European Territorial Cooperation Programme
Greece - Italy
2007-2013

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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes

IRMA

Experiments regarding sensors evaluation for greenhouses - Research report regarding the use of sensors for irrigation management.

WP6, Action 6.4.

Deliverable 6.4.3 - 6.4.5

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IRMA info

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Experiments regarding sensors evaluation for greenhouses - Research report regarding the use of sensors for irrigation management.

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Foreword

This report contains a description of the activities carried out by CNR-ISPA (P4) in the framework of WP6 - Specialized research actions, Deliverable 6.4.3 and 6.4.5 - Experiments regarding sensors evaluation for greenhouses - Research report regarding the use of sensors for irrigation management.

The activities focused on testing sensors for growing substrate parameters measurement (moisture and electrical conductivity), and sensor-based irrigation management strategies in greenhouse, with the aim to provide tools for irrigation decision and plant water requirements study. We implemented both laboratory and on-field activities, focusing on important greenhouse vegetable crops (namely tomato and lettuce) in Mediterranean environment. We also developed a pre-commercial prototype for the automatic sensor-based irrigation in greenhouse.

Beside an introductive examination of the state of the art and of the concepts at the base of the carried out activities, a description of the experiments and of the results is included in this report.

We outline that the full dataset from the experiments is at the moment under use or consideration for publication in scientific international journals, with the aim to present the outcomes of the IRMA project to the wide scientific community. Therefore, in order to be compliant with the universal requirement for scientific publication (the material should not have been previously published elsewhere, except in a preliminary form) we will not include in this report the full set of data; however, we will give anyway an exhaustive overview of the findings of the project activities.

All the publications that will arise from the activities carried out in the project will clearly refer to the IRMA project as source of funding for the conducted research.

Introduction

Modern agriculture, in all its sectors, is facing a major challenge to adapt to the many changes that the current social, economic and environmental scenario forces. To sum up, the attention reserved to the development and the search for innovations (product and processes) to maximize productivity in the broad sense of the agricultural industry (with techniques that enable higher yields and, at the same time, lower costs), consider essential the search for **solutions aimed to increase the use efficiency of resources (especially water and fertilizers) and to reduce the environmental impact**.

This new paradigm is required by more and more restrictive legislation to protect the environment, and the increasing attention of consumers and farmers to environmental sustainability of productions (often motivated by the added value that a environment-friendly production process can give to their productions). Although those conditions are widely accepted and shared by all the actors of the agricultural sector (producers, institutions, scientific community), **there is often a difficult diffusion of innovations proposed in this direction, which in many cases remain confined within research institutions, finding no concrete application for the scarce economic convenience of the same, for the excessive technical difficulties and the lack of technologies easily applicable to the real production conditions; often just to shortcomings in the transfer of innovations from research to farm**.

Agriculture, for the technical features related to the production processes used, is closely linked and dependent on the water resources. High water consumptions in agriculture, in most cases, are excessive in relation to the real needs. The not rational irrigation, intended as excessive supply of water and consequent run-off, besides determining an inefficient use of the water resource, is also the main cause of leaching of fertilizer salts, especially in areas with intensive agriculture (such as greenhouse industry), with the consequent risk of pollution of surface and groundwater reservoirs. Since agriculture is an important source of non-point source water pollution, it may be necessary to adopt agricultural practices which minimize the release of pollutants to meet societal goals and satisfy government regulations (Blackstock et al. 2010).

The increasing competition for water resources exerted by urban settlements and other productive sectors (industry, tourism, recreation), associated with the shortage of good quality irrigation water in Mediterranean environments, creates a potentially strong motivation for farmers to equip themselves with more efficient irrigation systems. The advantages of these systems often include the reduction of water use and consistent labor costs savings (Nemali and van Iersel, 2006). The basic principle to make efficient irrigation is to irrigate plants when they require it and in sufficient quantity to satisfy their requirements.

In greenhouse conditions, irrigation assumes a crucial role, since the entire water availability for the crop needs to be satisfied by the human supply. Currently, the most widespread irrigation automation system, if present, is based on timers, able to automate irrigation on the base of a pre-fixed schedule. The main disadvantage of timers is that they cannot take into account the real needs of the irrigated crop, which change very quickly depending on environmental conditions and growth stage of the crop. Programming the timer, then, is typically conducted empirically, regardless of the monitoring of the water status of the growing media and the related water availability for plants. It follows that potentially much of the irrigation takes place when the plant would not actually need, resulting in waste of resources and potential environmental issues, as mentioned (Nemali et al., 2007; Nemali and van Iersel, 2006).

Among the different irrigation management approaches, the one based on the measurement of the growing media (soil or soilless substrates) water status represents probably the most directly applicable, since it is directly related to the water availability for plants (Jones, 2007; van Iersel et al., 2013)**.** The use of sensors for the measurement of the growing media water status is able to overcome the approximation of mathematical models used to describe the dynamics of the water in the substrate – plant – atmosphere continuum – generally based on the relation between evapo-transpiration and environmental conditions - and to avoid laborious laboratory determinations, generally not applied in the production facilities. The possibility to measure with sufficient accuracy the substrate water status, through using specific sensors, allows to set when and how much irrigation is required, which should take place when a threshold value is reached. Automation of irrigation can be obtained connecting moisture sensors to specific devices able to process the sensors output and decide when pumps should be switched on.

