Intelligent Solution for Improving Winery Operations: Wine Production Management System

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Abstract

Winemaking is a complex process that requires years of experience and intelligent techniques to achieve the best quality of this beverage. We have developed a wine production management system based on Raspberry Pi microcontrollers. The system provides a secure, easy-to-use, clean, and fast interface on any system, available as a mobile, website, or desktop application. The system is designed to make every day in the winery easier, helping workers with their most challenging tasks. This part of the report focuses on everyday tasks and duties in wineries and the improvements that come with implementing the wine production management system. This article describes the intelligent solution to a wine production management system designed to facilitate wine production and improve product quality. The system will focus primarily on improving the fermentation process and aging of wine through automatic temperature reading, the ability to control temperature, entering data on fermentation progress, and reviewing data on time charts. All data will be collected in a database accessible to the winery staff. An intelligent solution to improve winery operations will include temperature sensors and thermostats connected to the Raspberry Pi microcontroller, making it easy to enter data into the database. The entire system will be implemented so that no employee will have a problem using it.

Keywords

Intelligent winemaking, Raspberry Pi microcontrollers, Wine production management system, Fermentation control, Temperature sensors, Vinification automation

1. Introduction

Winemaking, an age-old art that marries tradition with science, is an intricate process that requires expertise and innovative techniques to achieve the pinnacle of beverage quality. Recognizing the multifaceted challenges inherent in this ancient craft, we present an intelligent solution to elevating winery operations, the wine production management system. This system, built on Raspberry Pi microcontrollers, represents a transformative approach to modernizing winemaking. We have endeavored to create a robust yet user-friendly wine production management system in response to the evolving landscape of technology and industry demands. This system offers a secure, intuitive, and user-friendly interface accessible on various platforms, be it mobile, web, or desktop applications. The overarching goal is to alleviate the daily burden that winery staff face, empowering them to overcome challenges with newfound efficiency.

This article delves into the intricacies of everyday tasks and responsibilities within wineries, shedding light on the enhancements ushered in by implementing our intelligent wine production management system. Central to this discourse is exploring the impact of our innovative solution on wine production and its potential to improve product quality. At its core, our intelligent solution focuses on refining the critical processes of fermentation and aging. Through the implementation of automatic temperature readings, precise temperature control, real-time data entry tracking fermentation progress, and a review of comprehensive time charts, our system strives to usher in a new era of efficiency and precision in winemaking.

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An essential facet of our approach lies in establishing a centralized database that provides winery staff seamless access to collected data. This accessibility ensures a streamlined workflow and informed decision-making processes. The inclusion of temperature sensors and thermostats, seamlessly integrated with Raspberry Pi microcontrollers, simplifies data entry, contributing to the overall user-friendly design of the system.

This paper presents a comprehensive overview of our intelligent solution, articulating its role in facilitating wine production and enhancing product quality. By incorporating cutting-edge technology into the winemaking process, we aim to simplify daily tasks and empower winery staff with the tools they need to thrive in an ever-evolving industry. We strive to usher in a new era of intelligent winemaking by meticulously implementing a wine production management system. In the modern world, wine plays an essential role in everyday life. Many people may not even imagine their dinner or night without a glass of one of the oldest and most common beverages. Value is considerable in culture and business: When we go to business meetings, a good understanding of which wine to choose can present us in a good light. The variety of wines makes them attractive to collectors and allows them to be matched to any meal. Wine has an excellent power of unification, and some countries have built on this precious beverage. Italy, France, and Spain are the largest producers in the world. France produces 49.1 mln hl [1]. Generally, winemaking has essential steps: cultivation, harvesting, crushing and pressing, fermentation, clarification, aging, and bottling.

2. Related Work

This part of the research provides an overview and analysis of several relevant papers. The selected papers cover various topics of intelligent systems [2, 3], such as intelligent energy management systems, e-waste management, document management systems, knowledge management systems, trust management systems, and quality management systems in wineries.

Cantino et al. [4] present a sustainable perspective in wine production for common-good management. This case study on biological "reserve" contributes insights into sustainable practices and common-good management. The experiences shared in this paper may guide the proposed intelligent system's approach to sustainability and community-oriented practices in winery operations.

