Title

Irrig-OH: an open-hardware device for soil water potential monitoring and irrigation management

Authors

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Abstract

Sustainability of irrigation practices is an important objective to be pursued in many countries, especially in regions where water scarcity causes strong conflicts among different water uses. The efficient use of irrigation water is a key factor in coping with the food demand of an increasing world population and with the negative effects of climate change on the water resources availability in many areas. In this complex context, it is important that farmers could dispose of instruments and practices that enable a better management of water at the field scale, whatever the irrigation method they adopt.

In this paper, we present an open-hardware device based on the Arduino technology that was developed to allow the continuous monitoring of soil water potential in the root zone for supporting the irrigation scheduling at the field scale. The structure of the device is flexible and can be adapted to host different types of sensors. The results, obtained managing the irrigation in a peach orchard, show that the adoption of the device, together with a simple irrigation scheduling criterion, allowed a significant increase of the water use efficiency without causing a reduction of the quantity and quality of the crop production.

Keywords

Soil water potential, real time monitoring, irrigation scheduling, peach orchard, northern Italy

1 Introduction

The possibility to collect continuous measurements in order to study, analyze, describe, understand and eventually support the management of a particular process or event is one of the most important scientific and operational objectives. Monitoring activities often reflect a compromise between the amount and type of measurements needed and the resources available to collect them. Manual measurements can be time-consuming and labor-intensive, resulting in low frequency samplings. If outdoor field research is involved, collection times can fall when labor is unavailable, on weekends or when other duties take priority, or when inclement weather does not permit field activities. Automating the data-collection process can reduce labor requirements and greatly increase the frequency and regularity of measurements, but at the cost of added expense for electronic data collecting instrumentation.

A vast number of electronic solutions are nowadays available for automated sensing and monitoring, but several problems exist that can limit their practical application (Fisher and Gould 2012). Monitoring equipment developed by private industries often contains proprietary technology that manufacturers do not wish to release, and it is often designed to operate with a limited number of manufacturer's sensors. Consequently, if a number of different measurements is required, a single manufacturer may not provide all the needed sensors, and the replication of some devices in the monitoring systems may be necessary due to incompatible technologies.

In this context, open–hardware environments give the possibility to implement *ad hoc*, stand-alone platforms and microcontrollers for precision agriculture as well as for environmental monitoring in general, directly interfaceable with a lot of commercial sensors or devices, using electrical schemes and informatics libraries freely downloadable from web sites (Wang et al. 2006, Camilli et al. 2007, Vellidis et al. 2008, Siuli and Bandyopadhyays 2008, Pierce and Elliot 2008, Dursun and Ozen 2011).

Recent papers have highlighted the high performances and the wide range of applications of microcontrollers like Arduino or Raspberry, that can be considered small, low-power, low-cost computers packaged within a single chip (Noordin et al. 2006, Fisher 2007, Vellidis et al. 2008). The microcontroller runs a program that is created and uploaded by the programmer to operate different components within a circuit. The programmer can modify the program and change the function of the circuit without changing the circuit physically. Many types of sensors and auxiliary components, such as memory chips, clocks, and communications devices, are available that interface directly with microcontrollers, simplifying circuit designs and putting electronic design within reach of people with limited electronics background and knowledge. Examples of customized microcontroller devices developed to satisfy specific monitoring requirements can be found in Moody et al. (2004), Zhang et al. (2009), Bri et al. (2008), Gordon et al. (2010).

The interest in obtaining continuous monitoring of important variables at an affordable cost is particularly acute when the irrigation management is considered. Among the different water uses, irrigation is responsible for a large share of the total water consumption in many countries. With regard to Europe, in the Water Saving Potential report by EU (Strosser et al. 2007), water used for irrigation is estimated to be about 70 billion of m^3 per year. The adoption of innovative tools to support irrigation management can significantly increase the water use efficiency and reduce the water consumption, as indicated by the results of several European projects, such as FLOW-AID or FIGARO.

Irrigation devices for the continuous monitoring of soil water status are a potential solution to improve yields and increase WUE, also in agricultural contexts with low water availability but high crop water requirements (Miranda et al. 2005, Coates et al. 2006a; Dursun and Ozden 2011). Over the last thirty years, sensor-based irrigation solutions have been widely studied in many agricultural contexts, from orchard to ornamental plants (Stone et al. 1985, Jacobson et al.

1989, Zazueta and Smajstrla 1992, Meron et al. 1995, Wyland et al. 1996, Testezlaf et al. 1997, Abreu and Pereira 2002, Kim et al. 2008, 2009). More recently, thanks to the development of informatics and telecommunication technologies, a number of studies focused on soil water status monitoring based on wireless sensor networks (WSNs) were developed (Oksanen et al., 2004; Zhang, 2004). In terms of automatic control of irrigation system components, Miranda et al. (2003), Coates et al. (2006a), Mendoza-Jasso et al. (2005) and Coates et al. (2006b), developed site specific applications in which soil water status information were used for governing the electrovalves of the irrigation system.

The continuous monitoring of soil and/or plant water status gives the possibility to determine “when” and “how much” to irrigate preventing crop water stress and improving crop yield (Doraiswamy et al. 2004, Coates et al. 2005). In particular, soil water potential (SWP) represents a basic soil variable, crucial when plant water use is considered. Since plant water uptake responds to soil water potential, rather than to the volumetric water content, it is reasonable to assert that SWP is the key monitoring variable for supporting the irrigation scheduling (Fisher and Gould 2012; Thompson et al. 2007a). The traditional device for measuring SWP is the hydraulic tensiometer. Tensiometers allow the direct measurement of SWP, have a medium-low cost and may not need power supply, but they require a complicated maintenance, have a slow response to changes in soil water content and are subject to cavitation below -80/-100 kPa. Granular matrix sensors, which measure the electrical resistance within a porous medium where the water matric potential is at equilibrium with the surrounding soil (Campbell and Gee 1986), represent an alternative to hydraulic tensiometers. In this case, SWP is derived from the measured electrical resistance through suitably calibrated conversion functions (Scanlon et al., 2002). Granular matrix sensors are less accurate than tensiometers, but their robustness and reliability justify the wide operational use by farmers in many areas (see, e.g., Centeno et al. 2010; Loiskandl et al. 1999; Shock and Feibert 2002) and their adoption in WSN applications (Vellidis et al. 2008).