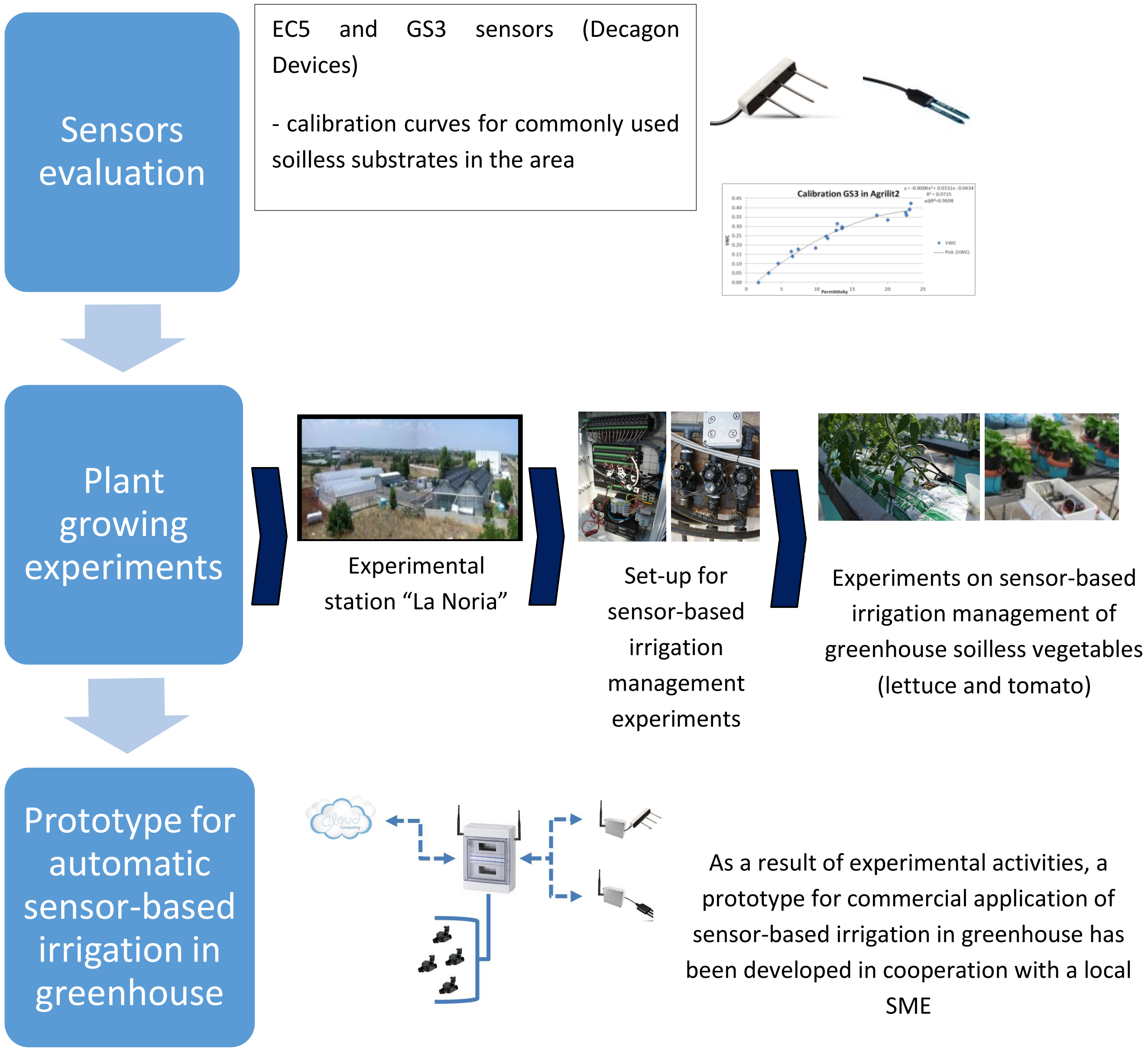
The basic idea for the use of moisture sensors for the control and automation of irrigation is simple: the moisture level in the growing media fluctuates according to the evaporation and the plant water use; sensors detect this change and can automatically activate the irrigation when the level reaches a threshold value predetermined by the operator. In this way, the frequency of the irrigations is automatically adjusted according to the real consumption of the crop (van Iersel, 2015). That is commonly defined the "***let the plant decide***" approach, since it is based on the plant request to be irrigated according with the evapo-traspirative demand and the growth stage. Several studies demonstrated as this strategy allows to save water and increase the water use efficiency. Up to about a decade ago, the main reasons for not using moisture sensors to control irrigation were high costs, unsuitable size, unreliable measurements performed by the available moisture sensors and lack of precise information for a correct irrigation management based on sensors use. Nevertheless, **in the last few years new generation of moisture sensors, reliable and affordable, is available**. These probes are available in convenient sizes to be used for modern cultivation greenhouse techniques. The attention of the scientific community has turned towards the assessment of several types of soil moisture sensors (tensiometers, neutron probes, TDR, FDR) which, however, have found poor diffusion at agricultural commercial level for the above mentioned reasons. In recent years, however, the latest generations of sensors offer lower cost and increasing reliability. This creates interesting perspectives about the implementation of automatic irrigation systems simple, cheap and efficient (Pardossi et al., 2009; Lichtenberg et al., 2013). Most of these sensors are based on a similar principle: the measurement of the dielectric permittivity of the substrate. Although the physical principles at the basis of these measurements can be complicated to understand, it is sufficient to refer to the fact that the dielectric permittivity is related to how the substrate is able to influence an electromagnetic field. Most of the components of the soil or soilless growing media, have a negligible effect (dielectric constant around 4) while the water has a very large impact on electromagnetic fields (dielectric constant around 80). Therefore, the changes of the dielectric constant of a substrate are an excellent indicator of its water content. The working principle of the sensors consist in applying electrical energy to the parts of the sensor in contact with the substrate; the sensor sends a voltage return that depends precisely on the dielectric constant. The voltage return may be converted into volumetric water content (VWC) with a calibration equation, specific for the substrate measured, and linking the two parameters.

As previously mentioned, in recent years the market offers a relatively wide range of sensors, for different characteristics and costs. Some of them must necessarily be connected to portable devices reading. They have a rather high cost, require the physical presence of the operator to take readings and are designed primarily for the monitoring and control of soil moisture. Others, however, permit readings in continuous and in-situ of the parameters in object. These sensors measure the dielectric constant of the medium through technology capacitance / frequency domain, are scarcely affected by the salinity of the soil and have a very competitive cost. Several models are also able to combine the possibility to measure different soil parameters (namely moisture, temperature and electrical conductivity) in a single sensor.

Numerous experimental evidences describe these sensors as a useful tool for automating irrigation in greenhouse. The interest for commercial applications of smart-irrigation based on soil moisture sensors is growing fast, and there is a need to develop skills and to collect information on how the use of those sensors could be applied to important greenhouse crops in Mediterranean environment.

The ISPA – CNR activities in the framework of WP6.4

We focused on the use of soil moisture sensors for the automatic irrigation management of Mediterranean greenhouse vegetables in soilless conditions. A schematic workflow of ISPA – CNR activities in this framework is reported in the Figure 1.



Sensors evaluation

EC5 and GS3 sensors (Decagon Devices)

- calibration curves for commonly used soilless substrates in the area

Plant growing experiments

Experimental station “La Noria”

Set-up for sensor-based irrigation management experiments

Experiments on sensor-based irrigation management of greenhouse soilless vegetables (lettuce and tomato)

Prototype for automatic sensor-based irrigation in greenhouse

As a result of experimental activities, a prototype for commercial application of sensor-based irrigation in greenhouse has been developed in cooperation with a local SME

Figure 1: Workflow of the CNR – ISPA activities in the framework of WP6 with focus on the use of soil moisture sensors for the automatic irrigation management of greenhouse vegetables in soilless conditions in Mediterranean environments.

In our experiments, we used EC5 and GS3 Decagon Devices sensors. We selected those models as result of previous personal experiences and because of the relevant number of scientific reports dealing with the use of those sensors. Our approach was based on the integration between volumetric water content measurement through FDR sensors and substrate water potential measurement through tensiometers.

We decided to test the application of sensor-based irrigation in growing conditions similar to that diffused at commercial level in the area where the studies have been carried out (Apulia region), however representative of greenhouse industry situation in Mediterranean area.

SUBSTRATE-SPECIFIC CALIBRATION

As a preliminary activity, we tested the sensors in substrates typically used for growing soilless vegetables. We focused on perlite and peat:perlite mixtures, and we used those substrates also for the cultivation experiments carried out in the following stages. This preliminary phase included the implementation of substrate-specific calibration curves to convert sensor readings into volumetric water content (VWC), and observations on the substrate EC measurements (refer to “Experiments regarding use of saline water for cultivation in greenhouse”, WP6, Action 6.5., Deliverable 6.5.3 of the IRMA project for details on this part of the study), being this still a weak part of the substrate sensors use.

The substrate-specific calibration equation needed to convert the dielectric value, directly measured by the sensor, to substrate water content was obtained using the procedure described by Nemali et al. (2007). Briefly, to obtain a range of water contents in each substrate, from dry to near saturation, different volumes of deionized water were added to perlite samples of about 2L and mixed thoroughly to obtain uniformity. Substrates were then transferred into glass beakers with known volume (1170 mL). Before inserting any probe, the initial weight of the beakers and substrate was determined. Three GS3 probes connected to a CR1000 datalogger (Campbell Scientific, Inc., Logan, UT, USA) were inserted carefully in each beaker so as to not compress the substrate during insertion. After measuring the output from the probes, the substrate in the beakers was dried in a forced-air oven maintained at 105 °C. The substrate was weighed after drying, and used to determine the substrate water content. The volumetric substrate water content was determined by converting grams of water in the substrate to milliliter of water assuming that 1 g of water = 1 mL.

