Sensors for modeling the effects of climate change on grapevine growth and wine quality

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Abstract: - This paper describes recent advances in sensor technology and wireless radio frequency (telemetry architecture) with the capability for measuring climate change with weather and atmospheric conditions. When combined with GPS (global positioning system) functionality enabling geo-referenced information to be gathered and analysed in real-time, new opportunities emerge for the development of wireless sensor networks (WSN) for decision making in precision agriculture (PA). The use of WSN technologies in precision viticulture (PV) to date is mostly confined to on-farm and narrow regions within a city or in the case of a larger region the data collection is limited to monitoring weather conditions alone. This paper reviews three application scenarios: a) within a vineyard b) regionally within the state of Washington in the USA and c) cities within the Asia Pacific Region. It then details the development of a system proposed for comparative analysis of viticulture management information from two countries, namely Chile and New Zealand that have the same latitude but are at different longitude points. The paper looks at a variety of remotely located real-time sensors (telemetry devices), associated hardware devices (server, workstation, architectures and topologies) and software suitable for data collection, logging, distribution and streaming. Data gathered by the sensors is relayed via a series of repeaters to a workstation, which logs the data and is connected directly to the Internet for transmission to a server acting as the final collection and data analysis point for a comparative information matching synthesis. The data collected is to be used for building models that could enhance our understanding about the effects of climate change on grapevine growth and wine quality within major wine regions in the two countries being studied in the initial research. Finally, the paper describes variable parameters considered for analysis in this research so far in relation to plant growth, weather, climate, atmospheric influences such as climate change, pollution and also wine quality factors such as soil, terrain and grape variety.

Key-Words: - Telemetry devices, plant growth factors, weather data, GPS, precision viticulture and GPS.

1 Introduction

Recent technological advances in remote micro-electro-mechanical systems (MEMS), digital electronics and wireless radio frequency technologies with GSP information, their functionalities combined with the Internet, provide opportunities for the development of multi function sensor nodes wireless telemetry networks for use of these devices in a wide range of application areas, including Precision Agriculture (PA) [1]. The deployment of small sized low-cost and low-powered multifunctional sensor nodes, designed to communicate undeterred in short distances is increasingly seen as feasible, particularly because of the node-to-repeater-gateway topology enabled by wireless sensor networks (WSN). Sensor nodes of contemporary design consist of sensing, data logging and processing, with communications components, all contained in very small devices. These are available at steadily decreasing manufacturing and maintenance costs with longer battery life and energy optimisation features. [2 3]. Recent studies reviewed in section 2 show how WSN with remote real-time sensor nodes can serve as a useful tool in precision viticulture (PV). They could enhance on-farm management decision making, such as the engaging an helicopter to disperse cold air mass for avoiding frost, and with the use of the Internet, to streamline the data collected through sensor networks and display them online, the latter regionally within the state Washington in the USA and in cities from the Asia Pacific Region, mark a significant improvement over its traditional use [4,5].

Apart from the benefits multifunctional WSN can offer to grapevine growers in vineyard management, data gathered through telemetry devices can be used to model important and interesting aspects that link viticulture practices and enology, one such significant aspect being the ability to model the effects of climate change on grapevine growth and wine quality for the world's major wine growing regions. The variability of climate change across the globe is inconsistent [6] and so are its effects on plant growth. In the case of a vineyard, during berry ripening atmospheric conditions influence the berry components, such as sugar and proteins levels that form the wine aroma and color which in turn define the fineness of the wine. This notion of linking vineyard conditions and berry components to wine quality comes from the centuries-old Mediterranean *terrior x cultiva* concept (for details please see [7,8]). Sections 3 and 4 detail a WSN proposed for modeling the effects of climate change on grapevine and wine quality in different wine regions using example data deemed as reflective of the factors related to the concept and in this example being collected from vineyards in Chile and New Zealand that have the same latitude but with at different longitude points. The paper looks at the WSN sensor components, associated hardware, software, for data collection, logging, distribution and streamlining the data monitored from remote sensors to a central server system for comparative analysis of weather, climate, atmospheric influences on plant growth, berry components (formation of sugar and proteins) and wine quality, such aroma, colour and taste.

2 WSN in precision agriculture

WSN deployed in croplands, orchards, and vineyards, are used for measuring site conditions, (mainly using environmental, weather and atmospheric data), using parametric variables, such as air, 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 [9]. 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:

1) fog or smoke clouds to reduce radiative heat loss from the surface.
2) 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 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 to 4 degrees C.
3) 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.
4) 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 10

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 [11,12].

