Sensor data acquisition for climate change modelling

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Abstract: - This paper describes recent advances in sensor technology and wireless radio frequency (telemetry architecture) with the capability for measuring changes in weather and atmospheric conditions that permit modellers to analyse the climate change, its variability and effects on viticulture across the world's major wine producing regions. 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 this 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 determinants such as soil, terrain and grape variety.

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

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 multifunctional sensor nodes and 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 communication 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 within the Asia Pacific Region, mark a significant improvement over its traditional use [4,5,6].

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 varying 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 [7] 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 colour which in turn define the fineness of the wine. This notion of linking vineyard conditions and berry components to wine quality comes from a centuries-old Mediterranean *cultiva x terrior* concept (for details please see [8,9]). Sections 3 and 4 detail a WSN proposed for modelling 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, with data being collected from vineyards in Chile and New Zealand that have the same latitude but 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 as aroma, colour and taste.

2 WSN in precision agriculture

WSN deployed in croplands, orchards, and vineyards, are used for measuring site conditions, (mainly of environmental, weather and atmospheric), with parametric variables, such as air, soil temperature, solar radiation, relative humidity, wind and terrain properties, for on-farm 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 [10]. 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 [11].

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 [12,13].

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. 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 and sensing in vineyards

Using a ZigBee[1] [14] multi-powered wireless acquisition device as a PV tool, local grapevine growers from the world's oldest Demarcated Region of Douro, managed to learn more about the natural variability of their vineyards described to be challenging due to the region's unique topographic profile, pronounced climatic variations and complex soil characteristics. The research conducted at laboratory and in-field set ups showed how the variability of all these conditions could be measured via a mesh-type ZigBeeTM network consisting of MPWiNodeZ element as acquisition

[1] ZigBee is one among the various standards established for wireless communications, 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.

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 irrigation pipe, all of this without any replacement, and hence lowering labour cost.
2) simplistic and compliance to IEEE standards along with an ability to accommodate up to nine sensors.

2.2 Regional and on-farm WSN in Washington

The WSN system being implemented in the agricultural applications in the Washington state consists of two major networks 1) regional AgWeatherNet, an agricultural weather network and 2) on-farm AgFrostNet, used for mobile, real time farm operations [4]. This is an ongoing collaborative research effort between 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. The research was initiated to upgrade the Public Agricultural Weather System (PAWS) in the Washington State. The 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 combined with air temperature/ relative humidity for calculating the dew point.

2.3 WSN in the Asia Pacific Region

A complete Internet based GPRS (or General Packet Radio Service), 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, rainfall, 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 PA/PV.

3 The climate change and Viticulture

The WSN ability to capture and relay real time data (displayed online) for analysing 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. The reasons for this are elaborated upon based on [7,15,16,17]:

1) The variability of climate change across the globe is inconsistent hence the degree of the impact caused varies and factors related need to be incorporated in the modelling.
2) Even though all climate models predict that the climate change would invariably impact on all vegetation, its effects on the geographic range of different species in each system would be different. The climate change effects on viticulture are anticipated to be dramatic, the reason being that grapevine varieties thrive in very narrow climatic conditions or niche and therefore, even with a small change in temperature in the world's major wine regions, viticulturists and wine makers would find it challenging to continue with the production of quality wine in style and appellation being produced now. Wine makers to a greater extent depend on viticulturists to harvest berry with the ideal aroma, colour protein composition without compromising maximum sugar content for producing finer wine of premium quality. The climate change effects are predicted to be very harmful in the Mediterranean as the region is at its peak temperature for producing quality wine.
3) Even within grapevine varieties the heat unit requirements/ cold hardiness vary significantly so does their unit yield price. For example, the requirements are low for Riesling whereas those for Cabernet Sauvignon are high and the unit yield price for the latter is twice as more than that of the former. This is why viticulturists are advised to select sites for commercial vineyards based on three factors and they are climate (length of the growing season, Growing Degree Day (GDD) summation, Mesoclimate and Absolute and relative elevation), soil (Internal water drainage, Organic matter, Texture and soil pH) and proximity of hazards [16]