Examples of calibration curves defined during the study are reported in Fig. 2.

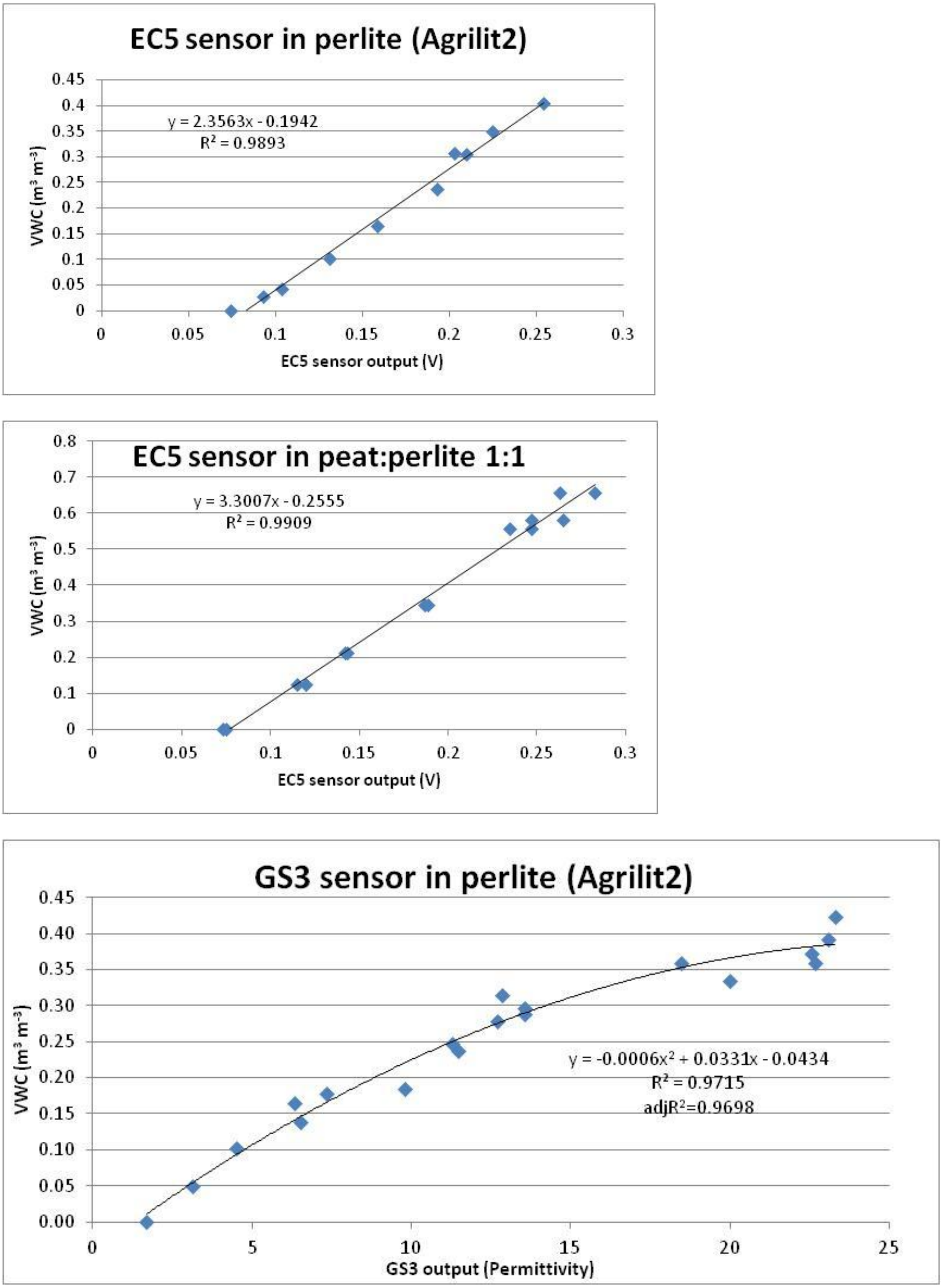
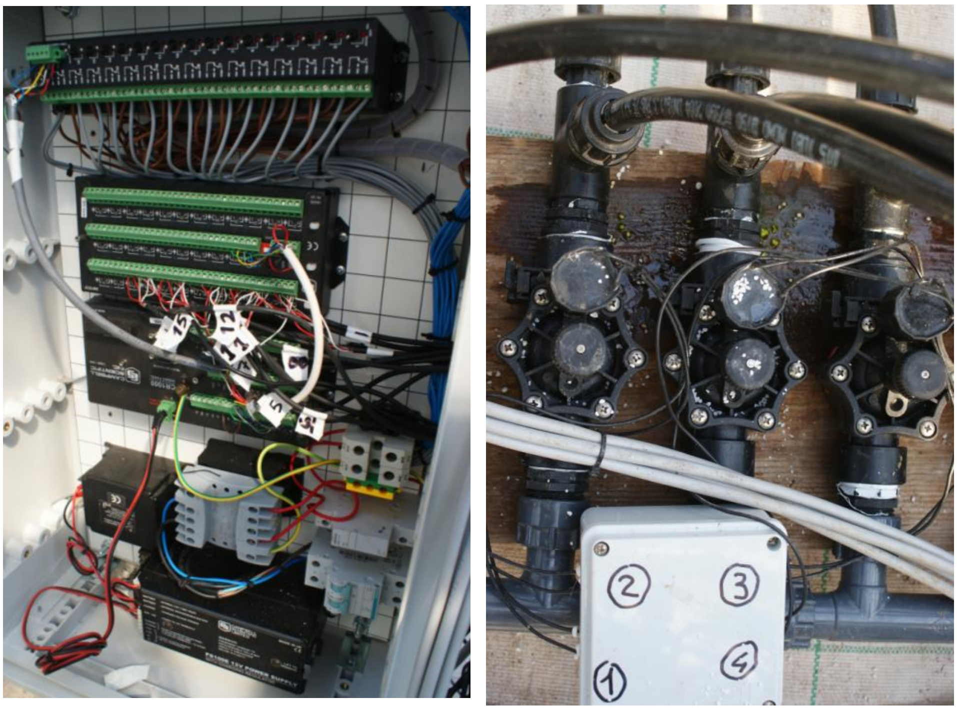


Figure 2: Substrate specific calibration of EC5 and GS3 sensors on growing media used for the cultivation experiments (perlite (Agrilit2, Perlite Italiana, Italy) and peat:perlite 1:1 (v:v) mixture).

We developed an automatic irrigation system intended for experimental purposes, based on a CR1000 Datalogger (Campbell Scientific), a relay driver (SDM16AC/DC controller; Campbell Scientific) and a set of irrigation solenoid valves and/or water pumps. The system was able to collect the soil moisture sensor measurements, to process the data according to specific programs developed in CR Basic language for each specific experiment, and to activate irrigation automatically (Picture 1).