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 PA is becoming feasible and cost effective endeavor. With the recent advent of low cost, low powered remote sensor nodes, a significant increase in the extent of coverage area and the sensor parameters measured at real time and remotely 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 and sensing in vineyards

Using a ZigBee[1] [13] multi-powered wireless acquisition device as a PV 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 [14]. The research conducted at laboratory and in-field set ups shows how the variability of all these conditions could be measured via a mesh-type ZigBeeTM 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, possibly three sources, namely, photonic, kinetic and with potential to obtain from moving water in the

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[1] 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.

irrigation pipe 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.

2.2 Regional and on-farm WSN in Washington

The WSN system being implemented in agricultural applications consists of two major networks 1) regional AgWeatherNet, an agricultural weather network, for the Washington State, and 2) on-farm AgFrostNet, used for mobile, real time farm operations [4]. This is a collaborative research effort by the Agriculture and Extension Centre, Washington University and Washington Tree Fruit Research Commission, C&M Orchards as well as USDA Cooperative State Research, Education and Extension Service, initiated to upgrade the Public Agricultural Weather System (PAWS) in Washington State. PAWS, originally installed in the mid 1980s, to provide weather data and related information on an Internet website, lately developed problems with its aging telemetry devices and this led the authorities to venture into the new WSN system. The two networks have been successfully implemented, except for sensor node power issues, for full details please see www.weather.wsu.edu. Sensors currently supported by the on-farm WSN are able to monitor: air temperature, leaf wetness, relative humidity, rain gauge, wind speed, wind direction, soil moisture, pressure and switch closure with other forthcoming. The main interest of the frost protection application is monitoring air temperature; the node is designed to monitor other sensors useful in frost/ freeze production, such as wind speed and combined air temperature/ relative humidity for calculating the dew point.

2.3 WSN in the Asia Pacific Region

A complete Internet based GPRS solar powered weather station developed by **Harvest** [5] is described to be capable of reporting real time weather data through web pages every 60 minutes. This also has an ability to issue frost alarms immediately. The basic unit has sensors for temperature, rain fall, wind speed and direction, soil moisture and humidity for calculating the dew point temperature. The website consists of live data gathered from stations installed in China, New Zealand and Australia displayed using graphs and bar charts all for weather conditions alone. The basic unit supports up to five sensors, three wireless and two wired, however the unit and the other accessories required to set up are expensive, hence their use could not be cost effective in precision agriculture/ viticulture.

3 The proposed WSN system

The WSN system proposed herein is designed to capture and relay data on weather and environmental conditions, the major influencing factors that reflect the climate variability, and their effects on phenological stages of various grapevine varieties to local work stations and then to a central server. All these variables are measured simultaneously through sensors attached to nodes located in vineyards and relayed in real time via repeaters, gateways and the Internet (Fig. 1).

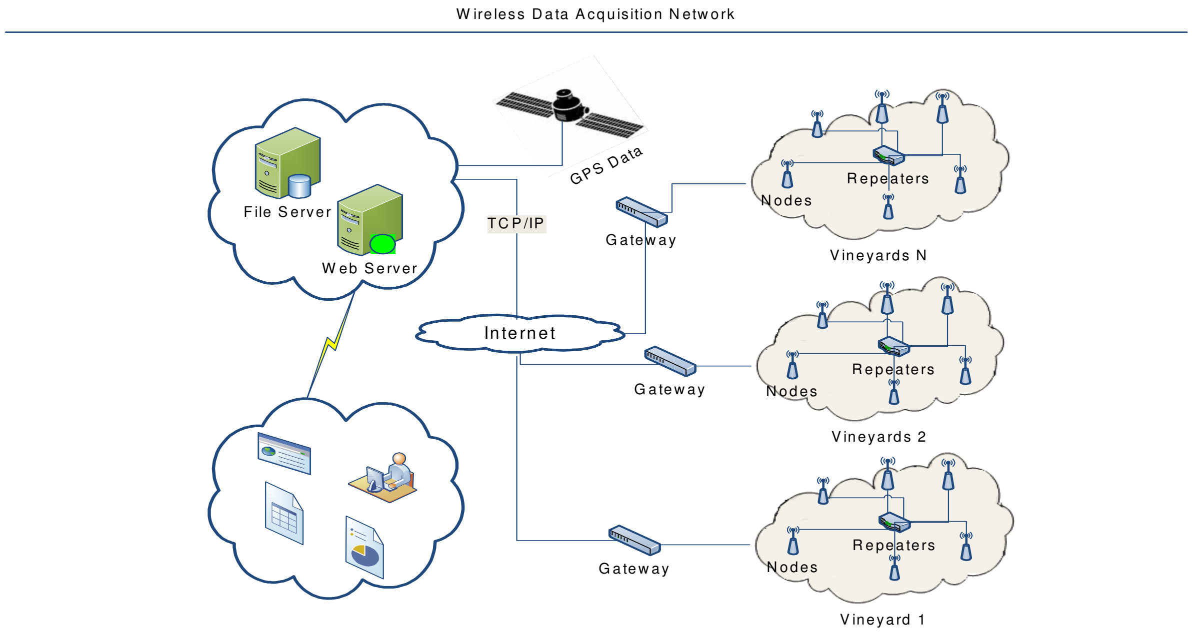


Fig 1: A schematic diagram of WSN layout for modeling the influence of climate change in weather, atmospheric and environmental conditions and on grapevine varieties and wine quality in different styles. The WSN transmits real time data collected through remote, wireless telemetry devices via repeaters, gateways and the Internet to a central sever for display and comparative analysis on the variability in climate change across the world's major wine regions and grapevine varieties.

