An IoT-based insular monitoring architecture for smart viticulture

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***Abstract*—Modern Information and Communication Technologies (ICT) have evolved into an ever developing digital ecosystem. In such a sophisticated system information is typically transmitted through interconnected software and hardware structures, better described as the well-known concept of *Internet of Things* (IoT). Embedded physical devices are producing data related to the observation of human activities and natural phenomena. The arrival and establishment of IoT technologies have created the methodology of Wireless Sensor Networks (WSN) as a novel monitoring infrastructure. In the wider context of IoT several nodes can be equipped with specialized sensors that gather physical quantities in accordance to network structures. The sensor and actuator technologies that enable smart solutions into reliable, heterogeneous, wireless networks, especially designed to provide dissemination across countless sensors are embedded in almost everything. Agricultural industry throughout the world is constantly searching to maximize economic, environmental and qualitative benefits of its operation. Secondly, most processes are not utilizing modern automation for effective agro-production. Optimized agriculture as an automated mean of environmental parameters monitoring has exploited novel capabilities presented by ICT. For instance, viticulture is an exquisite procedure related to mesoclimate and soil conditions; thus, it demands control and efficient quality assessment in the process. In this work, we take into account all aforementioned observations and propose a modus operandi for optimized, ICT-based wine production by the assessment of natural conditions during cultivation and harvest. Our ultimate future goal is to establish a Knowledge Base for optimal winery through the exploitation of semantics and related applications on top of efficient environmental monitoring. Being a preliminary attempt to model this broad task, we herein assess the model and architecture of sensing devices and their support capabilities.**

I. Introduction

Modern inter-connected world has become subject of perpetual interactions of the living environment and information technology. The forthcoming Web 3.0 includes the concept of IoT that has attracted mega interests from various fields of research and industry. Internet of Things (IoT) operates within and amidst billions of connected devices of the modern digital world [1]. The latter perpetually generates an enormous amount of data creating meaningful capabilities for several domains. However, the enormity of information imposes a clear challenge with respect to the management and exploration of data in real or almost real time [2].

In this framework WSNs operate on the added benefit of enhanced deployment and flexibility of sensing devices, while improve reliability and efficiency of their operation. IoT, WSN, social media and cloud computing corroborate the transformation of human recognizable information onto the surface of Semantic Web research. Data must be enriched with semantically background knowledge, in order to expose standard service interfaces [3]. Therefore it is of high importance to integrate the inteligibility and comprehensibility of both aspects of natural and human environment.

The always increasing demand for food and farm products calls for the introduction of modern ICT in agriculture. The recently evolved term of *precision agriculture/farming* denotes a “system” that introduces variable management practices within a field based on on-site conditions [4]. Such a system is typically implemented through novel technological features and components, such as global positioning system (GPS), geographic information system (GIS), environmental parameters monitoring by deployed sensors in the field, remote sensing and data analyzing techniques. Those technologies drive for improved crop production and environmental quality in the field area. The accurate representation of field condition is based namely on soil sensing and satellite remote sensing [5]. The former is implemented through the deployment of field sensors, the latter by capturing light reflectance on plant canopies from satellite imagery [2].

Recent technology advancements have driven sensing systems to become a feasible solution for many innovative applications [6]. Apart from integrated monitoring solutions (e.g., meteorological stations), several systems that rely on low-power embedded micro-controller platforms have been proposed [7]. Such systems make use of the digital and analog I/O ports of platforms for sensor extensions alongside with custom or open source software components. They focused on the development and integration processes supported by base stations developed on tiny, yet powerful microcontrollers, such as Raspberry Pi[1] or Arduino[2], which are mainly used to incorporate sensing, automation and connectivity capabilities. Open hardware platform supports data manipulation by deployed

[1]https://www.raspberrypi.org
[2]https://www.arduino.cc/

applications installed in both sensors and base station, and networking through embedded connectivity protocols.

