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AN INNOVATIVE SYSTEM FOR VINEYARD MANAGEMENT IN SICILY

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1. Introduction

Sicily has witnessed a considerable increase in high-quality wine production during the past few years. The growing demand of the market decreed a great success for Sicilian wines, and quality standards of grapes are consequently growing higher. Wine quality depends on many factors, such as the choice of the variety, the stock, the training system, the pruning as well as the environmental parameters (with regard to micro- and macro-climate) and the cultivation techniques performed in the vineyard. The micro-climate around the grapevine, in particular, is influenced by the whole climatic parameters in the cluster area that governs its growing and ripening.

Monitoring the micro-climate of the grapevine allows to conveniently perform the most important cultivation techniques (soil management, pesticide treatments, green pruning, harvest) thus reducing the operating costs of the vineyard, and increasing the overall quality of the grapes.

In order to achieve seamless and effective monitoring, a thorough sensing of relevant physical quantities must be carried on in the vineyard, during the growth of the grapes and vines. However, this process inevitably results in collecting large amounts of data, whose relevance depends on how effectively higher-lever information can be extracted from raw measurements. As already mentioned, such information might regard land composition, the presence of parasites or the influence of the application of chemicals, all of which are extremely valuable to the enologist during decision making; more specifically, the present work describes a study on the potential correlation between local and global environmental parameters.

Improving the quality of the overall winemaking process will be achieved by using an innovative infrastructure based on Wireless Sensor Networks (WSNs) [Akyildiz 2002]. Furthermore, the same infrastructure may be used to implement a real-time, pervasive, non intrusive, low-cost, and highly flexible distributed data analysis methodology.

Wireless sensors are a class of tiny devices with programmable computing capabilities, equipped with sensing and communication features, and characterized by a limited energy supply. Common wireless sensor networks consists of a large amount of those small nodes; this pervasive technology is typically used for such tasks as environmental and habitat monitoring, motion monitoring or, more generally, tasks that require collecting data and extracting information from remote or hostile environments. Sensed data flows from remote nodes toward a sensor designated as the sink, the *base station*, that acts as a collector and an interface to the external world.

Wireless sensors are comparable to fully functional computers, hence, they are not just able to collect measurements of physical quantities mirroring the sensed phenomena, but also to perform distributed computations as those quantities traverse the network toward the sink node. Data are thus shared amongst the sensors, they may be manipulated or merged in order to reduce the overall transmissions and enhance the network lifetime.

The most relevant difference between traditional networks and wireless sensor networks is represented by their limited power supply. Typical usage of those sensors requires them to operate in inhospitable sites, so there is little room for human intervention after deployment; an obvious goal is thus the maximization of network lifetime or, in other words, the minimization of any possible waste of energy.

Recently, WSNs have also been employed in the specific area of farming monitoring and a few preliminary works describe applications for precision agriculture [Baggio 2005; Chiti 2005; Zhang 2004]. Some

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studies have been performed regarding a prototypal smart sensor array for measuring soil moisture and soil temperature; for instance scheduling irrigation in cotton is targeted in [Velledis 2008], while greenhouse climate control using wireless sensors is analyzed in [Carrara 2008]; however, applications of wireless sensors in agriculture and food industry are still rare. As regards applications involving vineyards, some researchers have studied the peculiar needs and priorities of people working in such environments in order to investigate the potential for sensor networks in agriculture using ethnographic research methods [Burrel 2004], while others [Galmes 2006] have considered the expected lifetime of a wireless sensor network deployed on a fictitious vineyard from the energy consumption point of view. Finally, an interesting application of wireless sensors in a vineyard was performed by measuring some characteristic parameters of the plants, such as leaf temperature, growth rate, diametric growth of the trunk, photosynthesis and transpiration [Masi 2007].

An immediate advantage arising from the adoption of a WSN-based approach in agriculture is that corrective actions on the cultivations may be timely and selectively chosen; furthermore, the system allows to build a history of past events, and stored data may be analyzed in order to extract potentially hidden correlations among the sensed environmental variables and the obtained results. The availability of a considerable amount of precise data, superior to what is commonly attainable through traditional random sampling, allows for the construction of accurate models, and thus favours the proposals for cultivation process improvements.

This methodology does not merely suggest to increase the granularity of sensing by deploying a large number of sensors in the environment, or to increase the sensing rate; rather, the proposed infrastructure offers the possibility of carrying on advanced analyses by acting as a more complex, intelligent, distributed system. The technical advantages arising from the pervasive control over the vineyard conditions will then allow for a rationalization of the interventions and result in an increase in the overall quality of produced wine.