Atik et al. [5] present a prototype of a piezo-based intelligent power management system for efficient street lighting. This work demonstrates the application of intelligent power management systems that can inspire similar innovations for energy-efficient solutions in winery operations.

Kahhat et al. [6] examine e-waste management systems in the United States. While focusing on a different industry, the insights into effective waste management systems could be valuable for understanding and improving sustainability practices in winery operations.

Alade [7] discusses designing and implementing a web-based document management system. This paper is relevant in wine production management, as efficient document management can streamline processes and improve operational effectiveness.

Maier and Hadrich [8] contribute to understanding knowledge management systems. This source provides a broader perspective on knowledge management, which can be insightful for designing intelligent systems that can optimize the use of knowledge in winery operations.

Jenyo et al. [9] propose a trust management system for the Nigerian cyber-health community. Although the context differs, trust management systems can be adapted to enhance trust and reliability in winery operations, especially in supply chain and data management.

Aggelogiannopoulos et al. [10] provide a case study on implementing a quality management system in a small Greek winery according to the ISO 9000 family. This work is directly relevant and provides a real-world example that could inform the development of quality management solutions in the context of wine production management systems.

Dhaliwal et al. [11] present a detailed study of the wine dataset and its optimization. While focusing on optimizing a wine dataset, this paper provides valuable insights into the data aspects of winery operations. Understanding how data can be effectively studied and optimized in wine

production is crucial for the proposed intelligent wine production management system. The optimization techniques discussed may inform decisions about data handling and analysis within the system.

McHugh et al. [12] introduce the concept of a database management system for semistructured data is relevant, especially in managing diverse and complex information in winery operations. Given the varied nature of information related to grape varieties, production processes, and quality metrics, the Lore system may offer lessons on handling semistructured data, which is common in the wine industry.

The selected research papers cover various topics that provide valuable insights for developing an intelligent solution to improve winery operations. These insights include energy efficiency, waste management, document handling, knowledge management, trust management, and quality control.

Hughey et al. [13] qualitatively evaluated three 'environmental management systems' in the New Zealand wine industry. This study is particularly relevant to the wine production management system as it delves into environmental management practices within the industry. Understanding how environmental factors are managed can inform the development of a holistic wine production management system that integrates sustainability practices.

Luciano et al. [14] present a medicine management system and its design and development. While the focus is on healthcare, system design, and development principles can be cross-applied to the wine production management system. Lessons learned in developing a system for managing medicine could provide insights into designing efficient and reliable systems for managing various aspects of wine production.

Turgay [15] explores blockchain management and federated learning adaptation in a healthcare management system context. This paper introduces cutting-edge technologies that may inspire innovative data management and security solutions in wine production. Blockchain and federated learning concepts could be adapted to enhance the integrity and security of data in winery operations.

Luciano et al. [16] present PARADAJuan, a web-based parking lot management system. Although seemingly unrelated, the multi-paradigm programming languages used in this system's development may offer insights into versatile approaches to designing and developing a wine production management system. The adaptability and flexibility demonstrated in this work can inform the customization and scalability of proposed intelligent solution for winery operations.

Incorporating insights from these additional papers (see Table 1) enriches the related work section by expanding the scope of relevant concepts and methodologies. The focus on environmental management, system design principles, emerging technologies, and multi-paradigm programming languages enhances the applicability and robustness of the proposed intelligent solution for improving winery operations.

Table 1.
The analysis of the research works related to intelligent solutions for improving winery operations.

Authors	Analysis
A. Baiano	Baiano [17] provides an overview of sustainability in the wine production chain. This paper is pertinent to our study as it addresses sustainability, a crucial aspect of the proposed intelligent wine production management system. Insights into sustainable practices in the wine industry may guide the integrating of environmentally friendly processes into the system.
A. Walsdorff, M. van Kraayenburg, C. Barnardt	Walsdorff et al. [18] present a multi-site approach toward integrating environmental management in the wine production industry. This work contributes valuable insights into environmental management practices, which can inform the proposed system's sustainable and environmentally responsible features.
A. Walsdorff, M. van Kraayenburg,	This study [19] complements the previous reference, providing further details on the multi-site approach toward integrating environmental

