# Blueberries field irrigation management and monitoring system using PLC based control and wireless sensor network

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***Abstract*— The irrigation procedure in agriculture is a key factor in achieving good yields and plant performance. Water stress at critical times in the development of the blueberry crop can dramatically affect fruit yield and quality. However, blueberry plants may not show visual signs of stress. An automatic system of irrigation management is essential to long-term plant health. This paper presents a system capable of controlling an irrigation system autonomously. By acquiring humidity and temperature data, the system is capable of deliver proper quantity of water at the most advisable period, through the usage of a Programmable Logic Controller, optimising the water supply. The system is also accessible on the webpage created for it. The project includes wireless communication between the sensors boards and the main control board allowing the user to easily place the sensors wherever he wants.**

***Keywords*— *soil temperature; soil humidity; PLC; autonomous irrigation.***

## I. Introduction

Agriculture represents an important part of water usage in Europe, around 30%, and for that reason it is necessary to optimise irrigation management [1]. An efficient irrigation system brings lots of benefits for an agricultural producer, as he saves water, he also obtains optimal conditions of survival and production for the plants. Optimal growth conditions for crops depend mostly on humidity of the soil and temperature.

Key points for blueberry irrigation in order to improve water use and to maximize blueberry production and health are: (1) blueberries have a shallow root system 20–30 cm; (2) proper irrigation design is essential in the early phase of orchard development and (3) it is important to effectively monitor irrigation to maximize blueberry production [2].

The automatic irrigation control appears with the first electronics device which include a timer associates a soil moisture sensor (a Tensiometer or a Granular Matrix Sensor). If the soil matric potential exceeds a limit value, the irrigation begins [3]. These irrigation control devices were/are powered by batteries but an article at the International Asia Conference on Informatics in Control (2010) presents the solution to power this device with photovoltaic panels [4]. In order to improve the irrigation controls and offer the producer possibility of monitoring the irrigation, these systems included wireless sensor networks (WSN). So the producer can have the information of soil moisture and temperature via his mobile phone [5] or through a web page [6]. In [7] is shown an example of a system that combines the moisture sensor Watermark to a ZigBee and then communicates with the computer through RS232 protocol. Other authors use ZigBee to communicate with the central unit (wireless information unit/microcontroller) where the algorithm runs to control the solenoid valve. The central unit also can transmit the data to a web page through a GPRS module [8].

In this article, the system makes use of a Programmable Logic Controller (PLC) that is capable of taking independent decisions without requiring the presence of the agricultural producer, being able to actuate the solenoid valve and the irrigation pump on its own. The system must be autonomous to decide how and when the water should be delivered. The acquired data are the humidity and the temperature of soil (sensorial module). The central control unit interacts with the user via a dedicated webpage (Fig. 1).

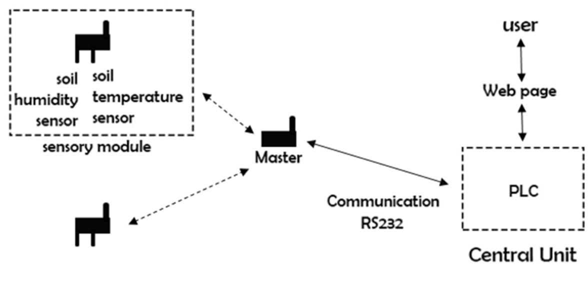


Fig. 1. Proposed system

## II. Sensorial module

The proposed system adopted a sensorial scheme that is based on the system proposed in [9] and uses the interface SMX, a soil moisture transmitter that is an electrical interface

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for Watermark sensors. SMX is responsible for collecting data from temperature and humidity [10].

The humidity of soil is acquired through the resistive moisture sensor Watermark 200SS. The sensor has been greatly used for this purpose, due to its durability and low price. It consists of two electrodes embedded in granular matrix, so that the resistance between the electrodes depends on moisture and temperature only.

The amount of water in the soil changes the electrodes resistance and provides the soil matric potential that represents the soil moisture [11].