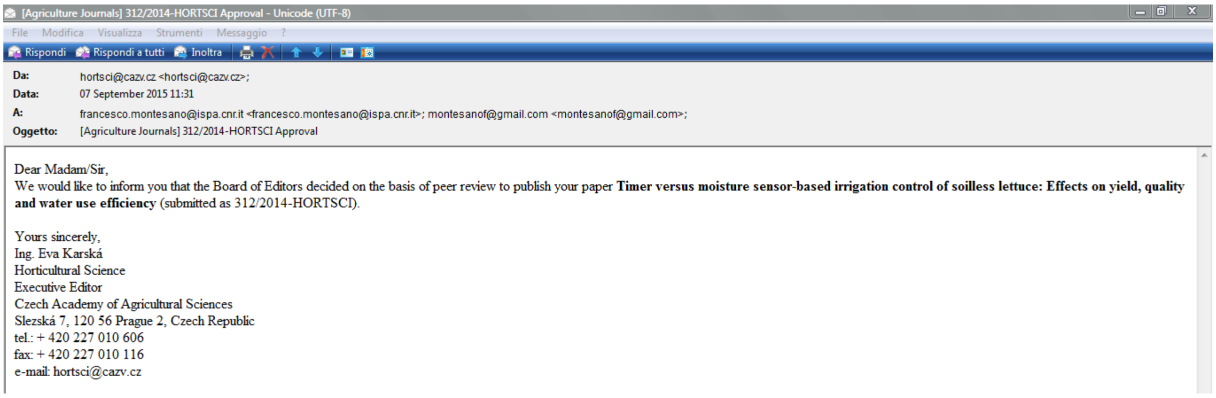


Picture 1: Experimental system for sensor-based irrigation.

Hereafter we briefly report two tests carried out in the framework of Action 6.4, respectively on lettuce and tomato.

TIMER VERSUS MOISTURE SENSOR – BASED IRRIGATION CONTROL OF SOILLESS LETTUCE

The present study has been reported in the manuscript "*Timer versus moisture sensor-based irrigation control of soilless lettuce: Effects on yield, quality and water use efficiency*", accepted for publication in "Horticultural Science" journal, to which readers are referred to more in-depth review of the study. This journal provides immediate open access to its content on the principle that making research freely available to the public supports a greater global exchange of knowledge.



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A: francesco.montesano@ispa.cnr.it <francesco.montesano@ispa.cnr.it>; montesanof@gmail.com <montesanof@gmail.com>;
Oggetto: [Agriculture Journals] 312/2014-HORTSCI Approval

Dear Madam/Sir,
We would like to inform you that the Board of Editors decided on the basis of peer review to publish your paper **Timer versus moisture sensor-based irrigation control of soilless lettuce: Effects on yield, quality and water use efficiency** (submitted as 312/2014-HORTSCI).

Yours sincerely,
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Hereafter is reported a synthetic description of the study (Picture 2-3).

Description of the study and principle results

Efficient irrigation management of soilless greenhouse crops is crucial for qualitative and quantitative improvements in vegetable production and for sustainable use of water. We compared the effects of timer- ('Timer') and soil moisture sensor-controlled irrigation on the water use, yield and quality of lettuce (Lactuca sativa L.) grown in soilless substrate (peat-perlite,1:1 v/v). We also compared two different volumetric water content (Θ) thresholds for irrigation (0.30 ('Θ=0.3') and 0.40 m3·m-3 ('Θ=0.4'), respectively above and below the substrate easily available water (EAW) limit). The most nutrient solution (NS) was applied in the 'Timer' treatment, with 17 and 42% less NS used in the 'Θ=0.4' and 'Θ=0.3' treatments, respectively. Irrigation volumes fluctuated daily in the sensor-controlled treatments according to real plant water consumption, with little or no leaching, while 18% of applied NS in 'Timer' leached out from the containers. Plants in 'Timer' and 'Θ=0.4' treatments had higher fresh weights (24%) and leaf area (13%) than plants irrigated at the lowest Θ threshold, but no differences in dry weight were observed among treatments and percent dry matter was 20% higher in the 'Θ=0.3' plants. Leaf chlorophyll content, net CO_2 assimilation rate, stomatal conductance, leaf transpiration and leaf tissue chemical composition were similar in all treatments, with the exception of nitrate concentration, which was lowest in the ‘Θ=0.3’ plants. Water use efficiency (WUE) as a function of the total applied irrigation water was lowest in ‘Timer’, due to the large volume of NS applied and the volume lost by leaching. Precision sensor-controlled irrigation based on Θ measurements could be used as an effective approach to increase the overall WUE and to improve the quality of soilless-grown lettuce. Maintaining a substrate moisture level slightly below the conventionally defined EAW range reduces the water content and nitrate concentration of lettuce grown in soilless substrate.

Photo 2-3: Experiment on Timer versus moisture sensor-based irrigation control of soilless lettuce

USE OF CAPACITANCE SOIL MOISTURE SENSORS FOR ASSESSING THE EFFECTS OF DIFFERENT SUBSTRATE WATER CONTENT ON GROWTH AND WATER RELATIONS OF SOILLESS TOMATO

The increasing availability of low-cost and reliable substrate moisture sensors offers interesting perspectives for rational and automatic irrigation management of soilless greenhouse crops and for research on plant water relations.

The knowledge of the effects of different substrate volumetric water content (VWC) levels on plant growth is crucial for the determination of proper irrigation set-points.

An experiment was conducted to assess the effects of different VWC levels on soilless tomato growth and water relations (Picture 4-5).

Tomato plants were grown in a greenhouse in perlite bags. An automatic irrigation system used substrate moisture sensors (EC5, Decagon Devices, Pullman, USA) to control irrigation solenoid valves, in order to keep growing media at four different VWC levels (0.15, 0.20, 0.25 and 0.30 $m^3 \cdot m^{-3}$). Set-points were chosen according to a preliminary test aimed to realize a in-situ moisture release curve, using containers of similar shape and size of the perlite slabs used in the cultivation trial. The containers were filled with perlite at different moisture levels; tensiometers were installed in the substrates and left to equilibrate until tension reading was stable (Picture 6).

The system was able to get the substrate VWC at the desired different set-points. Substrate water potential was monitored during the experiment using tensiometers. The four VWC levels resulted, respectively, in a mean substrate water potential of -130, -101, -42 and -34 hPa.

Plant growth was similar for plants grown at 0.30 and 0.25 $m^3 \cdot m^{-3}$ in terms of leaf area, fresh and dry weight, with higher values than plants grown at 0.20 and 0.15 $m^3 \cdot m^{-3}$. Plant water status was affected by the VWC level in the substrate, with higher and similar values of total leaf water potential for plants grown at the two highest VWC levels than those grown at lower VWC. The most severe effects of water stress were observed on plants grown at 0.15 $m^3 \cdot m^{-3}$ which showed the lowest leaf relative water content (respectively 64.4% vs 84.8% at higher VWC levels) and membrane stability index (respectively 68.6% vs 83.9% at higher VWC levels). The water retention curve and hydraulic conductivity analysis performed on the perlite substrate used in this experiment revealed little or no available water below a VWC of about 0.15 $m^3 \cdot m^{-3}$. However, plants grown at 0.15 $m^3 \cdot m^{-3}$, were able to uptake water from the growing media and thus to survive, although showing reduced growth and symptoms of water stress.

Results seem to confirm that soilless growing media generally hold easily available water in a matric potential range from 0 to -100 hPa, with the majority of free available water present between matric potentials of 0 to -50 hPa.


