Internet of Trees: A Vision for Advanced Monitoring of Crops

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Abstract: Ecosystem preservation and production maximisation are competing objectives in agriculture. Reducing the need of undifferentiated or late interventions on the crops would reduce the number of disease treatments needed, as well as the consumption of water and fertiliser. This objective is only attainable through crop monitoring systems able to reach a single plant. Precision agriculture employ continuous and pervasive monitoring of crops, that in turn allows fast and targeted interventions. The aim of this paper is to highlight the problems that can be found in designing a wireless sensor network (WSN) able to measure environmental parameters such as relative humidity, irradiance and volatile pollutant concentration and introduces a possible solution that we named the Internet of Trees.

1 INTRODUCTION

To optimise production and reduce waste of resources, a detailed knowledge of the health state of the crop, soil, water and nutrient reservoir needs to be built (Ehlers and Goss, 2016). Up to now, such information has been extrapolated by airborne LiDAR or by processing satellite images. Both techniques have high costs and suffer from low resolution (Estornell et al., 2014; Cunha et al., 2015); moreover, even if these approaches allow to evaluate the state of health of the crop, they have poorly results on early detection of plant disease (Zhang et al., 2019). On the other hand, the Volatile Organic Compounds (VOCs) have been demonstrated to be early markers of the state of health of the plant (Martinelli et al., 2015).

To this purpose, several techniques such as gas chromatography mass spectrometry (GC-MS) or electronic noses have been used to detect and estimate volatile compounds in crops (Martinelli et al., 2015). Nevertheless, these techniques have been used to estimate gas concentrations in single points within the crop that cannot supply any information on the state of the whole farm. To this purpose, we will investigate how to design a wireless sensor network endowed with a customised set of sensors able to detect volatile pollutants and the relevant VOCs, and a tool for data collection, processing and visualisation, able to extrapolate detailed maps of the crop health.

The parameters measured by each node provide information on the status of the crop with a detail that depends only on the number of nodes composing the network, and that can reach even a single plant. In addition to local information, trends and dynamics across fields can be obtained in post-processing and this derived information can be useful to organise farming interventions. With the aim of highlighting the different information that can be extrapolated by the WSN, an appropriate system of data collection, processing and visualisation needs to be implemented. In the implementation of a such pervasive network two main problems arise: (i) Long time working time of the single node, i.e. low energy consumption and energy harvesting. (ii) Network reconfiguration in case of node failure, and easy access to single node information.

In this paper, we will introduce a WSN to monitor the environmental parameters of the crop and a web based platform for data collection, processing and visualisation. In particular, we will clarify which are the main characteristics that a WSN for precise agriculture should have and how can be obtained thanks to an integrated design of the hardware and software.

Our user target is initially the agronomy community, with the goal to expand it to the farmer community when the system will be more widespread.

In the following sections, we will describe our

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idea of the hardware and network architecture, and the features that they should have to fulfill our requirements to guarantee adequate monitoring performance. At the end of every section we will present some implementation examples.

Related Work

In the last years, precision agriculture has been identified as a promising research field to improve the monitoring and managements of crops.

While few studies propose crop automation solutions (e.g. automated ventilation in (Stipanicev and Marasovic, 2003) or irrigation as in (Sahu and Mazumdar, 2012)), the majority of them focus on crop monitoring, using mainly humidity, light and temperature sensors (Fisher and Kebede, 2010; Dan et al., 2015; Patil and Kale, 2016; de Lima et al., 2010; Yoo et al., 2007; Jiber et al., 2011).

We refer to the extensive review papers in precision agriculture for more information on the state of this research field (Liaghat et al., 2010; Brisco et al., 1998; Ge et al., 2011; Jawad et al., 2017).

Novelty

While the use of WSNs for monitoring, management and prediction purposes is not new, to the best of our knowledge no previous work addressed the goal of integrating chemical sensors in the network nodes for precise agriculture. Such an ambitious goal would allow to understand the disease diffusion process, their correlation with other environmental parameters, and to build more accurate disease prevention models.

2 HARDWARE ARCHITECTURE

The hardware part of the network, i.e the nodes, have to fulfill several main tasks: (i) Acquire the sensor data. (ii) Communicate the sensor data. (iii) Harvest energy. (iv) Minimize the energy consumption. In Figure 1, a schematic representation of a possible architecture of a WSN node satisfying the aforementioned constraints is shown. The node is based on a micro-controller (μC) and at least a wireless interface. The μC is assisted by a Battery Management (BM) and a Maximum Power Point Tracking (MPPT) circuit, for the power management, finally electronic interfaces are required for the physical and chemical sensors.