The temperature sensor chosen was the Watermark 200TS, a thermistor that has a negative temperature coefficient (NTC). A circuit board was designed and built to test and calibrate the two sensors and is shown in Fig. 2.

The prototype board has a voltage divider where the temperature sensor is connected and an LMC555 timer provides an alternating-current (AC) supplied to the moisture sensor. The AC current is important to prevent the galvanic effect and to convert the circuit output to a value of frequency, which is then provided to the microcontroller.

The wireless sensor network (WSN) sends the data collected by each sensorial module to the master board using nRF24L01 radio module. The master board forwards the data to the central unit through RS232 protocol (Fig.3) [12].

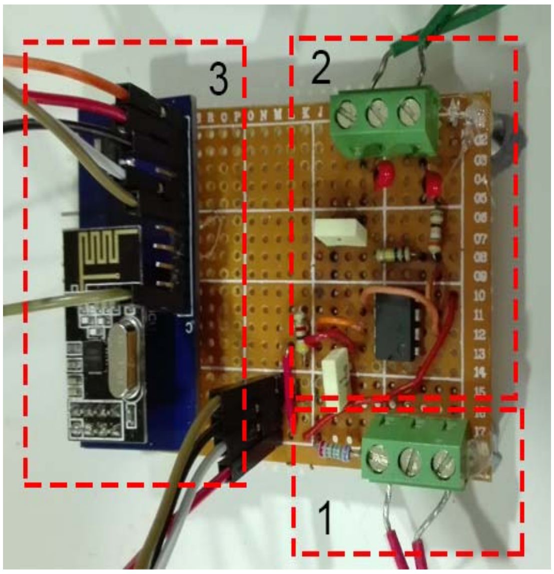


Fig. 2. Prototype of the sensorial module. (1) voltage divider and temperature sensor terminal; (2) LMC555 timer and soil moisture sensor terminal; (3) microcontroller and radio module.

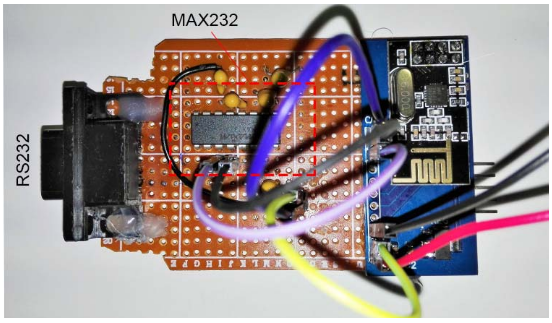


Fig. 3. Master board.

## III. Central Control Unit

### *A. Data processing*

All system data processing is made at the central control unit to save power in the sensorial module.

So after receiving the necessary information via RS232, the central unit must calculate the water potential according to the sensors' calibration equation, the soil water content in % and the temperature in ºC.

For the soil water potential measured in the Watermark 200SS, the equation applied is [13]:

$$P = \frac{8-3.213\,R_S-4.093}{1-0.009733\,R_S-0.01205\,T_c} \tag{1}$$

with $P$ the soil water potential in $kP_a$, $R_s$ the resistance of the sensor in kΩ and $T_c$ the soil temperature in ºC.

The water potential is related to the soil water content through the van Genuchten model [14]:

$$\theta = \theta_r + \frac{(\theta_s-\theta_r)}{[1+(\alpha\,|P|)^n]^m} \tag{2}$$

where, $\theta$ is the soil water content in $cm^3/cm^3$, $\theta_r$ is the soil residual water content in $cm^3/cm^3$, $\theta_s$ is the soil saturated water content in $cm^3/cm^3$, $\alpha$ is a scale parameter in $kP_a^{-1}$ and $n$ and $m$ are the shape parameters of soil water characteristic.

For the temperature calibration, it is applied the Steinhart-Hart, as follows [15]:

$$\frac{1}{T_K} = A + B\,\ln R_T + C(\ln R_T)^3 \tag{3}$$

with $A, B, C$ the constants of the thermistor, (depends of the material), $T_K$ the temperature in K and $R_T$ the thermistor resistance at temperature $T_K$.

