

# Wireless Sensor Networks for Climate Data Management Systems

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**Abstract:** This paper presents a framework for wireless sensor networks designed to capture and monitor micro-climates in a crop field. Recent developments and advances in wireless technology as well as affordability give rise to this emerging field in the realm of precision agriculture. The main purpose of this research is to develop an efficient telemetry system for measuring and storing micro-climates and environmental data. The data collected is to be used for building various models that could enhance our understanding about the effects of climate change on grapevine growth and wine quality within major wine regions in several countries being studied in the initial research.

We propose a system architecture for wireless sensor networks and a database model for handling and storing sensor data streams in real-time. This architecture utilises Wireless Sensor Networks (WSN) located in several vineyards in three continents. It collects data from WSN and continuously transmits physical or environmental conditions at different locations to a remote central data server. A web based application developed to enable remote online access to WSN data with interactive data retrieval and visualization functionalities.

**Keywords:** - vineyard monitoring, wireless sensor network, weather data, precision viticulture.

## 1. INTRODUCTION

The rapid development in wireless communication and embedded micro-sensing technologies in recent years has made wireless sensor networks possible. A Wireless Sensor Network (WSN) is a network consisting of a large number of distributed wireless sensor devices. WSNs can be used in various monitoring situation where sensors are usually stationary. WSNs have been employed in both military and civilian applications such as target tracking, habitat monitoring, environmental contaminant detections and precision agriculture (Camilli *et al.*, 2007, Xianghui Cao *et al.*, 2008).

Communications in WSNs are data-centric and intended to deliver collected data to a central location for storage, mentoring and further data processing. There are resource-constrained in dealing with storage space, processing power for sensor nodes, communication bandwidth, and energy. There are number of challenges in research and real world implementations of WSNs. Sensors are usually powered by batteries which have limited power. Thus, sensor hardware and protocol design to save the limited energy and affordability becomes an important issue. The other issues include improving network's stability and robustness enabling self organizing and recovery capabilities. This gives rise to new challenges in information processing and data management in large-scale sensor networks. In-network data processing techniques, from simple reporting to more complicated collective communications, such as data aggregation, broadcast, multicast and gossip should be developed. On the other hand, data collected by sensors can intrinsically be viewed as signals. By exploiting signal processing techniques, collective communications can be done in more energy-efficient ways. Moreover, distributed data management schemes need to be devised when sensed data is collected from different sources at different rates.

This paper outlines an implementation of WSNs proposed in (Shanmuganathan *et al.*, 2008) as part as a wider project referred to as Eno-Humanas (see [www.geo-ingormatics.org](http://www.geo-ingormatics.org)). It presents implementation of WSN system within selected vineyards located in three continents (South America, Asia an Australisa). A web application is developed to provide end users with near real-time data acquisition and visualization capabilities.

## 2. WSN IN PRECISION AGRICULTURE

WSN deployed in croplands, orchards, and vineyards are used for monitoring site conditions (mainly of environmental, weather and atmospheric) with parametric variables, such as air, soil-moisture, soil-temperature, solar-radiation, relative humidity, wind and terrain properties, for management decision making purposes. For instance, in temperate regions, severely cold winter temperatures can significantly impact grapevine productivity through tissue and organ destruction caused by freeze injury (Goffinet, 2008). Hence, viticulturists need to decide on when to begin one or a combination of the following active frost protection measures to avoid any freeze damage as soon as a warning has been issued in the weather forecast:

- *fog or smoke* clouds to reduce radiative heat loss from the surface.
- *wind machines*: on calm, clear nights, the air layer near the ground is colder than that of aloft, causing a temperature inversion. Wind machines or flying helicopters are used to bring the warmer air down to the crop level to replace the cold air layer at the surface, effective with large temperature differences between air layers near the surface and those up higher. Equipment and operating costs are high. Effectiveness varies in the range of 1 °C to 4 °C.
- *sprinkling*: very low rates of water applied through irrigation can be effective in preventing freeze damage through the release of heat during cooling and freezing. Effective range has been reported as low as -60C for low growing berry and vine crops, when 1.5 to 2.5 mm per hour of water was applied.
- *heating*: intended to add enough heat to the layer of air surrounding the crop and through radiant heat to the crop to maintain the temperature above the freezing point