With more details, the micro-controller perform the data reading from the sensors, manage the energy harvesting and the power consumption and elaborate

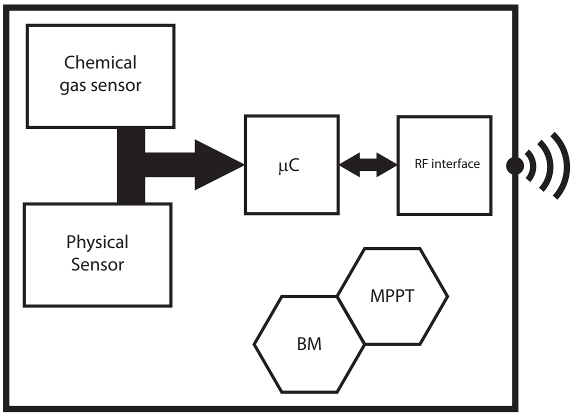

Figure 1: Schematic representation of the sensor node architecture. In particular three main parts are highlighted: the battery management (BM) and the Maximum Power Point Tracking (MPPT) circuits; the Microcontroller (μC), the Radio Frequency (RF) interface; the physical sensors (Light intensity and Temperature) and the chemical sensors (Relative Humidity, VOC sensors).

the data to send to the RF interface. The RF interface should supports different protocol, in order to allow the communication in long range (LoRa), but sometimes a single node short range communication could be useful to download single node information, perform node debug, or simply for updating the node GPS position during the installation procedures.

The MPPT and BM circuits have the role of optimizing the power transfer from a photovoltaic panel towards the battery, preserving the battery functionality and energy in order to guarantee a continuous functioning of the nodes in the long period without maintenance. The solar energy appears as an obvious source of energy since these nodes will be placed onto the tree in a crop, nevertheless the foliage could sometime darken the panel.

3 SENSORS

Light, water and CO_2 are the three main components that sustain the plant life (Ehlers and Goss, 2016), any lack of these three components have an effect on the state of health of the plant, at the same time, light and temperature have effect on the fruit maturation (Uzun, 2007), VOCs are markers of state of health of the plant (Martinelli et al., 2015), and the levels of plant bioregulator (Rademacher, 2015) have effect on the flowering, fruit formation, ripening, fruit drop, defoliation, etc.

In order to extract the information about the state of health of the plants and if they are suffering a lack of water or nutrients, several sensors have to be integrate into the sensor nodes. Fundamentally, three kind of sensors should be integrated: (i) Physical sensors to measure temperature and radiance, (ii) Chemical sensors to estimate VOCs, gases and vapors, (iii) Electro-chemical sensors to evaluate the levels of bio-regulators.

Physical sensors enable to know the surrounding condition of the crop environment. Light intensity and temperature are the main physical quantity that should be measured since they are correlated with several plant conditions and fruit maturation. Commercial available physical sensors reach level of performance that satisfies the need of the application.

Different consideration have to be done for chemical gas sensors and electro-chemical sensors. Chemical gas sensors have to perform two different tasks: (i) quantify gas, vapors and VOCs, (ii) discriminate the different VOCs; these tasks require different sensor approaches. In volatile quantification, selective sensors are more appropriate, whereas, in volatile discrimination an approach based on electronic nose (Gardner and Bartlett, 1994) is more efficient. In both cases, the research in low power, adjustable selectivity, and stability are still going forward. Among the different kind of chemical sensors, polymeric based (Bai and Shi, 2007) and metal oxides (Polese et al., 2017; Polese et al., 2015; Zhu and Zeng, 2017; Sun et al., 2012) show interesting characteristics.

On the other hand, electro-chemical sensors need to be functionalised to detect the appropriate bio-regulator, this generally needs the interaction with chemist or biologist to optimize their structures. Examples of this kind of sensors can be find elsewhere (Khater et al., 2017; Maiolo et al., 2016).

4 NETWORK ARCHITECTURE

WSNs for precise agriculture need to cover large cultivated area, work for long time without maintenance, and to be re-configurable under node failure or node integration. We found that the Thread network protocol (https://www.threadgroup.org), and in particular OpenThread, the Google open-source implementation of it (https://openthread.io/) satisfy these requirements ant it has be chosen in order to have a re-configurable network that can easily prevent node failures and work under stringent energy constraints.

A traditional Wireless multi-hop structure will be employed, with a small number of border routers connected to the Internet, and a dense network of nodes equipped as described in the previous section. This solution is adequate for crops that need to accommodate hundreds of nodes and a limited (less than 32) number of routers. For bigger crops, a solution based on Contiki and RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks) might be more appropriate (Ellmer, 2017).