The main objective of this paper is to illustrate Irrig-OH, an open source Arduino platform equipped with low-cost sensors for monitoring SWP and soil temperature, and to show the potential of this simple and robust technology to support irrigation scheduling. In addition to describing the Arduino-based microcontroller platform and its principal components and sensors, the paper presents the results of a case study on a peach orchard where Irrig-OH was used to support irrigation scheduling in order to increase the water use efficiency.

2 Device and software characteristics

2.1 Hardware

The Irrig-OH soil water potential monitoring device is designed around the Arduino platform (Fig. 1), following previous experiences reported by several Authors who assembled open hardware and low cost instrumentations for precision agriculture applications, such as Fisher and Gould (2012), Fisher and Kebede (2010), Toller et al. (2012). Thalheimer (2013) and Bacci et al. (2007).

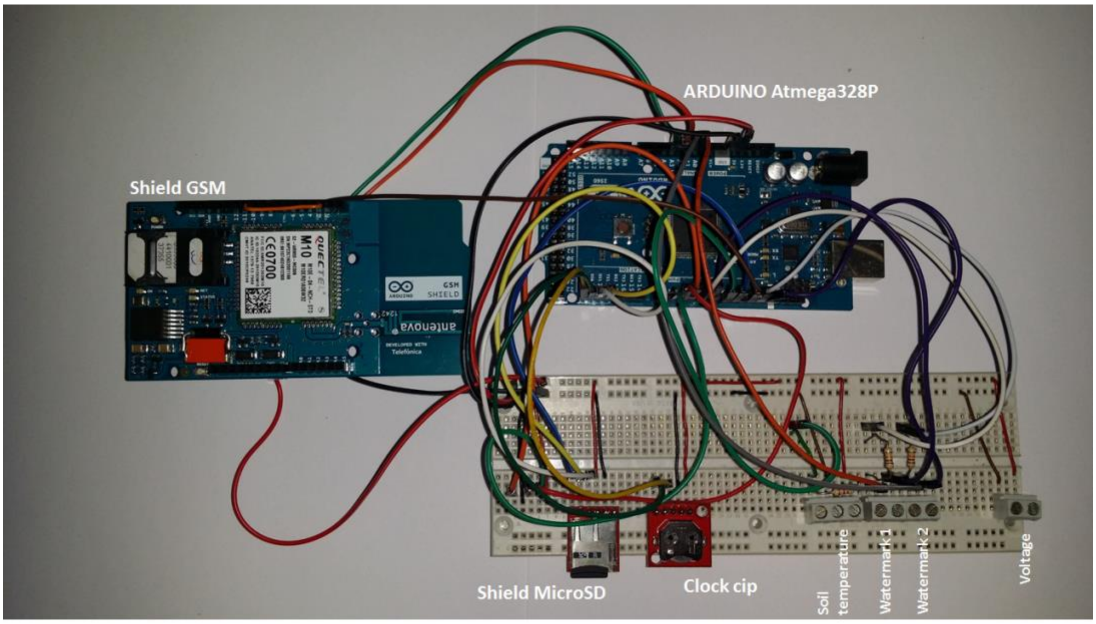

Fig. 1. Irrig-OH hardware platform. In the picture, each shield component is separately shown using the prototype board for cable connection, while in the field prototype each shield is overlapped to each other through mating pin connections.

Arduino is a microcontroller located on a small printed circuit board (PCB) which is fitted with sockets to allow easy connection of external devices to digital and analog input and output (I/O) pins. This particular hardware package stems from the dedicated integrated development environment (IDE), running on a personal computer (PC) under Windows, Mac OS X or Linux, which was designed for the non-expert programmer and integrates and significantly simplifies the different steps of editing, compiling, and uploading software to the microcontroller. Arduino can be connected to a separate PCB or a breadboard equipped with interface circuitry to adapt the signals to different components of an experimental system, and thus gain control and monitor abilities (Koenka et al. 2014).

In the case of our station, the microcontroller is based on an Atmega328P 8-bit (Atmel Corporation, San Jose, CA USA) and the communication with the external components, like sensors, is performed by a standardized protocols I2C developed by Philips Semiconductors. The board itself is not design to store data. It has a small memory to store a program that enables it to interact with the sensors. A specific board is designed to add external memory. Thus, the measured data are stored locally in an external MicroSD card of 2 GB opportunely located on a MicroSD shield (Sparkfun Eletronics, Boulder, CO USA) also equipped with a DS1307 real time clock/calendar chip to make sensor readings at regular time intervals. The prototype is powered by a 5W solar panel which recharge in continuous a battery of 12V.

The Arduino GSM Shield, equipped with a radio modem M10 by Quectel, supports the GSM data transmission. The internet communication is via http interface with a protocol TCP/IP. The communications to the project backend are designed to use JSon over a RestFull service. This communication pattern is a *de-facto* standard in mobile and IT world (Koenka et al. 2014). This solution allows to develop a single backend able to communicate with the acquisition board. The adoption of Json format to send data and eventually retrieve data, minimizes the amount of data transferred by GSM, but it offers clear and standard format.

The versatility of the Arduino platform permits to connect it with a variety of sensor typologies (both passive and active), provided that they have an operating electrical range from 0 to 5V. In the prototype version of the microstation three sensors were installed: two granular matrix sensors measuring the SWP, and one temperature sensor. Data stored in the card include the raw data (electrical resistance output signal) measured by the granular matrix sensors and the soil temperature measured by the temperature sensor.

The frequency of data acquisition can be set by the programmer on the basis of the final user needs. High frequency SWP measurements are usually necessary to capture the dynamics of soil water conditions, especially when irrigation or precipitation events take place and, as a consequence, the soil water status changes rapidly. In the microstation prototype, sensor measurements were recorded every 5 minutes on the MicroSD card, and successively sent via internet to a Web server database which can be freely interfaced with the farmer’s mobile devices.

