Ciência Téc. Vitiv. 28(2) 71-76.2013

TECHNICAL NOTE/NOTA TÉCNICA

PROTOTYPE TO CONTROL ALCOHOLIC FERMENTATION TEMPERATURE IN WINEMAKING

PROTÓTIPO PARA O CONTROLO DA TEMPERATURA DE FERMENTAÇÃO ALCOÓLICA DURANTE A VINIFICAÇÃO

Pedro L. Neves[1], Carlos Lebres[1], Goreti Botelho[2,3]*, Nuno M. Fonseca Ferreira[1]

[1] Instituto Politécnico de Coimbra, Instituto Superior de Engenharia de Coimbra, Departamento de Engenharia Eletrotécnica, Rua Pedro Nunes - Quinta da Nora 3030-199 Coimbra, Portugal.
[2]Instituto Politécnico de Coimbra, Escola Superior Agrária de Coimbra, Departamento de Ciência e Tecnologia Alimentar, Bencanta, 3045-601 Coimbra, Portugal.
[3]Unidade de I&D CERNAS, Escola Superior Agrária de Coimbra, Instituto Politécnico de Coimbra, Portugal.
*corresponding author: G. Botelho. Tel. +351 239802940, Fax +351 239802979, e-mail: goreti@esac.pt

(Manuscrito recebido em 09.01.2014. Aceite para publicação em 14.02.2014)

SUMMARY

Portugal stands out as a recognized country in the production of superior quality wine, the two main reasons being the edaphoclimatic conditions and the grapevine heritage. To maximize quality it is important that the various steps of the winemaking process be submitted to effective control and monitoring. Since the alcoholic fermentation is a crucial stage of the winemaking process, this paper describes a low cost prototype to perform the supervision and control of the alcoholic fermentation process in a winery. To demonstrate the viability of the practical application of this solution in real conditions, a prototype was installed in the winery of Escola Superior Agrária de Coimbra (ESAC), to control the fermentation temperature of white must in a medium size vat.

RESUMO

Portugal assume-se como um país de referência na produção de vinhos de qualidade superior pelas condições edafoclimáticas e património vitícola que possui. Para potenciar a qualidade verifica-se a premência que as diversas etapas do processo de fabrico do vinho sejam submetidas a uma efetiva monitorização e controlo. Sendo o processo de fermentação alcoólica uma das etapas mais importantes do processo de produção de vinho, apresenta-se uma solução de baixo custo para efetuar a monitorização e controlo do processo de fermentação alcoólica numa adega. Para comprovar a viabilidade prática desta solução, foi instalado na adega da Escola Superior Agrária de Coimbra (ESAC), um protótipo que efetuou em condições reais, o controlo da temperatura de fermentação de mosto branco numa cuba de média dimensão.

Key words: monitoring, alcoholic fermentation, temperature, interface, communication, ZigBee.
Palavras-chave: controlo, monitorização, fermentação alcoólica, temperatura, interface, comunicação, ZigBee.

INTRODUCTION

Viticulture and oenology are some of the most dynamic sectors of the Portuguese economy, due in part to the diversity and quality of grapes, soil and weather conditions (Moreira *et al*., 1996; Paulo *et al.*, 1997).

For an oenologist or winemaker the control during winemaking of the must fermentation process is as important as measuring a number of grape quality parameters, including soluble solid content, reducing-sugar content, titratable acidity, pH, tartaric and malic acid contents and sensory attributes (Reynolds, 2010a,b), for which several techniques have been developed for the assessment of chemical changes in the main internal quality properties of grapes during on-vine ripening and at harvest time (González-Caballero *et al.*, 2010, 2011; Ghozlen *et al.*, 2010).

In the area of oenology, several studies and solutions have emerged proposing a more automated and efficient winemaking process. Relative density control in winemaking (Moreira *et al.*, 1996; Paulo *et al.*, 1997), design of temperature monitoring system for red wine fermentation based on ZigBee (Fumeng and Shouyuan, 2012), wireless sensing platform for remote monitoring and control of wine fermentation (Aleixandre *et al.*, 2013; Ranasinghe *et al.*, 2013), multipurpose optoelectronic instrument for monitoring the alcoholic fermentation of wine (Jimenez *et al.*, 2011), and the design of temperature control system for rice wine fermentation (Shengyi and Xinming, 2013) are examples of recent studies performed. Nevertheless, current market solutions are not very customizable, and are expensive, making the technology affordable only to large producers. In this context, and taking into account the demands of the market, the low cost solution presented here is adaptable to any setting in small and medium capacity wineries. Thus, even the lower wine expression producers in the market, can implement a system for alcoholic fermentation monitoring, enabling them to improve their wine quality.