4) On the other hand, unlike annual crops that could be moved easily to new areas as regional favourableness changes, reestablishment of grapevines considered as long-lived species would be costly and time consuming.
5) Modelling 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 modellers [12].
6) Apart from the above complexity, understanding the correlations between complex natural process actions and reactions often described with terms such as "cryptic" and "chaotic" requires that data captured for modelling, 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 challenging, if not impossible until recently. The advent of low powered low cost multifunctional wireless sensors (telemetry devices/ nodes) with more computing, data logging and relaying capabilities and with an ability to use these technologies combined with the Internet, enable modellers the capture of data required for analysing the complex processes such as the one being studied in this research, the effects of climate change on grapevine plant growth and wine quality.
7) Finally, besides the above factors disease, weed and pest control, especially existing and new exotic introductions are identified as major areas of deficiency in terms of how these factors would affect major crops. For example, Predictive model results of [15] showed despite European grapevine being more tolerant of cold than olive, still seen as susceptible to climate effects, not only in yield but also in the quality of the grapes and the wine produced from them.
8) The following are the major areas described for further research [15]: a) to develop physiologically based systems models of major cropping systems to forecast the effects climate change on crops and the dynamics of extant and new exotic pest introductions and b) to expand weather-gathering data systems, more importantly to include data on solar radiation. A case study discussed in the report on an invasive pest of grape, the vine mealybug (VMB, *Planococcus ficus*), its spread throughout California's grape-producing areas and the efforts to control the pest present an interesting scenario of the kinds of climate change issues. Extensive biological control efforts undertaken to control VMB, is reported as "to date elusive" in achieving success. Some introduced natural enemies that have very different tolerances to temperature considered to be complicating the problem. For this study the analysts used a physiologically based model of grape, VMB, and its natural enemies, to examine the distribution and abundance as affected by extant weather at 105 locations in California over the period 1995–2004 and mapped the results on to a GIS.

4 WSN in viticulture

The section looks at some recent use of WSN in modelling plant responses in viticulture.

In [13], an Intel Research Berkeley Lab effort to use a WSN with thousands of wireless sensor devices throughout a vineyard is discussed. The sensor nodes deployed in the vineyard are described as capable of collecting temperature reading every minute and storing them for further computation of the hourly highest and lowest temperature. The WSN is seen as a useful management tool in guiding the irrigation schedule for the vineyard, and helping the viticulturists in making a better harvesting decision.

In another example [17], the results from a 6-month deployment of a 65 node multi-hop WSN presented show how the wireless sensor devices could be utilised in precision viticulture for analysing hourly weather conditions combined with many landscape variables of a vineyard in the Okanagan Valley in British Columbia, Canada. Using the data gathered through this network the authors analysed the intra block variations by modelling the lowest temperature of the vineyard blocks during grapevine dormancy period for frost damage prevention purposes. By overlaying the lowest temperature recorded and topographical factors during first arctic outflow, on GIS map established some correlation between temperature and vineyard elevation.

The study concluded that wireless sensor networks as better than standard data loggers. More interestingly, through this effort the analysts were able to measure the difference of over 35% of heat summation units (HSUs) in as little as 100 meters and found that this could well suit the typical varieties of Tuscany in Italy and The Rhine in Germany generally grown in 20% HSUs, the varieties being considered Sangiovese and Reisling respectively.

