Computational intelligence and geo-informatics in viticulture

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Abstract

Geo-informatics is a field of science that combines geodetic and spatial information processing methods with computing hardware and software technologies. Research being conducted by the authors extends this blend of science and technology by utilising contemporary computational techniques for data analysis and some sensor and telemetry technologies integrated with spatial information processing methods. The geo-spatial technologies of Geographic Information Systems (GIS), and Global Positioning Systems (GPS) have had a transformational effect on both the science and industry of this field, as has the advent of wireless telemetry devices. The introduction of what has become known as 'computational intelligence' has added a new dimension to the approaches taken for analysing geo-coded data and furthermore, to the kind of predictions that can be made from it. One domain of application for geo-informatics is in viticulture and enology in which the demand for scientific analysis of the industry due to globalisation has led to widespread research. Thus, the influence of the technologies used in this field have been significant, the changes can be seen across the whole wine industry from grape growing to wine production. The early entry of computing into viticulture and indeed to geo-referenced data analysis began with rule based expert systems (ES), but increasingly, there is a demand for greater precision in the information outcomes from geo-spatial data analysis, especially in agriculture, horticulture and viticulture. The authors are integrating previous scientific methods with state-of-the-art computational technologies to record, transfer and analyse data using artificial neural networks and fuzzy logic. This paper ***reviews developments in geodetic and computer science over the past two decades and briefly describes the work currently being undertaken by the authors in this field****.*

1. Introduction

"Every technology has its time" [1]:p1. When a new technology is first introduced, opinion is usually divided on its potential usefulness or viability. Very often, its capabilities are overrated. Some technologies exceed expectations of course, but in other cases after some time of frustration when the technology fails to meet its expectations, a realistic evaluation of its actual performance can occur [1]. Such is the case with the emergent field of Geo-informatics, sometimes referred to simply as Geomatics. In the past few years, several new technologies that emerged to impact significantly on the approaches taken to collect and analyse data and particularly in the instruments used for both tasks. Some observers have referred to these changes as being of unprecedented transformation. Today, Geographic Information System (GIS) are used across a broad spectrum of applications and are not seen as the domain of geo-spatial specialists alone. Relational database management systems that were once restricted to numeric and text data types now support spatial data, including fixed and moving images, not simply location co-ordinates. These systems are being used by city-planners and economic trend analysers, architects, design engineers, land surveyors, agriculturalists, horticulturalists, viticulturalists as well as professionals from many more disciplines [2-5].

The integration of geospatial data and analysis has led to the development of sophisticated telemetry devices with functionality including wireless transmission capability. This has provided what is generally regarded as an exponential improvement in data logging and reporting capability. The field is characterised by very large amounts of data and this combination of hardware and software technology has enabled more accurate and timely information to be produced, which has led to better decision making. Remote sensing took a significant step forward when satellite imagery was made available in a reliable and cost-effective manner, which has served to enrich the data sets available for analysis[4]. This phenomenon is discussed first, subsequently, the use of computational intelligence for analysing geo-coded data in Viticulture and Enology is looked at with its significance from the perspective of precision, compared with earlier work using rule based Expert Systems. Finally, an outline of a proposed system with its major components and data compiled for analysis, in the initial research, is given.

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2. Computational intelligence to geo-coded data analysis in viticulture

The first Expert Systems (ES) used domain precise knowledge in the form of rules and decision points based on prevailing conditions in the data. Computational Intelligence, as it is defined by contemporary computing literature, utilises artificial neural nets (ANNs) and fuzzy logic to analyse multidimensional data generated on/off-line with wireless, remote sensing devices and from aerial/ satellite imagery. Recent published work using this approach includes the analysis of geo-coded data from grape varieties, ecological factors such as soil, irrigation, solar radiation, climate and terrain as well as factors that influence fruit ripening and its composition, such as sugar, protein and flavour. These systems applied within and among vineyards are generally focused on modelling grapevine crop growth, blooming and berry formation conditions integrated to produce high quality wine with its major components such as alcohol, acid and flavour at appropriate ratios upon fermentation. At a regional level, the incorporation of geospatial analytical systems has also led to the modelling of grape varieties and crop growth conditions. These have been correlated against the most famous grapevine regions in the world and integrated with global wine style and quality measure. Most studies appear to have used sensory variables, such as taste, consistency and fullness/vintage ratings and global market needs, an emerging and popular field called bio-economy. Using recent simulated data on climate change, modellers have been able to predict the future grapevine optimum/peak periods or "good years for different wine types" in the Mediterranean and other well-known wine producing regions by means of climate regions versus wine varieties [6, 7].

