A Low cost automatic weather station developed at school, opportunity for students to meet the job world

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Abstract

This work fits some issues of climate change awareness, experimentation of low cost technologies in environmental monitoring and maker movement. The intensification of extreme events and disasters due to climate change has lots of different impacts in agriculture, industry, and human activities. Heat waves, desertification, deforestation, sea level rise, loss and damage, world water system crisis are key aspects. Adaptation strategies must start from the knowledge and the availability of additional information. Crowdsourcing of weather data offers a way for the augmentation and densification of real time collected data. The diffusion of a large number of sensors can be possible through the use of low cost sensors and technologies.

For these reasons a project has been started for the implementation of a very low cost weather station for measuring atmospheric parameters. The project has been fully developed in a high school by students under the supervision of teachers, experts, involving potential stakeholders interested in the use in agriculture. Some traditional sensors, tipping bucket raingauges, magnetic reed devices anemometers, capacitive/resistive thermohygrometers, and an innovative impact piezo-element raingauge have been adapted to the development of the weather station. An Arduino-based control system has been implemented. The fully automatic equipment sends real time data using wi-fi. A remote system collects data from different independent measuring points.

Keywords: education, weather, agriculture

1. Introduction

Information Technology (IT) is a driving factor in the process of globalization, as it drives the innovative use of resources to promote new products and ideas across nations and cultures, regardless of geographic location. The spread of IT and its applications has been extraordinarily rapid. Just 30 years ago, for example, the use of desktop personal computers was still limited to a fairly small number of technologically advanced people. Today all the aspects of life in the industrial societies are based on information technology that consequently has entered decisively in the educational chain, to adapt society to this sudden and continuous evolution.

The introduction in the educational processes of cheap and easy microcontrollers and microprocessor boards resulted in net changes both in the teaching methods and learning efficiency in high school. Some studies have shown that the open hardware microcontroller boards can enhance the integration of new teaching methodologies with traditional ones, with very satisfactory results in terms of learning levels attained [1]. These electronic boards present several advantages for the development of projects, as they are very easy to use board and, thanks to its open-source nature, a vast user community who share their ideas, projects and solutions supports them. In this way the contents of the laboratory sessions are directly related to the lecture demonstrations, especially if lecture demonstrations show physical examples of computational concepts and create a desire to learn more about the inner workings of the system shown. We experienced that taking advantage of this interest, very often students perform similar activities during the laboratory sessions. This method reduces the level of abstraction, while maintaining a high level of theoretical knowledge. As a consequence it is suitable for enhancing the school-job integration process

as additional tool to the proven job alternation method.
Open hardware technologies have a positive impact on all sectors of the economy, primary, secondary and tertiary, including the agriculture applications. For example in recent years some technological progress have been created a new generation of agriculture based on a fully protected and automated environment to be used for food production, using technologies to optimize climate control, irrigation and other growing processes. These technologies have several names: food computer, Control Environment Agriculture (CEA) [3].
Although the CEA is a pioneering limit, most farms are pursuing technology-based pathways aimed at improving the reliability of production processes. The process of maximizing production takes place through the full control of all the variations of the environmental parameters and ensuring intervention in situations influencing the final products. Atmospheric monitoring is the main instrument used for environmental control in the farm. Climate-smart agriculture fits in the use of technology in agriculture, as it proposes the introduction in the farms of weather stations networks for resources and outputs optimization. The accuracy of instruments used in agricultural applications is not comparable to that of trust networks, as very high precision measurements are not required for agricultural applications, but there is a tendency to an increment of their measurement accuracy. Despite the use of low cost sensors and technologies, several works showed that by appropriately developing the systems, "homemade" instruments could have an equivalent efficiency as compared to commercial devices [4]. The development of low cost technologies and sensors with measurement accuracies is suitable for several applications as agriculture, weather monitoring, hydrological risk prevention, urban hydrology, etc. For this reason several scientific and technological project are very often oriented to study new solutions for the development of low cost instruments and compare the resulting measurements with standard results [15], [16].
The present work describes a project that addresses all these aspects, spanning from the experimentation of innovative educational methods in an Italian high school (the B. Cellini institute of Florence), and the scientific community to the world of smart-industries and precision agriculture.
Based on these considerations a project has been started for the implementation of a very low cost weather station able to merge traditional and innovative sensors for measuring atmospheric parameters. All the phases of the project: initiation, planning, implementation has been conducted in the high school by directly involving the students under the supervision of teachers. Some experts have been also involved in the field of weather observation and sensors development together with potential stakeholders interested in the use of weather stations in agriculture. The project perfectly fits the maker movement philosophy as the way to joint DIY with educational purposes with the goal of getting into the workplace.