During the field experimentation of the prototype, three steps had been taken to verify the good functioning of the device and to reach its final configuration (Fig. 2). In Step 1, the microstation was only composed by the Arduino board and the MicroSD shield. Data were stored in the MicroSD card and downloaded manually on a PC. From the PC, the recorded data were sent via internet to the Web server. In Steps 2 ad 3, data recorded in the field were stored in the MicroSD card and automatically sent via internet to the Web server through a GSM module (Step 2). In these cases, the double data storage on MicroSD and on the Web server shall be considered as a safety procedure to protect data against possible loss. In Step 3, the Web page was set up with the aim to provide the irrigation advice to end users reaching them through mobile devices as phone, tablet and portable PC (Fig. 3).

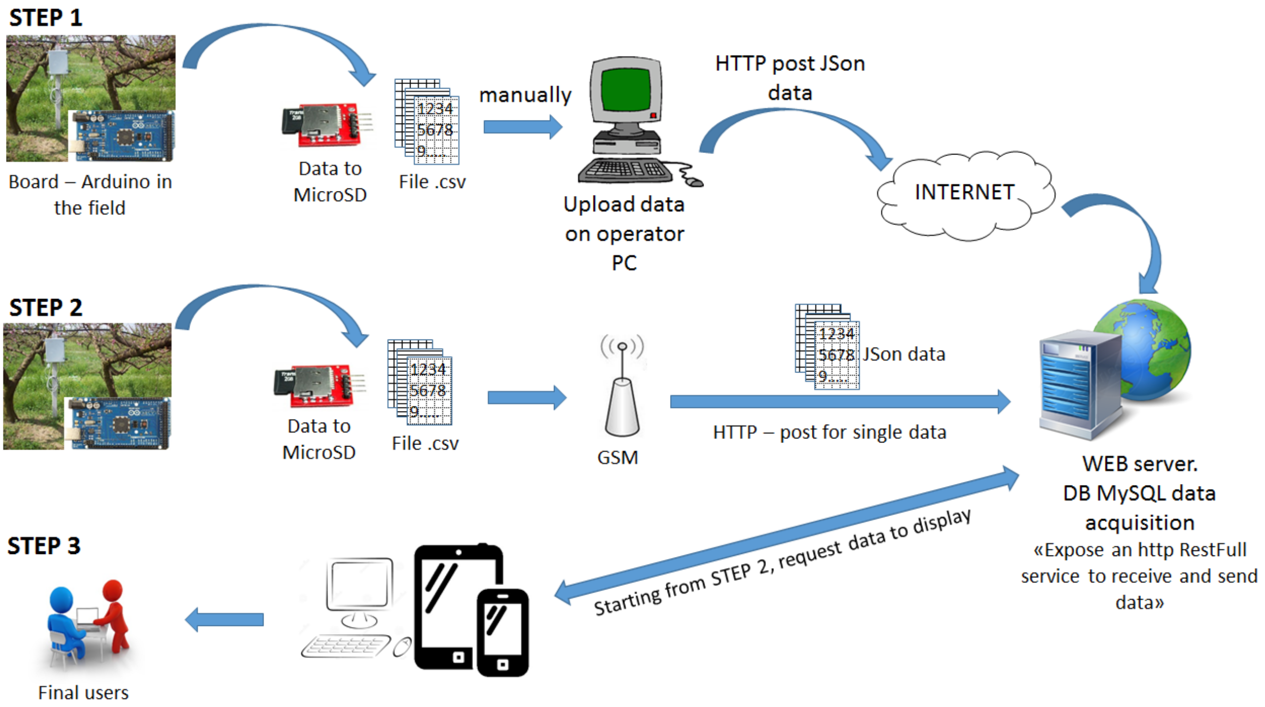

Fig. 2. Information flux diagram, from the field to the end user’s mobile devices

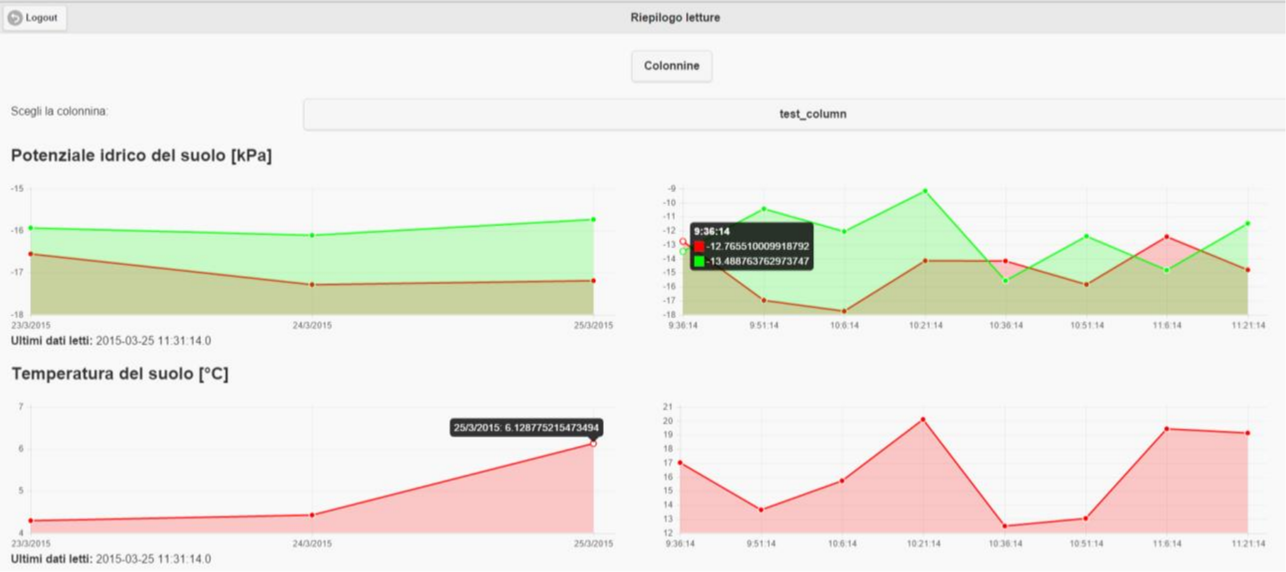

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Fig. 3. Examples of the Web page configuration. In the left, maximum daily SWP at the two depths in the soil and temperature are shown. In the right, the same data relative to the last two hours (with a time step of fifteen minutes) of a specific day are illustrated