The aim of the present study is to monitor the micro-climate of the grapevine in order to control spring period hazards, reducing the operating costs of the vineyard and increasing the quality of grapes. For this purpose a Wireless Sensor Network was used, and a comparison was performed between the data measured by the wireless sensors and the data provided by the fixed meteorological station of the local government agency (SIAS - Regione Siciliana).

2. Materials and Methods

The research was developed in 2008 within the VirtusVini project, which included the installation of a wireless sensors network for continuous monitoring of the most relevant environmental parameters in the vineyard at Aziende Agricole Planeta (Menfi, Sicily).

The 8-year vineyard, in the phase of increasing productivity, was trained with a hedgerow system; the planting layout was 2.50 x 1.00 m, and the variety was Chardonnay. The experimental plot, set at 220 m above sea level on average, was flat and 1 ha wide. Thirty sensor nodes were uniformly distributed over the entire area, and each node was located at the 2nd line of the hedgerow steel wires (1.00 m off the ground).

Commercially available boards were used in order to speed up the design process; however, they had to be customized due to the presence of application-specific sensors.

The requirements elicitation phase, conducted at the earlier stage of the project, had pointed out that the two most relevant factors for the development of healthy grapes are temperature and relative humidity. Nodes were thus equipped with the corresponding sensors; in particular, the *Sensirion SHT11* combined temperature/relative humidity sensors were used. Their characteristics are summarized in Table 1.

A final consideration regards the connection between the sensory network and the data storage server; this was realized through a IEEE 802.11 (WiFi) channel in order to allow future extension of the same monitoring structure to nearby fields; the bridge between the IEEE 802.15.4 network used by the sensor nodes and the WiFi one is realized by a Stargate board, equipped with both interfaces.

Different types of nodes were deployed in the main monitored area; the characteristics of their processors boards and radios are summarized in Table 2. Figure 1 shows a scheme of the actual deployment in the vineyard; all nodes were TelosB motes equipped with temperature and relative humidity sensors.

Measure	Sensor	Characteristics
Temperature and relative humidity	Sensirion SHT11	Temperature range: -40° C to +123.8° C) Temp. accuracy: +/- 0.5° C @ 25° C Humidity range: 0 to 100% RH Absolute RH accuracy: +/- 3.5% RH Low power consumption (typically 30 µW)

TABLE 1 - Sensors used in the experimental tests and their characteristics.

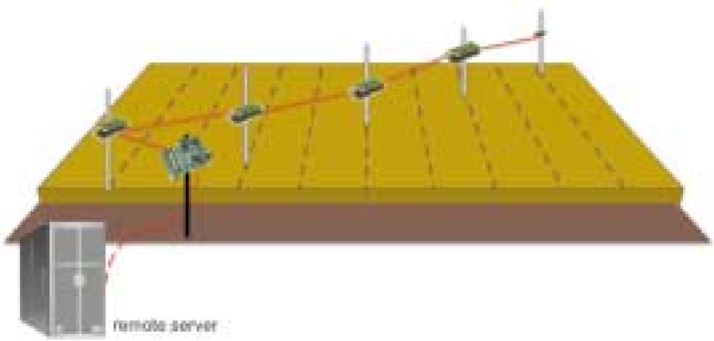

Fig. 1 - Scheme of the nodes position in the vineyard.

As regards the processor and radio units, the TelosB nodes were selected as they offer good performances in terms of transmission range; moreover they are already equipped with an integrated sensor board containing the sensors necessary to sense micro-climate-related quantities. Such nodes are commercially available and the ones used for this project are produced by Crossbow; they are fairly configurable, for instance new sensors may be added, and, above all, their behaviour may be fully programmed via an ad-hoc programming language.

In our application, the nodes' behaviour was customized to meet the specific application's needs. The sensing rate of each node was not required to be particularly high, and was set to 1 time per hour; this choice appears to be reasonable also for the goal of maximizing the network lifetime.

Nodes in the vineyard network communicate on a IEEE 802.15.4 link, but at the application layer, a specialized protocol was designed in order to ensure robust data gathering, while limiting energy consumption.

In order to optimize the overall network lifetime, we exploited some of our previous research experiences in the field of data gathering for WSNs, and implemented a customized version of our protocol for robust and energy-efficient data gathering on the nodes of both networks. As already explained, although the deployment of the nodes is statically set, both environments present dynamic characteristics, so that transmissions may still incur in losses.