4

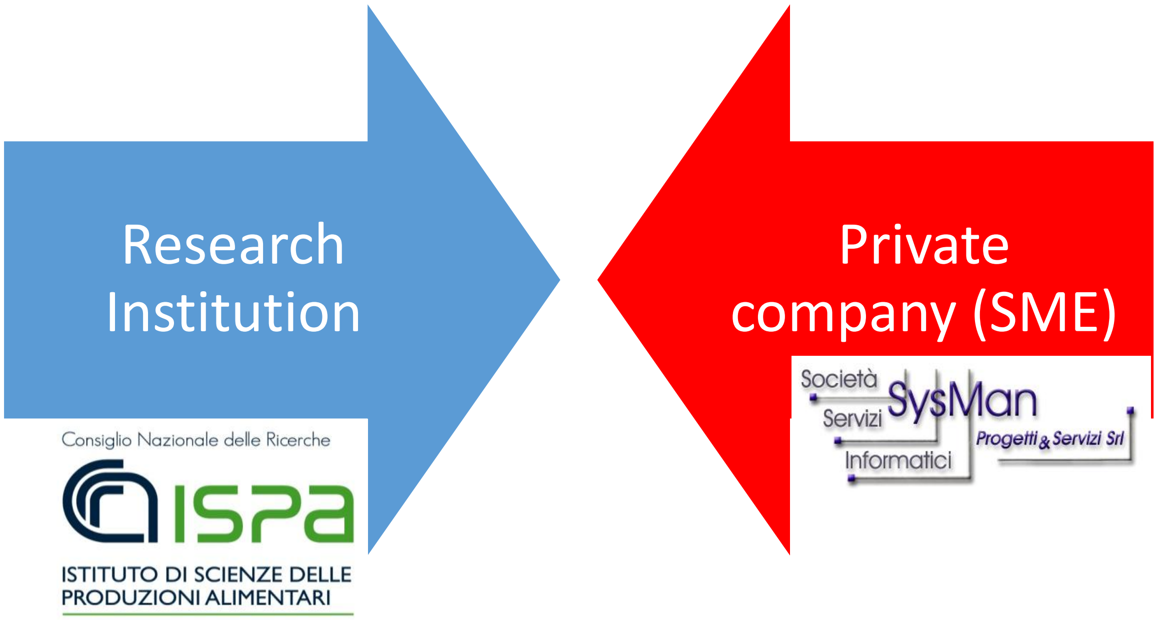

5

Picture 4-5: Experiment on the use of capacitance soil moisture sensors for assessing the effects of different substrate water content on growth and water relations of soilless tomato

Picture 6: In-situ moisture release curve.

PROTOTYPE FOR AUTOMATIC SENSOR-BASED IRRIGATION IN GREENHOUSE

As a result of WP 4.3 experimental activities, **a prototype for commercial application of sensor-based irrigation in greenhouse** has been developed in cooperation with a local SME (Sysman Progetti e Servizi srl).



A detailed report of this activity is reported hereafter.

1. Engineering of the solution

According to the specifications outlined in the terms of the project, it was necessary to design a low-cost remote controlled RTU, compatible with the equipment already owned by the CNR ISPA. To reach this goal, the most advanced technologies (possibly, open-source) were identified in order to reduce the number of components required for the development of the solution and to minimize, therefore, prototyping and development costs.

The proposed solution consists of three different stages (Fig. 3):

- **Networking**: connection to the cloud to allow the remote monitoring and the setup of user's preferences;
- **Measurement**: data acquisition through SDI-12 compliant soil sensors;
- **Actuation**: monostable electrovalves driving to provide planned irrigations.

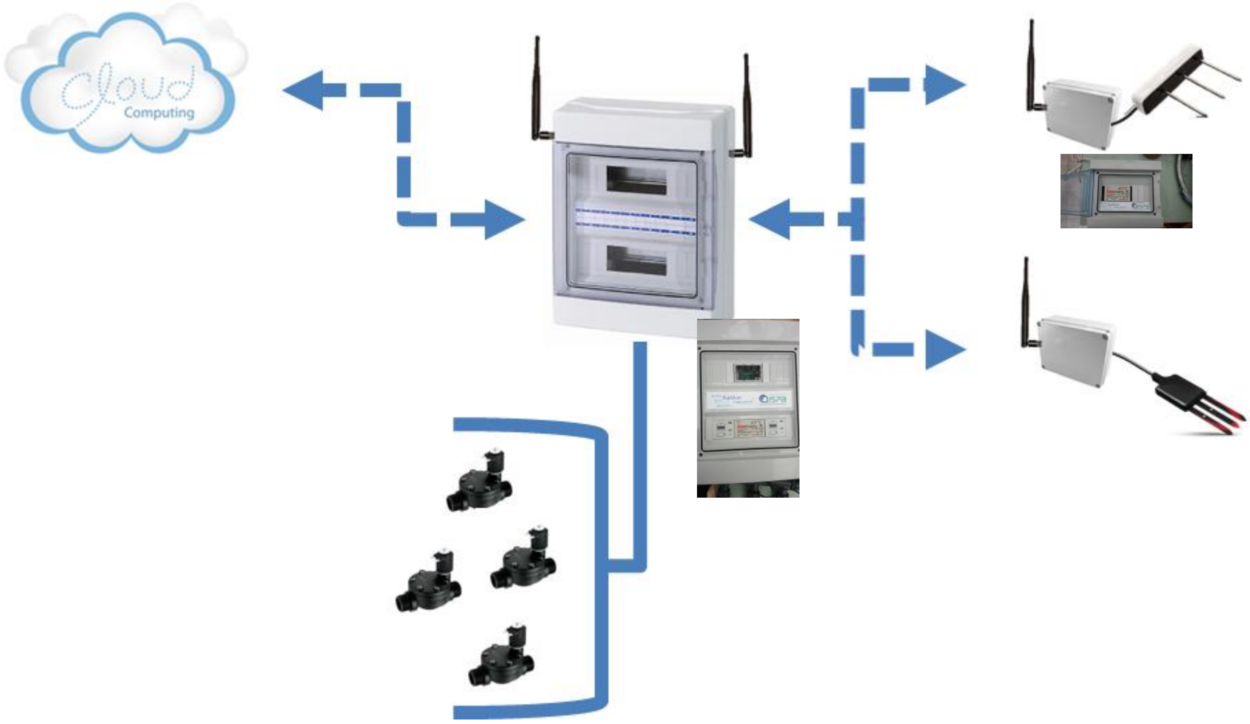
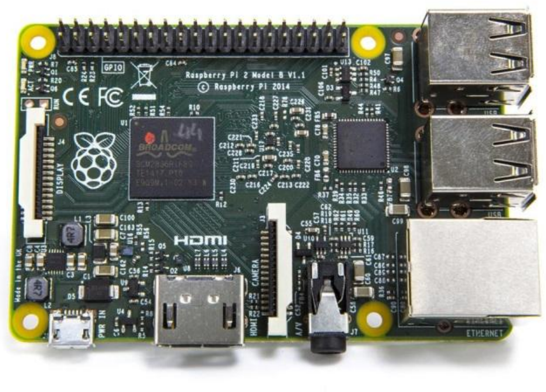


Figure 3 – Block diagram of the developed solution

The development of the solution concerned the design of custom hardware and software in order to achieve the required goals.

1.1 Hardware design

The core of the system is a Raspberry Pi (Picture 7), a low-cost single board computer, characterized by an extremely small form factor. The device is equipped with an ARM Cortex-A7 quad-core processor, 1GB of RAM, 40 GPIOs, Ethernet interface, 4 USB ports, full HDMI output, UART/I2C/SPI communication ports and a microSD (SDHC ready) slot.
On the Raspberry Pi is installed the last version of the open-source and Debian-based OS, Raspbian.



Picture 7 - Raspberry Pi 2 model B

To connect the CPU to the cloud is used the Huawei E303 3G USB dongle (Picture 8), connected directly to the USB hub of the single-board computer.

Picture 8 - Huawei E303

Moreover, the Raspberry Pi is equipped with the Maxim DS3231 IC, an extremely low-cost and high-performance real-time clock, useful to activate the scheduled irrigations even in case of unreachable network.
The communication between the RTC and the CPU is based on I2C protocol.