2.2 Software program

Using the Arduino IDE installed on a personal computer, a microcontroller program is written to read the real time clock, acquire the measurements of the sensors with a given frequency, and store the time series of measurements onto a MicroSD card. The software is written in the Wiring language based on C and C++ codes (http://wiring.org.co). The software code for this microstation is shown in Appendix 1 and 2, or it is freely available from the Authors on request. The code consists of a simple clock and calendar schedule based on the clock time counter. The program carries out sensor readings at regular time intervals (5 minutes in our case) but it can be set to different values modifying the setup declaration variables. To optimize memory use, the A/D readings of the sensors are reduced from their original 10 bit to 8 bit resolution before storage. The data transfer function of the program retrieves the resistance data from the SWP sensors and transforms the original A/D values to pressure units (kPa) on the basis of the typical calibration function provided by the manufacturer (see par. 2.4). For setting time, date and logging interval, as well as for retrieving or erasing data from the memory, a simple menu can be accessed via a serial connection with a PC. This menu also offers the options of reading actual sensor values and the current software settings at any given time.

A forthcoming modification of the software will offer the option of setting the threshold values directly from the user interface (on mobile, tablet or PC) without the intervention of a programmer to modify the microstation code.

2.3 Sensors

The prototype version of Irrig-OH includes two types of sensors connected to the Atmega board: Watermark sensor 200SS and Dallas Semiconductor DS18B20 respectively for SWP and soil temperature measurements. The Watermark 200SS is a granular matrix sensor with internal electrodes measuring the electrical resistance (R) of the porous cup reference material (Irrometer 2010). The sensor consists of stainless steel electrodes imbedded in a defined and consistent internal granular matrix material that acts like a soil in the way it moves water. The electrical resistance of the matrix material, which is in equilibrium with that of the surrounding soil, is measured and then used to estimate the

SWP value through a suitable calibration function. Due to its low cost, the Watermark sensor can be included in the range of products that can be used both for research and for practical applications (Thompson et al. 2006, 2007b, Centeno et al. 2010; Loiskandl et al. 1999; Shock and Feibert 2002), although its accuracy is not comparable to the more sophisticated soil moisture sensors based on time domain or frequency domain reflectometry technologies (Terzis et al. 2010). The sensor has an average lifetime of about 5 years and once placed in the soil it does not require specific maintenance. The sensor can provide estimates of SWP over a wide range of tensions, namely from approximately 0 to -240 kPa (Centeno et al. 2010). It operates at low voltages (5V), but requires alternating-current excitation (AC) rather than direct one to avoid polarization of the metallic components (Fisher and Gould 2012). The procedure to create the AC current is implemented in the software program (see Appendix 1), and consists in the inversion of polarity on the pins to which the SWP sensors are connected to. Soil temperature values are measured by the DS18B20 sensor. Its operating temperature range is between -55°C and +125°C, and the accuracy over the range -10°C to +85°C is ±0.5°C. The DS18B20 derives power directly from the data line ("parasite power"), eliminating the need for an external power supply. Its applications include HVAC environmental controls, temperature monitoring systems inside and outside buildings, equipment or machinery, process monitoring and control systems.

2.4 Data processing and real time irrigation advice

The formulation of the irrigation advice is carried out by a software application, running either on PC or on mobile devices, that processes the real-time sensors measurement. First of all electrical resistance output signals need to be elaborated to derive SWP estimates. This is achieved by using suitable calibration functions. In the last decades several authors have developed different calibration curves for the Watermak 200SS sensor (Eldredge et al. 1993, Intrigliolo and Castel 2004, Leib et al. 2003, Thomson et al., 1996, Shock et al. 1998). Allen (2000) stated that a combination of three different functions, each one valid within a specific range of output electrical resistances ($R \leq 1\ Ohm$; $1\ Ohm < R < 8\ Ohm$; $R \geq 8\ Ohm$, respectively) produces the best solution, providing reliable SWP estimates up to values of -200 kPa (Nolz et al. 2014). Since the sensor performance varies slightly with temperature (T), a temperature-correction factor is included in the calibration equations. The Eq. 1 shows the calibration curve applied to convert electrical signals into SWP values.

$$\begin{cases} SWP(kPa) = -20 \cdot \{R \cdot [1 + 0.018 \cdot (T - 24)] - 0.55\} & for\ \ R \leq 1\ Ohm \\ SWP(kPa) = \dfrac{(-3.213 \cdot R - 4.093)}{(1 - 0.009733 \cdot R - 0.01205 \cdot T)} & for\ 1\ Ohm < R < 8\, Ohm \\ SWP(kPa) = -2.246 - 5.239 \cdot R \cdot [1 + 0.018 \cdot (T - 24)] - 0.06756 \cdot R \cdot 1 + [0.018 \cdot (T - 24)]^2 & for\ \ R \geq 8\ Ohm \end{cases} \qquad \text{(Eq.1)}$$

Critical to the use of SWP estimates for irrigation scheduling is the definition of a SWP threshold, possibly variable with the crop development stage, below which crop may suffer of water stress and growth limitations. Unfortunately, published scientific and technical studies on the definition of SWP thresholds for different crops are quite limited and often contradictory (e.g., Thompson et al. 2007b, Medici et al. 2014), thus, more research are needed in this field.

Once the threshold is set, the irrigation advice is given to the farmer following a simple criterion based on the comparison of the current SWP measurement with the SWP threshold for the specific crop phenological phase, as well as with the SWP value at the field capacity. In particular, irrigation has to be start as soon as the current depth-averaged

SWP value drops below the threshold value, and it has to be stopped when the irrigation volume applied have restored the field capacity conditions, i.e. when the depth-averaged SWP reaches the field capacity value. This standard criterion could be modified by the programmer if local conditions and practices suggest that different strategies are more effective.