Thus, the main objective of the present work was to develop a friendly and low cost control system to monitorize the alcoholic fermentation temperature in real time.

MATERIAL AND METHODS

Prototype Architecture

The monitoring and control system consists of three distinct parts (Figure 1): the database, which is allocated on an online server and is used to record all information, the interface that allows a user to interact with the system in a simple and intuitive way, even being outside the winery, and finally, the local control unit (LCU) controls the alcoholic fermentation temperature, and records data measured from the sensors.

Figure 1 - Prototype architecture.
Arquitetura do protótipo.

Database

The database has two essential roles in the system, in addition to being used to store the winery's physical configuration, and save the fermentation information measurements; it is also used as a platform to control the fermentation parameters in each vat. So, with the database installed on the online server, the users can interact with the winery from anywhere in the world, and they can use different platform types, such as a web page, dedicated software interface or a smartphone application.

Local Control Unit

The local control unit (LCU) is a low cost device, even as a prototype, it has a cost less than 60€. It interacts directly with fermentation dynamics, it's located near the vat and it can assess the state of fermentation and act in accordance with the user's defined parameterization. LCU consists of a central processing unit (CPU), several sensors and actuators, one interface and a wireless transceiver (Figure 2). Based on sensors, the LCU get the temperature of clarified must (whites) or must with pomace and skins (reds), i.e., the designed prototype can run with both red and white winemaking process. As on this part are described the LCU's features, both terms should be used, through wireless communication receives the target temperature and the CPU performs a control algorithm (PID controller), to control the cooling pump. Periodically using a radio frequency (RF) Zigbee unit, LCU sends the fermentation values to another ZigBee unit connected on a PC by USB.

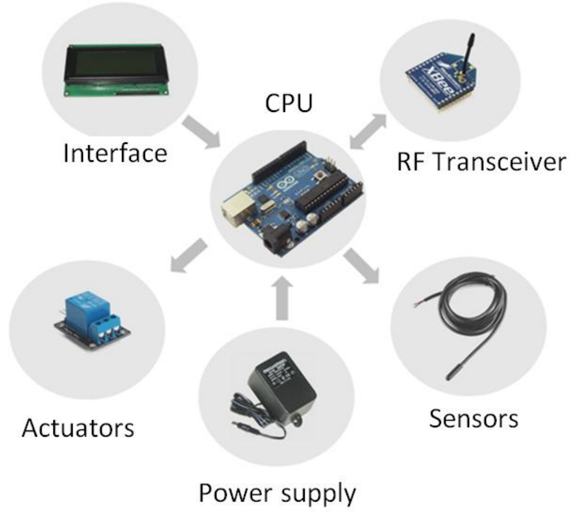

Figure 2 - Local Control Unit Diagram.
Diagrama da Unidade de Controlo Local.

Interface – PC Application

The PC application, in addition to receiving the messages from the RF ZigBee unit, is a platform for the user interface. The interface developed using the Visual Studio in C # language, provides a platform for the user to interact with the winery, and the database.

The application lets the user view and parameterizes the technical features from each vat present in winery, at any time; consult the evolution of fermentation taking place in each vat; define the control fermentation parameters; consult and update the fermentation historic information.

This last feature, even after alcoholic fermentation is finished, allows the user to add additional notes such as: report the wine's final result, customer feedback, and sales results. All of this saved information will allow for the improvement of the fermentation process in subsequent years.

Figure 3 shows the layout of the PC interface. The small window is the vat menu, where the user configures the fermentation settings, and the largest window is the winery menu, that shows all winery's vat state. Apart from these two windows, there are other windows to manage user access level, configure the winery, configure system settings, and consult historical fermentations database.

Figure 3 - Interface – PC Application.

Aplicação para PC – Interface.