2.1 Vintage to modern information management systems in viticulture

The centuries-old Mediterranean grape growing and winemaking industry is pooling resources in an effort to gain further understanding of the relationship between genetic (cultivars), environmental factors such as climate and soil (referred to as "terrior" as per the French approach) in order to improve cultivation practices or "vintages" aimed at producing finer wine [6, 8, 9]. In the last two decades, research into the development of information management systems using geo-coded data and computational intelligence on-site in the vineyards has intensified in order to gain a more complete understanding of regional factors and influences on production. Techniques for identifying the complex interactions among these factors range from modelling the effects of the environment, such as climate, atmosphere, soil type, terrain, minerals, transition metals and irrigation of saline water on the development of rootstock, to crop growth and berry ripening rates, protein conversion in different varieties and their composition, within and among vineyards. It is interesting to note that there have been significant developments in the areas of precision viticulture, daily vineyard operation influences, resource management issues and grape vine genetics [6, 8, 10-13].

2.2 Expert systems in viticulture

From the early 1990's, Experts systems (ES) became popular in horticulture, especially in production management and pest control [14]. They are generally built on knowledge from domain experts and literature sources using Boolean Logic to create processing rules, then implemented as conditional tests such as IF THEN statements in computer programmes. Literature reviewed for this paper reveals that the majority of ES applications developed, demonstrated capabilities for providing advice for crop growers, generally centred on pest and disease control. For example, a case study in [15] discusses an Australian Viticulture Advisory Programme called AusVit, which is an expert system capable of providing advice to vineyard managers and grape growers about pest and disease risk in their vineyards and what appropriate actions might be taken when they are identified. The advice was generated based on vineyard data and a profile, which included input from weather stations and vineyard monitor…all hand manually entered at that time. The computer programme interpreted the data by using a series of simulators and a rule based ES. In [16] an expert system for the management of *Botrytis cinerea* in Australian vineyards is presented. The ES was developed with an aim of improving decision making by grape growers in the management of this particular grapevine species. The late 1990s system was developed using knowledge from published literature on the species, as well as general literature on plant pathology and viticulture. Using up to six factors, namely, growth stage, conidial infection, mycelia infection, injury, symptoms and cultivar susceptibility, the ES was able to calculate the disease risk. Using this disease risk as well as an economic threshold and duration of protective cover provided by fungicides, it was able to generate a decision scenario of whether or not to apply fungicide/s. Intelligent simulation and management expert systems based on hierarchical structures have been developed to optimise the management of resources during various vineyard operations, such as human power, grape process equipment and thermal power (refrigeration or warming of grapes) [17]. In a more recent work, an ES has been developed with a database containing information on 161 grape problems including 55 arthropods, 48 diseases, 25 phytotoxicity problems, 13 nutritional disorders, 9 abiotic disorders, 6 wildlife damage and 5 physiological disorders along with abilities for adding 2007 problems. Based upon the information released in Version 1, it was refined in 2006 before being tested by a panel. The test by a panel of users to see the usefulness of the ES version 2 included vineyard managers. Despite the developments observed in the use of ESs, their application to viticulture management has come under severe criticism for being inconsistent, out-dated and variable in outcome quality [15]. In view of these issues, the authors of that work presented a putative knowledge management system with a server designed to represent each publication and expert as a separate knowledge base with a meta-knowledge base allowing for different kinds of access to the server. Different client systems were then allowed to connect to the knowledge server to meet different user needs such as forecasting, advice, explanation, education and training as well as abilities to serve the research community with regards to literature review and hypothesis testing. A further development to this approach is presented in [18]. The latest multi agent diagnostic expert system is described as capable of running on several servers providing support to a large group of clients that communicate with the servers via networks. The system is described as providing architecture to co-ordinate the behaviour of several specific agents, using such platforms as client-server based processing for diagnostic and treatment agents.

2.3 Geo-coded data in viticulture

Some initial research (1987) on the distinctive geographic "setting" of viticulture in California, compared geographic information on the temperature of this famous wine growing region with that of the birthplace of the noble wine varieties in France. In this study the paper initially looked at the bio-geographic backgrounds of the top quality grape varieties among wines and precise climatological preferences of these wines. It also examined the spatial pattern of the California wine climate regions before the comparison.