2.5 Economic cost of the components

Tab. 1 summarizes the approximate commercial cost of the main components used to build the Irrig-OH prototype. Costs indicated in the table refer to the purchase of the single components, consequently lower costs can be expected in the event of the purchase of larger quantities. The table shows that a SWP station with real time data storage and GSM transmission on fttp web can be assembled at a cost of about 170 Euro. Almost 50% of the total cost of the station is due to the data transmission modulus; the next most expensive components are Watermark sensors and the microcontroller, which require 12% of the total cost each. The cost of the Web server is about 15 euro/year, but the price can be extremely variable in function of providers.

Tab. 1. List of main materials included in the microstation and their cost

Main components	Part number	Supplier	Cost* (Euro)
Microcontroller	Arduino UNO (Atmega328)	Sparkfun Eletronics	20
Real time modulus	DS1307	Robot Italy	10
MicroSD 2GB	TS2GUSD	Monclick srl	3
Arduino GSM shield	TSGGSM_900	Robot Italy	80
MicroSD shield	DEV-09802	Sparkfun Eletronics	10
5W/12V solar panel	MM005-12/1	3LCO	10
12V/6Ah sealed lead acid battery	-	EL.MA.M	10
1 Waterproof temperature sensor	DS18B20	Emmeshop srl	7
1 Watermark sensor	200SS	Challenge Agriculture	20
TOTAL			**170**

*** The cost of SIM card and telephone tariff plan is excluded**

3 The case study

3.1 Materials and methods

In order to test the operational use of the Irrig-OH microstation prototype in the field, an experiment was carried out during the agricultural season 2014 at the Dotti farm of Montanaso Lombardo (Lodi, Italy) (45°20'21''N, 9°27'05''E, elevation 83 m s. l.), with the purpose of comparing the farmer's traditional management of irrigation in a peach orchard, and the scheduling based on the SWP measurements provided by the microstation. The Dotti farm is a research facility of the University of Milan, covering an area of 9.2 hectares subdivided into five fields (Fig. 4). The farm is served by a pressurized irrigation system fed by an electrical pump of 5.5 kW (flow rate discharge 15-33 m^3 h^{-1}, maximum water head 51-40 m). Water supply is provided by an irrigation canal (the Muzza canal), flowing South–East of the farm, and it is conveyed by a pipe in a cement tank having a storage capacity of 1000 m^3. Fields are irrigated by means of drip or microsprinkler lines, each of which can be opened or closed by a regulation valve installed at the beginning of the line. Farm irrigation scheduling is time-based and automatically managed by a programming system controlling the pump to cover daily all the parcels, allocating about 2 hours of irrigation for each field. However, the pump can be manually activated and the irrigation can be delivered at any time to any desired field. This is useful especially during and after rainfall events, when the soil moisture is high and fields do not need irrigation.

The experiment was laid out in the Ronchetto field, in two rows of peach trees of the Spring Crest cultivar planted in year 2001 (grafted onto GF677 rootstock), with a plant layout of 6 m x 2 m and a grassy aisle. Rows are constituted by 33 trees irrigated by means of microsprinkler lines having 32 emitters (about 2 m apart from each other) providing 40 l h^{-1} at 2 atm pressure. Emitters are located at 1 m from each tree (Fig. 5A and B). The surface watered by each microsprinkler has a radius of about 3 m. Results of the soil textural analysis carried out for samples collected in different points of the two rows at the two monitoring depths are shown in Fig. 6 (Soil Taxonomy 11th, 2011). Soil texture is sandy-loam, and the field capacity SWP value was consequently estimated to be about -10kPa.