Once in (1) the temperature should be in degrees:

$$T_c = T_K - 273.15 \tag{4}$$

## B. Soil parameters

As the relationship between the soil water potential and the soil water content is different for each soil texture and composition, the related parameters are also different.

The soil characterisation is based on the parameters field capacity $\theta_{fc}$, wilting point $\theta_{pw}$ and saturation $\theta_s$ (Fig. 4). The saturation occurs when the soil is filled with water and no air left in the soil so the plant will suffer. The field capacity characterises the situation when the plant is allowed to receive sufficient water to blooming well while the soil is filled with air and water. The wilting point corresponds to the state in which the water absorbed by the plant is lower than the water the plant needs to survive.

These two last parameters, field capacity and wilting point, are the most important parameters to be defined in the algorithm [16]. In our work the adopted values were defined according to [17]. Concerning the wilting point, it was assumed that it is a good approximation for the soil residual water content [18].

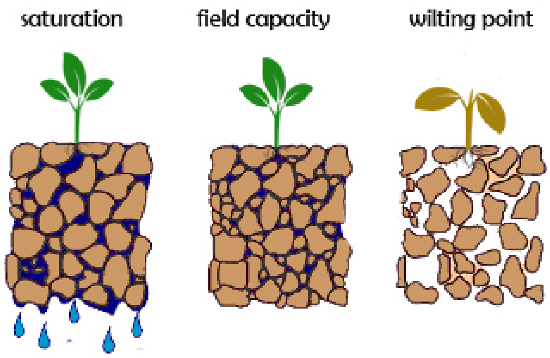


Fig. 4. Illustration of soil status conditions

## C. Algorithm

The main objective is to ensure that the plant gets the necessary field capacity and to increase the water-saving through only the activation of the irrigation when the volumetric water content in the soil reaches or falls below 1.1 of the wilting point: $\theta_{pwm}$ (Fig. 5).

In the case of blueberry, the irrigation is not feasible when the temperature is above 30ºC ($T_M$ – maximum temperature for which the irrigation is possible) because the plant will not absorb any water. For this reason, the temperature is also a parameter to be considered in the algorithm.

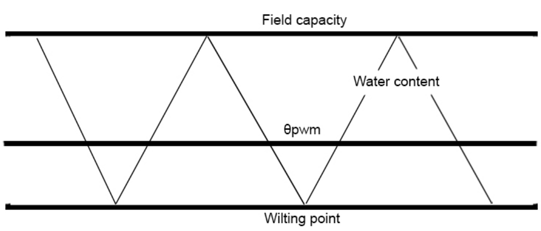


Fig. 5. Schematic illustration of the limits to irrigation

The parameters and requirements of the agricultural system for the production of blueberries were defined with the collaboration of an agronomist engineer that helped calculating the watering duration for each solenoid valve.

Based on the data taken from the sensorial systems, an algorithm was designed and applied to the control unit (Fig. 6).

The programme on the PLC starts by updating all variables that the user changed at the web page, then the timer is initiated. When counting is finished the PLC receives the data from sensorial module and proceed to the data processing. With this information the PLC runs different conditions to make its decisions (enable/disable the watering). If the volumetric water content is below the wilting point than one alarm is activated at the web page. After this the condition of the temperature is tested and then it is verified if the volumetric water content is in the range indicated for irrigation.