Our research initially focused on the system design of an integrated climate monitoring approach, which consists of meteorological stations and custom designed monitoring devices. Furthermore, the work aims at the development of research and innovative processes for the export of applied results and the support of small local winegrowers, who, aided by appropriate services, tools and equipment, will be able to choose quickly, efficiently and with sufficient accuracy appropriate biotypes or even new varieties for their vineyards soil and other characteristics. In this process, the use of multiannual data that has not yet been recorded and organized will also be exploited. The proposed system model also aims at improving the efficiency of existing crops, rationalizing their wine-growing potential and helping producers to improve the quality of grape production through specific proposals and corrective actions resulting from the automatic study of specific area characteristics and the way in which the vineyard responds to several soil and climatic conditions.

II. Related Works

The issue of monitoring methods for viticulture in insular areas is not adequately assessed on recent research works. IoT applications present customizable recording systems that are remotely operable. Additionally, cloud computing and several web platforms facilitate further analysis of gathered information in and inference capabilities on the basis of expert systems.

The impact of various types of barrel during aging on the wines quality is being investigated by Morais et al, [8] through a winery control protocol. They developed an integrated monitoring system based on the Raspberry pi model 2 as a sink node that focuses on the chemical composition and quality of the produce. Additionally, the system's aim is concentrated at the development of a prediction model based on the *mySENSE* IoT platform that supports data dissemination and semi-automatic analysis. This work's main purpose is to locate substantial differences in oxygen consumption between the different wood barrels used in Tawny Port wine aging process.

In the work of Borgogno-Mondino et al, [9] Remote Sensing (RS) is used to monitor agro-environmental factors' impact on vineyard reaction. They trialled satellite-derived Prescription Maps (PM) through aerial imagery by assessing the color of vines (vigour), with special regard to the intra-vineyard variability presented on the NDVI[3] maps. The deployment of remote sensing in optimizing and controlling wine production requires the acquisition of field data in the need for further calibration on RS measurements. The authors proposed a monitoring system for agronomic applications that remote assessment of the region of interest.

Canete et al, [10] presented a real-time monitoring platform for the control of structural health and ullage of Fino wine casks on wine aging process. They deployed a detection system for possible crevices on the cask's surface, which source the level of wine inside the container aiming at maintaining the balance between ullage and wine. A novel approach of obtaining information inside the barrel is introduced in the form of the prototype *"Smart Cork"*, which provides the capability to real-time monitor and resolve any issues. The deployed device is consisted by an Arduino microcontroller, connectivity capabilities and four sensors: humidity, temperature, luminocity and distance. The system is designed to give on-site warnings and disseminate the recordings at a cloud platform, user accessible by a web UI[4]. In contrast to our approach the authors implemented a methodology subsequent to the harvest during aging in order to evaluate the suitability of the fine process of wine processing in real time.

The subject of insular environmental monitoring by implementing an IoT platform was discussed by Naumowicz et al. [11]. A three year design and deployment of a Wireless Sensor Network system was deployed, aiming at seabird monitoring on Skomer Island[5]. The research team developed a real-world deployable sensor network to investigate the habitat of Manx Shearwater (Puffinus puffinus) seabird. The project is based on battery powered sensor nodes based on generic extension boards (MSB430MS) and installed near the entrance of the bird's habitat monitoring air temperature and humidity, movement on the entrance (passive infrared PIR), identity of individual bird (were marked previously with RFID tags) and weight of individual grid (with custom made scales). Their research was remote deployed and offered dependable recordings on specific implementations, but lacked repeatability and broad applicability.

In summary our approach differs on combining on-site operation of meteorological stations and embedded apparatus for atmospheric and soil monitoring. Contrary to a controlled application of monitoring during the wine aging circle, our proposal presents an integrated monitoring system that focuses prior to vine harvest. Additionally, the gathered data is to be employed on a knowledge base for optimized wine production through an integrated semantic platform in the direction of Artificial Intelligence.