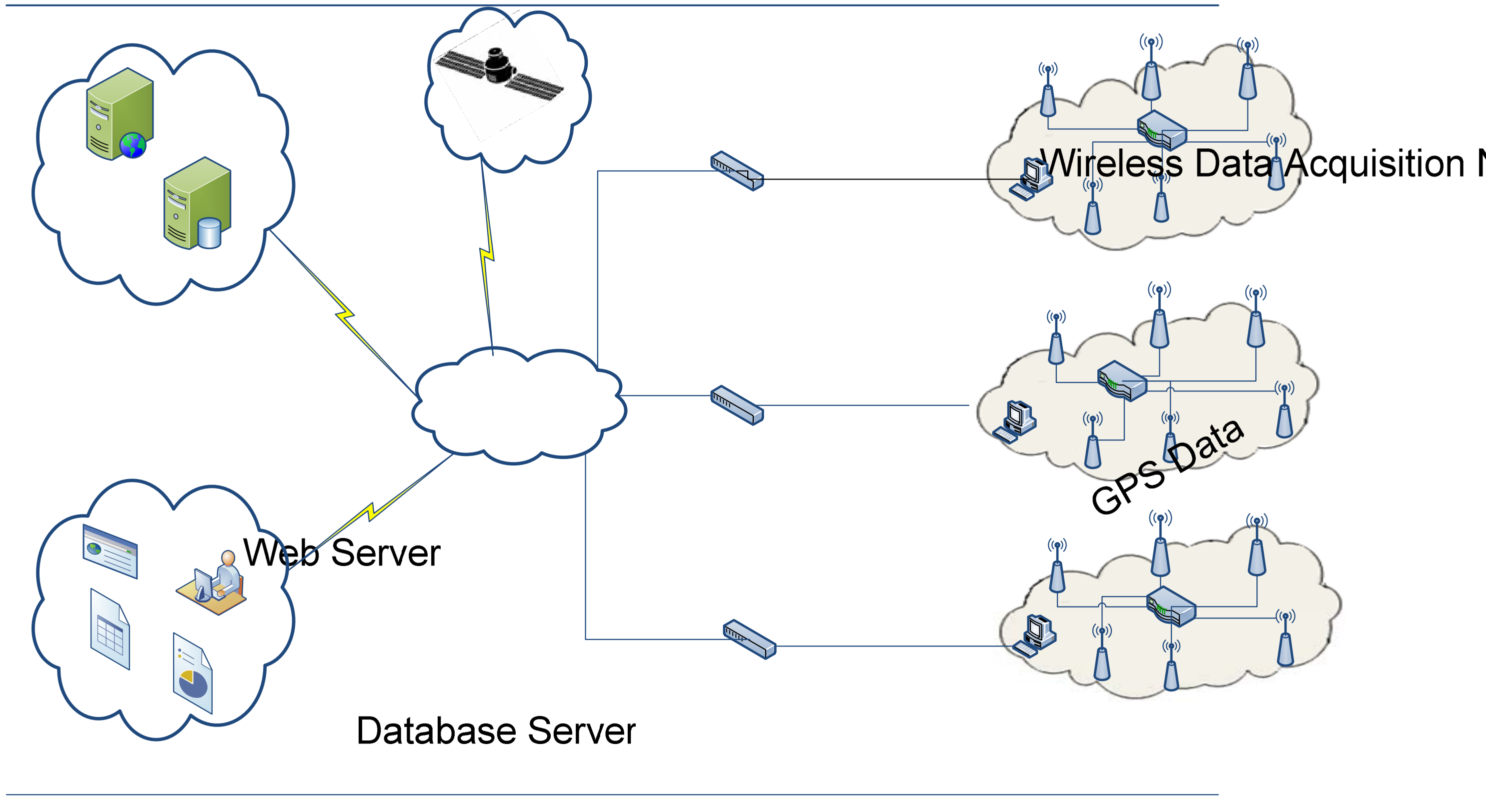

Fig 1: A schematic diagram of WSN layout for modelling the influence of climate change in weather, atmospheric and environmental conditions and on grapevine varieties as well as wine quality in different styles. The WSN transmits real time data collected through remote, wireless telemetry devices via 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.

5 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) to a central server for comparative analysis.