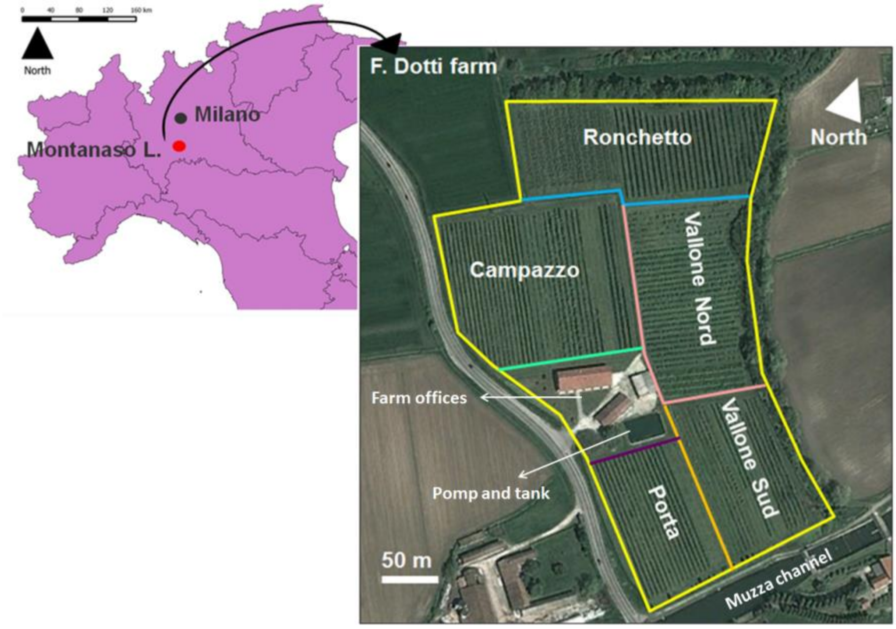

Fig. 4. F. Dotti farm and position of the different fields

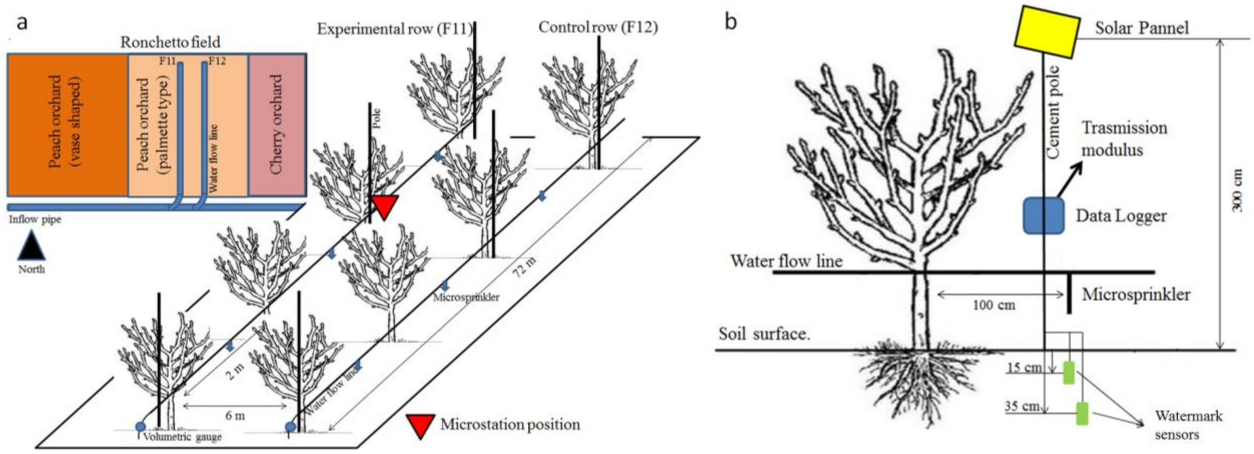

Fig. 5. a. Ronchetto peach orchard. b. Irrig-OH microstation and Watermark 200SS sensors position

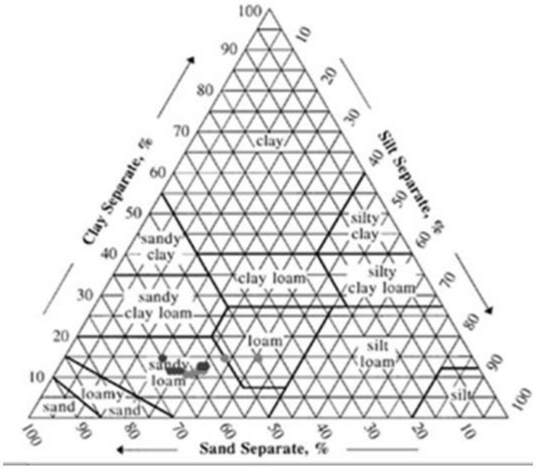

Fig. 6. USDA texture triangle and results of the laboratory analysis for the experimental site

The experimental activity was carried out from March 29th to June 18th 2014. During this period, one row (hereafter called Experimental row or F11) was irrigated on the basis of SWP measurements (acquired in real time by the Irrig-OH microstation), opening manually the F11 gate valve only when the SWP threshold was exceeded and successively closing it when the field capacity was restored. The second row (hereafter called Control row or F12) was irrigated according to the normal practice adopted by the farmer.

Standard meteorological variables (rainfall, global radiation, air temperature and humidity, wind speed and direction), were measured at daily intervals over a grass coverage located at about 100 m from the experimental field, by an agro-meteorological station managed by CRA (Italian Council for the Research and Experimentation in Agriculture).

Two Watermark 200SS sensors were installed at a depth of 15 and 35 cm in the middle of the F11 row, to avoid the influence of field boundaries, as suggested by Abrisqueta et al. (2012) and Fisher and Kebede (2010). The SWP measured by the upper sensor was also influenced by the evapotranspiration of the herbaceous surface under the peach trees, while the lower sensor was located at a depth above which the 60% of the crop roots volume is expected to be included, according to Layne and Bassi (2008). Following Thompson et al. (2007b), sensors were placed about 15 cm perpendicular to the microspinkler line and halfway (50 cm) between the microsprinkler line and the plant’s trunk. At 25 cm of depth, between the two SWP sensors, the DS18B20 temperature sensor was installed to monitor the soil temperature.

For the irrigation scheduling of F11, three different SWP thresholds were adopted (-20, -25 and -30 kPa) according to different phenological phases, as suggested by Medici et al. (2014) and Layne and Bassi (2008). In particular, from flowering period to the end of cellular division, the SWP threshold was set to -20 kPa to provide an adequate water supply to this delicate phase. Similarly, in the last part of the growing season (maturation), the SWP threshold was set to -25 kPa, given that fruits have to increase their diameter up to the harvesting time. The pit hardening is the phase where the water requirement is lower, so that the SWP threshold was set to -30 kPa.

When the average of the SWP values at the two measuring depths reached the threshold, an irrigation application was started and continued until the average SWP reached the value of -10 kPa, corresponding to the field capacity. This took between 2 and 3 hours to occur.

The actual water consumption for the F11 and F12 rows was measured through two volumetric gauges (Irrigazione srl, MI, Italy) installed at the head of each irrigation line beyond the gate of the valve. For each irrigation event, initial and final volumes, as well as the duration, were recorded.

To assess the peaches development, at the thinning shoot and at the harvested phenological phases 130 fruits for each row were randomly picked from the trees and successively measured for determining weight and dimension. Weight was measured by a precision balance (accuracy +/- 0.1 g), while the size was evaluated measuring the three diameters (horizontal, vertical, and lateral) using a caliper (accuracy +/- 0.01 mm). For the two growing stages, fruit weight and size distributions were analyzed. Moreover, after the thinning shoot (from May 9th to the harvesting time) the horizontal diameter of 12 selected fruits (6 fruits for each row belonging to 3 different trees) were monitored to estimate the fruit growth curve. At the harvesting time, the sugar content of 40 fruits for F11 and F12 was measured by a refractometer (RHS-10ATC Sinotech, USA) to evaluate the peach production quality.

3.2 Experimental results

3.2.1 Irrig-OH performances

During the whole experimental campaign, all the data were collected without interruptions (100% of data stored). All hardware components responded reliably to the software commands. The power of the battery (and the solar panel recharge capability) was adequate to guarantee the acquisition also during the night. Sensors did not need any maintenance. Only one preventive measure was adopted during the Irrig-OH microstation installation: all cables were inserted in PVC corrugated flexible tubes to avoid that animals like rabbits, hares or mice can damage them.