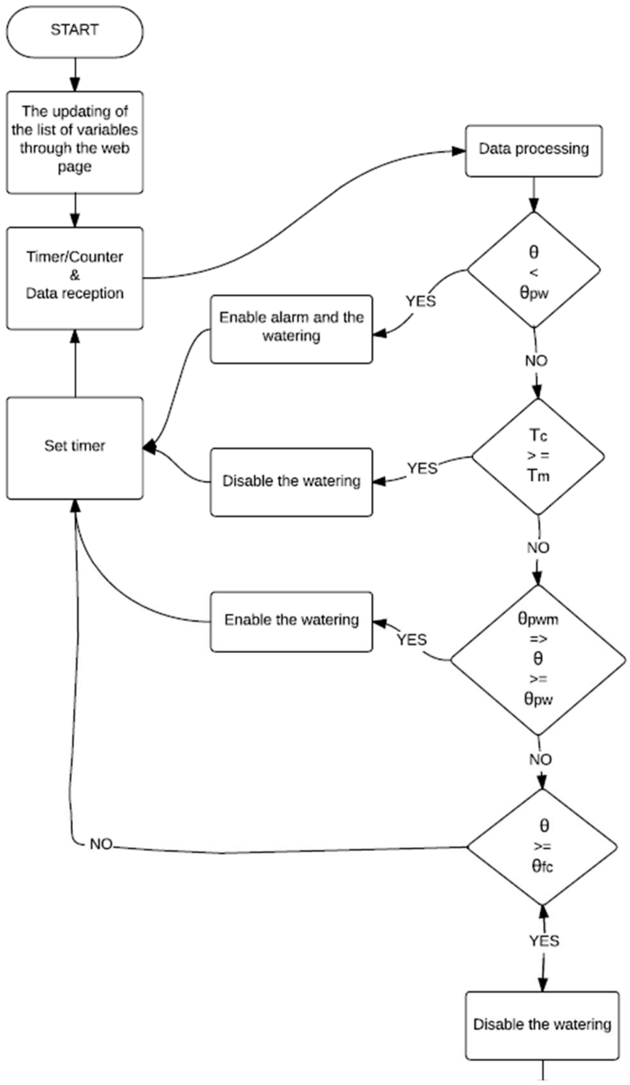


Fig. 6. General operation flowchart

## D. Central control unit Hardware

The central control unit comprises a S7-1220 PLC from Siemens, and an RS232 communication module. This communication module, CM 1241, is also a Siemens product, and is responsible for transmitting a reading order to the sensors and receiving the acquired data from the sensors (Fig. 7).

A dual driver/receiver MAX232 device that converts TIA/EIA-232-F inputs to 5-V TTL/CMOS levels and vice-versa was included in the system, between the master and the communication module CM 1241.

The motivation to use a PLC was firstly the interest in automation and then because the PLC is a robust device, resistant to thermal shock and to dust. The PLC is a modular equipment, this mean that it is easy to add or remove input/output modules or communication modules, without the need of a new hardware design. So the farmer can change the number of solenoid valves or pumps and the system easily adapts to the new configuration.

In this case, it is proposed a system capable of controlling the irrigation but also possible to adapt for the implementation of the control of existing solar trackers [19] or fertigation systems.

In addition to the modules shown in Fig. 7, the PLC is connected to the internet through a modem or a GSM communication module to provide the information to the user via a webpage.

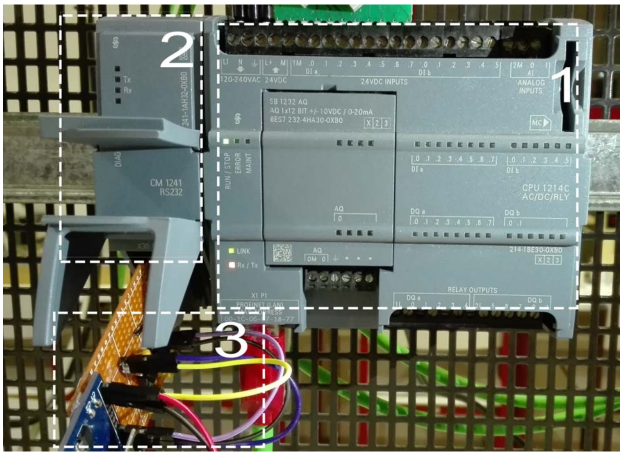


Fig. 7. Central Control Unit. (1) PLC; (2) module CM1241; (3) master.

