant power signal. In our system this goal is achieved by uninterrupted charging of node batteries using solar panels, strengthening the robustness of network.

6.3 RSSI and Temperature

The correlation between temperature and RSSI has been studied thoroughly [6, 7, 8]. Despite the controversial results, the dominant conclusion is the negative impact of high temperature on RSSI [6, 7]. Observing Fig. 8 and Fig. 9 a visible inverse pattern between temperature and signal strength on both nodes is noticed, indicating a negative correlation. At midday, when the outdoor temperature reached the higher values (above 30° C), the RSSI values fell, respectively. The reduction of RSSI is linear and inversely proportional to the increase of temperature. On the contrary, during the night when the temperature lowers, the signal strength is stronger, characteristically.

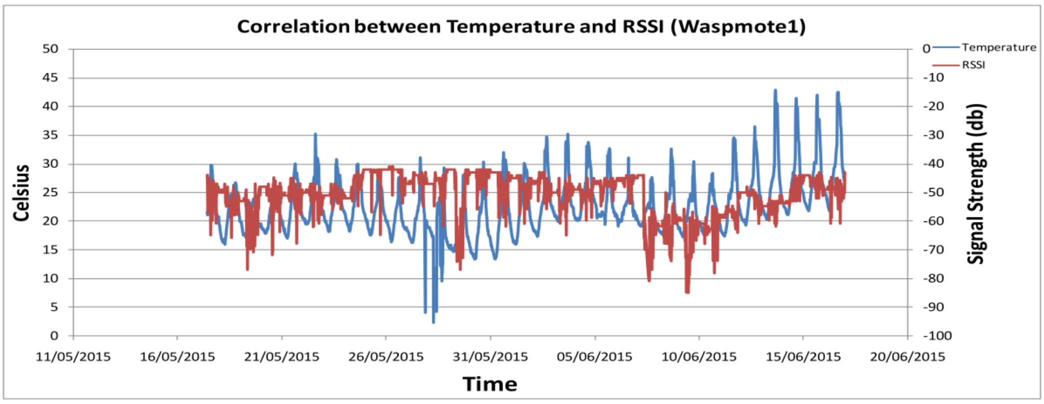

Fig. 8. Correlation between Temperature and RSSI in 1st node

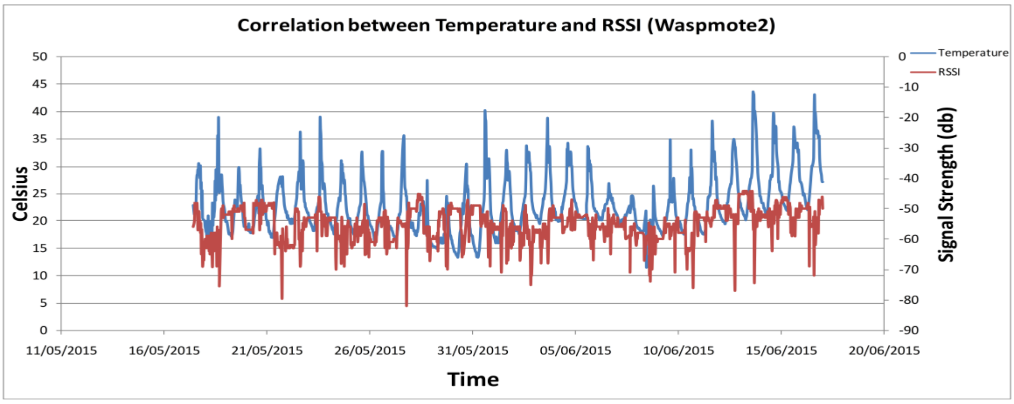

Fig. 9. Correlation between Temperature and RSSI in 2nd node

The explanation of the correlation of temperature with RSSI lies in the sensitivity of hardware. Specifically, the high temperature creates leak current in semiconductors and in the transceiver which results in a drop of the signal strength. The negative effect of high temperatures from the sun, it should be taken seriously into account during deployment of nodes in a WSN. Their placement should be in shady places, in protective boxes having proper heat insulation. Also, we should keep in mind that if the wireless links of a WSN are unstable, reliability can be improved deferring communication between nodes during cooler periods (evening or night).

6.4 Packet Delivery Ratio and Packet Loss Rate

An interesting metric was the measurement of the Packet Delivery Ratio (PDR) of the system, which is defined as the number of packets received by the destination node (cloud database) compared to the number of packets that have been sent out by the WSN nodes. The higher the value of PDR, the better the system performance. We note in Table 1 that the PDR and PLR vary at satisfactory levels for both nodes, so that do not cause problems in system operation and the immediate and accurate information to the user.

Table 1. Packet Delivery Ratio and Packet Loss Rate

	Waspmote1	Waspmote2
Duty Cycle	6,66%	3,3%
Tx Packets	2867	1428
Rx Packets	2708	1357
Lost Packet	159	71
Packet Delivery Ratio	94,454%	95,028%
Packet Loss Rate	5,545%	4,971%

7 Conclusions and Future Work

The proposed system is a low cost PA system that can be easily deployed, as our experimental prototype demonstrated, in any small or large scale cultivation. The monitoring subsystem enables the precise observation of the real conditions in the cultivation. The web application provides a handy tool for remote and active crop protection, helping the farmer to prevent adverse situations (frost, diseases, sub-irrigation etc.) and to manage effectively required resources (water and fertilizer). Finally, the irrigation subsystem relaxes the requirement for farmer’s continuous presence (often on a daily basis) to irrigate the cultivation. At the same time, the system provides the ability to irrigate the crop precisely depending on local context of the field (soil composition, crop type, area exposure to natural phenomena etc.). With respect to irrigation we should also emphasize the ability of the system to operate proactively, based on user’s defined rules.

The experiment proved that the proper placement of the nodes is crucial. The nodes must be protected as much as possible from high temperatures. It is useful before the final placement, to make an assessment of the conditions that could affect the wireless sensor network (temperature, humidity etc.) by studying historical data of the region, in order to properly prepare the network taking into account the conditions that it will likely meet.

For future work, we propose a large scale deployment with more nodes and use of the Cluster Tree topology. Also it would be interesting to use a wider variety of sensors and to improve the autonomous irrigation based on more detailed rules or rules that the system learns by applying machine learning techniques [9]. In future expansion of the system, we will replace the ZigBee communication protocol with 6LoWPAN, so each node of the network (sensor nodes, coordinator, router, irrigation controller) will have a public IPv6 address, directly accessible from the Internet.

The reader can visit the web application and the components of the system in the website www.smartfield.eu.

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