5.1 The WSN network

The proposed WSN systems consist 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. Sensors can transmit data one-direction only whereas repeaters are capable of bidirectional communication. 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 with one or more sensors plugged into the WSN unit. Each node could consist of one or more sensors (Figs. 2 and 3). Some sensors could be used for sensing plant variables being considered for modelling. Data captured by each sensor could be transmitted within an interval as low as 10 second and up to 100 meters to a repeater from there to another repeater or a gateway to a computer. The repeaters can operate at two frequencies, 433 and 900 MHz and also could be adjusted to suit any country RF requirements.

5.2 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 to climate change or pollution and sensing plant physiological changes, such as sap rise, using the sensors.

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.

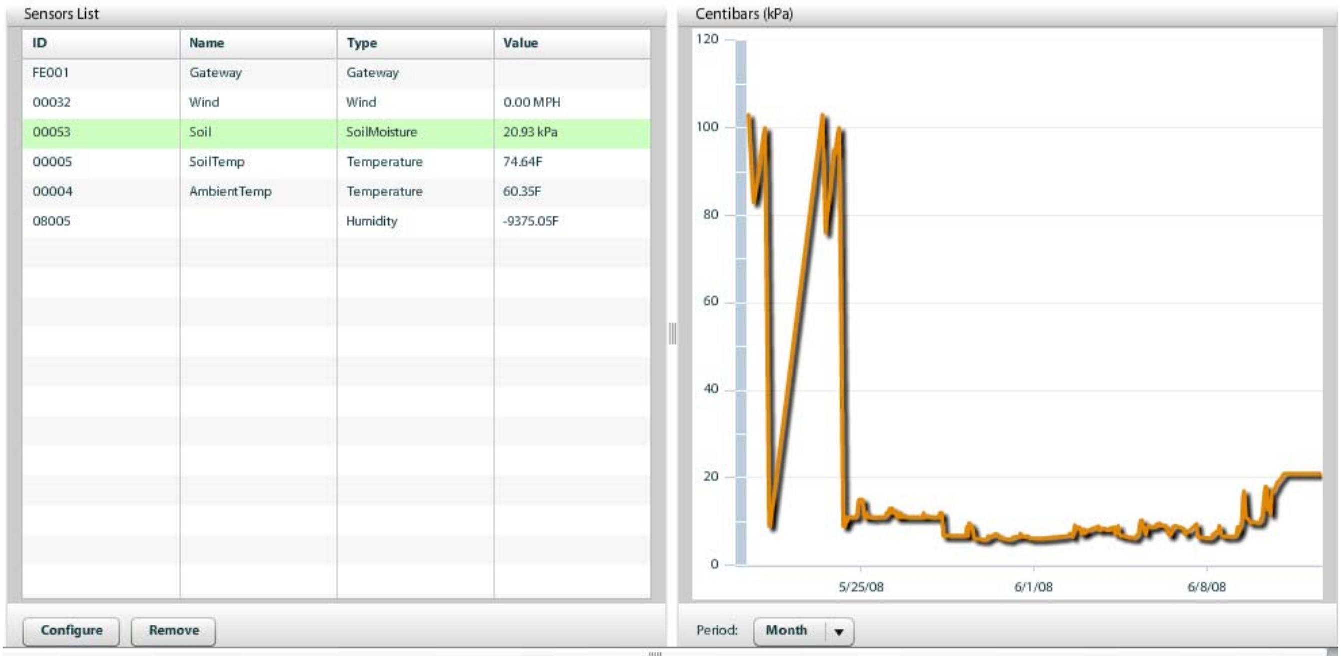

Fig 4: User interface for displaying the various data being collected from vineyards in Chile and New Zealand. Source: http://ilav.reports.cognetive-systems.com/cs/netbuilder/ilav.html