Our previous work proposed a network-layer protocol for WSNs based on the IEEE 802.15.4 standard [Messina 2007]; the protocol was devised to provide reliable data gathering in latency-constrained applications, and exploited both the flexibility of the IEEE 802.15.4 MAC layer and features of data aggregation techniques, such as implicit acknowledgment of reception. The proposed protocol operates over the existing MAC layer and provides reliable communication, while managing power saving and synchronization among nodes. Without relying on MAC-layer acknowledgments, it implemented caching and network-layer retransmissions, triggered upon detection of a link failure.

The monitoring of the main environmental parameters was performed from April 17th to May 27th, which is the most critical phase for the control of the main hazards for grapevines (such as mildew, powdery mildew and grape moth) because of the special environmental conditions that may occur. In addition to the measurements of the main environmental parameters performed by the wireless sensor network, the data collected from the Sicilian Agricultural Information Service (SIAS) station located in Sciacca were examined; this was the nearest available station to the site under investigation. SIAS is a service of the Sicilian Region, Department of Agriculture and Forestry that, through the combined use of meteorological, climatic and agronomic knowledge provides a very useful support for farm management, forestry and animal husbandry. Its network is composed of telemetry stations with varying number and type of configured sensors (therefore, different meteorological quantities are detected at each station). In this study, air temperature and relative humidity, averaged over a one hour time span, were considered for the period under investigation. The aim was to compare the data collected by SIAS, covering a very wide area,

Sensor Type	CPU			Memory	Radio		
	Descr	Energy per computation	Sleep power		Description	Energy per bit	Idle power
TelosB	TIMSP430 16 bit	*Active power* 3 mW	15 µW	48KB RAM 1MB Flash	CC2420 250Kbps IEEE 802.15.4 / Zigbee	430 nJ/b	7 mA
Stargate	Intel PXA255 32 bit	1.1 nJ/instr 1 mJ/beamform	20 mW	64MB SDRAM 32MB Flash	Orinoco Gold 11Mbps IEEE 802.11b	90 nJ/b	160 mA

TABLE 2 - Characteristics of the different types of sensor boards employed in the tests.

considering that the distance between the station and the studied vineyard was about 10 km, with the precision data reported by the platform of wireless sensors installed for our purpose.

Therefore, this research was aimed at identifying possible critical locations of focus of cryptogams and/or insects that may be harmful precursors of disease and infestation to the grapevine, and whose symptoms only appear after a certain period of time, due to the long incubation phase of the parasite. In order not to compromise the quality of the product, the chose remedy implies intervening with curative treatments of systemic nature, or following the traditional technique of the treatment schedule; unfortunately, both techniques present negative effects due to potential environmental damages, and to the cost of running the vineyard.

During the observation period, the length of 70 sample buds, uniformly distributed in the plot, was also measured in order to assess the growth of the buds themselves, as this constitutes an important parameter for identifying the location of parasites.

3. Results and discussion

Collected data were divided into four decades named A (April 17th-26th), B (April 27th-May 7th), C (May 8th-17th) and D (May 18th-27th).

Figure 1 shows the average growth of the buds in the period under observation. The plot shows that the increase is higher in decade A with an increase of about 55%, followed by B which shows an average increase of 30%, and finally C where an average increase of 17% occurs. In decade D, however, the growth shows a significant slowdown (only +4%) as the plants approach the end of the flowering stage, and fruit setting begins.

Temperature and relative humidity data recorded by the 30 sensors of the wireless network showed negligible differences among them; therefore, the average values recorded by all sensors were taken into account.

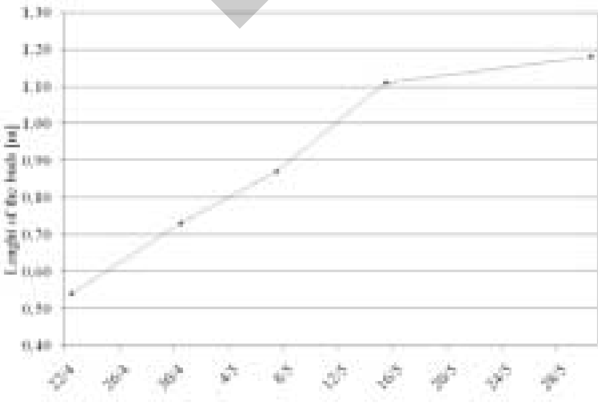

Fig. 2 - Mean growth of the buds during the examined period.

Figures 3 and 4 respectively report the average hourly values for temperature and relative humidity, both for the wireless sensors and the SIAS station.

