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An open-source and low-cost monitoring system for Precision Enology

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Abstract: Winemaking is a dynamic process where conditions could be strongly different between products of the same vineyard and even among each wine vat, due to microbiological and chemical process. This high variability means an increase in work in term of control and process management. As for Precision Viticulture, the winemaking process requires a site-specific methodology, in order to optimize cellar practices management and quality production. This kind of approach suggest a new concept of winemaking, which could be identified as Precision Enology. The Institute of Biometeorology of the National Research Council has developed a wireless monitoring system, which consists of silicone barrel bungs equipped with sensors for the measurement of physical and chemical parameters in wine stored in barrel. The present work describes an open-source evolution of the preliminary prototype, with Arduino based technology. Results have shown good performance in terms of data transmission and accuracy, demonstrating characteristics perfectly suited for monitoring with minimal size and power consumption. The system has been designed to create a low-cost product, which allows a remote and real-time control of wine evolution in each barrel, minimizing costs and time for sampling and laboratory analysis. The possibility to integrate a wide range of sensors on the system makes it a flexible tool capable to satisfy various monitoring needs in winemaking.

Keywords: Precision Enology; Wireless Sensor Network; open-source; Arduino; winemaking.

1. Introduction

Wine composition and quality are functions of many different intrinsic and extrinsic variables, and high-quality grapes production usually does not directly translate into high-quality wine. During vinification, a complex series of chemical-physical and microbiological processes transform grapes and must into wine. Frequently wine characteristic could be strongly different between products of the same vineyard and even among each wine vat, due to small differences in the evolution of those processes. This high variability means an increasing demand of control and process management and, in the end, increasing costs. As for Precision Viticulture, the winemaking process requires a site-specific methodology, in order to optimize cellar practices management and quality production. This kind of approach suggests a new concept of winemaking, which we therefore refer as Precision Enology. A careful control of those processes is of critical importance during every stage of the production, but manual sampling and measurements are time-consuming and frequently error-prone. Temperature is one of the most important parameter during the early stage of the vinification process, to monitor the exothermic microbiological activity. While large wineries frequently utilize fermenting steel vats equipped with temperature sensors, the smaller ones generally perform temperature measurements manually to reduce the cost of deploying wired sensor and actuation infrastructure. In this direction, many authors suggest solution to control this factor with low cost and wireless temperature monitoring system [1-4]. However a correct winemaking monitoring needs to control the evolution of many other processes and consequently many others parameters in addition to temperature. Furthermore, after the fermentation phase, which generally takes place in steel vats, wine undergoes an aging period in wooden barrels, in order to achieve the enological objective decided by the winemaker. Unlike the huge fermentation steel vats, little barrels (225 L) cannot be equipped with sensor and power supply, due to the large number of units present in the wineries, and the need of periodical movement. Barrels are often stacked at least five or six unit high, obliging operators to work under hazardous conditions in order to sample and monitor the wine. In that direction, Di Gennaro et al. [5] suggest a novel solution to realize a wireless monitoring system to control malolactic fermentation (MLF) in wine stored in barrel, which is a metabolic reaction that commonly occurs after the alcoholic fermentation, and its principal effect is a reduction in wine acidity. The first prototype proposed in 2013 was a device housed inside the silicone bung of the barrel, equipped with a temperature and pH sensor, able to collect and send data to a remote base unit. The present work describes an open-source evolution of that work, in order to realize a new instrument characterized by a lower cost and increased versatility. The system, named WineDuino, could support a large number of sensors, representing an easy tool for monitoring all winemaking processes.

2. Experimental Section

2.1. System design

The WineDuino system consists of a series of nodes integrated in the silicone bungs, allowing a direct monitoring of enological parameters during wine aging in barrels. Nodes acquire data and provide a wireless transmission to a coordinator node, which collects and forwards data to a remote server.

2.2. Hardware technical details

2.2.1 WineDuino node

The nodes have been developed and built with Arduino open source technology. The core is an Arduino Mini Pro board 3.3V and 8MHz [6], which is based on the ATmega328 microcontroller (Atmel Corporation, San Jose, CA, USA). It presents minimal dimensions (18mm x 33mm) and provides 14 digital and 8 analog channels with 10-bit resolution, which allow to manage a large number sensors. The board comes without pre-mounted headers, so microcontroller was programmed trough a six-pin header connected to an FTDI cable, to provide USB power and communication to the board. The board node (fig.1a) acquires data from sensors at four hourly frequency, and after readings, data are sent to the coordinator node through the Xbee S1 radio module, which ensures a 30m indoor range and provides fast 250Kbps RF data rate. This presents small dimensions module (27mm x 24mm) integrates a small wire antenna with 1mW transmit power and comes standard with 802.15.4 firmware at 2.4GHz and provides easily point to point, star and mesh (with DigiMesh firmware) network topologies.