2. Project description

The main objective of the project was to develop a low cost weather station to be used in farms for weather monitoring in crop grow control, viniculture, pest prevention for olives and other agriculture applications. Additional applications are in urban environments and in the integration with existing trust networks for better characterization of weather phenomena on very limited space and time scale scales, where major problems of extreme weather phenomena occurs.
There are two main types of weather stations influencing the design choices: the wired weather stations, in which the sensors and instruments are wiry connected for data transfer, that allow a high reliability in the performances, and avoid loss of data; the wireless weather stations are more easy to install but must be carefully designed for decrease the malfunction risk due to loss of connection. They certainly offer the advantage of excellent versatility to be used in difficult installation conditions, and the possibility to displace the sensors in different points, for a better customization of the environmental monitoring. For this reason, the chosen solution was that of wifi sensors, suitable for the development of a system compatible with technology of Sensor Web Enablement (SWE) and Internet of Things (IoT) recently emerged and very quickly developed, directly towards the introduction of regulatory standards and the progress to low-cost technologies. These technologies are becoming an integral part of the agriculture world and can be useful in areas where the food procurement is difficult.
In order to optimize a system using low-cost sensors, we conducted a small market analysis to look for the most used cost-effective sensors, with acceptable performances. The results of this market analysis, also confirmed by a series of published works suggested to use a widely diffuse set of sensors, the WS-1080 system [5]. This system is a stand alone system, it constitutes of an outdoor unit mounting a wind speed sensors, wind direction sensor, a tipping bucket raingauge and a thermohygrometer all managed by a central processing system that collect and transmit data at radiofrequencies to the indoor visualization panel. In the present project only the weather sensors have been selected from the SW-1080 system. A microcontroller board, for an easy prototyping and for educational purposes, has substituted the control and processing system. Both Arduino and Raspberry Pi are widely used for students education purposes in technology, programming, sensors connections. Arduino is a versatile microcontroller board suitable for developing a weather station control system [6]. It is an open-source platform used for computing based on a simple micro-controller board, and a development environment for writing software for the board. It can be used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical

outputs. Systems based on Arduino can be stand-alone, or can communicate with other apparatus through a series of additional boards and cards. The boards can be assembled by hand or purchased pre-assembled; the open-source IDE can be downloaded for free.
A careful analysis of the sensors characteristics is preparatory for the correct design of the sensor signal interface [7],[8],[9],[10].

Wind speed
The speed sensor has a reed switch in it. The switch opens and closes twice for one revolution of the cups. The documentation of the sensors declares that a wind speed of 1.492 MPH (2.4 km/h) causes the switch to close once per second.

Wind direction sensor
Eight reed switches are mounted radially at 22.5 degree angles. Each reed is connected in series to a resistor of different value. All the circuits are connected in parallel to the two poles of the output cable. With the use of an external resistor, a voltage divider can be created. A magnet closes the reed switches, and may close two at a time due to their proximity to each other. As the wind direction changes the vane actuates the corresponding reed switches and the wind direction can be known. Measuring the voltage output with an analog-to-digital converter on your microcontroller allows you to determine the direction the wind vane is pointing.

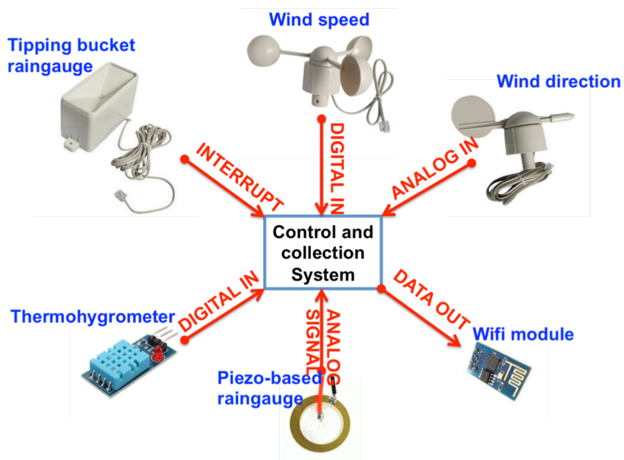
Raingauge
The rain gauge is a self-emptying tipping bucket type. Each 0.011" (0.2794 mm) of rain causes one momentary contact closure that can be recorded with a digital counter or microcontroller interrupt input.