3.2.2 Irrigation scheduling and water consumption

During the experiment SWP values for both sensors never went below -35 kPa. The lowest value, observed for the -15 cm sensor on the 25th of May, occurred after more than two weeks without rainfall and with a high atmosphere evaporative demand (vapour pressure deficit as low as 1.5 kPa). The main rainfall events occurred at the end of April and few days before the harvesting time, for a total amount of rain of about 300 mm from the end of March to the end of June. The mean soil temperature during the entire experimental campaign was about 19 °C. As shown in Fig. 7a, the Watermark sensor at -15 cm responded faster than the sensor at -35 cm to rainfall events or irrigation applications, as expected. From the Fig. 7a and b, the water depletion curve in the soil is linear but slightly different at the two depths, with a mean slope of about 1.11 kPa day^{-1} for the sensor at -15 cm, and 0.56 kPa day^{-1} for the sensor at -35 cm. The different behavior is probably due to the different soil water uptake, which at -15 cm is governed at the same time by soil evaporation, grass root suction and peach root suction, while at -35 cm it depends only by peach root suction.

For the experimental row F11, three irrigations were applied in the middle of April and two during the last days of May, for a total water volume of 13.3 m^3. In the control row F12 24.9 m^3 of water were supplied in eleven irrigation applications (Fig. 7b). Up to endocarp hardening phase (begin of May) the soil was kept well watered fixing the SWP at -20 kPa. During the pit hardening period (about the entire month of May), only one irrigation was performed to restore the SWP (which reached the peak of -30 kPa) at the field capacity. From the end of May to harvesting time (maturation process) another irrigation was performed to guarantee a SWP higher than the threshold (-25 kPa). For both rows, irrigation was interrupted about eight days before the harvesting time and, due to the rainy weather conditions that characterized the summer 2014 (23 rainy days in July), irrigation was never performed during the post-harvest period.

When the water use for irrigation over the whole agricultural season is considered, water saving in F11 with respect to F12 was found to be almost 50%.

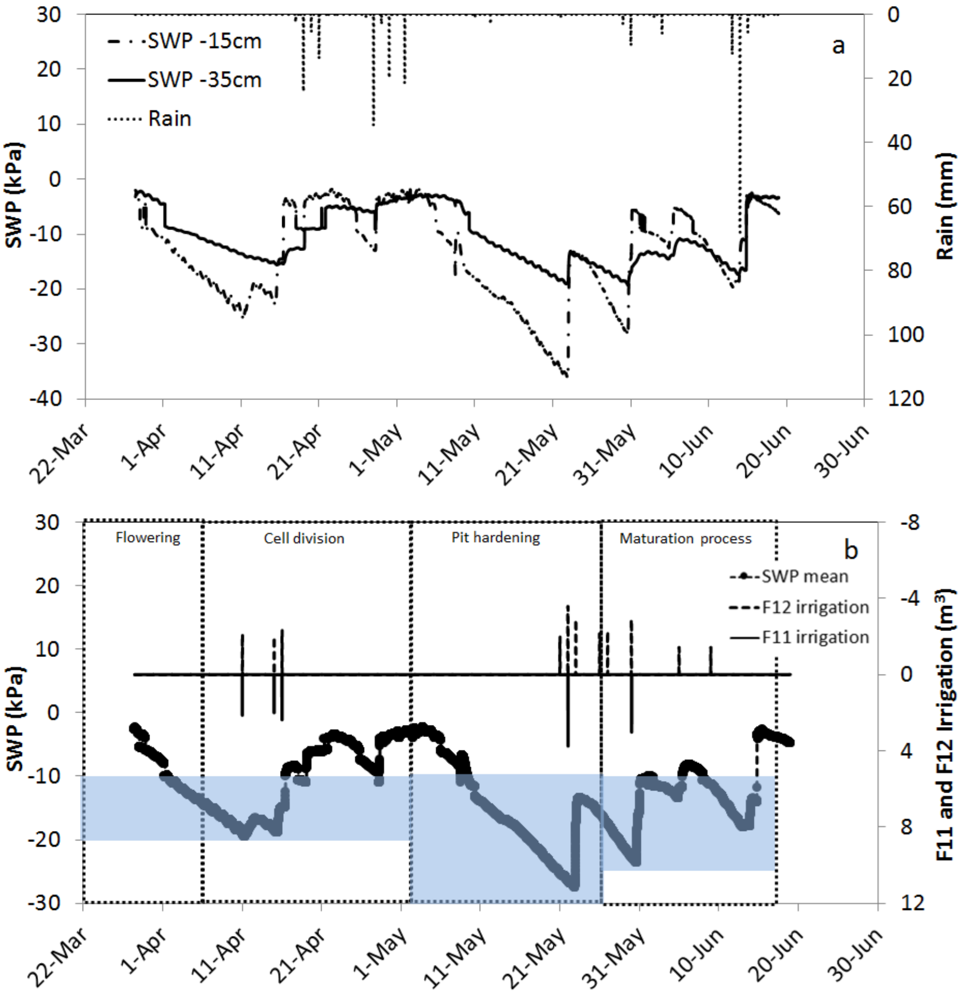

Fig. 7. a. SWP monitored at -15 and -35 cm and rainfall. b. Average SWP, SWP thresholds and irrigation volumes. vertical lines indicates the duration of the phenological stages, while the blue strips the range of SWP (minimum and maximum values) allowed for each stage

3.2.3 Crop yield and water use efficiency

In Fig. 8, the monitored fruit diameters from the post thinning shoot period to the harvest are shown. Mean values (squares and triangles in Fig. 8) and standard deviations of diameters of the six fruits for each row were computed. For each of the two data series and for each monitoring date, mean ± standard deviation values were subsequently calculated. In Fig. 8 the minimum and the maximum of the two mean ± standard deviation values are illustrated (dotted line in Fig. 8), showing the low variability in peach diameters for each of the two data series and between the two data series. In Fig. 8, the irrigation events are also reported in order to allow the evaluation of their potential effect on the delay in phenological development. In spite that four additional irrigations occurred in F12 from 21 May to 9 June with respect to F11, no appreciable change in fruit diameter was observed.