In a similar manner, WSN could be used for a wide range of possible sub programmes such as, in crop sensing (stress, nutrient yield, potential) environmental (soil-moisture, compaction nutrient and disease), Seeding (seed bed preparation-seed zone versus rooting zone management, placement in the profile, moisture seeking, uniformity across machine) fertilising (placement in profile), spraying (incorporation into soil profile, spot spraying) mechanical weed control (inter row and inter plant), harvesting (quantity and quality assessment and separation) that could enable agriculturists and horticulturists in their daily on-farm

operations as well as decisions relating to the long term management of the farm, such as economic viability of a pest control measure (Mcbratney *et al.*, 2005 and Ankur Suri *et al.* 2006).

### 2.1. WSN and Sensing in Precision Viticulture

As described earlier in this section, the use of WSN for monitoring a variety of site conditions for on-farm decision-making in Precision Agriculture (PA) is becoming feasible and cost effective. With the recent advent of low cost, low powered remote sensor nodes, a significant increase in the extent of coverage area and the number of sensor parameters measured at real time could be observed. In view of this fact, three scenarios that explain the benefits and constraints of remote wireless sensor deployment in viticulture are outlined herein.

### 2.2. WSN in Vineyard Monitoring

Vineyard monitoring is an emerging application field in PA. Applying a ZigBee<sup>TM1</sup> (Wang *et al.* 2006) multi-powered wireless acquisition device as a precision viticulture tool, local grapevine growers from the world's oldest Demarcated Region of Douro, are able to learn more about the natural variability of their vineyards that is described to be challenging due to the region's unique topographic profile, pronounced climatic variations and complex soil characteristics (Morais *et al.*, 2008). The research conducted at laboratory and in-field setups shows how the variability of all these conditions could be measured via a mesh-type ZigBee<sup>TM</sup> network consisting of MPWiNodeZ element as acquisition devices, to improve quality and quantity of their products. There are two major features that could be considered as significant in this MPWiNodeZ device:

- 1) the nodes powered by batteries are recharged using energy harvested from the surrounding environment. Three possible sources, namely, photonic, kinetic and with potential to obtain from moving water in the irrigation pipes from wind, all of this without any replacement, and hence involve no labour cost.
- 2) simplistic and compliance to IEEE standards along with an ability to accommodate nine sensors.

Many proprietary and open technologies are in use for observing, communicating, analysing and reporting these variables. Several international initiatives have created the conditions for interoperability among these systems at technical, organisation and political levels. Examples include the Global Earth Observation System of Systems, the Open Geospatial Consortium's, Sensor Web Enablement (SWE) initiative (OGC SWE, 2007). SWE allows for the integration and analysis of streams of sensor data from multiple and diverse sensors in a standards-based and thus interoperable manner (Fleming, 2007). Collection, management and analysis of these data can be automated and adaptive, handling the disruption of service from some sensors or the addition of new sensors.

This research project is a prototyping effort to show the industry how state-of-the-art devices could be used in precision viticulture as a management tool to improve their yield in terms of quality and quantity hence we do not intend to abide by any industry standards at this stage.

## 3. MODELING THE EFFECTS OF CLIMATE CHANGE

The WSN ability to capture and relay real time data for analyzing the variability in climate change and its effects on plant physiology in this case, in different grapevine varieties simultaneously is significant. This is because modeling the relationships between the climate change, its variability captured in weather and atmospheric conditions and the surrounding environment using parametric variables along with their effects on grapevine and wine quality requires both data on the cause and effects recorded without any time discrepancies and of course with spatial information. Gaining more insights into natural systems and their functioning including climate change involves many complex, dynamic and diverse processes with nonlinear interactions that pose huge challenges to modelers (Ankur Suri *et al.*, 2006). Apart from the complexity, understanding the relationships between complex natural process actions and reactions often described with terms such as "cryptic and chaotic" requires that data captured for modeling, to be reflective of spatial and temporal variations and that this time and spatial variations match the plant responses sensed in quantifiable

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<sup>1</sup> ZigBee is one among the various standards established for wireless communications by IEEE, the major ones being LAN, IEEE 802.11b ("WiFi") ([IEEE, 1999b](#)) and wireless PAN, IEEE 802.15.1 (Bluetooth) ([IEEE, 2002](#)) and IEEE 802.15.4 (ZigBee), more widely used for measurement and automation applications.

parametric variables; this has been considered to be as challenging, if not impossible until recently. With the advent of low powered low cost multifunctional wireless sensors (telemetry devices/ nodes) with more computing, data logging and relaying capabilities and their convergence with the Internet enable the capture of data required for analyzing the complex processes such the one being studied in this research, the effects of climate change on grapevine plant growth and wine quality.