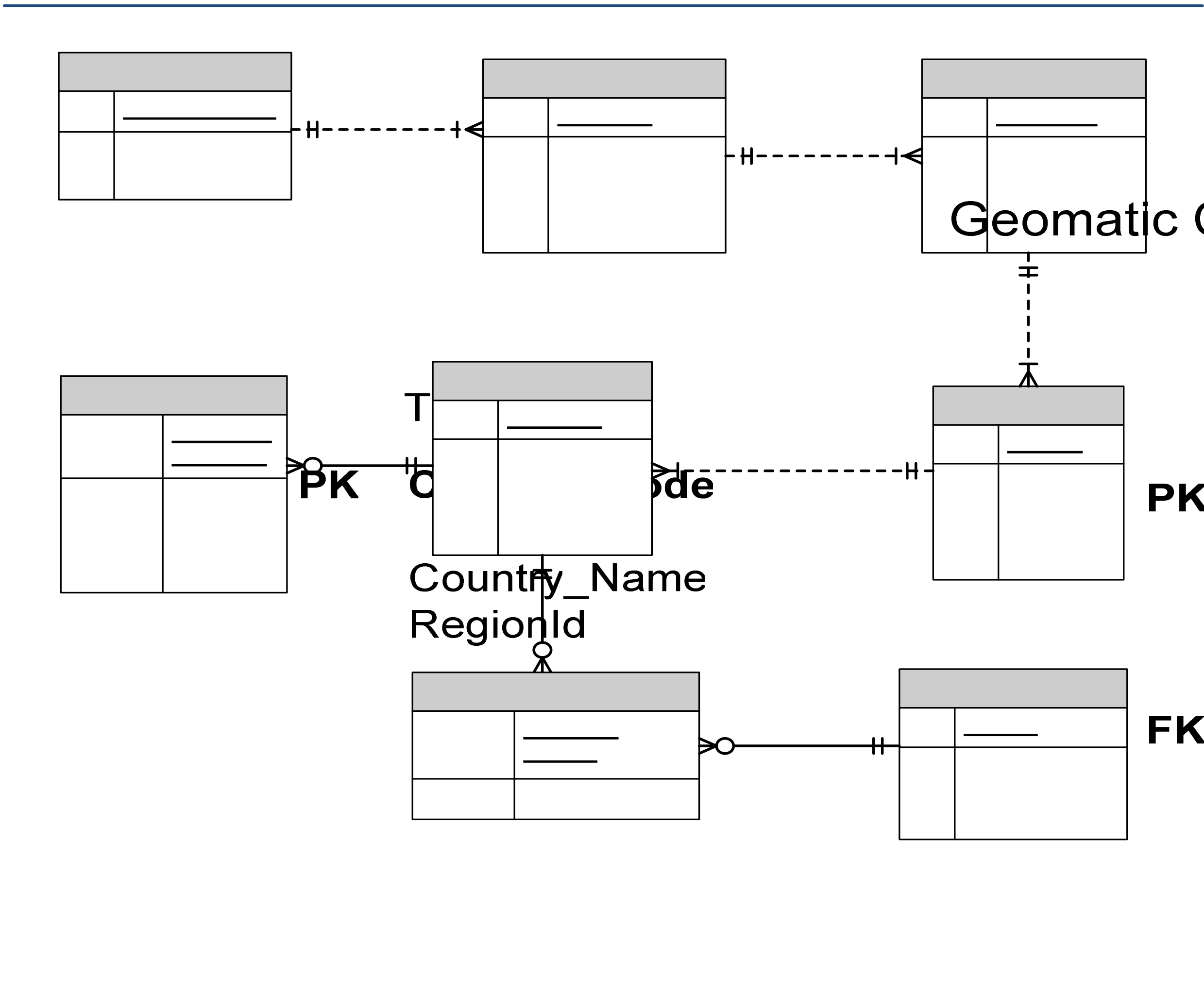

Fig 5: Database showing the relationships between the main entities on world's wine regions and grapevine

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.