Based on literature reviewed for some research [19] published in 1997, the authors observed a paucity of applications utilising GIS in this area of study. They citied Baxevanis (1992), de Blij (1991), Dickenson (1991), Elliot-Fiske (1991), Rodolfi (1991), Scienza (1991), Unwin (1991) and had some personal communications with individuals considered to be experts in the field. Not long after, it is noted that a new trend in the use of GIS techniques for determining land suitability when selecting "optimal sites" for vineyards. This northern Italian study was seen as the pioneering effort in this investigation. Meanwhile, in [20] some early 1990s efforts were made by the Italian government and a number of academic institutions to integrate geospatial data with a prototype of wine-viticulture cadastre for managing agricultural development planning. This is elaborated on in the paper cited above. The publication, titled "GIS on network" gives details on the development of a national database integrated with GIS for taxation and planning.

Research that has explored the suitability of the regional aspects of wine grape production using physical characteristics of an established region in eastern California is reported in [19]. This late 1990s research attempted to discern any unique combination of environmental parameters in vineyards that can be quantitatively identified. It focused on developing a GIS method to describe the spatial pattern of vineyards using soil and physiographic parameters. The researchers were able to identify differences in 6 variables namely, slope angle, storie index[1], slope aspect, soil depth, water-holding and cation exchange capacities at the (95%) confidence interval and rooting, runoff and clay content at the (85%) confidence interval. Hence, the findings of the study concluded to be supportive and contributing to the literature on the significance of soil and topographic using the then referred to as GIS methodology.

It is also interesting to note on a mid 1990s research report [21] on a three year (1990-92) study that looked at the increasing interest in developing more sustainable viticulture practices among growers, consumers and policymakers. The study covered a whole range of issues ranging from effects of cover crops to fertilisation, leaf removal on yield and quality parameters. The study included many aspects on viticulture and enology nonetheless had no relevance to spatial related aspects.

The phenomenal growth observed over the last few decades in viticulture especially, in Australia, New Zealand, the United Stares, Chile and South Africa, has introduced a new breed of competitors to the once European dominated global wine market. Since the

[1] Storie Index is a numerical expression/ value that refers to the suitability of a soil for general intensive farming based upon (Soil conservation Service 1974 p 43) and consists of 4 factors and they are: soil profile, surface index, slop and specific soil limitations. It is a multiplicative index with a hierarchical suitability system ranging from 1 to 6 (i.e., most to least suitable).

early 1990s, the global wine market with the so called "new" and "old" wine producing countries has witnessed an intense demand for scientific analysis of the grapevine growing and wine industry to produce consistently good or finer wines [9, 22, 23] to which both sets of countries have responded well.

Both grape and wine rely on environmental conditions as well as the skills of grape grower and winemaker hence, viticulture not surprisingly, has a strong association with location. Traditionally, viticulturists relate grape varieties and wine style to a region, such as Marlborough in New Zealand and, say a large area such as the Mediterranean. Based on this traditional view other studies [24, 25] have investigated the application of GIS to grapevine growth and vineyard management. The authors in these two papers demonstrate the spatial and temporal variables associated with the growth of grapevines and management of vineyards as ideally suited for GIS applications. The issues specific to viticulture discussed in the two publications included scale variation, significance of location, factors that affect production and quality, vintage, the annual cycle of the vine and harvest of fruit, extreme events risks (i.e., frost, pests, disease), trans-seasonal and intra-seasonal cycles, sustainability, quality and integrity of the final product, traceability and the reputation and value of the final product.

Wine grape expansion witnessed in the Cape Floristic Region of South Africa over the decade soon after the lifting of trade sanctions in 1992 combined with the naturally fertile soil of this region posed a threat to the indigenous biodiversity and its natural habitat. This led to research into modelling the land use change and its impact on the conservation planning and management of this region [26]. In this study, researchers analysed wine farmer, cellar and co-operative information gathered through a survey integrated with environmental information, such as climatic, topographic and hydro-geology and soil, using a 1km x 1km lattice structure to identify patterns in a heterogeneous regional and local agro-ecosystem based on a systems approach The cellar and wine farmer location details were mapped to the lattice with presence/ absence points demonstrating the analysis of geo-coded data derived from raster-polygon based GIS sources.

2.4 Developments in Precision Viticulture

Understanding the impact of plant-soil-water dynamics at different phonological growth stages on plant physiology is the key to achieving improved yield or quality in vineyard management [27]. In view of this fact an Australian report reviews the county's technological contributions to precision management of irrigated viticulture over the past two decades. The authors focused on an integrated approach of mapping soil spatial properties to generate irrigation management zones, evaluation of their performance and the use of near continuous soil-water profile dynamics in making irrigation scheduling, implementation and management strategies, such as regulated deficit irrigation (RDI) and partial root zone drying (PRD). Many more studies have reported on the complex and challenging issues relating to managing the dynamic relationship between site, soil, water phonological stage, vine and wine quality within and among vineyards [28]. There is also research reported outside of Australia into these factors integrated with the irrigation management in grapevines which are a traditionally non-irrigated crop [29-32].