Authors	Analysis
C.A. Barnardt	management in the wine production industry. The multi-site perspective may offer a comprehensive understanding of the challenges and opportunities associated with environmental management in diverse winemaking settings.
B. Fernández, I. Seijo, G. Ruiz-Filippi, E. Roca, L. Tarenzi, J.M. Lema	Fernández et al. [20] focus on the characterization, management, and treatment of wastewater from white wine production. This is relevant to our study as it addresses an essential aspect of winery operations. Understanding wastewater management practices can contribute to the proposed system's overall efficiency and environmental sustainability.
B. Bravdo	Bravdo [21] investigates the effect of cultural practices and environmental factors on wine production and quality. This paper provides valuable insights into the impact of external factors on wine production, contributing to the system's capability to adapt and optimize processes based on environmental conditions.
G. Anastasi, O. Farruggia, G. Lo Re, M. Ortolani	Anastasi et al. [22] explore monitoring high-quality wine production using WSNs. The incorporation of WSN technology for monitoring aligns with the proposed intelligent solution. Lessons from this work may be applied to enhance the system's real-time monitoring and control aspects.
J.E. Jones, F.L. Kerslake, D.C. Close, R.G. Dambergs	Jones et al. [23] review viticulture for sparkling wine production. While the focus is on viticulture, the insights into production processes and quality factors are relevant to our study. Understanding specific requirements for sparkling wine production can inform the system's adaptability to different wine types.
J.-I. Latorre-Biel, E. Jiménez-Macías, J. Blanco-Fernández, J.C. Sáenz-Díez	Latorre-Biel et al. [24] discuss decision support in the Rioja wine production sector. This work contributes to our study by addressing decision support, a critical component of the proposed intelligent wine production management system.
K. Grainger, H. Tattersall	This book by Grainger and Tattersall [25] provides insights into wine production and quality. While a broader resource, it can contribute general knowledge and best practices in wine production, which may inform the development of the proposed system.
L. Bencini, G. Collodi, D. Di Palma, A. Manes, G. Manes	Bencini et al. [26] present a real implementation and deployment for wine production management based on Wireless Sensor Network (WSN) technology. This paper complements, providing practical insights into implementing WSN technology in wine production management. Lessons learned may guide the integration and deployment of similar technologies in our proposed system.
P. Benedetti	Benedetti [27] offers valuable insights into integrated solutions for the wine industry. Understanding integrated solutions can contribute to developing a comprehensive and cohesive intelligent wine production management system.
R. Merli, M. Preziosi, A. Acampora	Merli et al. [28] focus on sustainability experiences in the wine sector, aiming toward the development of an international indicators system. This work is highly relevant as it addresses sustainability metrics. Incorporating such indicators into proposed system can enhance its ability to monitor and optimize sustainability aspects in winery operations.

Integrating these additional papers enriches the related work section by incorporating diverse perspectives on sustainability, environmental management, decision support, viticulture, and technological implementations in wine production.

3. Wine Production Management Process

3.1. Cultivation and harvesting

The first step in wine production is cultivation. Many fruits can be used for wine production, but the most popular is the grape. It grows on vines. There are different methods of vine cultivation. During cultivation, it is essential to cut the vines properly, which guarantees an increase in the level of sugars, polyphenols, and aromatic compounds, which affects the quality of wine. Grapes are harvested with a proper sugar level without an excessive loss of acidity. Harvesting is done manually or mechanically. It is important to create conditions that limit the risk of oxidation and the development of undesirable microorganisms.

3.2. Crushing and pressing

From the harvested grapes, the stalks must be separated from the fruit. Suitable machines are used for this. The fruit is pressed, and the juice is separated from the marc to obtain the must. During this process, the must initially start to ferment.

3.3. Fermentation

During fermentation, they must be placed in a closed tank (a stainless steel tank). The fullfill of the tank ensures that unwanted oxidation is avoided, which would occur if fermentation must come into contact with oxygen. Natural fermentation starts 6-12 hours after crushing and pressing. It takes 10 to 30 days or even longer. During fermentation, the sugar level in the must is checked using a refractometer - a device that measures the sugar level. The sugar level tells us about the progress of fermentation. The sulfur and acidity levels are also examined. It depends on the level of acidity and whether the wine is dry or semi-dry. For example, semi-dry wine has an acidity level of less than 7mg/l and a sugar content of about 7%. Acidity is measured by pouring 10 ml of must into a test tube and adding the indicator liquid until the mixture is entirely violet. The determination of the tube measures the level of acidity.