## E. Webpage

The webpage was designed so that the users can interact with the algorithm running on the PLC and obtain information about the state of the soil. The website was developed in html and in AWP commands, and then uploaded to the PLC (Fig. 8). The AWP commands allow to interact with the PLC variables (to write or read variables in the CPU).

On the webpage the users can introduce irrigation properties field capacity, water stress threshold humidity and temperature limits and the number of sensors readings per day.

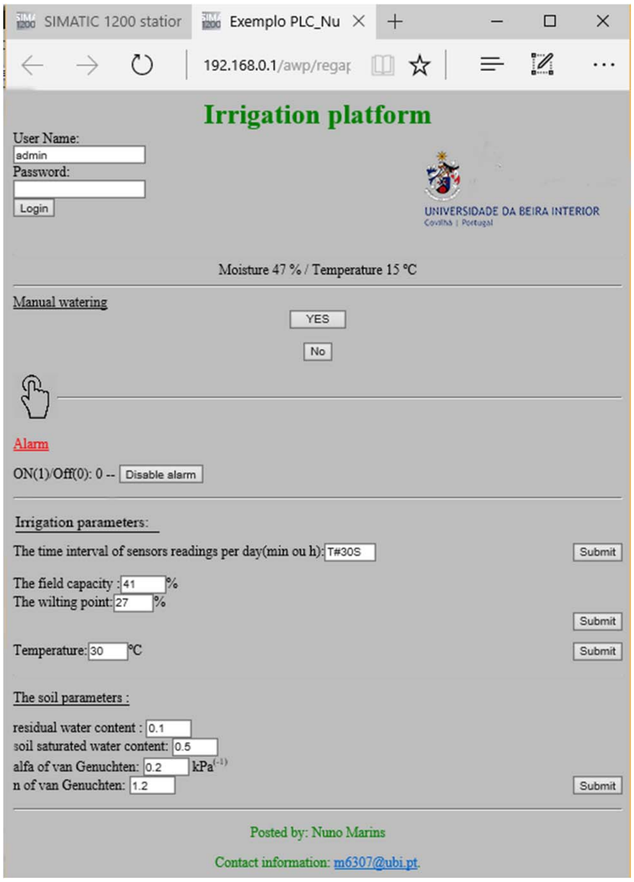


Fig. 8. Web page for irrigation system

He can also introduce the soil parameters (van Genuchten model) and be signalled by alarm when the blueberry plant reaches a critical state (very low humidity).

This information can be managed according to the season, plant ages, soil texture and adopted for other kind of orchards. The user can also decide between manual watering or not.

# IV. Experimental Validation

The proof of concept presented in this paper for an intelligent irrigation management system was tested in the laboratory (Fig. 9).

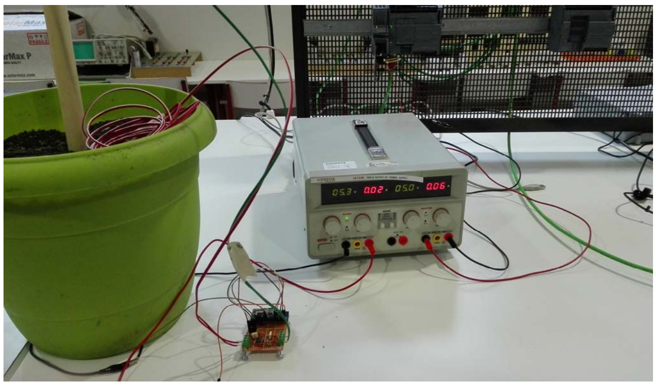

Fig. 9. Experimental setup

As an example, it is shown in Fig. Fig.10 the values of the parameters stated to be controlled and the values achieved by using the designed irrigation system.

For example, the obtained soil water content $\theta$ ($H\_Final$ in the tag table) was 47 % and the temperature $T_c$ ($T\_Final$ in the tag table) was 15ºC.

