A Wireless Sensor Network Platform Optimized for Assisted Sustainable Agriculture

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***Abstract*— The paper illustrates an efficient wireless sensor network platform, suitable for application to assisted agriculture in (but not only in) developing Countries and remote regions. The platform has been conceived in order to minimize power consumption, during all the phases of data acquisition, sampling, and compression, with an efficient and performing communication protocol, with extended transmission range and radio coverage optimization. Sensor nodes have been provided with energy harvesting facilities, to avoid any need for direct power supply or battery replacement. The resulting nodes are consequently autonomous, easy to locate and relocate, and scalable. A further work has been done to minimize dimensions and costs, in order to deploy capillary installations. Furthermore, thanks to the work done from the side of the channel optimization, it has been possible to acquire not only standard environmental parameters, but also high definition pictures. Images of plants, trees, as well as fruits and leaves are taken every hour, and forwarded to a central gateway, interfaced with the Internet. A team of agronomists and biologists checks the state of the cultivation from remote, providing the farmer with continuous assistance at a reasonable cost. This is extremely important in Developing Countries, taking into account that in those locations experts cannot reach the fields and cannot provide the farmer with specialized, continuous consultancy, both for economical and logistic reasons. In a global scenario, where new diseases arise rapidly and continuously, the remote assistance provided by an expert can minimize farmer's risks to loose his harvest and reduce his revenues. The set of environmental parameters, together with the visual collection of cultivation conditions, is useful also to generate a culture database, particularly useful in developing regions, where there is almost never historical recorded trace, in particular about possible associated diseases and infections. Last but not least, the platform allows a significant improvement of the sustainability. Thanks to the assistance of the agronomist, the farmer can minimize the use of pesticides and chemicals, as well as reducing the number of additional treatments, resulting in significant advantages, in terms of production costs and organic quality.**

Keywords—component; Internet of Things, Wireless Sensor Networks, Intelligent Agriculture

I. INTRODUCTION

In a Developing Country, the farmer, who is in the same time the plant cultivator, the good stocker and the product seller, is the only responsible for the cultivation, where he mainly applies his empirical but effective agronomic competence [1]. In the recent years, because of weather changes and vehicular transportation of infections, the historical know how handed down by the previous generations has revealed to be insufficient, and new diseases and infections arise almost every season. Adopting external consultancy by an expert is not possible, for economical reasons, but also for logistic complexity: regions lack of experts and the few available cannot travel regularly to any field. If the farmer has the possibility, he may adopt chemical treatments, which are very expensive and reduce his net margin. In this way, the sustainability of the cultivation, as well as the natural quality of the goods, is drastically affected.

It is a matter of fact that the only possibility to seriously help the farmer is represented by an autonomous, independent, tentatively continuous analysis of the cultivation state, with regular feedbacks about the actions that are needed. Reporting the acquired data over the Internet, could allow a troupe of agronomists and biologists to assist the farmer, or a large number of farmers, in real time, for a huge number of cultivations, cancelling logistics and organization costs: the consultancy cost would be shared among many farmers, and no transportation (or very limited one) would be required.

Both in organic and conventional agriculture. the most relevant instruments to operate a pervasive control, is represented by a capillary, continuous and constant monitoring of any event occurring to the cultivation, both from the side of the plants and the one of the surrounding environment. In developed Countries, this is possible by activating periodic "in field" controls. In Developing Countries, this would generate relevant expenditures, (personnel, equipment, fuel) and logistics complexity (travelling on dirty roads, bad weather limitations, personnel availability). All these factors limit the frequency, and consequently the efficiency, of the control, which can be performed rarely during the season, while infection conditions may vary rapidly during the day.

Even more, environmental sustainability is becoming a relevant objective in any agriculture cultivation [1]. Sustainability has several facets, the most relevant one being represented by the effort to increasingly contain the use of chemical agents, in particular pesticides. I.e., the European Union is promoting, any agriculture practice that eludes the use of pesticides. REACH (**R**egistration, **E**valuation, **A**uthorization and Restriction of **Ch**emical substances) is a European Community regulation to improve the protection of human health and the environment [3], which calls for the substitution of dangerous chemicals with safer alternatives. In September 2008, the European Union issued new and revised Maximum Residue Limits (MRLs) for the roughly 1,100 pesticides ever used in the world [4].

For all the reported reasons, we have addressed the problem by constructing a wireless sensor network (WSN) platform, which reports data over the Internet.

