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Development of an integrated, low-cost and open-source system for precision viticulture: from UAV to WSN

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ABSTRACT

In recent years new technologies to support agriculture are becoming more accessible. Wireless Sensor Networks (WSN) are networks of sensors located within the cultivated area able to measure, collect, process and sometimes share in real time many micrometeorological parameters. In the last years it has become possible to combine high spatial resolution images, quick turnaround times and low operational costs in order to generate useful remote sensing products for vegetation monitoring. Remote sensing platforms based on unmanned aerial vehicles (UAVs) represent a tool for this purpose, providing low-cost approaches to meet the critical requirements of spatial, spectral, and temporal resolutions needed. In the present work a low cost and open source agro-meteorological monitoring system in vineyard was designed and developed, and its placement and topology was optimized using a set of UAV-taken multispectral images.

Keywords: Unmanned aerial vehicles, Wireless sensor networks, Remote sensing, NDVI, Vigor maps, Italy.

1. INTRODUCTION

Wireless sensor networks (WSN) are composed of various sensor modules connected to a node with radio modules (motes) that transmit the data from nodes to a base station where the data is stored. A WSN can be applied to any system, but its versatility and flexibility require extensive research and development. In Precision Viticulture (PV) the WSN can be fundamental where access for the measurement of environmental parameters is difficult and when a multi-point monitoring station is necessary (Wang et al., 2006; Camilli et al., 2007; Matese et al. 2009).

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The node placement plays a fundamental role in optimizing monitoring, using as few nodes as possible. The within-vineyard variability strongly influences the micrometeorological parameter acquired in different vineyard parcel (Matese et al 2012). Sensor placement has been well studied over the years (Guo et al. 2010; Zou and Chakrabarty, 2003; Damuut and Gu, 2012), In general the sensor placement problem is solved either with a deterministic or a non-deterministic placement approach. Non-deterministic sensor placement is often referred to as random placement, while deterministic placement is often called controlled placement in some texts. In many deterministic algorithms, the positions of the sensors is optimized to achieve the best coverage, connectivity or to maximize network lifetime as the case may be.
Many protocols have been proposed to calculate the relative positions of nodes in a network. Kunz and Tatham (2012) describe categorized localization algorithms as centralized or distributed on the basis of their computational organization. In centralized algorithms, nodes send data to a central location where computation is performed and the location of each node is determined and sent back to the nodes. In distributed algorithms, each node determines its location by means of the communication with its neighbor nodes.
In this paper, a deterministic sensor placement strategy was applied using ancillary data from remote sensing images for node placement. Those images allowed the optimal node positioning in terms of maximum variability coverage within the vineyard.
Due to a lack of resolution, common satellite maps are not an ideal solution to determinate vineyard variability, for their difficulty in properly discriminating canopy from soil pixels. A solution to overtake this problem is the use of airborne remote sensing that allows working at very high spatial resolution. However, some specific limits of airborne remote sensing are still the high operational costs and the lack of time flexibility associated with the scheduling of flight plans.
In the last decades the development of unmanned aerial vehicles (UAV) platforms, characterized by small dimensions, has offered new opportunities for crop management and monitoring, capable of timely providing high resolution images, especially where little productive areas have to be monitored (Lelong et al., 2008)

2. MATERIALS AND METHODS

2.1 Experimental sites

The research was conducted on a 1.22 ha vineyard located in Tuscany (Italy) at Villa Montepaldi farm. It is cordon-trained vineyard planted in 1998 with Cabernet Sauvignon in a NW-SE direction, with vines spacing of 1.0 and 2.8 m. The main climate characteristics of the site area, according to the 30-yr mean (1961–1990), the average temperatures of the coldest (January) and hottest (July) months were 5°C and 22.2°C, respectively. Average annual rainfall was distributed over 87 days on average, with a relative minimum in summer and a peak in autumn (Matese et al. 2012).

2.2 Experimental Plan

The experimental plan consists in the deployment of a set of wireless nodes for real-time micrometeorological monitoring inside the vineyard, and involved the use of an UAV to evaluate at the beginning of the research homogeneous vigor areas in the vineyard by a preliminary drone multispectral survey.
The UAV utilized in this work is a modified Mikrokopter Hexa (HiSystems GmbH, Moomerland, Germany) six-propeller UAV (Fig.1) capable of flying autonomously to a user-defined set of waypoints (Primicerio et al., 2012).

Figure 1. Mikrokopter Hexa with custom-built camera mount.

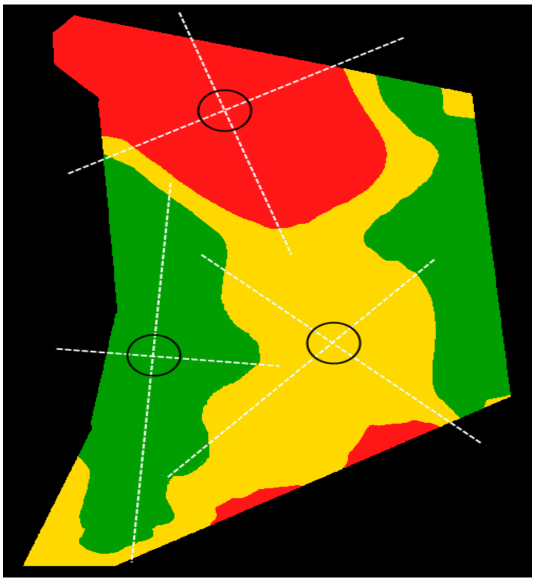

Figure 2. High(green),medium(yellow) and low(red) vigor areas with nodes positions (circles).