A custom protocol converter device was designed to acquire measured data. The developed board reads data from the soil sensors according to the SDI-12 serial protocol and then it sends the raw data through a serial UART channel to the next stage of the system.

The serial data, so, reach the CPU through an USB-to-Serial-Bridge stage, based on PL-2303HX integrated circuit.

Moreover, a wireless version of the protocol converter was developed. This version is based on the Texas Instrument’s MSP430 microcontroller, equipped with the low-power RF module CC110L.
The ISM communication frequency is set to 868 MHz, to grant a fast but stable link between the wireless nodes and the RTU.
The protocol converter was designed to work with all soil sensors whatever manufacturer is, providing a SDI-12 communication. The developed board broadcasts directly the SDI-12 commands to the desired wireless node and it allows to communicate with up to 64 soil sensors using a custom designed modular bus expander.
The actuation stage is based on a custom developed board. The board consists in a self-powered USB peripheral that allows to manage up to 14 distinct electrovalves. The USB protocol is intrinsically scalable and so it allows to connect up to 256 different peripherals of 14 electrovalves each.

The output pins of the microcontroller are connected to an array of optoisolators, in order to grant the galvanic isolation between the USB peripheral and the next 8-channels relay boards. The output of each phototransistor is connected to a NPN BJT transistor to provide the right amount of current to excite the relay’s coil.
The firmware of the MCU is coded to just hold high the output voltage of the GPIOs until the power off command is received. The entire board, therefore, is fully compatible with all monostable electrovalves and, so, it is fully vendor-independent.
The power supply stage consists of 2 power supplies 24VAC 40VA for the electrovalves and one 5VDC needed to power up the CPU and the relay boards.
All the devices are boxed in din rail enclosures and are mounted in an IP65 box (Picture 9).

1.2 Software design

1.2.1 Measurement

The acquisition of the measured data from the soil sensors is delegate to a service running on the CPU. The software is written according to a queue paradigm and allow to address the query commands to a single sensor according to its ID (consistently with the SDI-12 protocol). The software communicates through a virtual COM port with the cabled protocol converter or with the MCU-based wireless device.

At the boot, the CPU performs a handshake with the wireless and/or the cabled communication devices. Then the data acquisition is performed via the SDI-12 commands, according to the following pattern (Fig. 4):

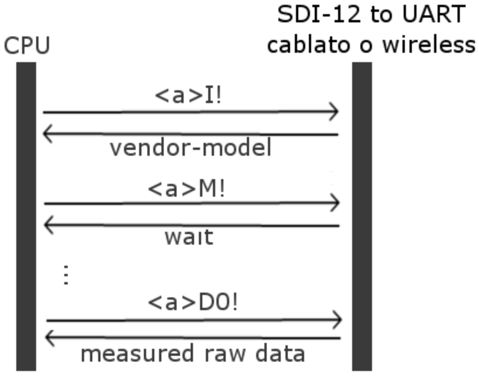


Figure 4 – Procedure for the sensor measurement.

The first query is needed to identify the manufacturer and the model of the soil sensor with address <a>. This step is needed to identify the right business logic to parse correctly the raw data returned by the sensor. After that, the CPU sends the command <a>M! and the sensor replies with the amount of time (in seconds) to wait until the measure is complete. After the suggested time, the CPU sends the command <a>D0! and the sensor sends back the raw data measured, that need to be parsed accordingly to the algorithm identified on the first step.

To make this system fully compatible with all compliant SDI-12 soil sensors, the software is written using a classes oriented structure, that will allow an easy and immediate implementation of new algorithm to parse new raw data structures.

All measurement and actuation operations are logged in a local log file to allow easier debugging and monitoring processes.

1.2.2 Actuation

When new measured data are acquired, the system estimates the current state of the irrigation plot, comparing the measures to the user defined set points: if set conditions are verified, the irrigation will start automatically.

The low-level communication between the USB peripheral and the CPU is managed by custom software, needed to send command to set or to get the status of each electrovalve. At the startup the CPU identifies the USB device comparing the manufacturer-Id /product-Id and reads the unique alphanumeric id of each USB peripherals. This operation allows to correctly address the command to each single relay. The code is written in according to a queue paradigm, to manage better all the resources and to improve the performances of the whole system.

The duration and the frequency of the irrigation are defined by the user and are stored locally. When the right conditions happen, the system runs an instance of the management service, in order to manage the entire irrigation, accordingly to the user configurations.

1.2.3 Cloud

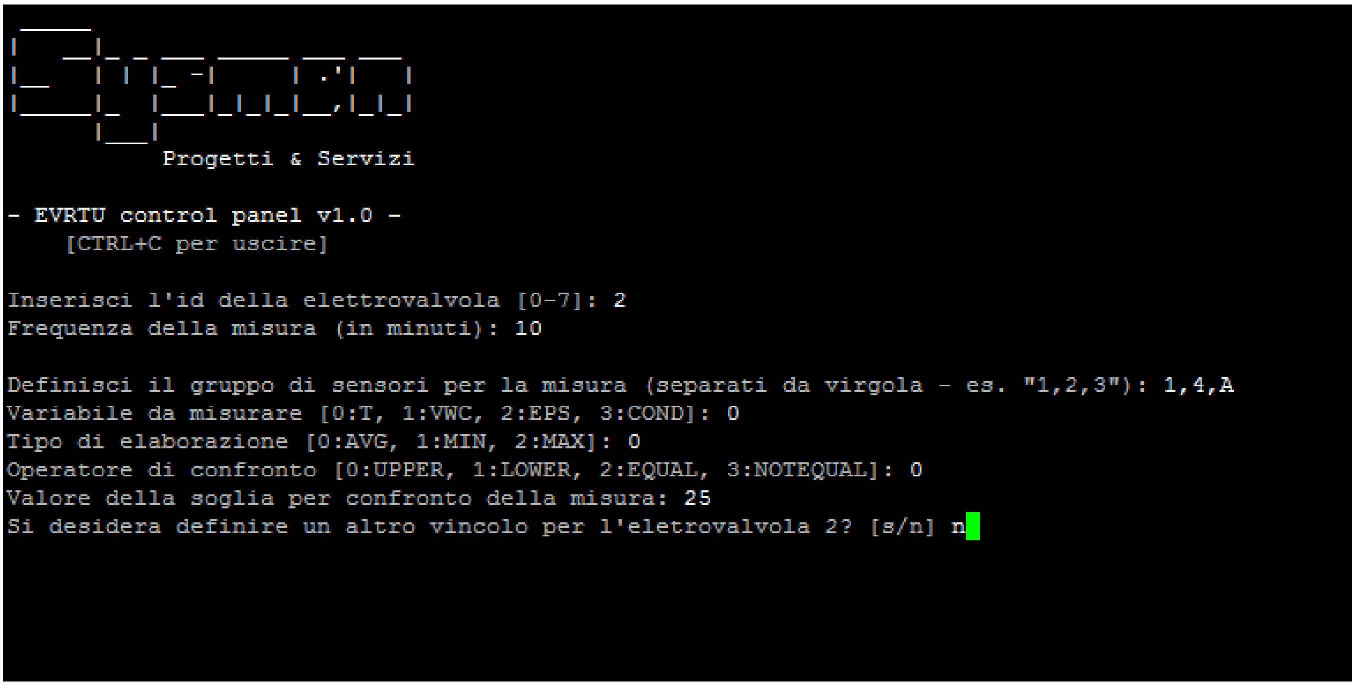
The Raspberry Pi, is connected to the cloud through a 3G/2G USB dongle. The networking is managed by a daemon that is able to establish, to verify and to restore automatically the link to the Net. The service starts at the startup of the CPU and, after the first connection, it keeps running to verify periodically the state of the network link.