II. WSN PLATFORMS FOR SUSTAINABLE AGRICULTURE

Let's consider viticulture as an example. From the agronomic point of view, viticulture uses an already well established method based on pheromone observation on lobesia botrana, and sticky traps for scaphoideus titanus. Unfortunately, for the most common fungal diseases, there are no available methods other than the constant monitoring by a qualified technician. The monitoring can be efficiently piloted, by knowing in advance the growing conditions, in particular the temperature, the humidity, and leaf wetness.

For this reason, during the last ten years, several attempts have been made, to set up meteorological stations within vineyards [5], In the usual application, stations are as frequent as the number of Municipalities involved, and each station may control, using a wireless channel, a number of sub-stations, which detect information about leaf wetness, with at least one substation every 25 hectares [6].

WSNs have significantly contributed to a better and capillary monitoring of the vineyards/ In general, WSNs are used to sense (control) parameters of various kinds, in very different application contexts: industry, services, trade, urban activities, logistics, and of course agricultural production. Both in the market and in the scientific literature, various examples of systems and platforms exploiting wireless communication schemes can be found. Some of them make use of international standards like Zigbee, Ultrawideband, Bluetooth, specifically dedicated to the acquisition of relevant quantities of data, respectively in industrial environments, in electromagnetically noisy environments, and in relatively small scenarios. Other (AdHoc, MANET) are constructed following the specific needs of the implementer, and they are usually based on the need to minimize energy consumption, with typically very small data to be transmitted. All mentioned systems make us of unlicensed frequency bands, to minimize maintenance costs and management.

With the advent of WSNs, it has been possible to increase the number of sensing nodes [7], transforming the traditional meteorological system into a more pervasive control of the cultivation [8]. The required computing effort is relatively small, as the acquisition frequency should be as frequent as one per hour [9].

More recently [10], WSNs have been proposed for an enhanced vineyard monitoring, which complements meteorological and environmental information with image acquisition. Plant images are acquired in strategic points chosen by the agronomist. In this way, the agronomic observation becomes almost continuous and the agronomist analysis can be automatically transferred inside the node, by implementation of image processing techniques. The inconvenient of the realization proposed in [10] is represented by the use of Wi-Fi, which allows the transportation of large amount of data, but unfortunately generates too much power consumption.

Fig. 1. Example of application of the proposed system

III. OUR WSN ARCHITECTURE

Our proposal is an ad-hoc platform similar to the ones used to acquire environmental and meteorological data, where the manufacturing cost of the sensor node is minimized, by an efficient selection of the system components. The aim is the realization of an ergonomic, low-cost, miniaturized platform, characterized by low environmental impact, low power consumption and high performance. Clearly, this monitoring solution cannot prevent all possible diseases, and the efficiency of a consultant through the Internet is much lower, compared to the one that he might give on site. Nevertheless, it appears as an effective trigger to connect farmers and experts, helping the formers in their daily operations.

Moreover, on the same network, in relevant places selected by the agronomist, high definition cameras are installed, in order to provide the expert with adirect photographic information. The scope is the one described in [10], without using wide band transmitting systems. In a way, by adding the image acquisition facility to an ad-hoc wireless sensor nodes terminal, we redefine the role of an ad-hoc WSN, overcoming the typical acquisition and transmission schemes that allow temperature, humidity, wetness monitoring.

As a consequence, the challenge is represented by the need to set up an ad hoc system, to be installed within leaves, an environment that is unfavorable to the radiofrequency propagation, with a capability to transfer data at a transmission rate typical of the wideband data access systems. The acquisition must be optimized, and the best compromise between the needs of the user and the constraint to limit energy consumption and space occupation must be reached: the only chance to favor an application on a large scale.

The technical concept is illustrated in Fig. 1, where we recognize a typical ad-hoc wireless platform, where sensor

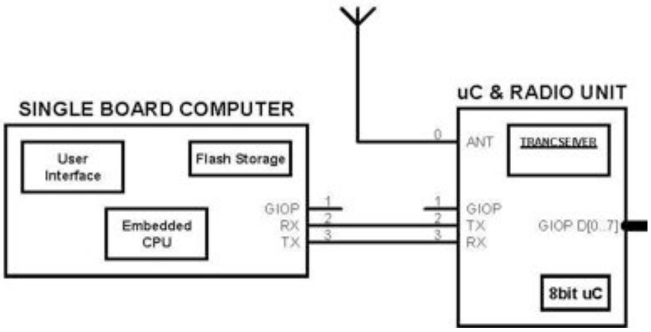


Fig. 2. Sensor Node Scheme

nodes are installed among the plants, and can be used not only to acquire, but also to establish a multi-hop communication structure, until the information is reported to the base stations, and from there to the Internet.