Thermohygrometer - DHT11
This sensor is very basic and cheap. It is made of two parts, a capacitive humidity sensor and a thermistor. There is also a chip inside that makes the analog to digital conversion and sends a digital signal with the temperature and humidity in the serial data pin. The digital signal is fairly easy to read using any microcontroller.

Piezoelectric-based raingauge
This sensor exploits the working principle of a piezoelectric transducer for extracting information about the rainfall drops impacting its surface. The direct measurement of the signal generated from a drop is related to its kinetic energy and consequently to its dimensions and terminal velocity. The signal of a drop impacting the sensor surface is characterized by dumped oscillation starting from the maximum value occurring at the impact. The rate of falling drops, the maximum amplitude and the duration are information related to the rainfall amount.
The weather station project is based on the sensors described above. However, additional sensors can be added through an appropriate characterization of the measurement acquisition systems.

3. System architecture
The selected sensors impose to adopt different kind of solution to ingest signals and measurements, both analogic and digital. A specific analysis has been conducted for every single sensor. The interrupt advice has been chosen to correctly detect every single tip of the tipping bucket raingauge. The raingauge tip as observed from a signal scope has duration of about 50 ms. That signal structure allows distinguishing by software the tip from other spurious signals. Further technical arrangements as the use of pull up resistor and a capacitor for spikes filtering have been introduced. The circuit for reading the wind speed sensor is very similar. Also wind speed could be measured by use of interrupt instructions, but other solutions are possible as the use of digital reading cyclically repeated. The values of temperature and humidity are registered through the digital data flow from the DHT11 sensor. As the wind direction information is related to a resistor value serially connected to the reed switch this signal can be ingested as analog input, computed with the voltage divider rule. The management of the impact raingauge requires high frequency sampling (> 4kHz) to correctly detect the signal waveform and extract relevant information. Finally a time clock module is needed to keep track of seconds and to chronologically locate the measurements. This is crucial for the tipping bucket rain gauge measurements where the precise instant of time must be registered to extract accurate rates of rainfall. Finally the wifi module can send the time located measurements to a remote collection center. This general connection scheme is shown in figure 1.

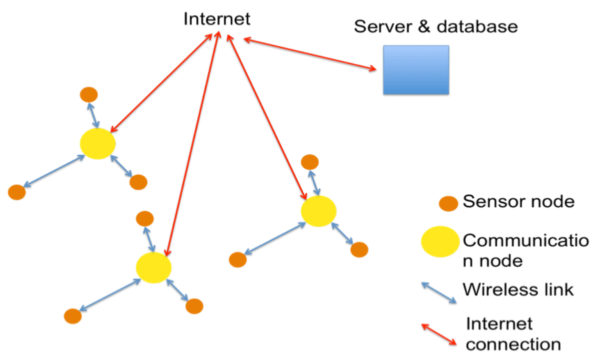
Figure 1. Connection scheme



Further sensors can be introduced in the scheme, by properly designing the hardware interface and the software module for signals management. The adoption

of a very common microcontroller system as Arduino, allowed exploiting the availability of lots of documentation in the Internet as community blogs and libraries already developed. This is essential when combining system development purposes in educational contexts, for a better students engagement.
The proposed architecture can be extended with duplicated modules, for example if required by the morphology of the farm. In some cases different sides of a mountain must be monitored, as different weather situations can affect them. The various nodes may have different purposes, for example the management of internal sensors in wine cellars, the control of the terrain humidity, etc.…
In case of different nodes they can be interconnected or connected to the Internet network. In any case the architecture must include an additional system acting as server for collecting, storing and real time visualizing measurements data (Figure 2).