**Default tag table**

| | Name | Data type | Address ▲ | Retain | Visibl... | Acces... | Monitor value |
|---|---|---|---|---|---|---|---|
| 28 | Tempo_C | Time | %MD100 | ☐ | ☑ | ☑ | T#30S |
| 29 | T0_time | Time | %MD104 | ☐ | ☑ | ☑ | T#2S_981MS |
| 30 | Res_AND | DWord | %MD108 | ☐ | ☑ | ☑ | 16#0000_0000 |
| 31 | Peso | DWord | %MD112 | ☐ | ☑ | ☑ | 16#0000_0000 |
| 32 | V_Time | UDInt | %MD116 | ☐ | ☑ | ☑ | 126 |
| 33 | V_ADC | UDInt | %MD120 | ☐ | ☑ | ☑ | 659 |
| 34 | R_T | Real | %MD124 | ☐ | ☑ | ☑ | 12766.86 |
| 35 | V_ADC_R | Real | %MD128 | ☐ | ☑ | ☑ | 659.0 |
| 36 | V_Temp_R | Real | %MD132 | ☐ | ☑ | ☑ | 14.98932 |
| 37 | T_Final | DInt | %MD136 | ☐ | ☑ | ☑ | 15 |
| 38 | V_Time_R | Real | %MD140 | ☐ | ☑ | ☑ | 1.26e-005 |
| 39 | R_S | Real | %MD144 | ☐ | ☑ | ☑ | -0.3001141 |
| 40 | P | Real | %MD148 | ☐ | ☑ | ☑ | -3.804858 |
| 41 | teor_r | Real | %MD152 | ☐ | ☑ | ☑ | 0.1 |
| 42 | teor_s | Real | %MD156 | ☐ | ☑ | ☑ | 0.5 |
| 43 | alpha | Real | %MD160 | ☐ | ☑ | ☑ | 0.2 |
| 44 | n | Real | %MD164 | ☐ | ☑ | ☑ | 1.2 |
| 45 | m | Real | %MD168 | ☐ | ☑ | ☑ | 0.1666667 |
| 46 | VWC | Real | %MD172 | ☐ | ☑ | ☑ | 0.4654127 |
| 47 | V_MinH | DInt | %MD176 | ☐ | ☑ | ☑ | 29 |
| 48 | H_Final | DInt | %MD180 | ☐ | ☑ | ☑ | 47 |

Fig. 10. Tag table PLC

One objective defined to be achieved with the final implemented system is the field irrigation management and monitoring autonomously. To do that it is considered the design of a PV system to supply the sensorial module, as shown in Fig. 11, providing a 5V voltage with a 0.02A current.

Thus, it is proposed a system capable of controlling the irrigation but also capable to be adapted for the implementation of the control of existing solar trackers [19] or fertigation systems.

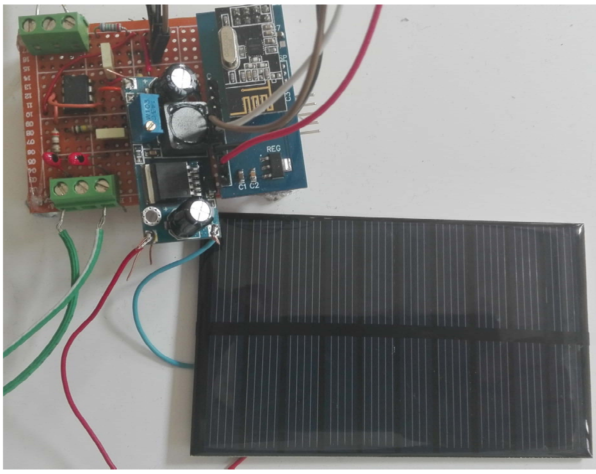

Fig. 11 Sensorial module and photovoltaic panel

## V. Conclusion

The system presented in this paper has as main objective the improvement of quality and quantity production of blueberries. The system is capable to be adapted to other of orchards or managed according to the season, plant ages and soil texture. It is possible to deliver proper quantity of water at the most advisable period optimising the water supply.

By the introduction of a webpage and wireless communication with humidity and temperature sensors placed near the plants, the user can easily change the system behaviour.