The drone is equipped with a Tetracam ADC-Lite camera (Tetracam, Inc., Gainesville, FL, USA) to acquire multispectral images. The images were georeferenced, orthorectified and digitally processed in order to provide NDVI maps. The NDVI map was subsequently processed to create equally populated 3-class vigor maps (Hall et al., 2003) that were used for optimal node placement inside the vineyard. Three homogeneous vigor classes were chosen inside the vineyard, and for each class, the coordinates of the centroid of the parcel with the largest area was evaluated and associated to the node placement coordinates. Then, one node for each centroid was installed in the vineyard (three in total) (Fig. 2). Centroids coordinates were estimated using MATLAB®.

2.3 WSN Deployment

A custom Wireless Sensor Network (WSN) system has been installed in the three homogeneous vigor areas identified by the UAV within the experimental vineyard, in order to test system performances in terms of micrometeorological monitoring during a 10 days period in July 2012. The system included a base station with solar radiation, air temperature, humidity, and wind sensors, and a set of peripheral wireless nodes located in the vineyard, with sensors for micrometeorological precision data monitoring.

Each station (Fig. 3) has been implemented with Arduino technology, an open-source project where ICT-Sensors models of circuits is licensed under Creative Commons. The hardware of the node utilizes a Seeeduino Stalker V2.1 (Seeed Studio) motherboard based on a programmable microcontroller ATmega328 8-bit (Atmel Corporation, San Jose, CA, USA). The microcontroller contains 32 kb of flash memory for program storage, six 10-bit analog-to-digital channels and an integrated radio module for data transmission. The base station was equipped with a GPRS module Shield V2.0 (Seeed Studio) in order to transmit data to a remote server. Each station was powered with 2W solar panel and a 6V,4.5Ah, battery.

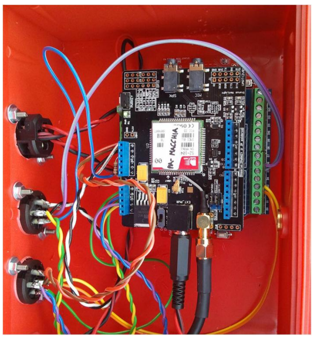

Figure 3. Arduino node

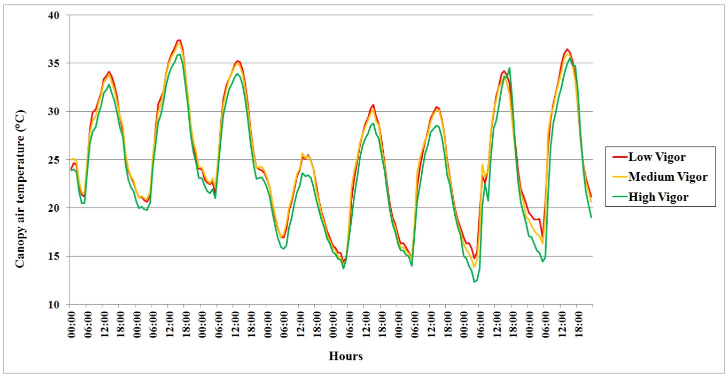

Figure 4. Canopy air temperature of the three vigor zones (1-10 July 2012).

Each node acquired three micrometeorological parameters: canopy air temperature and humidity, and solar radiation intercepted by the cluster. Temperatures and humidity parameters were measured by HTM2500LF sensor (Measurement Specialties, Inc., Toulouse, FRANCE), a dedicated humidity and temperature transducer positioned on the second wire around the middle of the curtain shaded under a solar shield. The solar radiation is acquired by a prototype sensor based on a silicon photodiode VTP4085 (PerkinElmer Optoelectronics, St. Louis, MO), with a spectral application range of 400 to 1100 nm and sensitivity 0.55 A/W (Matese et al., 2009), housed in a Teflon diffusing ball and positioned immediately above the cluster to simulate an exposed berry surface. Data collected by the nodes at hourly intervals were sent directly via wireless connection to the base station, which sent daily data to a remote central server designed for receiving, storing and processing data.

3. RESULTS AND DISCUSSION

The preliminary WSN tested in the experimental vineyard showed interesting results in terms of system performances and micrometeorlogical data acquired. A preliminary analysis of the data produced showed a significative difference in values from the different zones of the vineyard, thus validating the positioning strategy chosen.
As shown in Fig.4 air temperature data are able to differentiate the three zones in the vineyard.
The methodology presented in this work, although very simple in its principles, allowed taking into consideration the intrinsic differences in term of plant vigor of the vineyard, thus maximizing the potential resolution of the micrometeorological monitoring.
Of course, this was possible in our experiment due to the small vineyard extension that allowed a sufficient signal coverage in all the area in exam.
System performances in term of power supply and data quality were good but the system was tested only in a preliminary few days of experimentation.

4. CONCLUSION

Nowadays low installation costs allow the deployment of a multitude of sensors: it is becoming crucial to design optimal placement plans for these sensors not end up in the paradox where the multitude of information results in poorer significance. The paradigm of "low cost" and the integration of DSS (Decision Support System) data flows from WSN will make it possible the implementation of intervention strategies / response directly using real-time data.

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