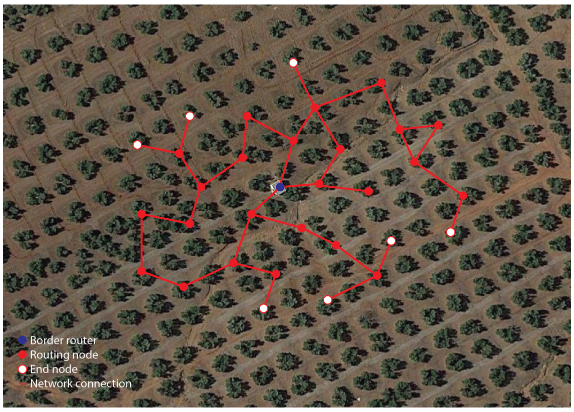

Figure 2: Example of WSN structure in olive orchard. In the figure, the different roles carried out from the nodes are highlighted.

We will develop adaptive algorithms to dynamically adapt the sensor report frequency depending on the energy requirements and the measurement variability in that space and time frame.

Location Mapping

After the installation phase, a GPS equipped device can map the position of the sensors, using a combination of anchoring during the pairing process and RSSIs-based multilateration for error correction (Hightower and Borriello, 2001).

5 DATA VISUALIZATION DASHBOARD

To build a dashboard, we will investigate the use of Google Data Studio (Snipes, 2018), as well as open-source solutions like chartist.js (Kunz, 2014) or candela, using the Resonant data and analytics platform. We aim at following the state-of-the-art of dashboard design best practices (Elias and Bezerianos, 2011).

The main interface of the dashboard will show a map of the crop, with an estimation of the health of the crop. By clicking on a region in the map, an historic trace of the health of that area will be shown.

The health parameter of an area is not the raw sensor data, but rather a time and spatial interpolated summary of the neighbouring nodes status, considering each sensor thresholds in an adequate time window. This is obtained using *health rules*, that are a set of conditions an area is supposed to satisfy. Health rules can be time-dependent (e.g. different during the night), and be as simple as independent thresholds for each sensor, but also encompass complex joint rules (e.g. humidity thresholds can depend on luminance values). Health parameters (low and high threshold, time and spatial tolerance) for each sensor can be manually set in a configuration section of the dashboard, or downloaded from an online database.

The user will be also be able to visualise the raw measurements from the sensors in this section of the dashboard. Advances health rules warning can be set up using modeling and predictive tools, as explained in the next section.

An example of a dashboard for an olive orchard is shown in Figure 3.

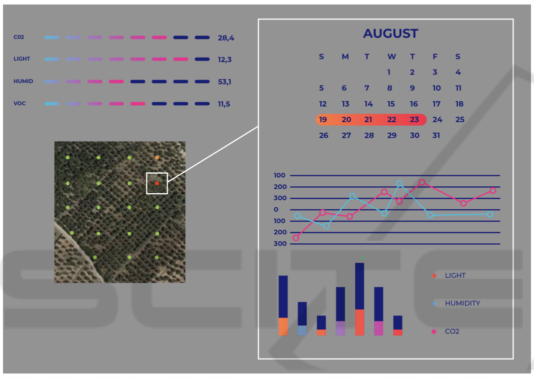

Figure 3: Example of data visualization dashboard for an olive orchard, (design elements from freepik.com).

6 MODELING AND PREDICTIVE TOOLS

We aim to build a database of health parameters and health warning rules, that depend on the geographic position of the crop and the type of cultivar. This will be obtained with an extensive analysis of the literature in the agriculture field. Moreover, farmers will be able to contribute to this database by inputting their configurations and their rules: the challenge here is to convert the farmer experience to algorithmic rules, to be able of learning from the agronomy community.

A challenging goal of this project is to be able to assist the planning of crop irrigation, fertilization and treatment: we aim to build health models able to early pinpoint the need of an intervention in an area, reducing the size of the area treated and potentially reducing the effect of the issue because of the model predictive abilities (e.g. for olive orchard (Testi et al., 2006; Moriana et al., 2003)).

7 CONCLUSIONS

In this paper, we introduced the main challenges that arise when designing a Wireless Sensor Networks for monitoring the health of a crop. In particular, we have identified the most important physicals and chemicals features that should be monitored to assess the health of a crop and potentially predict future issues. We discussed which characteristics a network node should have and the network protocols that should support.

Moreover, the use of an appropriate dashboard for the data visualization can help the user to understand the evolution of the state of health of the crop, and provide them with a tool to investigate how to optimize irrigation, fertilisation and the phytosanitary interventions in order to maximize the production and minimize the environmental side-effects. In the future, these approaches could also be directly used by farmers to improve agriculture worldwide.

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