A wireless network, such as the one discussed herein will enable the vineyard management to decide on the kind of measure (i.e., sprinkler system, gas/ turbine heaters/ helicopter and a schedule) required to prevent freeze damage to the crops. Further details on the frost prediction and wireless sensor network issues could be found at (Sallis *et al.*, 2008). Modelling macro-micro climate change effects is being contemplated with the use of WSN data obtained from vineyards located in three continents. This allows observing the variability in global climate change across the continents using prediction model values provided by NASA and other institutions. The models and results would be used in a comparative analysis on climate change effects on viticulture, especially its variability and its influence on grapevine “cultivars” or varieties and wine quality, such as aroma, colour and mouth feel as climate change effects on viticulture is described to be dramatic and varying across the globe significantly.

### 3.1. The WSN Network

The proposed WSN system consists of sensor nodes located in critical locations within vineyards for collecting weather, atmospheric and environmental data as well as plant related data such as leaf wetness and sap flow. Figure 1 shows the system architecture consists of three layers namely, mote layer, server layer and application layer.

*Mote layer:* This layer consists of all the wireless sensor nodes and a Base Station (BS). Each node has one or more sensors plugged into the hardware device with a transmitter, power supply (usually a small battery) and microcontroller. The nodes are distributed over an area of interest with special arrangement provided the distance from sensor devices do not exceed the maximum communication range. Therefore, energy optimized routing becomes essential. Data transmission from sensor nodes to the BS depends on application maybe continuous, event driven, query-driven or hybrid. In continuous approach, data is transmitted to the BS periodically according to predetermined intervals. In query and event driven

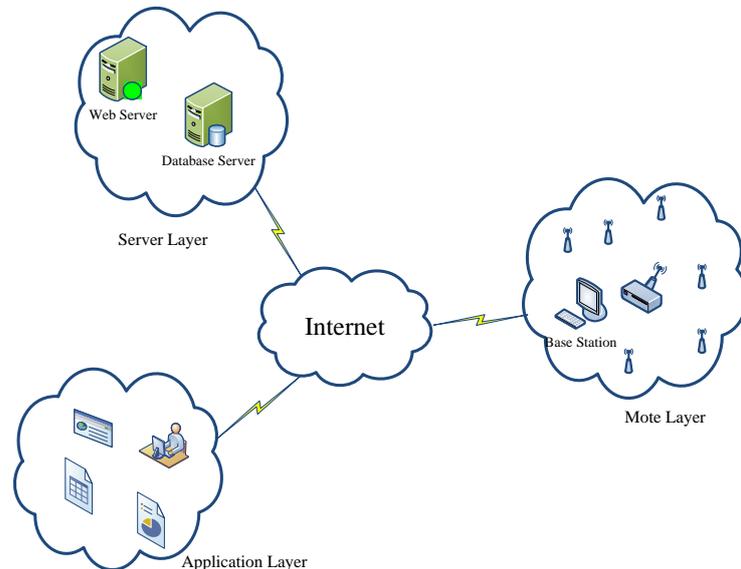


Figure 1: System architecture

models, data is transmitted when an event take place or query is generated from the BS. Hybrid model uses combination of these approaches to transmit data from sensor nodes to the BS. Various types of routing protocols such as data-centric, hieratical and location-based protocols are available (Ankur Suri *et al.*, 2006).

*Server layer:* Data are sent to the data server from the BS through the internet. Two main tasks performed by data server are to:

- 1) obtain and process data from the BS.
- 2) populate database with WSN data and enabling the application layer to access WSN data.

Server layer also deals with on-time data delivery from the BS and generates alarm when an undesirable event takes place.