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

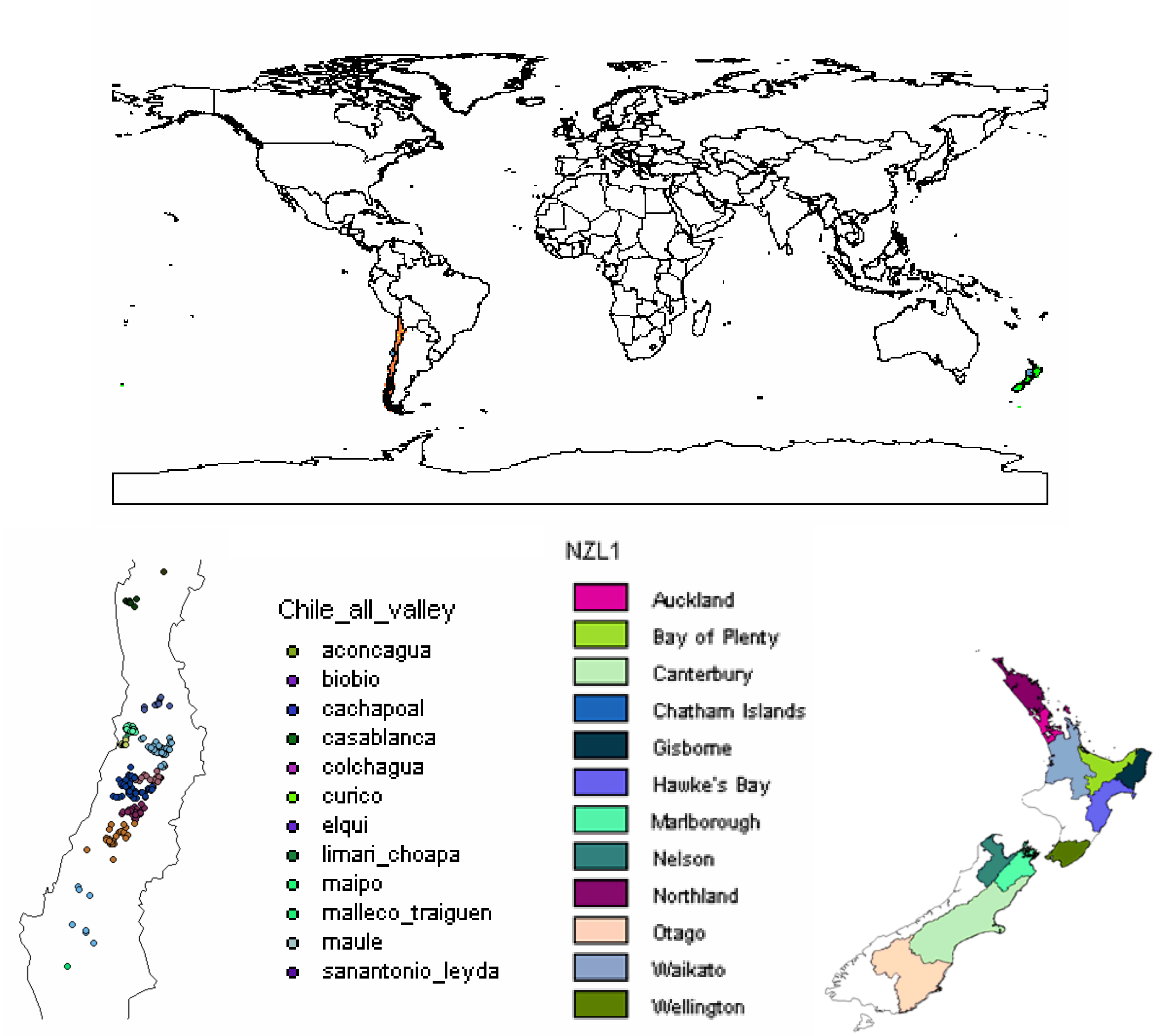

Fig 6: Maps showing the major wine regions in Chile and New Zealand. Currently weather sensor networks are being installed in Talca, Maule, Chile and Auckland, New Zealand.