III. Case study

Our work focuses on a study area located at the Ionian region of Western Greece including the islands of Corfu, Kefalonia and Zakynthos. When fully deployed, the proposed system will employ an integrated information system with its sub-modules, namely the components of web, computer, sensors, communication system and software. The system is designed to collect a small sample of local weather data by setting up a network of connected weather stations and soil sensors on selected real-life fields. Moreover the purpose of the system is to produce intelligent farming knowledge techniques in the direction of optimized, smart viticulture activities.

[3]Normalized Difference Vegetation Index

[4]User Interface

[5]UK National Reserve, located off the west coast of Pembrokeshire, Wales

In principal, insular regions are ideal for environmental monitoring applications with easily discernible limits and defined biomass flows [12]. The specific regions of interest, i.e., the Mediterranean islands of the Ionian sea, are characterized by insularity[6], "mediterraneanity"[7] and economical drivers based upon tourism, services and agriculture. Field research on remote areas prospect many challenges that could be solved through deployed sensor nodes. Readings from these nodes are periodically sampled and relayed into appropriate base station(s) in the form of physical systems of network infrastructures [2].

On the other hand, precision agriculture collects a sum of interdisciplinary subjects on the purpose of developing models and tools for the optimal use of data and resources in the direction of enhancing production [5]. A set of fundamental parameters is required, which can be summarized as follows in the order of importance: location and mesoclimate[8] of the vineyard, quality characteristics, drainage, delimitation / orientation of the vineyard, soil preparation and selection of the appropriate vine variety.

All aforementioned things discussed within this case study are based on equipment installation and data collection, implemented on each vineyard. The appropriate collection and process of components is focused on assimilating soil and atmospheric temperature and humidity, soil chemical composition, along with information regarding water drainage and management. Additionally, particularly importance is to be given on the layout and orientation of the vineyard, as they form crucial factors that act decisively on the wine cultivation and must be analyzed in detail in relation to the geographic characteristics of the cultivation modeling [10].

The herein discussed system aims at the improvement of existing vineyard crops, a more rational utilization of their wine-growing potential and producers' support for the qualitative upgrading of grape production. Specifically, the automated study of specific natural features of the area and how the vine meets the territorial and climatic conditions will further guide onto concrete proposals and corrective actions. When deployed, the system will be open and fully expandable, and its particularly important asset is based on low cost and accessible equipment upon a proper use of the organization of gathered knowledge.

IV. System Architecture

The system to be developed will include as a key element an Online Platform responsible for collecting data, such as sensor readings, information by wine growers and oenologists, and lastly wine variety characteristics. The basic elements supportive to the platform are the Database, the Search Engine, and the User Programming Interface through which the other parts of the system will be interlinked. The metrics that will be imported into the system will pass through two System Collectors, the Sensor Measure Collector, and the Data Collector. Collectors will be linked to the Web Platform via the User Interface and will send the data to the appropriate model each time.