2.5 Modern intelligent systems and geo-coded data analysis in viticulture

A novel GIS based vineyard support system developed to test, match and map cultivars to the landscape of untested terrains and climates of the Northern Great Plains, before planting to avoid vineyard failures is elaborated upon in [33]. The system also provides a better understanding of vineyard sustainability within the Northern Great Plains considered as being a region with marginal vineyard settings. The system is novel in that it attempted to capture the concept of "genotype x environment" (GxE) and build a "sense of place" using landscape and climate characteristics (as georeferenced information) integrated with the human dimensions of vineyard management. A similar regional scale study from Casitlla-La Mancha, Spain has been reported in [34] where a tool to support decision making on vine growing areas at larger scales, has been developed using georeferenced data. The system results were found to be useful in zoning the region's grapevine farms based on physiographic, farming capability and vine varietal factors. It provided a means to study the region's environmental, social and economic aspects in managing the land and water use in consideration of different stakeholder perspectives.

The availability of recent advances in remote sensing has led to a growing interest in the use of airborne multispectral and hyperspectral imagery in precision viticulture with greater flexibility especially in yield mapping integrated with soil or disease properties [35]. The paper based on a French research reported on the most recent developments in this area of spectral characterisation of vine canopy, varietal mapping with the capability to discriminate plant species that could be used as a tool in the certification of wine productions at regional and at vineyard scale in detecting mis-planting and managing inner species variability. Subsequently, the paper investigated the use of three main approaches namely, multiple-layer perceptrons, radial basis function neural nets and support vector machines for varietal mapping. Most recent developments in this field include the use of fuzzy logic (in satellite imagery pixel analysis) and delineation of vine parcels by segmentation of high resolution (in areal images) [36, 37].

3. Proposed system

In view of the above developments, the early stage of this research concerns the blending of established data collection (using state-of-the-art devices such as a set up posted in [38]) and analysis techniques for environmental modelling using contemporary computational approaches to data mining combined with an innovative intelligent approach to the use of real time wireless telemetry devices. The system focuses on an enological example in a comparison of environmental impact factors from Chile and New Zealand. It is intended that this example will inform the development of a scalable solution that can be generalized to other environmental impact studies. The work is broadly based within a geo-informatics framework from a Computer Science perspective and is concerned with the application of this field of science in what has become known as the bio-economy. The discerning aspect of this approach is that it uses telemetry devices for climate and atmospheric data collection, terrain and imbedded vine sensors for soil condition and growth spectrum analysis, data logging software based on real time analysis reporting from locations in both countries to a single server, (GIS) interpretation and result display software and a neural network modelling tool for scenario building and such early implementations from temporal data as weather prediction (www.geo-informatics.org/).

This system consists of features which distinguishes it from previous work relating to the identification of variables whose values when synthesized, determine the optimal growing conditions and that can be used to pre-empt the potential for producing high quality wine.

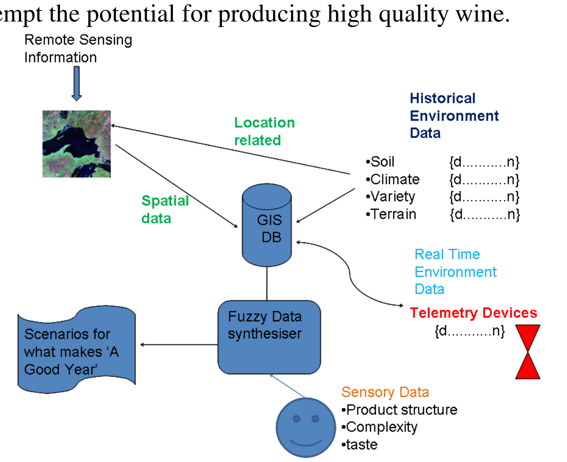

Figure1; Schematic diagram showing the system components and data elements chosen for analysis

4. Conclusion

Based on the recent developments in viticulture from the literature reviewed for this research, it is suggested that the combination of experimental methods using conventional and contemporary computational techniques, together with a range of field dependent software and hardware components, in a comparative study of data from two differently sized and situated countries located on the same latitude, is an example of the application of contemporary computational intelligence to analysing data received from a multitude of ultra modern devices and technologies.

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