3.4. Clarification

After fermentation, the wine is separated from the lees to undergo the clarification process [27]. This process makes the wine transparent and prevents unwanted aromas from developing. The clarification method may involve leaving the wine longer or adding the appropriate clarifying agents, such as protein and tannins.

3.5. Aging and Bottling

This is the last process that takes many years. The wine matures in oak barrels or bottles in dark, cold places. Aging has a very positive effect on the taste of the wine. There are many types of wine worldwide, and they differ in how they are produced. Some are based on tradition, while others follow the spirit of the times and rely on new technologies. The winemaking process is very complex and requires many years of experience and appropriate techniques to obtain the best quality of this beverage.

4. Application Model

The winemaking process has five basic steps: harvest, crushing and pressing, fermentation, clarification, aging, and bottling [29, 30]. Each of these steps is important. Our management model supports fermentation (Fig. 1) and aging (Fig. 1)because these steps require significant data analysis of sugar content, acidity, and temperature.

Collecting all data, such as the beginning and end of the fermentation date (the start date of wine aging) of individual batches and the types of wine produced, is also essential.

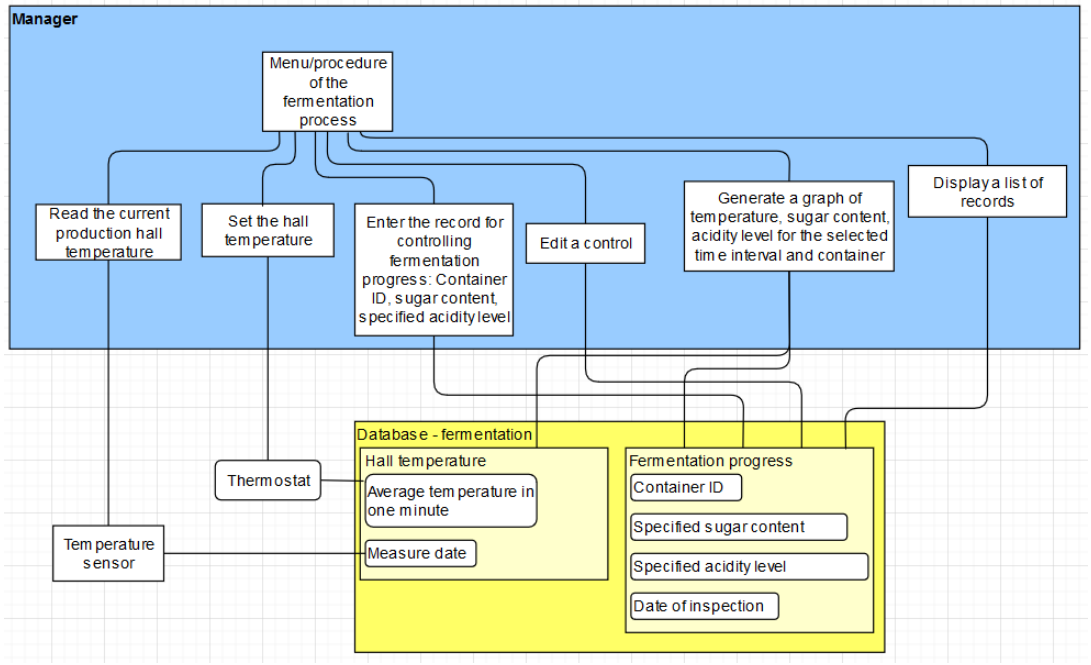

Figure 1: Fermentation process control system - Manager view

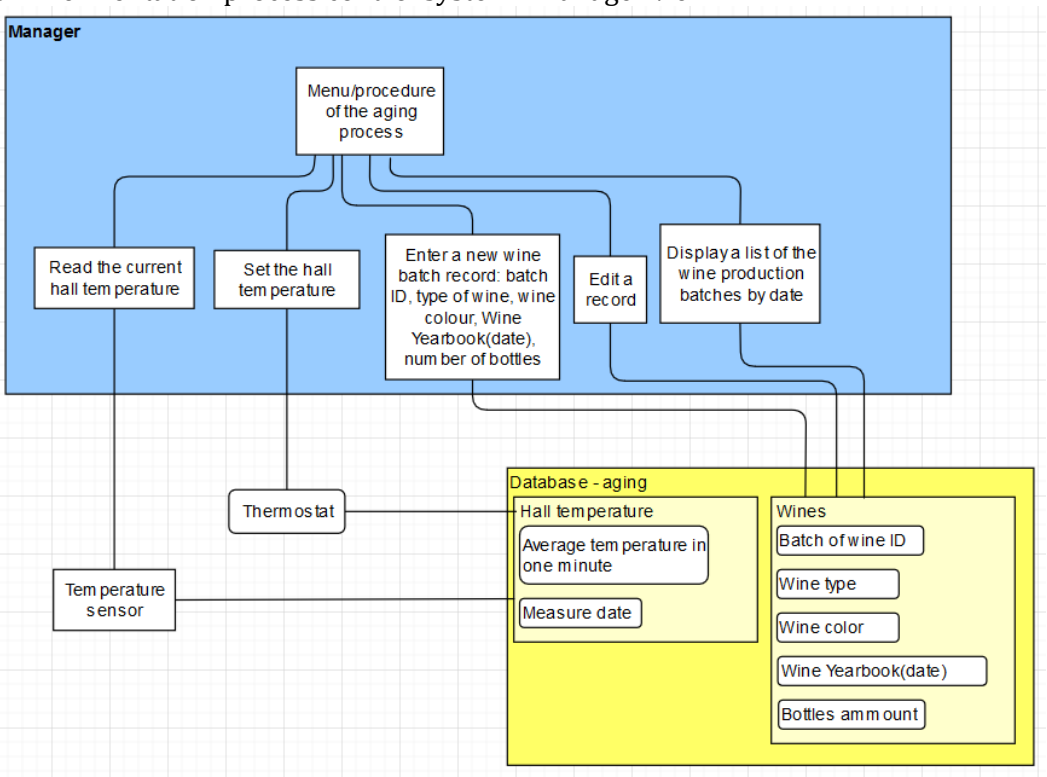

Figure 2: Aging process control system – manager view

The fermentation menu/procedure allows the employee to check the temperature in the rooms and set the appropriate temperature (Fig. 3). The worker can also, after checking the fermentation progress, enter a record in the database containing the date of the check, container ID, sugar content and acidity level and, if an error is made within two days, correct this error. The leader can also display a graph of temperature, sugar content in the container, or acidity level for a selected period (Fig. 1). He can also display the entire list of records and change any of them.