Interface – Android application

Another addition feature, that allows the user to interact with the winery from anywhere at any time, is a smartphone application (Figure 4). Although not all features of the PC application are available, this application is a very practical tool that allows the user to check the state of fermentation and easily change the control parameters. The application was developed for Android smartphones and interacts with the vat in the cellar by means of the online database.

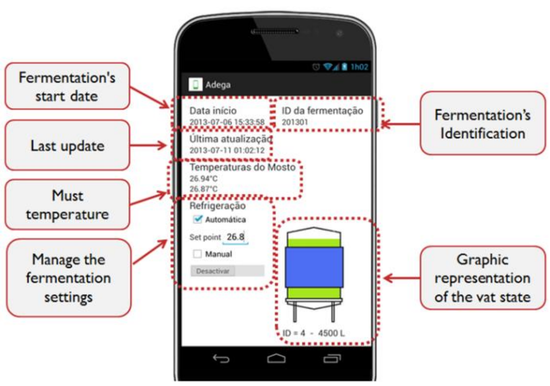

Figure 4 - Android application.

Aplicação para Android.

Low-cost wireless communication system

In order to maintain the low cost and flexibility of the solution, a system of wireless communication is the ideal solution. Thereby, at any time new units may be added, which can be moved without restrictions, avoiding the inherent limitations of a wired network. There are several low cost wireless technologies available on market, but the ZigBee's features are the most suitable for this solution.

The ZigBee is based on IEEE 802.15.4 standard, comparable to both Wi-Fi and Bluetooth standards, but it differs from these because it has much lower consumption, lower transmission data rate, a larger distance range, uses the frequency range of 868MHz, 915MHz and 2.4GHz, it supports transmission rates that can go up to 250 kbps, and it allows up to 65,536 devices on same network (Farahani, 2008). The ZigBee Alliance is a group of companies that maintains and publishes the ZigBee standard, and certifies devices that use the ZigBee standard (ZigBee Alliance, 2012).

A ZigBee network can work on different network typologies: pear-to-pear, star and mesh (Farahani, 2008). In mesh typology, devices that do not communicate directly can use their neighbor device to exchange information. Table I summarizes the main features of main wireless communication technologies used.

Unlike Wi-Fi (Wi-Fi Alliance, 2012) and Bluetooth standards (Bluetooth SIG, 2001), ZigBee technology was designed for networks with largest number of devices, using a low power and low data rate. In addition, the ZigBee standard allows exchange information using neighbors devices when tow devices don't communicate directly between them (Lee *et al.*, 2007; Fumeng and Shouyuan, 2012).

Table I

Wireless technologies main features

Principais características das tecnologias Wireless

Communication technology	Wi-Fi	Bluetooth	ZigBee
Network typology	Pear-to-pear	Star Pear-to-pear	Pear-to-pear Tree Mesh
Device max number	2	24 3-(Master) 21-(Salve)	2^{16}
Frequency	2.4 GHz	2.4 GHz	868 MHz 915 MHZ 2.4 GHz
Chanel number	14	79	1,10,16
Data Rate	11 Mbit/s 54 Mbit/s	1 Mbit/s	250 Kbps
Transmission type	Pear-to-pear	Pear-to-pear	Multi-up

PID Controllers

To perform temperature control, a classic proportional-integral-derivative (PID) algorithm was used. In general, a PID controller takes as its inputs the error, or the difference, between the desired set point and the output. It then acts on the error such that a control output, u is generated. Gains Kp, Ki and Kd are the Proportional, Integral and Derivative gains used by the system to act on the error. Controller parameters are described in Table II.

Table II
Controller parameters
Parâmetros do controlador

	Parameters		
Type	K_p	T_i	T_d
P	0.5 Kp		
PI	0.45 Kp	0.83T	
PID	0.6 Kp	0.5T	0.125T

The Proportional Integral and Derivative PID control action can be expressed in time domain as (Albanese *et al.*, 2010; Astrom, 2002):

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt - K_d \frac{dy(t)}{dt} \quad (1)$$

Taking the Laplace transform yields:

$$U(s) = K_p E(s) + \frac{K_p}{T_i} E(s) + K_p T_d sE(s) \quad (2)$$

And the resulting PID controller transfer function of:

$$\frac{U(s)}{E(s)} = K_p (1 + \frac{1}{T_i} + T_d s) E(s) \quad (3)$$

With a filter PID.