Fig. 2: WSN unit with microprocessor, transmitter, battery and built-in sensors for monitoring atmospheric temperature and humidity and wired sensors for wind speed/ direction and

Fig. 3: Wired sensors for monitoring soil temperature and humidity.

3.1 The WSN network

The proposed WSN systems consists of networks with sensors, transmitters and repeaters located in critical locations within vineyards for monitoring weather, atmospheric and environmental factors as well as sensing plant responses. So far, in this initial stage, sensor nodes have been installed in locations chosen for this research in Chile and New Zealand.

Each WSN node refers to a location where one or more sensors plugged into the WSN unit. Each node could consist of one or more sensors. Some sensors could be used for sensing plant variables being considered for modeling. Data captured by each sensor is transmitted within an interval as low as 10 second.

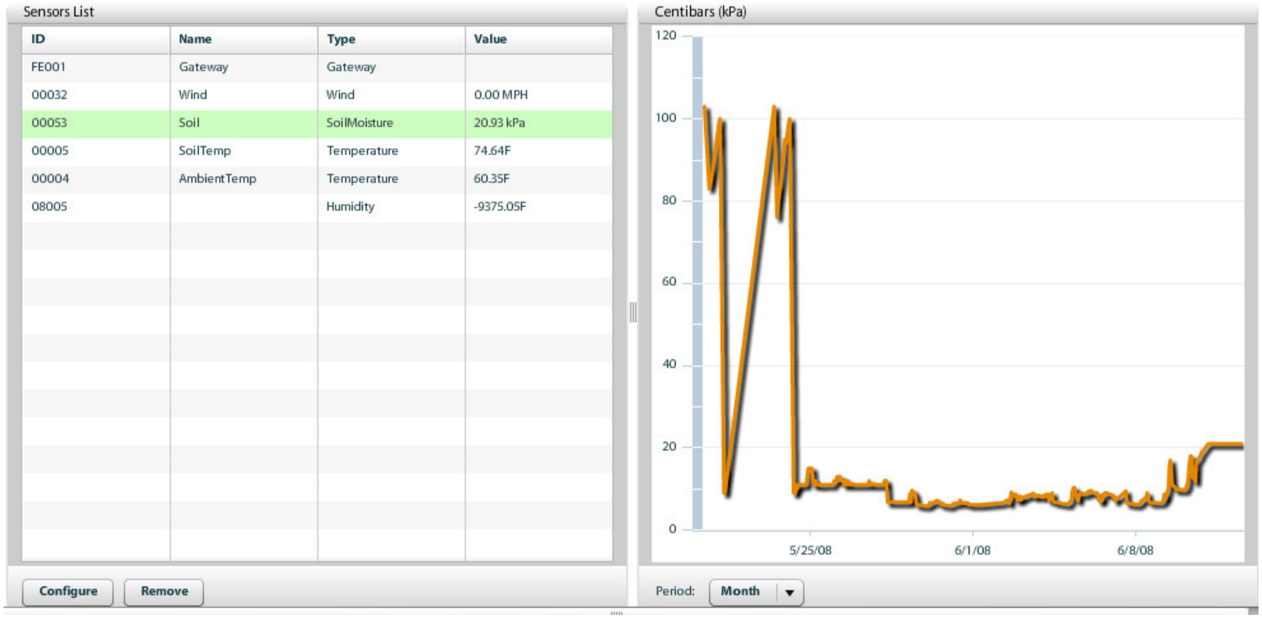
3.2 The WSN Sensors

The database design (Fig 5) details the entities and their relationships relating to the raw data being monitored on major influences in weather, climate, atmospheric conditions due climate change or pollution and sensing plant physiological changes, such as sap rise, using the sensors. The parameters measured from various sensors include:

1) Temperature
2) Wind Speed
3) Wind Direction
4) Wind Chill
5) Humidity
6) Solar Radiation
7) Pollution factors(CO_2)
8) Rainfall
9) Pyrheliometer
10) Barometric Pressure
11) Soil Moisture
12) Soil Temperature
13) Leaf Wetness
14) Sap Flow (volume and speed)
15) Dendrometer
16) Chromatographer

4 Modeling the effects of climate change

The WSN ability to capture and relay real time data (displayed online) for analyzing the variability in climate change in the world's major wine regions 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 non linear interactions that pose huge challenges to modelers [12]. Apart from the complexity, understanding the relationships between complex natural processes 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 parametric variables; this has been considered to be a challenging, if not impossible until recently. With the advent of low powered low cost multifunctional wireless sensors (telemetry devices/ nodes with more computing and data relaying capability and their convergent 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.