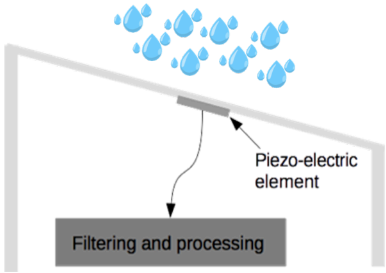
Figure 2. Sensors dislocation scheme



4. Technical aspects of the impact sensor prototyping

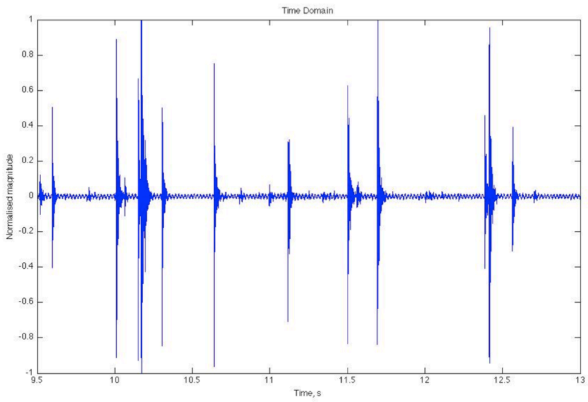
Although the other sensors are quite common, in this work, an innovative, very low cost instrument for characterizing precipitation in terms of both rain rate and raindrop size is presented, the impact rain gauge sensor, based on some ideas found in literature ([12], [13]). The instrument is an acoustic disdrometer working with the same principle as an ordinary microphone that converts sound waves in electric signals. A piezo detector, fixed to the bottom layer of the acoustic disdrometer, converts the vibrations caused by the drops impacting the instrument to an electric signal, which is the input for data logger and processing.
A prototype of the disdrometer (see Figure 1) was realised by assembling: a sheet of glass mounted on a wood frame; a piezoelectric element (used as a contact microphone) fixed to the bottom layer of the glass; a bipolar cable connected to the bipolar output of the sensor. In the proposed prototype implementation, the sound card of a personal computer was used as the signal acquisition system. The limited sampling frequency of the sound card (44kHz) is sufficient to extract the needed spectral and amplitude information correlated with precipitation occurrence.

Figure 3. Impact sensor



In the further prototype development the piezoelectric sensor has been connected with the microcontroller unit.
The signal processing is composed by two analysis algorithms; the first one is in the time domain, where the signal amplitude can be easily managed and the waveforms caused by the raindrop are characterized by an initial peak followed by damping oscillations due to the relaxation of the piezo-element to the equilibrium state. The hydrometeors impacting the sensor are distinguishable by displaying their amplitude versus time, as the amplitude of the initial peak is much greater than the background noise. The peak amplitude is correlated to the size of the impacting drop, as well as the transient time. The number of raindrops falling in a certain time interval is correlated to the rain rate. Some analysis limitations are due to the background noise amplitude introduced by the cable and the external acoustic noise (i.e., air conditioning machines in proximity of the sensors, traffic noises, airplanes, etc.).

Figure 4. Signal of impacting drops during a rain event



Some laboratory tests were conducted in order to investigate acoustic disdrometer sensitivity to raindrop diameter. Raindrops of 1, 3 and 5 mm diameters were falling down from a height of 18m (the roof of a building) in order to reach their terminal velocity before the impact with the instrument, thus simulating real rainfall drops. The results of this experiment showed the capability of the system in distinguishing different drop sizes.
Subsequently a processing algorithm has been developed to extract the signal information consisting of amplitude

and duration of each drop impact. The number of drops occurred during the reference time interval is the other key parameter. This instrument needs a calibration phase during some no rainfall periods to tune the algorithm to the noise typical of the surrounding environment and the instrumentation.
Finally the comparison of the impact sensor measurements with a reference system data has been performed, in order to verify the system rain rate estimation capability. The reference raingauge was a professional tipping bucket system providing cumulative rainfall measurements every 15 minutes.
Some results of this comparison relative to a case study of May 2017 are shown in next figures (5, 6, 7). For the impact sensors the average measurements relative to time intervals of 1 minute are available, measurement units (not absolutely calibrated) are on the right side. The reference raingauge measurements are cumulative rainfall amount, units on the left side. The measurements reported to a time instant are relative to the previous interval.