$$U(s) = K_p (1 + \frac{1}{sT_i}) E(s) - K_p \frac{sT_d}{1 + sT_f} Y(s) \quad (4)$$

A typical real approximation of a digital PID controller can be expressed as:

$$\frac{U(s)}{E(s)} = K_p (1 + \frac{1}{T_i} + T_d s) E(s) \quad (5)$$

$$u(k) = K_p e(k) + u_i(k-1) + \frac{k_p T}{T_i} \sum e(k) + K_p T_d \frac{(e(k) - e(k-1))}{T} \quad (6)$$

or with this digital approximation:

$$u(k) = uK_p + uK_i + uK_d$$
$$uK_p = K_p e_k$$
$$uK_i = K_i T \left[\frac{e_0 + e_1}{2} + \frac{e_1 + e_2}{2} + \Lambda + \frac{e_{k-1} + e_k}{2} \right]$$
$$uK_d = K_d \frac{y_k - y_{k-1}}{T} \quad (7)$$

Experimental test

The experimental test was realized on ESAC winery facilities (Figure 5), where the prototype performed in real conditions a white wine fermentation control in a cement epoxy resin protected vat with 4500 L of capacity.

Figure 5 - Partial view of ESAC winery.
Vista parcial da adega da ESAC.

A computer with the designed application was installed at the winery, near the vat, to exchange information with LCU. The communication between these two units was performed using the XBee module connected to PC by USB (Figure 6).

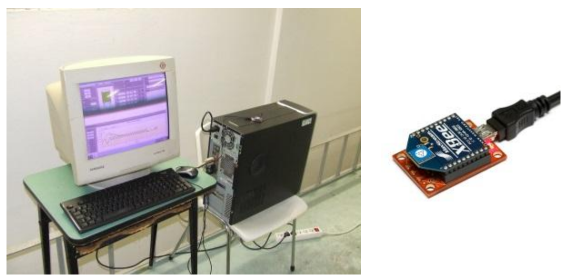

Figure 6 - Computer with application installed, and XBee module used for wireless communication.
Computador com o interface instalado, e módulo XBee utilizado para a comunicação wireless.

The LCU was placed near the vat, where the test was performed (Figure 7). It collected the must's temperature by two probes placed at different positions, one at the vat's bottom, and other at the vat's top. The LCU controlled the periods when coolant was circulating, to keep the desired temperature set by the user.

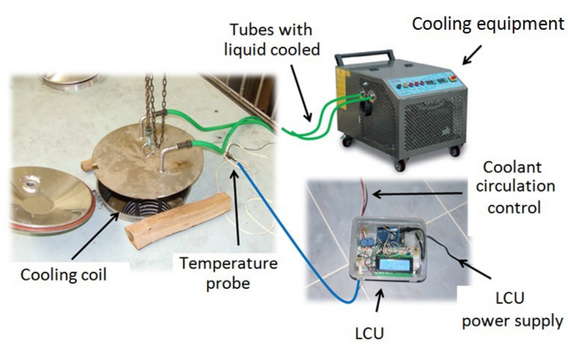

Figure 7 - Fermentation control system.
Sistema de controlo da fermentação.

White must description

The white must available for this research work was obtained from a blend of Portuguese white grape varieties (Bical, Maria Gomes and Arinto), harvested in September of 2012 from ESAC vineyards located near to the ESAC experimental winery. The grapes with an average potential alcohol content of 13.5 % vol., after their hand harvest were immediately destemmed and crushed (Mizar 60 Model, Puleo, Italy, 2005), and a solution of sulfur dioxide (60.0 g dm^{-3} of SO_2) was added to prevent oxidation and spontaneous fermentation. Then, the must and crushed skins were pressed inside an horizontal pneumatic press (PRM10 Model, Velo, Italy, 2005) and the must was pumped for a vat to have decantation during 24 h, with pectolytic enzymes addition (1.0 g hL^{-1}, Endozym Éclair, Pascal Biotech, France), at controlled temperature of 6.0 ± 2.0 ºC. After this static decantation, the clarified must was equally split for two same size vats (4500 L capacity each), and an inoculation with the same quantity of active dried yeasts after rehydration (15.0 g hL^{-1}, *Saccharomyces bayanus,* IOC 18-2007, Institut Oenologique de Champagne, France) was performed in both musts to start the alcoholic fermentation.