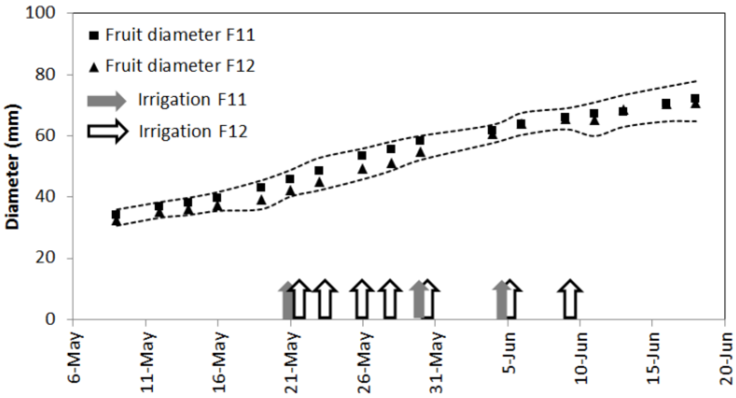

Fig. 8. Mean and standard deviation peach diameter evolution during the experimental campaign, from the thinning shoot period to the harvest. Irrigation events for both the irrigation treatments are also shown

In Tab. 2, the main statistical information related to the monitored fruits are summarised. From the thinning shoot to harvesting time the fruit diameter grew about 2.5 times and the weight more than 14 times. Both in terms of diameter and weight, fruits in each row were very similar among them (as demonstrated by the low coefficient of variation, CV, ranging from 0.06 to 0.26), and also between the two rows (as shown by the similar mean and standard deviation values for the two irrigation treatments). Measured sugar content was about 10%, with slightly greater values in F11 than F12.

Tab. 2. Statistical information for samples of peach fruits collected from F11 and F12 in two periods of the experimental campaign (thinning shoot and harvesting time)

	Thinning shoot				**Harvesting time**					
	Weight (g)		**Diameter (mm)**		**Weight (g)**		**Diameter (mm)**		**Sucrose content (%)**	
	F11	*F12*	*F11*	*F12*	*F11*	*F12*	*F11*	*F12*	*F11*	*F12*
Min	2.85	5.28	17.03	20.77	93.50	103.80	53.30	53.30	7.00	6.40
Max	22.00	17.46	34.93	32.45	287.90	282.40	75.00	77.00	14.20	15.00
Mean	11.85	10.30	27.73	26.27	152.67	161.56	63.05	63.48	11.23	9.88
St.Dev.	3.07	2.37	2.58	2.16	31.79	33.04	3.96	3.95	1.83	1.86
CV (-)	0.26	0.23	0.09	0.08	0.21	0.20	0.06	0.06	0.16	0.19

In 2014, Spring Crest peach yield for the two rows was 1268 kg for F11 and 1231 kg for F12. The WUE (water use efficiency) calculated dividing the peach yields by the irrigation volumes used in this study, was 95.6 kg m^{-3} for F11 and 49.4 kg m^{-3} for F12.

4. Conclusion

Open – hardware environments (such as Arduino or Raspberry) give the possibility to implement *ad hoc* stand-alone platforms and microcontrollers for environmental monitoring, directly interfaceable with a lot of commercial sensors, using electrical schemes and freely downloadable informatics libraries. Obviously, this flexibility is paid for with the need to have skills and understanding in these new technologies, and thus the end-user must necessarily rely on enterprises able to develop equipment designed to meet his needs. On the other hand, the development of *ad hoc* solutions of this type would undoubtedly constitute a new work sector for small business enterprises of computer and electronics experts and, simultaneously, lower the investment costs for technical solutions paid by the end users.

In this sense, the added value of Irrig-OH with respect to other similar prototypes reported in the literature, is not specifically related to the design, the development and the application of the microstation, but to the idea of making the hardware project and the software design freely available to all the interested people, in order to facilitate and expand the adoption of these technologies.

The rapid rise of internet use and the accessibility to computer resources led to the concept of "open source software" as a means to provide free and transparent access to computer codes so that individuals could review, modify, and improve them, as well as distribute their works. The Irrig-OH microstation is based on open software and open hardware technologies and it is aimed at improving the irrigation management at the farm level, supporting the irrigation scheduling optimization through the continuous monitoring of the soil water potential (SWP) in the root zone. The objective is to offer to farmers a simple and cheap way to obtain the essential information on when and how much to irrigate, using low-cost sensors and technologies that can be easily interfaced with mobile applications. The core of the device is an electronic prototyping platform that controls data acquisition, storage and transmission. The acquired data are then processed by a software application, running either on PC or mobile devices, that provides the irrigation advice. This advice may be used by the farmer to activate manually or automatically the irrigation valves.

Irrig-OH prototype was tested in 2014 on a peach orchard (Spring Crest) in northern Italy, where two rows of 33 trees were irrigated differently: the first one according to the irrigation advice provided by the device, the second on the basis of the irrigation schedule usually adopted by the farmer. Results showed a water saving of nearly 50% using the Irrig-OH device, without consequences on the quantity and quality of the production. These first results indicate that the use of the open-hardware platform with simple and robust sensors may provide a reliable and effective support to irrigation scheduling at very low cost (i.e., about 170 euro).

The prototype illustrated in this paper, due to its modularity and scalability, may be easily expanded and exploited for different purposes. For example, additional sensors may be added to the device, measuring for instance the crop temperature to monitor the crop water status, or soil solution parameters to provide useful information for the fertigation scheduling. Moreover, the limited cost opens wider opportunities to implement extensive networks of soil water status sensors and to use them for different purposes, including the drought alert and management, or also the prevention and management of hydrogeological risks.

Acknowledgements

The research was carried out in the contest of the RISPArMiA project, funded by the Fondazione Italiana Accenture and the Fondazione Collegio Università Milanesi, which are kindly acknowledged.

Furthermore, we wish to thank E. Quattrini, A. Arioli, L. Nazzari, D. Zanoni, M. Todaro, I. Spairani, A. Moreno for their invaluable technical support during the field experiment, and Prof. D. Bassi and Prof. O. Failla for their comments and suggestions on physiological aspects of the peach crop. Lastly, we wish to acknowledge Prof. L.O. Medici of the Departamento de Ciencias Fisiologicas of the Universidade Federal Rural do Rio de Janeiro (Brasil) and M. Thalheimer of the Research Center for Agriculture and Forestry of Laimburg (BZ, Italy), for their personal communications on irrigation SWP thresholds and suggestions on the Arduino platform.

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