IV. BASE STATON AND REPEATERS

The base station (BS) and the repeaters have been implemented in a modular way, by minimizing the equipment cost, optimizing flexibility and scalability, and aiming to reduce implementation times. A single board computer (SBC) running an open source operating system has been used as main data processing unit. The communication component has been managed using a transceiver manufactured by Texas Instruments, model CC1110. As an SBC, a Raspberry model B has been implemented. The BS bloc diagram is reported in Fig.3. Fig. 4 shows the implemented device, where the radio interface has been interfaced to the SBC via a standard serial port. The transceiver has the characteristics listed in Tab. I, and it has been configured to work, alternatively, at 865 MHz or 433 MHz, depending on the system requirements and the propagation scenario. The higher frequency is preferable when sensors are located in line of sight, while the lower one simplifies the installation process in a hilly, complex scenario.

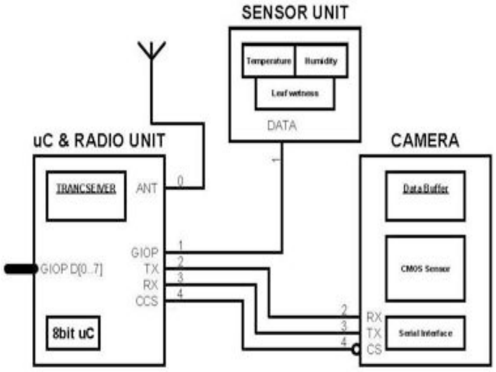


Fig. 3. Base Station Scheme

Fig, 4. Base Station Implementation

TABLE I. TRANSCEIVER DATA

PARAMETER	VALUE
Frequency bands [MHz]	315/433/868/915
TX Current consumption [mA]	31
RX Current consumption [mA]	22
Sleep power consumption [uA]	0.6
Data rate [kbps]	1.2 - 250
Sensitivity [dBm]	-110 (@ 2.5 Kbps)
Output power [dBm]	10
Frequency modulation	2-FSK/GFSK
Amplitude modulation	OOK/ASK

V. SENSOR NODES

The sensor node (SN) is the relevant component of the system. The node controls the environmental sensors and the camera (when present). The data acquisition is managed by the transceiver, together with the transmission to the BS. The antenna is specifically designed and integrated on board, and the power supply is provided by a dedicated photovoltaic harvester. The sensor scheme is reported in Fig. 2.

A. *Environmental Sensor*

Several sensors can be managed by the transceiver. For our first implementation, we have selected localized temperature and humidity units. The chosen unit is produced by Sensirion, Model SHT21 (Fig. 5). Tab II lists the main sensor characteristics.

TABLE II. ENVIRONMENTAL SENSOR DATA

PARAMETER	VALUE
Data interface	I2C
Power consumption	2.3uW
Humidity range	0 - 100% RH
Temperature range	-40 - +125 °C
Footprint	3 x 3 mm

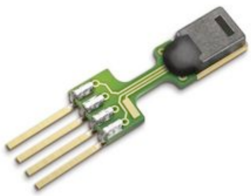
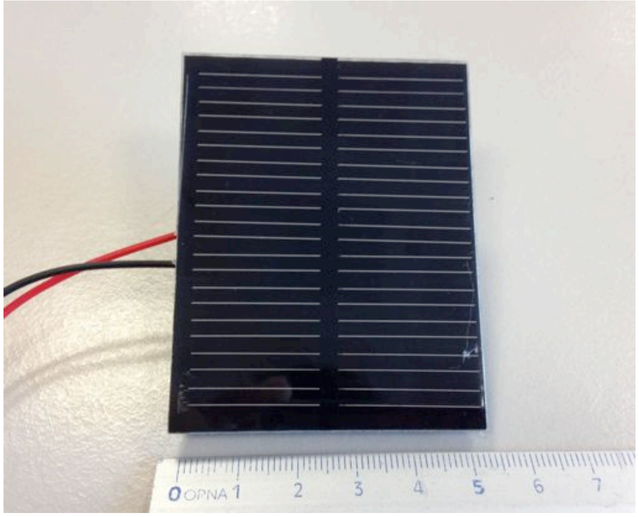


Fig. 5. Example of application of the proposed system

B. Cameras

The camera used is the OV5642 from OmniVision. It is able to capture and process pictures with different resolutions, ranging from 320 X 240 to 2592 X 1944 pixels. Furthermore, it is able to compress images and to generate a JPEG data stream. An external microcontroller can be interfaced in order to set the camera. The image acquisition processing is carried out without external intervention and the image data are sent to the microcontroller through a serial interface. The module has a power save mode which aims to increase the energy autonomy, ranging from 270mA in active mode (when the image is taken) to 25uA in power save mode.