ID	Name	Type	Value
FE001	Gateway	Gateway	
00032	Wind	Wind	0.00 MPH
00053	Soil	SoilMoisture	20.93 kPa
00005	SoilTemp	Temperature	74.64F
00004	AmbientTemp	Temperature	60.35F
08005		Humidity	-9375.05F

Fig 4: User interface for displaying the various data being collected from vineyards in Chile and New Zealand

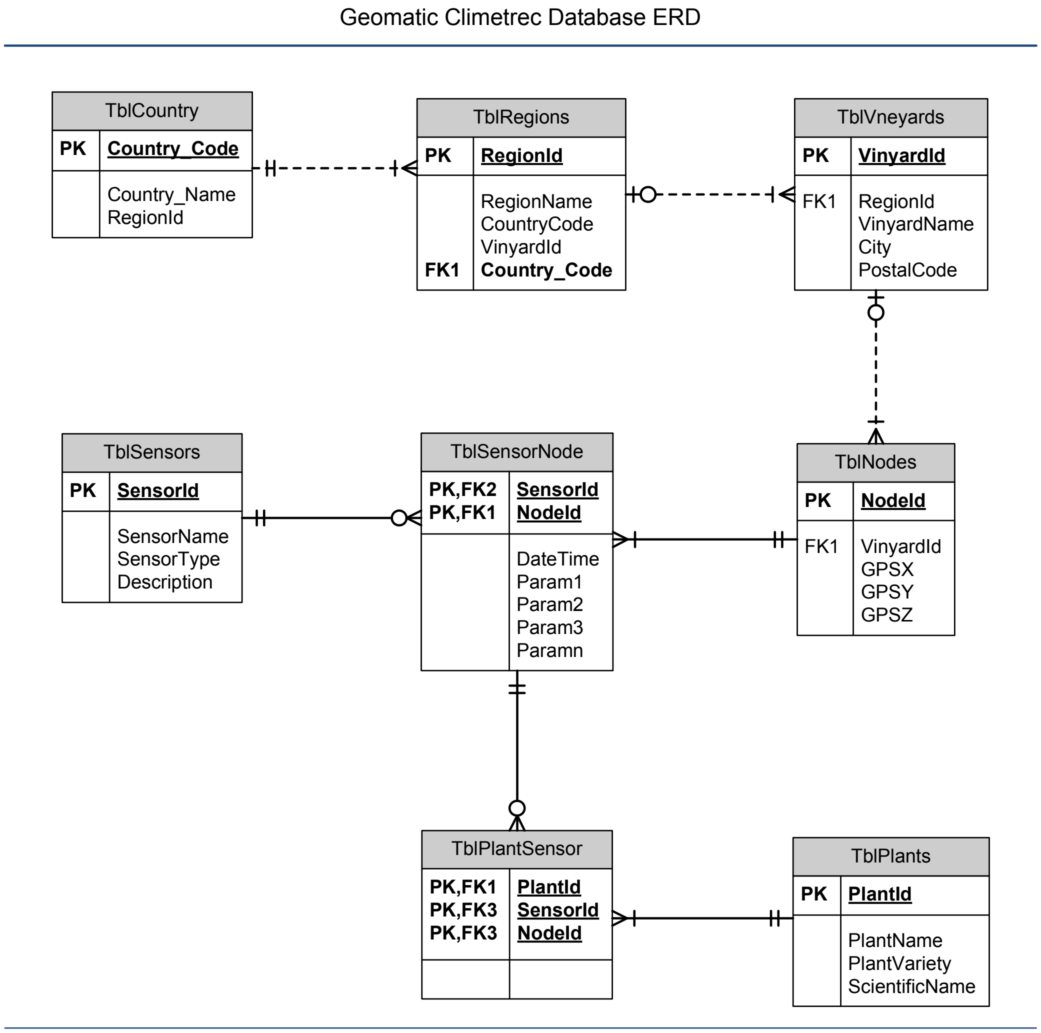


Fig 5: Database showing the relationships between the major entities on world’s wine regions and grapevine

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 used (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. TblSensorNode contain all the captured data from various sensors.

5 Conclusion

The paper looked at the recent advances in remote wireless multifunctional sensor (telemetry) 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 providing weather atmospheric, environmental conditions and plant physiology, and 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 an example proposed herein 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.

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