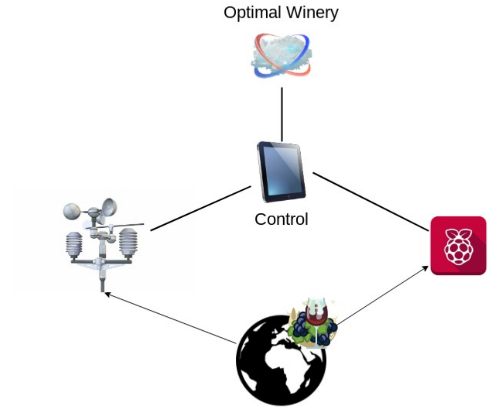

Fig. 1. Monitoring Concept

A. Networking and Data concepts

The requirement for an automatic environmental monitoring application is the dissemination of data and information between the systems involved [2]. The transmission of the records is carried out by means of local or remote communication. Necessary for data representation, authentication, error detection and signaling is the use of sharing protocols. Variables are taken as binary values from an electronic system and then managed by the software. We then share them in the systems involved through network communication and represent them as technical sizes (e.g., temperature in ^{o}C). The purpose of each study determines the methodology of analyzing and mapping the variables. Therefore, information not provided manually by end-users (e.g., via appropriate web-based "Forms") will be collected in an automated way by local weather stations and ground sensors to be installed in selected areas and if available from other weather public information sources in the Ionian Islands. For this part of the system, no user interface is required, but a server part, which is referred to as a "Harvester". The weather station and the various sensors will be regularly connected to the internet using the GSM mobile telephony system, will communicate with the server and then their measurements will be downloaded to a JSON record [9]. Each record is an ontological representation of the corresponding variable that describes the existing correlations of an element or between elements of a group, entity, or category.

B. Hardware

The implementation of the project depends on the construction of a system for recording the current state

[6]small size, limited natural resources and relatively inaccessible

[7]climatic, geological and human induced factors specific to the Mediterranean region

[8]climatic characteristics of a particular site/ filed

[9]http://json-schema.org/

of the environment. The system incorporates software and hardware structures based on accessible open-source technologies. Additionally, the recording accuracy requires the compliance with scientific research principles specific to the studied physico-chemical variables. Recording methods present some technological limitations that may affect the fidelity of the research results. Therefore, the design of an integrated environmental monitoring platform operates at interdisciplinary level and combines different methodologies among themselves.
The system's hardware components are consisted by *1)* meteorological stations, *2)* soil sensing devices and *3)* networking structures. he sensing, recording and connectivity procedures are implemented by the initial two components, while the latter operates to disseminate the gathered data into a repository.

1) Meteorological stations: The stations are an integrated monitoring system for the purpose of mesoclimate analysis [13]. The deployment scheme consists of a station equipped with a sum of sensory devices. The monitoring of climatic conditions is carried out by the operation of three meteorological stations in each respective area of interest. Each station consists of a air temperature and humidity sensor, wind speed and wind direction, a rain gauge, a solar radiation sensor, and a soil temperature and humidity sensor. The stations operate independently of the electricity grid and are powered by solar panels that then accumulate energy in three-cell type batteries.

2) Soil sensing devices: The sensing devices are based on the Raspberry Pi 3 b+ microcontroller[10], which has a variety of capabilities and interfacing peripherals. Its low cost, accessibility and utility along with its supports a plethora of software and hardware protocols on which enable several IoT applications related to automation, robotics and sensing. The sensing device is designed in accordance to Raspberry's connectivity and scalability capabilities. The development of the on-site soil measurement system has been designed considering the coexistence between the involved hardware and software components. The sensors operate autonomously and are located at the vineyards in order to continuously measure soil temperature, humidity and acidity, along with solar luminance, air temperature and humidity and precipitation levels. In addition, the custom devices are powered by a 0.5 Watt solar collector, being noteworthy that specific recording tolerances have been set to keep the correct sequence of measurements. In summary, the device is a customizable environmental monitoring unit which supports communication protocols among other platforms for further dissemination of the measurements. The system's main feature is the ability to collect variables in real-time through remote data transmission. This allows the recognition the physical state of each site at a given time that the recording takes place.

[10]https://www.raspberrypi.org

V. Discussion and Future work

At this point, the herein discussed system's deployment is due to agglomerate the first round of results in order to evaluate its operationality. All above mentioned sensors and equipment have been deployed in the field and are currently tested and initial data are gathered. In the very near future, resulted recordings will be filtered into a developing semantic infrastructure for further assessment and utilization. The latter includes components such as data analytics, Artificial Intelligence tools and methodologies, methods of statistical processing, semantic analysis and automatic deduction. Effectively, the acquired knowledge aims at extracting meaning and additional semantic knowledge / conclusions regarding the optimization of viticulture in the respected insular areas.

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