Fig, 7. The photovoltaic harvester

Fig. 6. Antennas working at 433 MHz (top) and 868 MHz (bottom)

C. Transceivers

As a transceiver, the same component exploited for the BS has been implemented. Characteristics are the same listed in Tab I, even if in this case the transceiver is used to acquire/store data from the sensors and the camera, in addiction to commands reception and data transmission.

D. Antenna

The typology chosen for the mentioned application is the resonating magnetic radiator, which is significantly efficient in lossy media, where the field region is characterized by a wave impedance as small as the one of the medium surrounding the antenna. The radiator is omnidirectional, and consequently the communication range is limited. In RFID and WSNs technology, this limitation does not affect the performance of the system, as those systems are in any case characterized by EIRP limitations.

To minimize the circuit dimension, we have identified an efficient magnetic antenna that allows the realization of matched loop radiators, by embedding the matching circuit inside the loop [11]. An example is shown in Fig.6, bottom left (868 MHz), where the antenna is a standard circular loop and the two curvilinear transmission lines are inserted in series, to cancel the imaginary part of the impedance that can be measured at the loop terminals. To reduce the dimensions of the antenna, allowing an extended minimization of space occupation, more complex geometries have been exploited. In this way, it has been possible to synthesize small antennas, embedded inside circumferences having a radius down to 60% of a standard circular loop. To this purpose, a geometrical shape similar to a flower, where the number of petals is optimized to increase the current path, has been introduced, as

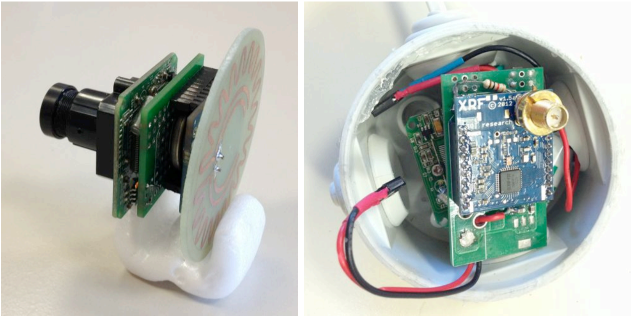


Fig. 8. The SN “nude”, with embedded radiator (left) and external radiator (right)

shown in Fig 6, top (433 MHz) and bottom right (868 MHz). As one can see, the 60 % size reduction is almost confirmed.

E. Harvester

According to the agronomist constraints, one image per hour is a good starting point to monitor the condition of the plant. Consequently, the duration of the full transmission of the image depends on the resolution of the camera and the data rate. As an example, for the calculation of the energy budget we might consider a duration of about 6 minutes for a high resolution image transmitted in average coverage conditions. For the following 54 minutes the system sleeps, with a power consumption as small as 0.8uA. Consequently, the total power consumption is 27.5 mW/h. Assuming that the system works 10 hours per day, the total power consumption is 330 Mw/day.

In order to minimize the costs, a rechargeable battery with a capacity equal to 850 mA/h @ 3.7 V has been used. This battery is able to power the system for about 8 days. So, a solar panel has been chosen as energy harvester in order to recharge the battery. According to this power budget a panel with dimensions 7 x 5.5 cm has been chosen. Assuming 3 sun hours per day, the panel provides 500 mW/day. In this configuration the system is complete and fully autonomous without time limitations: the batteries are almost perpetual and they can be recharged regularly by the solar panel.

Fig. 9. Two SNs installed in a vineyard. Left: with internal harvester, right, with external harvester

Fig. 10. A first example of image acquired by a SN in Sorii San Lorenzo, Barbaresco, Italy

F. Full Sensor Node

The Sn is assembled by packing all the mentioned devices together, taking care of minimizing the overall dimensions. The package has been chosen in order to survive to normal working operations within the vineyard, together with the capability to resist to any kind of weather condition. Fig. 8 shows an example of the SN, “nude”. Fig 9 shows the same, within its own package, which has been designed in order to be waterproof.