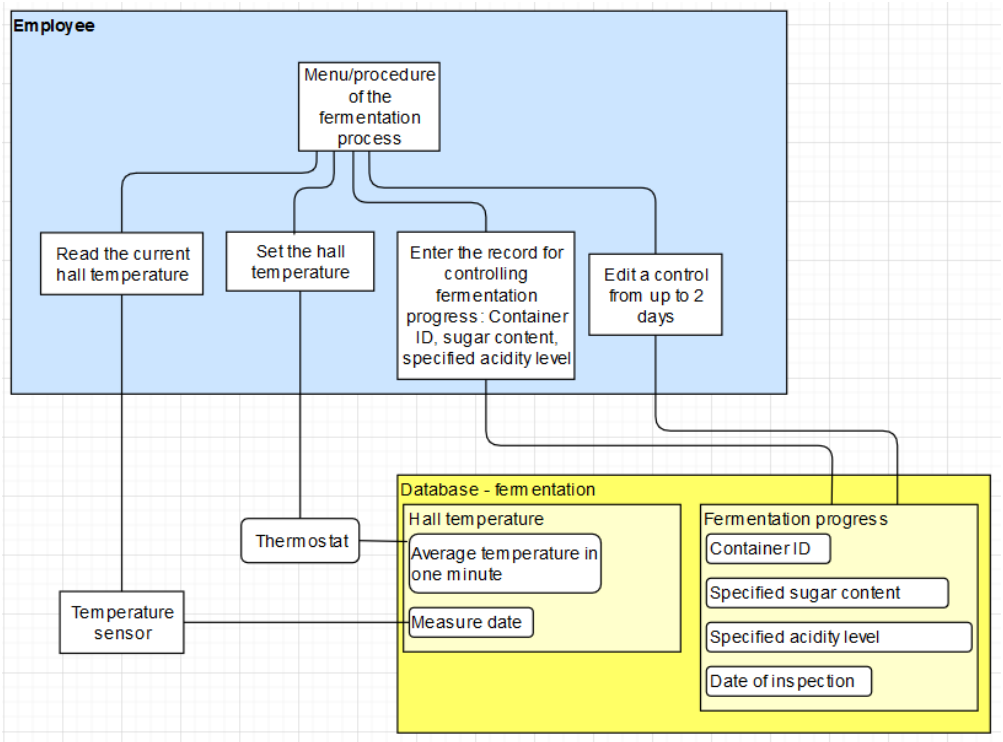

Figure 3: Fermentation process control system - Employee view

The aging menu/procedure also allows the employee to check the room temperature and set the appropriate temperature (Fig. 4).

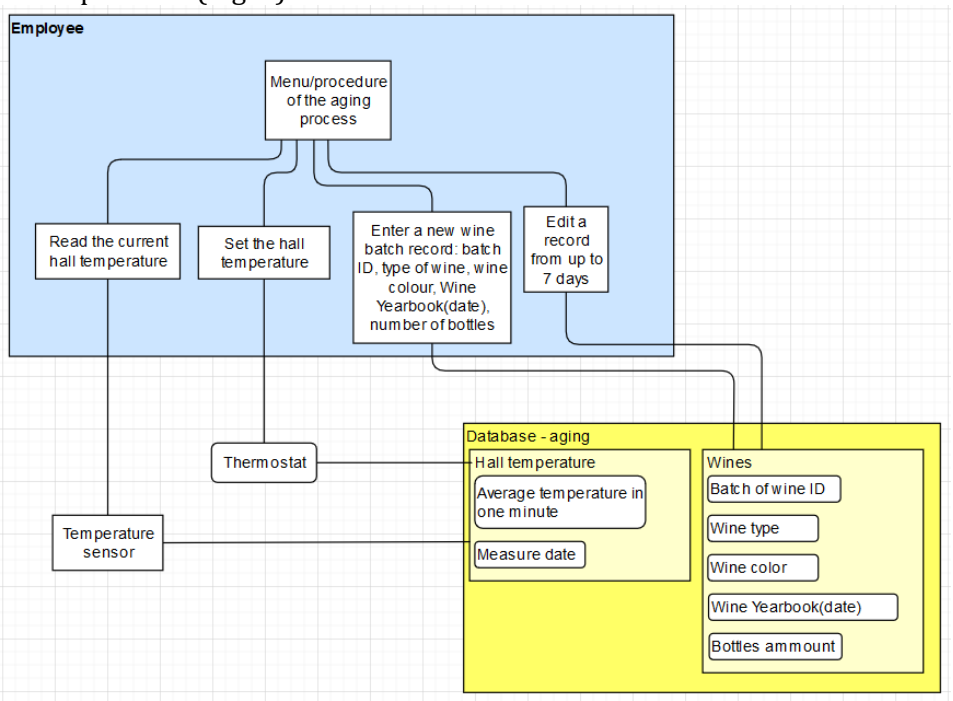

Figure 4: Aging Process Controlling System - Employee View

The employee can also enter a new record for a new batch of wine placed in the room by entering the batch ID, the type of wine, the color of the wine, the vintage of the wine (date), and the number of bottles. If a mistake is made, he/she can edit the record within seven days of its creation.

The leader displays a temperature diagram for the selected period and a list of all wine batches sorted by date (Fig. 2). He can also edit any record of wine batches.

5. Sensor Model

Our wine production management system does not need a lot of computing power to save data from temperature sensors and record temperature, fermentation progress, and aging progress, so we decided to use Raspberry Pi microcontrollers. Thanks to this solution, our product will be much more affordable and convenient to implement than computers. The sensor model (Fig. 5) also includes a display, keyboard, temperature sensor, and thermostat.