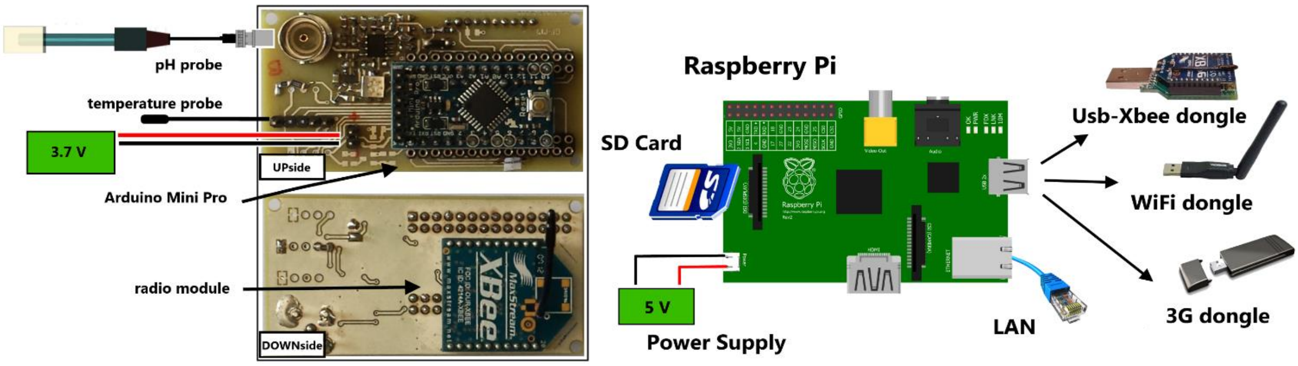

Fig.1a – 1b Schematic of WineDuino node (a) and Coordinator node (b) hardware.

Each node is powered with a 3.7V at 2300mAh Li-Po battery. A shield board has been developed ad-hoc to support Arduino Mini Pro and Xbee S1 radio modules, and provide slots for power supply and sensors. The first application of WineDuino system was aimed to measure temperature and pH to control MLF evolution in wine. To provide compatibility with different commercial pH probes, an amplifier circuit with BNC connector and a trimmer were mounted on board allowing to calibrate the readings according to the construction parameters. Node casing is realized with an IP65 plastic box (100mm x 50mm x 50mm) mounted over the silicon bung. Sensors are housed inside a stainless steel dipstick (AISI 310), which cross through the bung with the sensors at the end in direct contact with wine, approximately in the middle of the barrel (fig.2). The dipstick (20mm diameter and 300mm long) is physiologically inert and suitable for food contact. For the temperature probe was chosen the DS18B20 (Dallas Semiconductor Corp., Dallas, USA), a 1-wire digital sensor, characterized by low cost and short time response. It provides 9 to 12bit temperature measurements, in an operating range of -55°C to 125°C, with ± 0.5°C precision. The pH measurement is realized by a 3550 - ASP200-2-1M-BNC pH Lab

Electrode (Phidgets Inc., Calgary, AB, Canada), it is an economical combination electrode ideal for your general-purpose applications, with impact-resistant epoxy body. The electrode provides a fast, stable response and is ideal for prolonged pH readings. The sealed, gel-filled design requires virtually no maintenance, which is a prerogative for this kind of application. The probe measures 120 mm (length) x 12 mm (diameter), can withstand temperatures up to 80°C measuring pH levels from 0 to 14, and it provides a BNC connector. WineDuino system sensors were been calibrated following the protocol of the previous work proposed by Di Gennaro et al. [5].

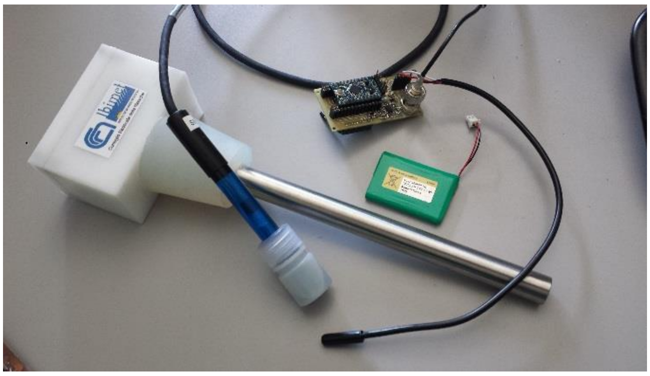

Fig.2 WineDuino node with sensor and dipstick.