5.2 The results

The data so far collected for this research from Auckland and Chile are not enough for a comparative analysis of climate effects on grapevine however, location details and graphs on weather and atmospheric conditions (Figs 4, 6 and 7 respectively) show how major wine regions in the two countries could be studied for this purpose. The graphs of hourly variations in conditions being monitored show potential to model the correlations between the parametric variables chosen in the analysis. This is seen as useful in gaining information relating to vineyard block management decision making based on micro climate effects on the vine varieties. This is especially useful in making decisions relating to the suitability of a crop variety, based on its climatic and environmental requirements such as the ideal crop maturity/ berry ripening conditions that could help the wine maker to produce premium wine. WSN data is seen as useful in averting any potential impact that may cause form any natural variability on some factors, such as growing degree day summation (heat units), irrigation schedule management, for instance establishing frost patches within the vineyard could help the management in replacing the patch with crops that could withstand the temperature drop.

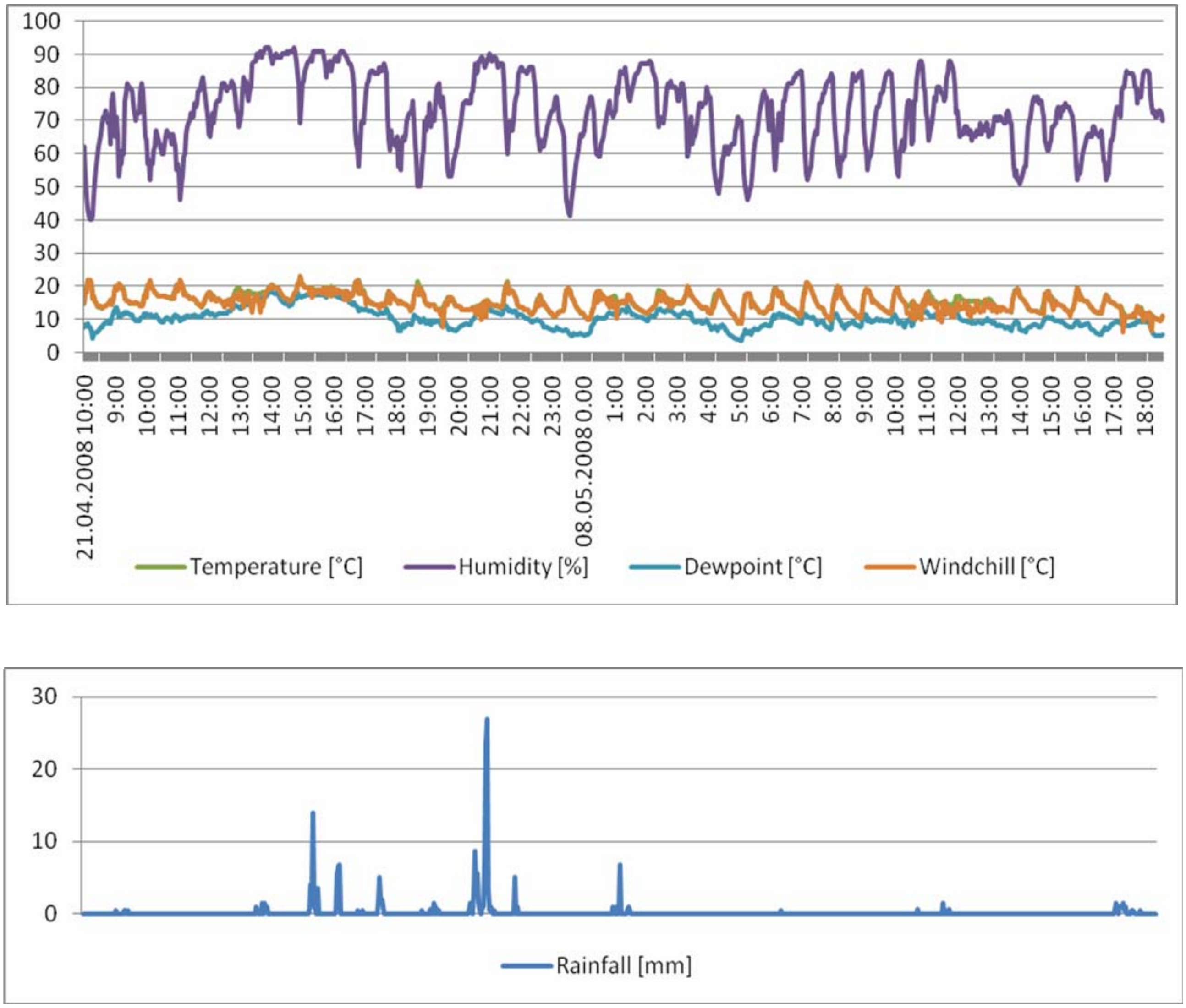

Figure 7: Graphs showing hourly fluctuations in temperature, humidity, dew point, wind chill and rain fall in Auckland.

6 Discussion

The quality of wine in a glass to greater extent depends not only on the wine making process but on the protein and sugar components in the grape berry used to produce the wine. The ratio of the latter two in turn depends on a whole range of factors that could be classified into two major categories, *cultiva x terrior* based on a centuries-old Mediterranean concept. The term *Cultiva* means variety and there is no direct translation for the term *terrior,* however, it could be referred to all factors relating to a place, meaning, climate (weather and atmospheric conditions), environment (soil, terrain and altitude) and cultivation practices (irrigation, pruning, fertilising, weed and pest control measures). Hence in order to avert damage or undesirable outcome resulting from any unfavourable conditions posed by natural factors viticulturists take some deliberate measures/ informed decisions, such as frost prevention measures explained in section 2. This is a common practice and literature reviewed for this research as well reveals evidence in support of the fact. Apart from the historic knowledge and data, more recently scientific research as well is aimed at helping viticulturists in putting together their best effects in producing the berry with colour and aroma proteins at required ratio without compromising sugar concentration enabling the wine maker to produce finer wine in style and appellation.