Also, the control of existing solar trackers or fertigation systems can be associated to the irrigation control and monitoring.


## Acknowledgment

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## References


[1] B. Werner and R. Collins, Towards efficient use of water resources in Europe, no. 1. European Environment Agency Report, 2012.

[2] V. H. P. Wilk, G. Carruthers, C. Mansfield, "Irrigation and moisture monitoring in blueberries," Profitab. Sustain. Prim. Ind., vol. 827, pp. 1-10.

[3] R. Muñoz-Carpena and M. D. Dukes, "Automatic Irrigation Based on Soil Moisture for Vegetable Crops," Dep. Agric. Biol. Eng. UF/IFAS Ext., pp. 1-4, 2014.

[4] X. Liu, J. Ling, L. Yao, H. Wu, and J. Tao, "Engineering quality control of solar-powered intelligent water-saving irrigation," CAR 2010 - 2010 2nd Int. Asia Conf. Informatics Control. Autom. Robot., vol. 3, pp. 254-257, 2010.

[5] Zhang Feng, "Research on water-saving irrigation automatic control system based on internet of things," 2011 Int. Conf. Electr. Inf. Control Eng., pp. 2541-2544, 2011.

[6] M. Usha Rani and S. Kamalesh, "Web based service to monitor automatic irrigation system for the agriculture field using sensors," in 2014 International Conference on Advances in Electrical Engineering, ICAEE 2014, 2014, pp. 1-5.

[7] P. Patil, V. H., S. Patil, and U. Kulkarni, "Wireless Sensor Network for Precision Agriculture," 2011 Int. Conf. Comput. Intell. Commun. Networks, pp. 763-766, 2011.

[8] J. Gutierrez, J. F. Villa-Medina, A. Nieto-Garibay, and M. A. Porta-Gandara, "Automated irrigation system using a wireless sensor network and GPRS module," IEEE Trans. Instrum. Meas., vol. 63, no. 1, pp. 166–176, 2014.

[9] D. K. Fisher, "Automated collection of soil-moisture data with a low-cost microcontroller circuit," Appl. Eng. Agric., vol. 23, no. 4, pp. 493-500, 2007.

[10] E. Interface and G. B. Sensors, "Electrical Interface for WatermarkTM or Gypsum Block Sensors.," no. 510, pp. 1-15, 2002.

[11] B. Vandewalle, E. Educator, F. County, J. Rees, E. Educator, C. County, G. Zoubek, E. Educator, and C. County, "Principles and Operational Characteristics of Watermark Granular Matrix Sensor to Measure Soil Water Status and Its Practical Applications for Irrigation Management in Various Soil Textures," vol. 5, pp. 1-14, 2014.

[12] J. M. G. Figueiredo, "PLC based Structure for Management and Control of Distributed Energy Production Units," January, 2010.

[13] R. B. Thompson, M. Gallardo, T. Agüera, L. C. Valdez, and M. D. Fernández, "Evaluation of the Watermark sensor for use with drip

irrigated vegetable crops," Irrig. Sci., vol. 24, pp. 185-202, 2006.

[14] M. T. van Genuchten, "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," Soil Sci. Soc. Am. J., pp. 1-7, 1980.

[15] S. R. Systems, "Calibrate Steinhart-Hart Coefficients for Thermistors," pp. 1-3, 2012.

[16] "An Introduction to Soil Moisture Concepts." [Online]. Available: http://hydrogold.org/education.soil_moisture_concepts.html.

[17] B. GHANBARIAN-ALAVIJEH, A. LIAGHAT, G. H. HUANG, and M. T. VAN GENUCHTEN, "Estimation of the van Genuchten Soil Water Retention Properties from Soil Textural Data," Pedosphere, pp. 456–465, 2010.

[18] M. B. Kirkham, "10 - Field Capacity, Wilting Point, Available Water and the Non-Limiting Water Range," Princ. soil plant relations, pp. 153–170, 2014.

[19] Siemens AG, "Simply folllow the sun," pp. 1–8.