White wine sensory analysis

Paired preference tests were performed as described by ISO 5495 (2005). The white wine samples were coded with three digit numbers and were presented to the subjects in random and balanced order to eliminate first order carry-over effects (Williams, 1949). An amount of 30.0 mL of white wine was given to each panel judge in wine tasting glasses at 14.0 ± 1.0 ºC (ISO 3591, 1977). The samples were evaluated and water was provided to rinse the mouth between samples.

RESULTS AND DISCUSSION

In the first four days the alcoholic fermentation process was controlled by the cooling pump system. During this stage, the LCU ran in parallel mode, only measuring the temperature without controlling vat temperature. This allowed verify if the system was functional and tune the PID controller without putting the ongoing fermentation in danger. After the initial stage, the prototype became the master control of the fermentation process.

The graph present in Figure 8 was picked from the designed application, and it shows the temperature evolution. The density data were collected from daily (twice a day) must density control using conventional density measures (glass densimeter device). It is visible the difference on temperature's behaviour before the middle of the fourth day, when temperature was controlled by the cooling pump, and the following days when LCU starts to control the fermentation process.

One year later, the white wine produced under temperature control was compared with another one that was fermented in a similar vat but without temperature control. Both wines were sensory evaluated by an untrained panel of 33 subjects (25 females; 8 males; mean age 22.5 ± 8.8 years) who performed a paired preference test.

The results reached showed that a statistically significant preference by the fermentation controlled wine was found, at a significance level of 1.0 %. This sensory test demonstrates that there is a substantial positive impact in the quality and pleasantness of the white wine submitted to controlled fermentation temperature conditions, which was well recognized even by untrained subjects.

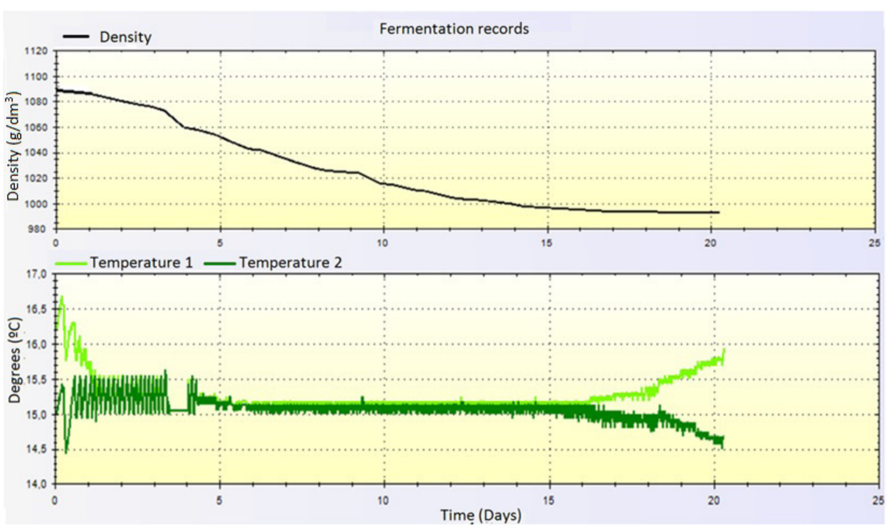

Figure 8 - Density and must temperature evolution.

Evolução da densidade e da temperatura do mosto.

CONCLUSIONS

The designed solution meets the initial objectives proposed, i.e., the interface allows user to configure and monitor the winemaker center, the local control unit enables control fermentation in each vat, and the database allows for the saving of information generated during the fermentation process by the system. The solution is modular and adaptable to any winemaking's center. Being modular could make the solution expensive, but this did not occur because it used low-cost hardware. In addition, the experimental test performed to show the viability of the designed solution, allowed the researchers to identify possible improvements to optimize the system and make it more robust.

ACKNOWLEDGMENTS

The authors wish to thank the CET-QA students and the colleagues from Science and Food Technology Department (ESAC) who voluntarily participated in the sensory analysis of wines.