For decade A, in which the vegetation had a very small growth, but was very sensitive to major adversities, the wireless platform reports temperature values ranging from 7°C to 36°C, while SIAS shows values between 10°C and 27°C. In particular, a larger difference may be noticed in temperature values de-

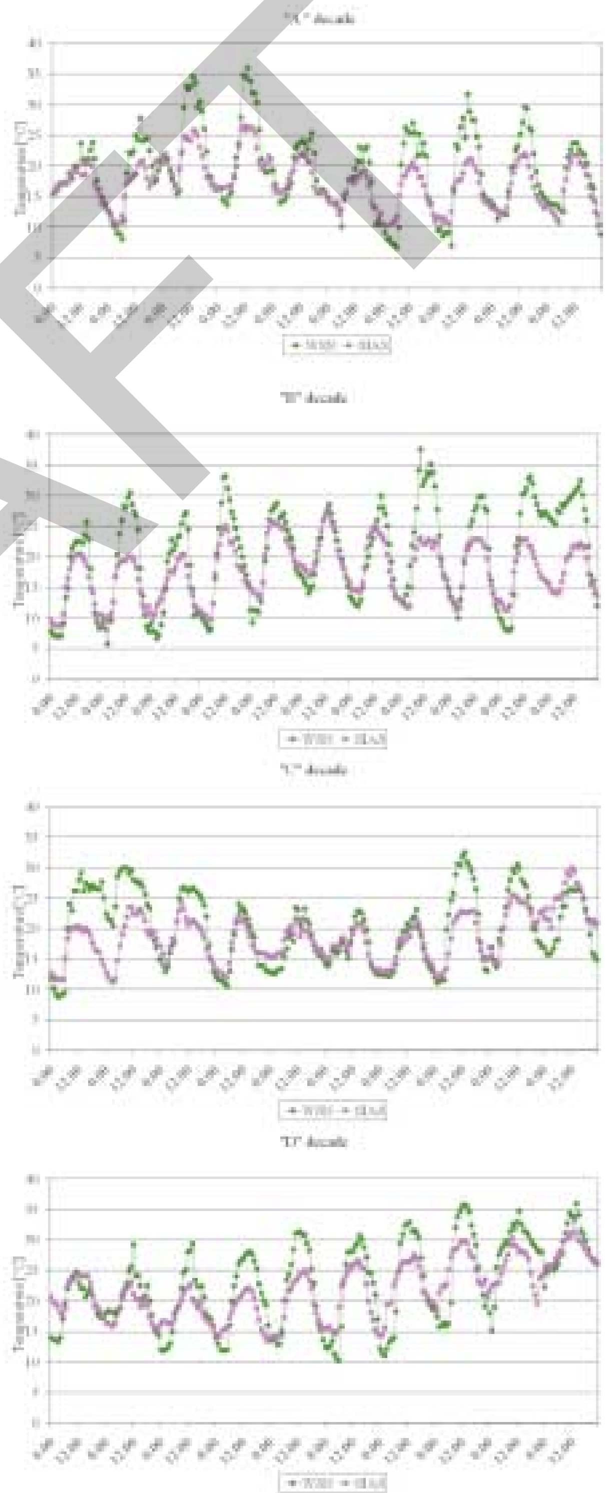

Fig. 3 - Temperature measured by the sensors.

tected by the two systems during daylight hours; there are, in fact, differences of up to 7-8°C, particularly when the temperature was higher than 20°C. In the same decade the values for relative humidity recorded by the two systems are very similar to each other. Overall, the relative humidity values in the first decade show a variability between 27% and 96%.

With reference to decade B, where the vegetation was in the full process of development, wireless sensors gave temperature variations between 6°C and 38°C, while SIAS recorded values between 8°C and 28°C. Also in that period, a considerable difference in the temperature values recorded by the two systems during daylight hours were reported; there were, in fact, deviations between the two measures of up to 15°C, when the temperature was higher than 20°C. In the same decade, the relative humidity values measured by the two systems are very similar and show a variability between 19% and 95%.