The RTU is connected through a Virtual Private Network (VPN) to a commercial cloud service (Microsoft Azure), thanks to an instance of OpenVPN: this choice grants the high stability of virtual private network and high security level during the data exchange.

1.2.4 Setup

Two different softwares were coded to interact with user and to set up the RTU configurations.

The first one consists in a textual console, available via SSH (Fig. 5). Following the displayed instructions, the user can setup all the preferences relative to a specific electrovalve, in dependency of one or a group of sensors and according to one or more set points.



```
 _____
|   __|_ _ ___ _____ ___ ___
|__   | | |_ -|     | .'|   |
|_____|_  |___|_|_|_|__,|_|_|
      |___|
           Progetti & Servizi

- EVRTU control panel v1.0 -
    [CTRL+C per uscire]

Inserisci l'id della elettrovalvola [0-7]: 2
Frequenza della misura (in minuti): 10

Definisci il gruppo di sensori per la misura (separati da virgola - es. "1,2,3"): 1,4,A
Variabile da misurare [0:T, 1:VWC, 2:EPS, 3:COND]: 0
Tipo di elaborazione [0:AVG, 1:MIN, 2:MAX]: 0
Operatore di confronto [0:UPPER, 1:LOWER, 2:EQUAL, 3:NOTEQUAL]: 0
Valore della soglia per confronto della misura: 25
Si desidera definire un altro vincolo per l'eletrovalvola 2? [s/n] n
```

Figure 5 - Textual consolle for the system set-up

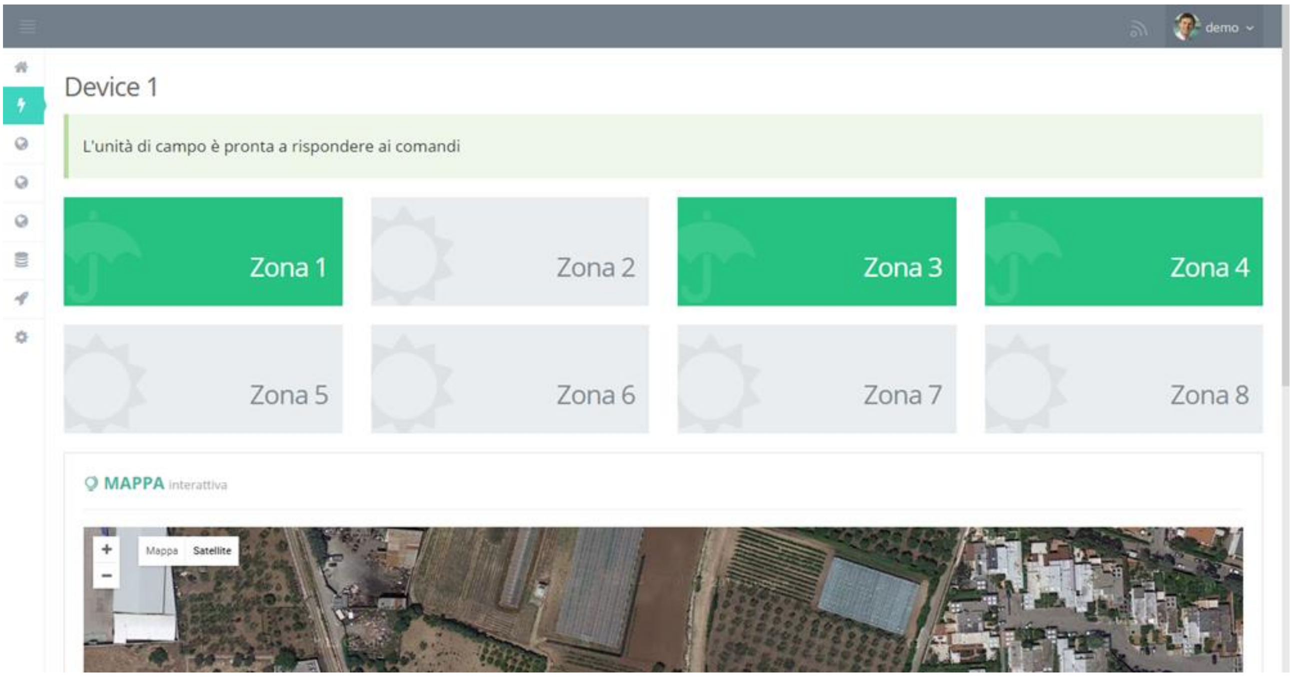
The required informations are:

- Id of the electrovalve;
- Measurement frequency;
- Address of the sensor or of the group of sensors from which acquire measures;
- Raw and calculated data (temperature, electric conductivity, dielectric permittivity, water content);
- Post-elaboration function (average, min/max value);
- Comparison type (greater, smaller, equal, not equal);
- Set point value.

It is possible to define more than one condition for each electrovalve: these will be the terms of the logical AND evaluated to start the irrigation.

The user configurations are stored into a local SQLite database, that is read then by the measurement service to estimate the plot condition.

The second tool to setup the system, is based on a PHP webservice. It consists in a web dashboard that provides a user-friendly GUI in order to monitor the real-time status of the electrovalves and to edit RTU configurations (Picture 9).



Device 1

L'unità di campo è pronta a rispondere ai comandi

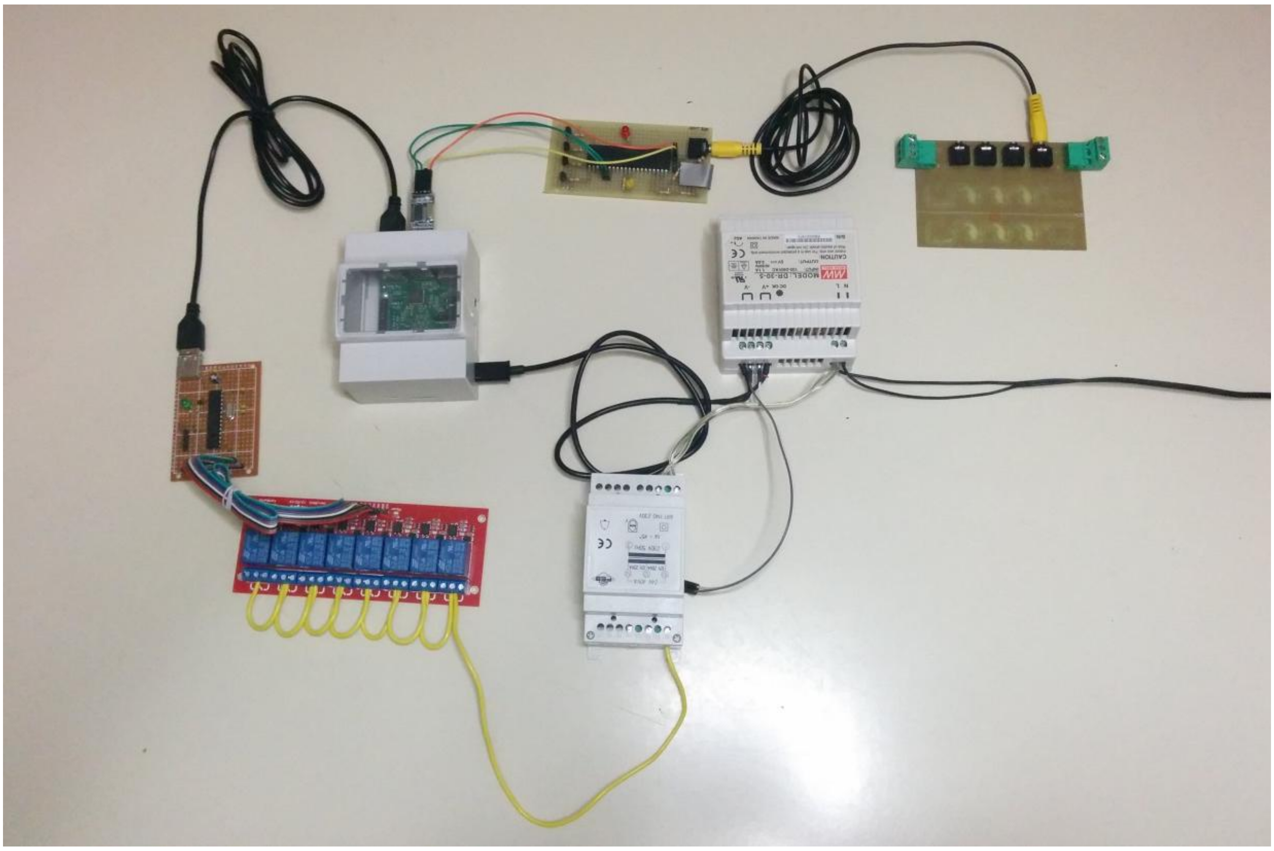
Picture 9 - Dashboard for the remote RTU administration