*Application layer:* This layer allows users of the system have remote access to WSN data using web browsers. This provides a powerful tool to visualize real-time WSN data and compare data from various nodes. In addition, the BS can be accessed remotely to modify sensor nodes' configurations.

#### 4. IMPLEMENTATION

In implementing the WSN described in Section 3.1 for monitoring environmental parameters within vineyards, commercially-available hardware was used. To conduct this study, nine vineyards were chosen in four countries (Chile, Uruguay, Japan and New Zealand, see [www.geo-informatics.org](http://www.geo-informatics.org)). One sensor node for each vineyard has been installed at initial stage of WSN implementation.

##### 4.1. Hardware Structure

The sensor nodes are small battery powered devices allowing wireless communication capabilities (see Figure 2). Sensors may be configured to send data to the BS in following manners:

*Periodically:* sensor node sends data according to predetermined intervals.

*Event-based:* sensor node starts sending data when a specific requirement is met. For instance, there may be no need for sending data to the BS unless temperature drops below a certain threshold in frost prediction task.



Figure 2: Soil moisture sensor and WSN unit with microprocessor, transmitter, battery and built-in sensors for monitoring atmospheric temperature and humidity.

In this study, data are sent to the BS periodically at various intervals for different sensors. In addition, an ultra light minicomputer with wireless communication capability is used to receive sensed data from sensor nodes. The BS also can be accessed remotely via internet to upload WSN data to the main off-site server.

##### 4.2. Database Design

Figure 3 illustrates the entities and their relationships relating to the WSN data acquired from each vineyard's BS. The parameters being monitored from various sensors include:

- Temperature
- Wind Speed
- Wind Direction
- Wind Chill
- Humidity
- Solar Radiation
- Rainfall
- Barometric Pressure
- Soil Moisture
- Soil Temperature
- Leaf Wetness
- Sap Flow (volume and speed)
- Chromatographer