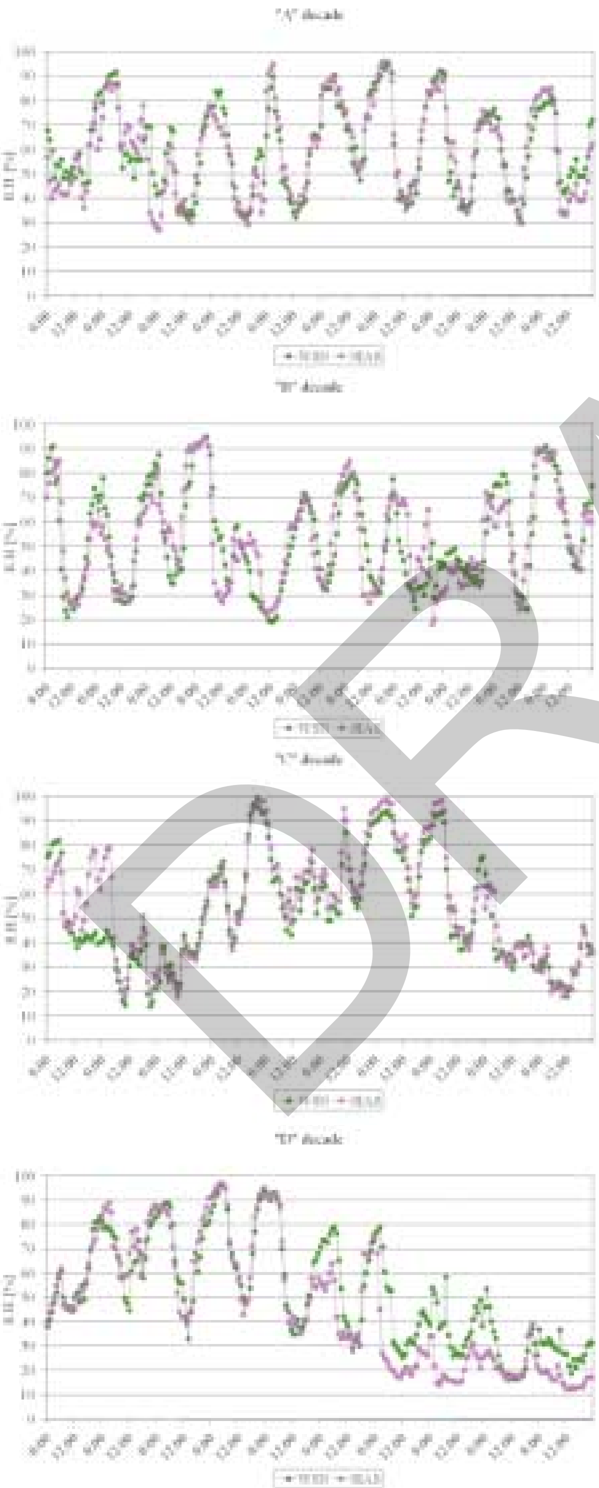

Fig. 4 - Relative humidity measured by the sensors.

In decade C, when the development of vegetation continued, the wireless sensors detected temperature values between 9°C and 33°C, while values recorded by SIAS were between 11°C and 30°C. Again, there was a noticeable difference in the temperature values recorded by the two systems during daylight hours; the maximum difference between the two measures was 10°C. During the same decade, the values for relative humidity recorded by the two systems are similar, with a variability between 15% and 99%.

With reference to decade D, where vegetation development significantly slowed down, the wireless platform provided temperature values with a variability between 10°C and 36°C, while SIAS recorded temperature values between 13°C and 33°C. During daylight hours there were major differences in the temperature values recorded by the two systems of up to 6°C. The values for relative humidity recorded by the two systems in decade D are very similar to each other, and show a variability between 14% and 97%.

4. Conclusions

The aim of this work was to monitor the main environmental parameters of the vineyard, in order to control the more common hazards of the grapevine for the period under consideration.

The following considerations can be drawn from the presented research:

– with reference to temperature, the data measured by the wireless sensors showed considerable differences compared to the data of the SIAS measuring station especially for temperatures above 20°C, the maximum deviation between the two measures was equal to 37%;
– with reference to relative humidity, the difference in data measured by the two types of sensors amounted to no more than 27%.

These differences are certainly to be attributed to the different methods of collecting environmental data for the two systems: the SIAS includes a portion of territory several tens of hectares wide through traditional hut weather. The WSN, on the contrary, allows for timely detection of the basic environmental parameters for the sustainable management of agriculture.

In conclusion, by continuously monitoring the environmental parameters within the vineyard it is possible to obtain useful information concerning the potential arise of serious hazards for grapevines. Our study showed that the microclimate of the vineyard may be considerably different from the climate of the macro-area closest to the plot. Monitoring the microclimate may thus be crucial as it may represent the key to a rational management of the vineyard, also with regard to a reduction of the costs of certain cultural operations.

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Summary

The aim of this study was to monitor the micro-climate of the grapevine in order to detect the adversities of the spring period (especially April and May), while reducing the operating costs of the vineyard, and increasing the overall quality of grapes. For this purpose a Wireless Sensor Network (WSN) was used. Furthermore, a comparison was performed between data measured by the wireless sensors and data provided by the fixed meteorological station of the Regione Siciliana (SIAS).

Keywords: Vineyard, Wireless sensors, Environmental parameters.