The web interface is written in HTML5, CSS3, JavaScript and jQuery. The pages are responsive to provide an improved user-experience even on mobile devices. The color of the area tiles indicates the current status of each electrovalve (green=on; grey=off). Clicking on the buttons, the user can toggle the status of the corresponding electrovalve.

In the administration section, moreover, the user can setup the conditions to be verified to start the irrigation.

2. Lab tests

The RTU has been tested in its final setup. The system has been tested with classical tests and with more specific ones to evaluate its reliability (Picture 10).



Picture 10 **-** Setup for laboratory tests

The setup used to test the whole system consisted in:

- 1 single board computer Raspberry Pi 2 model B;
- 1 dongle USB 3G Huawei E303;
- 1 protocol converter SDI-12 to UART;
- 1 USB to Serial Bridge PL-2303HX;
- 1 transceiver MSP430 + CC110L;
- 1 USB peripheral to manage relays;
- 2 8-channel relay boards 5VDC;
- 2 24VAC 40VA power-supply;
- 1 5VDC 3A power-supply;
- 8 Rain 24VAC monostable electro valves;
- 3 Decagon 5TE soil sensors;
- 3 Decagon GS3 soil sensors;
- 2 wireless nodes.

The measurement instrumentation used consisted in:

- Rigol DS1054Z 50MHz Oscilloscope;

- Agilent Keysight U1241A digital multimeter.

The boot time of the RTU is about 10 seconds and the 2G/3G connection is established in 1 minute after the complete boot up. The communication 2G/3G is stable like the VPN one.

During tests, measurement and actuation stages worked properly, without any bug or error, except a random delay of about 1 minute in the timing of the measurement frequencies.

The wireless link is stable and efficient as it is for the serial communication between CPU and the protocol converter.

Moreover, the measured data have been compared to the ones acquired by a commercial datalogger (Decagon EM-50g) and they result consistent.

Field tests

The field test was carried out in the greenhouses of the experimental farm “La Noria” ISPA – CNR (Mola di Bari, BA), in order to verify the whole system in a real environment (Picture 11).

The setup used for the tests consists in:

- 1 single board computer Raspberry Pi 2 model B;
- 1 dongle USB 3G Huawei E303;
- 1 SDI-12 to UART protocol converter;
- 1 USB to Serial Bridge PL-2303HX;
- 1 transceiver MSP430 + CC110L;
- 1 USB peripheral to interface relay boards;
- 2 8-channels relay boards 5VDC;
- 2 24VAC 40VA power-supplies;
- 1 5VDC 3A power-supply;

with:

- 9 Rain 24VAC monostable electro valves;
- 3 Decagon GS3 soil sensors;
- 2 wireless nodes.

Real environment tests, have confirmed the choice of the frequency of 868MHz in order to interface the wireless sensors: the communication was stable and allows to cover the entire area interested by the experimentation.

During the tests it was possible to realize that an increase of local humidity decreases a little the wireless power strength without compromising the functionality of the wireless communication.

All the hardware and software components met the outlined projects specifications and the whole system worked as expected.

Picture 11 - The prototype system under test in greenhouse environment.

Preliminary tests were also conducted in commercial greenhouses located in the area (Picture 12).

Picture 12 – Tests in commercial greenhouse conditions

Further tests will be conducted to perfect the prototype, improve its performance and increase its functionalities when used in real conditions of cultivation.

Conclusions

Providing the greenhouse sector with tools and skills for smart irrigation is a key-point to increase the use efficiency of resources, in particular water and fertilizers.

Soil moisture sensor-based irrigation is a promising approach to combine the need for optimal crop performances and reduce the impact of the greenhouse production processes. We demonstrated that real time monitoring of growing medium parameters and the automatic control of irrigation based on those readings can be an effective tool for scientists to assess the response of greenhouse crops to different irrigation set-points and irrigation management strategies, and for growers to optimize the crop performance in terms of yield, quality and resources saving.

Finally, the increasing interest for commercial application of sensor-based irrigation in greenhouse will probably lead soon to the release of affordable tools and devices for large applications in greenhouse industry.

References

Nemali, K. S., Montesano, F., Dove, S. K., & van Iersel, M. W. (2007). Calibration and performance of moisture sensors in soilless substrates: ECH 2 O and Theta probes. Scientia horticulturae, 112(2), 227-234.

Nemali, K.S., van Iersel, M.W., 2006. An automated system for controlling drought stress and irrigation in potted plants. Scientia Hort. 110, 292-297.

Blackstock, K.L., Ingram, J., Burton, R., Brown, K.M., Slee, B. (2010): Understanding and influencing behaviour change by farmers to improve water quality. Science of The Total Environment, 408:5631–5638.

Van Iersel, M.W., Chappell, M., Lea-Cox, J.D. (2013): Sensors for improved irrigation management in greenhouse and nursery production. HortTechnology, 23:735-746.

Jones H.G.(2007): Monitoring plant and soil water status: Established and novel methods revisited and their relevance to studies of drought tolerance. Journal of Experimental Botany, 55:2427–2436.

van Iersel, M.W. (2015). "Modern strategies for irrigation management in protected environments", in Modern technologies, strategies and tools for sustainable irrigation management and governante in Mediterranean Agriculture (IrriMed 2015), Proceedings – Book of Abstracts, eds. Montesano et al., (Valenzano, IT: CIHEAM, ISBN 2-85352-549-X), 127-130. http://www.irrigation-management.eu/images/Events/99IrriMed/IrriMED2015Abs.pdf

Pardossi, A., Incrocci L., Incrocci, G., Malorgio, F., Battista, P., Bacci, L., Rapi, B., Marzialetti, P., Hemming, J., Balendonck, J. (2009). Root Zone Sensors for Irrigation Management in Intensive Agriculture. Sensors 9(4), 2809-2835.

Lichtenberg, E., Majsztrik, J., Saavoss, M. (2013). Profitability of Sensor-based Irrigation in Greenhouse and Nursery Crops. HortTech. 23(6), 735-746.

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