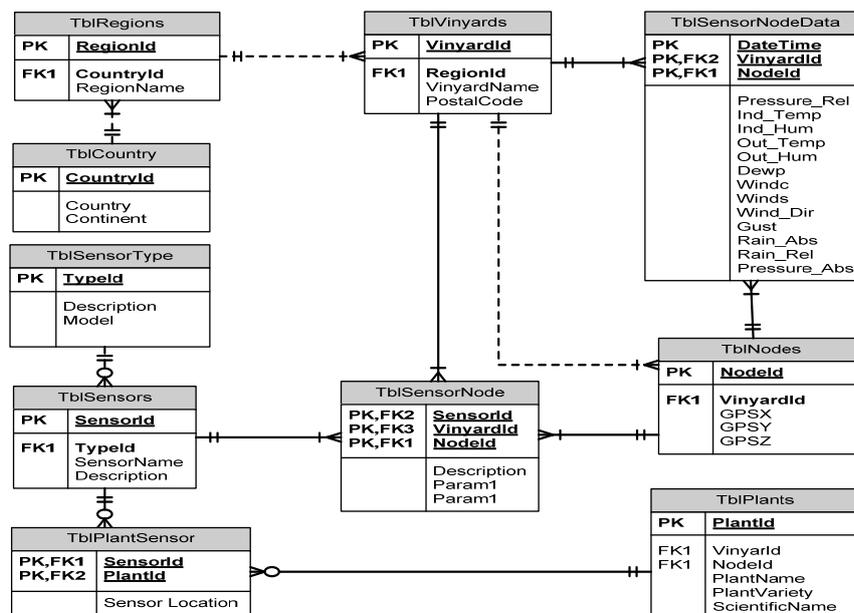


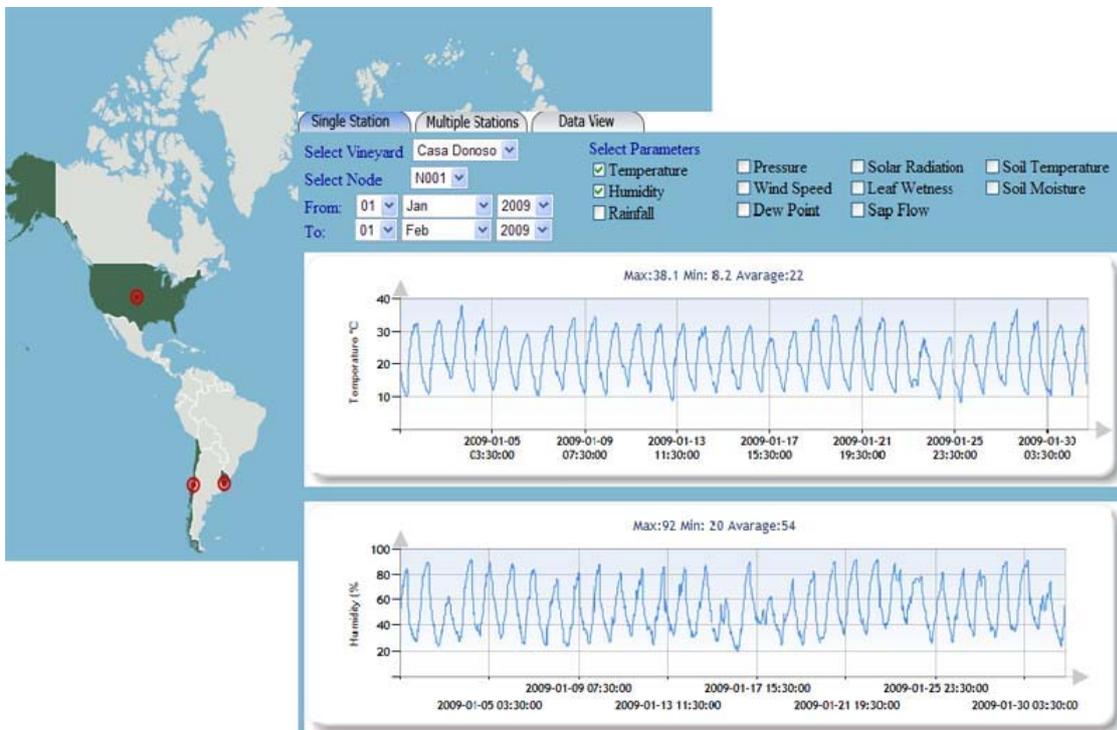
Figure 3: Database entity relationship diagram showing the relationships between the entities on WSN data obtained from vineyards located in various countries.

Each node may associate with one or more sensors. Some sensors may associate with a plant that being monitored (e.g. measuring leaf wetness and sap flow). In this study, data transmission to BS interval for climate data was set to one minute. The database was created using MySQL, a free and popular open source server.

The database comprises 10 tables and resided in Linux server environment. TblNode contains information about a particular node including GPS coordinates. A node may associate with one or more sensors. TblSensors contains information about various sensors type (i.e., sensors for temp, humidity, wind-speed, rainfall, etc). TblPlants contains all information about a plant being monitored. TblCountry contains name of all countries with their codes. TblRegions contain regions within each country. TblSensorNodeData contain all the captured data from various sensors.

#### 4.3. Web Access to WSN Data

Data stored in SQL database is readily available for further analysis and turning it into useful information. A web application was developed enabling users to access the WSN data over the internet. This interface was written in ASP.NET and C# to allow users interactively chose desired parameters and plot the results. Figure 4 shows a screenshot of database query to visualize temperature and humidity from a sensor node in a chosen vineyard.



**Figure 4:** Screenshot of a web-based visualization of Temperature and Humidity obtained from a WSN located in a vineyard in Chile.

#### 5. CONCLUSIONS AND FUTURE WORK

In this paper, a WSN system capable of monitoring and processing data from number of sensor nodes located in vineyards in three continents. The paper investigated the recent advances in remote wireless sensor devices, and how WSN of these devices could be combined with the internet and used in on-farm operations, such as management decision making, by monitoring weather, atmospheric, environmental conditions and plant physiology, and also for online display of climate information at larger scales, such as regionally within a state and cities in the Asia Pacific Region.

It is also possible that using the data collected with such WSN and from an example proposed herein relating to complicated natural processes could be modeled to gain more insights into these processes, such as the effects of climate change on grapevine and wine quality.

Further work will require additional nodes per vineyards to provide precise environmental data and stable data delivery for reliable on-line monitoring. The web-based monitoring can be further enhanced to include

various functionalities allowing users to send query to server. The server side may include procedure to generate and send warning (Via SMS or email) messages to relevant users when undesirable events are detected.

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