Figure 5. Impact sensor amplitude vs raingauge tips

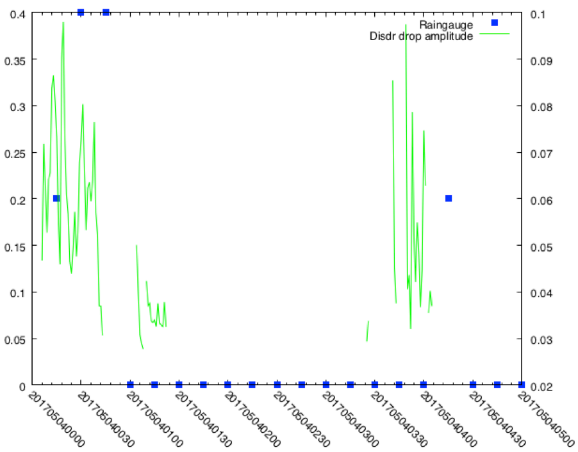


Figure 6. Impact sensor duration vs raingauge tips

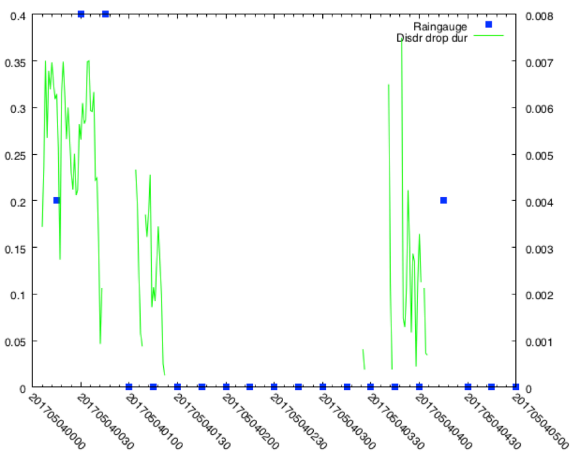
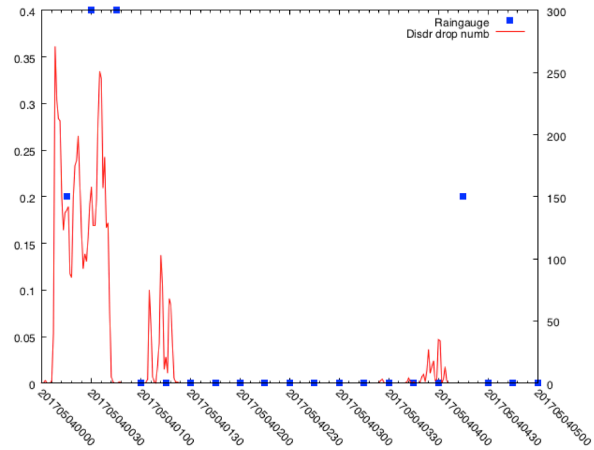


Figure 7. Impact sensor drop number vs raingauge tips



In the visualization of these images we have to take into account that any relationship between the two different measurements must include the integral operation, as the impact sensor provide instantaneous values and the raingauge outputs are cumulated quantities.
In the perspective of these considerations the figures show encouraging results both in the retrieved parameters and in the time synchronization. However an accurate work is needed for a definite calibration.

5. Conclusions and possible developments

The idea of this work fits some issues of climate change awareness, experimentation of low cost technologies in environmental monitoring and maker education.
In the last decades the increasing occurrence of extreme weather events in urban areas has highlighted some weakness and gaps of the observing network systems used by civil protection organizations. More specifically weather parameters are characterized by very high spatial and temporal variability so that the measurement networks fail to monitor them with the necessary precision to provide meaningful information at urban scale.
In addition to the known effects on the intensification of extreme events and disasters, climate change has been having lots of different impacts in agriculture, industry, and human activities. Food security emergencies, heat waves, desertification, deforestation, sea level rise, loss and damage, world water system crisis are key aspects of these impacts. In the context of adaptation strategies, the knowledge and the availability of additional information are critical. Crowdsourcing of weather data is a world wide emerging technology for the augmentation and densification of real time collected data. On the other hand the broad diffusion of a large number of sensors can only be possible through the use of low cost sensors and technologies.
Despite the low nominal cost of these observations, their actual use for applications alternative precision and smart agriculture, as climate change monitoring and adaptation

could be possible only through a massive work of sensor calibration to reach the standards of the WMO [14]. In any case also in absence of absolute calibration the quantification of measurements uncertainties is mandatory to give value to the amateur network observations.
All these aspects are included in the presented work, an attempt to develop a low cost weather station for educational purposes, but with lateral effects of awareness among students.

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