The recent advances in WSN of devices/ nodes and their use in PA and PV explained in section 3 showed how such multifunctional, low powered low cost, wireless telemetry devices, their functionalities combined with the Internet can be deployed at on-farm (vineyards), regional within a state and cities within the

Asia Pacific region scales, for measuring natural variability of complex process for daily management decision making purposes.

Finally, section 5 on proposed WSN, explained the use of the WSN for measuring the variability in climate change in major wine producing regions in Chile and New Zealand that have the same latitude but are at different longitude points and the climate effects on grapevine and wine quality. Hence, the results of this research could shed useful insights into the varying effects of climate change on the wine producing regions within the two countries being studied in the initial research as meteorological data available is not good enough to study the effects of such micro climatic variations. This is also vital as grapevine varieties are considered to be more sensitive to climatic variations than any other cultivated crops. The sample graphs of Auckland data gathered so far show potential in establishing the correlations between the climatic, environmental grapevine growth factors. It is intended to analyse these factors with wine quality and taste attributes analysed in [8] using text mining techniques which could ultimately help viticulturists in finding the suitable crop variety based on future climate effects on different grapevine and wine quality.

7 Conclusion

The paper looked at the recent advances in remote wireless multifunctional sensor (telemetry) devices, and how WSN of the functionalities 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 modelled to gain more insights into these processes, such as the effects of climate change on grapevine and wine quality.

8 Acknowledgments

This research covers the implementation aspect of weather monitoring and plant response sensing within a wider research effort to develop a set of tools for analysing geo-referenced data using intelligent and fuzzy data analysis methodologies. We thank our international collaborators Professors Leopoldo Pavesi and Mary Carmen Jarur Munoz from Universidad Catolica del Maule in Chile, also Howard Jelenik and Hank Ortiz of Cognetive Systems Inc, Irvine California (www.cognetive-systems.com) for their contributions.

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