2.2.2 Coordinator node

The coordinator node (fig.1b) is realized with a Raspberry Pi board model B [7], a small dimensions single-board computer (86mm x 54mm), which is an open source project intended to run a Linux kernel based operating systems. The design is based around a Broadcom BCM2835 SoC (Broadcom Corporation, Cambridge, UK), which includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU, 512 Mb of RAM, and an SD card for booting and storage media for the data received from nodes. Moreover, the board provides two USB and one 10/100 Ethernet ports. It requires 5V power supply via microUSB or GPIO header, and it was located on a side wall of the cellar inside an IP65 plastic box to ensure humidity protection. The coordinator node is equipped with a USB-Xbee dongle (Xbee S1 radio module), which allows to realize an 802.15.4 network communication with the node Xbee modules. Data collected are transmitted to the web server using the second USB port, through a 3G key or a WiFi dongle that will connect to an existing wireless connection, but eventually also via Ethernet.

2.3 Communication protocol and software

The system requires two types of communication protocols. Nodes transmit data with Xbee S 1 IEEE 802.15.4 networking protocol to the coordinator node, which then sends data to the remote server database with Wi-Fi technology based on IEEE 802.11 or 3G mobile telecommunications technology protocols. Data are stored in a MySQL database, which can be queried by many clients to provide textual data tables, graphical visualization plots and export data function in .csv format. The user can view data remotely via a browser or a dedicated app.

The software was developed with different languages for each part of the system. The nodes were programmed with Arduino IDE (Integrated Development Environment).The coordinator node is a server-like application software write in PHP, and thanks to ad-hoc developed API, it is possible to control data flow, in terms of data collection from nodes Xbee modules, raw data elaboration and transmission to the database. When data is received from the Coordinator node, it is then formatted in a JSON string, which will be next saved in the database to allow a dynamic data management. The output string contains information about node ID number, pH and temperature values (unit and °C), and battery level (V).

3. Results and Discussion

The system was analyzed in laboratory in order to evaluate performance in term of power consumption and sensors accuracy and stability. Moreover, a cost analysis was carried out to estimate the economic potential of this kind of open source system, in a perspective of a wireless sensor network constituted by several nodes. The system utilizes a four-hour cycle for data acquisition and transmission, more than appropriate for wine evolution dynamics. The nodes perform the reading of the sensors (16mA peak) for 15 sec and data transmission to the coordinator node (5mA peak) for 5 sec, then go into sleep mode with minimal power consumption (10µA) for the remaining cycle time. The nodes were equipped with a full capacity 2300mA Li-Po battery, but to estimate the available battery life, 80% of capacity was considered (1800mAh), giving an approximate autonomy of 60 days. This autonomy appears to be optimal in enological applications, and remote user can easily control battery level in real-time, ensuring enough time to replace the batteries. The calibration of temperature and pH sensors showed a good linearity with the reference sensors (data not shown). Regarding WineDuino system cost analysis, the price is about 130€ for each node (hardware and sensors) and 120€ for the coordinator node, whereas the first prototype [5] was much expensive, approximately the double. After this preliminary test phase in laboratory, the system will be tested in cellar conditions for the 2014 vintage.

4. Conclusions/Outlook

In the last years, WSNs are widely used for different monitoring solutions both in vineyard [8-11] and cellar [1-5, 13]. Temperature is a critical factor to control during alcoholic fermentation, but different stages of vinification process require the monitoring of many other parameters. Moreover, the development and installation of a monitoring system on steel vats could be relative simple, but the wood matrix of barrels could represent serious problems, both in term of positioning and obstacle for barrels management practices, as sampling, filling or movement. This paper presents an open source, low cost WSN applicable to every phase of the wine production process, without any impact to cellar management. The WineDuino system characteristics were evaluated considering the improvements over a previous prototype proposed from the authors [5]. The system is ready to use and easy to install, just replacing the common barrel bung. Power consumption test shows high performance in terms of battery life, ensuring up to 60 days of operating time. WineDuino node is less expensive than the first prototype, and presents no obstacle to cellar practice management, thanks to its non-invasive dimensions and wireless technology. The system provides high flexibility and customization features, allowing significant opportunity to monitor every critical stage of the wine production chain. In that direction WineDuino thus becomes a useful DSS (Decision Support System) for the winemaker to realize a Precision Enology approach in quality production.

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Conflicts of Interest

The authors declare no conflict of interest.

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