VI. INTERNET ACCESS

Data, once acquired, are transferred to the BS, and from there they are copied on a remote database, via an ftp channel over the Internet. The communication channel is realized by means of a standard 3G modem, directly implemented on the BS SBC. A web interface has been implemented, in order to allow the agronomist to access the database, to review images, to select the relevant ones, comparing them in a dedicated framework. Moreover, the user has the possibility to analyze the evolution of the environmental parameters, generating automatic graphs and cross-comparing the evolution of the vineyard along the years (in the future, when enough data will be available).

VII. THE CURRENT EXPERIMENT

The first experiment has been implemented in the Municipality of Barbaresco, Piedmont, in the Sorii San Lorenzo vineyard, which belongs to the wine producer Gaja. The same experiment could be replicated anywhere else in the World. One BS has been implemented in the farmhouse, while sensors have been deployed up the hill. The vineyard is represented in Fig. 1, showing a picture taken from the farmhouse, exactly from the same position where the BS has been installed. SNs have been deployed in several positions, both in line of sight and not. For this reason, the communication between the BS and the SNs has been implemented in an adaptive way, in order to optimize the living

Fig. 11. A second example of image acquired by a SN in Sorii San Lorenzo, Barbaresco, Italy

time of each SN: every SN transmits using the highest modulation rate permitted by its distance/visibility from the BS. In this way, 2 MB pictures are transferred in a time comprised between 45 and 745 seconds. To optimize the transmission time, we are now implementing a multi-hop system making use of repeaters, which will allow a line of sight condition to all SNs.

Fig. 10 and Fig. 11 show examples of data acquired using the monitoring system. A complete gallery of the images collected during the experimentation is available for consultation on the iXem Labs website [12]. The experiment has been activated on May 1st, 2013, and since then, for the whole season (until November 30th), the SNs have been active and in good working conditions. The energy consumption has been kept under constant control, and the very small harvester has been able to supply power to avoid any loss of data. From the side of battery duration, the experiment cannot be considered significant, as its duration was limited to one season. Nevertheless, the same harvesting configuration was previously adopted on a WSN platform used to monitor avalanches [13], where a duration of at least five years was testified, even if weather conditions where extremely tough and much worse than the ones found in a farm all over the World.

VIII. ECONOMICAL EVALUATION

With reference to the specific experiment that we have run during 2013, we have identified the minimum number of sensors needed for an adequate control of the cultivation: 2 Sn per hectar. We have estimated a fabrication cost of about 65 USD per SN, with one BS needed every 20 SN (cost per BS 78 USD). The average cost for a chemical (systemic) treatment is at least 120 USD per hectar, with about 10 treatments required per season. The average cost for a non-chemical (contact) treatment is at least 50 USD, with about 15 treatments required per season. During season 2013, in our experiment in Barbaresco, we have compared to similar productions, the former provided with remote monitoring, the latter without. In this way, we have demonstrated that the remote monitoring has given the possibility to cancel the chemical treatments, and reduce for a 50% the contact treatments. Even if these results should be validated on a larger scale and the system should be applied to a real Developing scenario, the experiment shows the applicability of the platform and its economical sustainability. In terms of man power, we have estimated the time required by the expert to analyze data coming from one hectare: it corresponds (in average) to 1 minute per day. In terms of costs per season, it corresponds to 3 hours per hectare per season, an amount relevantly less than the one corresponding to the saved treatments. It is then clear how the WSN application represents not only an advantage for the sustainability, but also a relevant money saving for the farmer.

IX. CONCLUSIONS

The work presented in this paper proposes a remote monitoring solution to provide farmers in Developing Countries with high level, low cost assistance to accelerate the efficiency of their cultivations, improving the environmental sustainability of the whole process and the quality of the production. The validation, for the moment, took place in Italy, where all parameters typical of a Developing scenario were reconstructed. The technological platform, the agronomical result, and the economical outcome were evaluated and validated on a lower scale. The next step will involve a large scale set-up in a real Developing scenario.

ACKNOWLEDGMENT

This work has been possible, thanks to the collaboration of Cantine Gaja, who provided access and use to their vineyards, and Stazione Sperimentale per la Viticoltura Sostenibile, who provided suggestions and agronomical consultancy. The authors thank Dr. Angelo Gaja, Mr. Giorgio Culasso, and Dr. Ruggero Mazzilli for their relevant and fundamental support.

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