REFERENCES

Albanese D., De Santo M., Liguori C., Paciello V., Pietrosanto A., 2010. Biosensor-based intelligent measurement system for wine fermentation monitoring. *In: Proceedings of the 43rd Hawaii International Conference on System Sciences,* Hawaii.

Aleixandre M., Montero E., Santos J.P., Sayago I., Horrillo M.C., Cabellos J.M., Arroyo T., 2013. Wireless and portable sensor system to differentiate musts of different grape varieties and degree of grape ripeness. *In: Proceedings of the Sensors, 2013 IEEE*, Baltimore.

Astrom K.J., 2002. *PID Control, Control Systems Design.* Department of Mechanical and Environmental Engineering University of California, Santa Barbara.

Bluetooth SIG, 2001. Bluetooth Specification Version 1.1.

Farahani S., 2008. *ZigBee Wireless Networks and Transceivers.* Newnes, United States of America.

Fumeng Z., Shouyuan C., 2012. *Design of temperature monitoring system for red wine fermentation based on ZigBee.* Information Technology in Medicine and Education (ITME 2012), Vol.1, Hokkaido.

Ghozlen N.B., Cerovic Z.G., Germain C., Toutain S.; Latouche G., 2010. Non-destructive optical monitoring of grape maturation by proximal sensing. *Sensors,* **10**, 10040-10068.

González-Caballero V., Pérez-Marín D., López M.-I., Sánchez M.-T., 2011. Optimization of NIR spectral data management for quality control of grape bunches during on-vine ripening. *Sensors,* **11**, 6109-6124.

González-Caballero V., Sánchez M.T., López M.I., Pérez-Marín D., 2010. First steps towards the development of a non-destructive technique for the quality control of wine grapes during on-vine ripening and on arrival at the winery. *J. Food Eng.*, **11**, 158-165.

ISO 3591, 1977. Sensory analysis–Apparatus–Wine-tasting glass. International Organization for Standardization, Genève.

ISO 5495, 2005. Sensory Analysis-Methodology-Paired Comparison. American National Standards Institute, New York.

Jimenez F., Vazquez J., Sanchez-Rojas J.L., Barrajon N., Ubeda J., 2011. Multi-purpose optoelectronic instrument for monitoring the alcoholic fermentation of wine. *In: Proceedings of the Sensors, 2011 IEEE.*

Lee J.-S., Su Y.-W., Shen C.-C., 2007. A comparative study of wireless protocols: Bluetooth, UWB, ZigBee, and Wi-Fi. *In: Proceedings of the 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON),* Taiwan.

Moreira G.M, Martins de Carvalho J.L., Hogg T., Vasconcelos I., 1996. Medição da densidade na fermentação de vinhos através da dinâmica térmica do processo. *Engenharia Industrial,* **2,** 18-21.

Paulo A., Moreira G.M., Martins de Carvalho J.L., 1997. Relative density control in winemaking. Industrial Electronics, ISIE '97. *In: Proceedings of the IEEE International Symposium,* Guimarães.

Ranasinghe D.C, Falkner, N.J.G., Chao P., Hao W., 2013. Wireless sensing platform for remote monitoring and control of wine fermentation. *In: Proceedins of the 2013 IEEE 8th International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP)*, Melbourne.

Reynolds A. G., 2010a. *Managing wine quality.* Vol. 1: Viticulture and wine quality. 606 p. CRC Press, Woodhead Publishing Limited, Cambridge.

Reynolds A. G., 2010b. Managing wine quality. Vol. 2: Oenology and wine quality. 651 p. CRC Press, Woodhead Publishing Limited, Cambridge.

Shengyi Z., Xinming W., 2013. The design of temperature control system for rice wine fermentation. *In: Proceedings of the 2013 2nd International Conference On Systems Engineering and Modeling (ICSEM-13)*, Atlantis Press, Paris.

Wi-Fi Alliance, 2012. Wi-Fi org. Retrieved from URL: www.wi-fi.org [accessed in 22 November 2013].

Williams E.J. 1949. Experimental designs balanced for the estimation of residual effects of treatments. *Aust. J. Sci. Res.*, **A2**, 149-168.

ZigBee Alliance, 2012. Retrieved from URL: http://www.zigbee org/ [accessed in 20 November 2013].