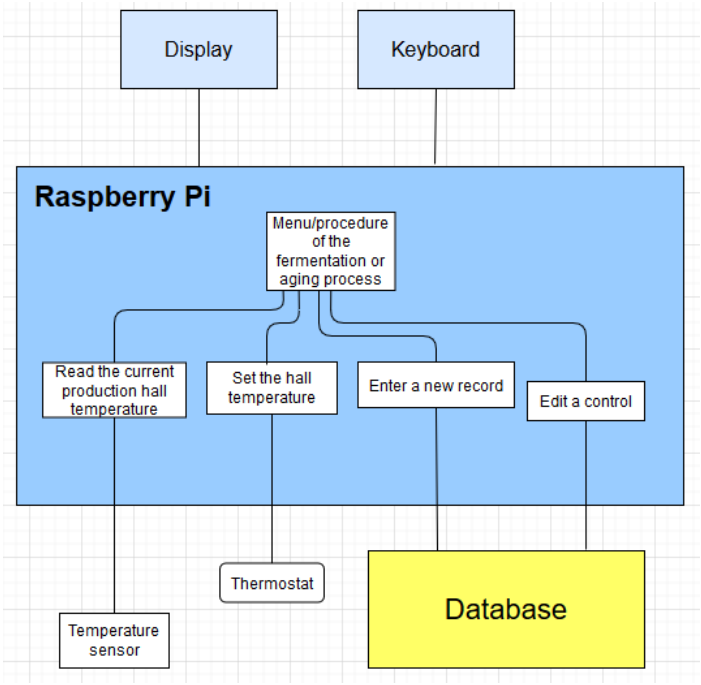

Figure 5: Sensor Model

Sensor model components are connected to Raspberry, which is connected through a local network to a database, allowing all necessary data to be collected.

5.1. Wine Production Management System in the Winery

This part of the report focuses on daily tasks and duties in wineries and the improvements that come with implementing the wine production management system. The first part contains information about average winery duties and employee's routines. The second part of this chapter describes changes resulting from introducing the system.

5.2. Labor Day in the vineyard

Working in a winery is an unparalleled task. Every worker has to cope with many different and uncommon roles. Classic demands from employers can vary by the wine produced by the winery, the spectrum of wines made, and obviously through the technological development of the vineyard. The most common tasks of everyday tasks are transfer operations, pump operations, making additions to wines, and cleaning.

5.2.1. Cleaning

Cleaning tasks must be done with great care. Many elements of the winery need sanitization, such as

- cellar fittings
- hose

- fixed process lines.
- stainless steel tanks
- tank trucks
- barrels
- processing equipment used for grape and wine

Cleaning methods can vary, but standard tools are pressure washers or water hoses used to clean most of the above-mentioned elements. Additionally, hand scrubbing is inherent in cleaning minor elements such as pumps, hoses, or fittings. Most workers not only clean elements but also determine if there is any need for cleaning or sanitation. Usually, it is determined by visual inspection or by checking microbiological status with the appropriate tool.

5.2.2. Equipment and transfer operations

Transfer operations are everyday tasks such as dragging and lifting wine hoses that can be under pressure. The fittings must attach those hoses to various elements such as pumps, tanks, transfer lines, or washers to transfer liquids or for cleaning purposes.

The other tasks included in transfer operations are manipulating tank heads in different ways to open and close tank doors.

Equipment operations depend on the warehouse size, but they are expected to move any container of wine with any vehicle or lift with operating barrel conveyor lines. The most crucial task in equipment operations is manipulating the weight of barrels or other containers to a specified amount.

5.2.3. Miscellaneous responsibilities

- The addition of chemicals and portions of additions is measured, mixed, and transported to the tank heads to add them to empty or filled tanks.
- Using hand devices to scan barrels for various barrel operations.
- Measurement of the amount of liquid in tanks using measuring tapes or other devices.
- Record measurements and calculate gallons on work orders.
- Reading and following instructions in work orders.
- Creating excellent and proper documentation of operations performed on work orders.
- Measure and mix yeast and ML culture and add them to the tank with wine.
- Monitoring the equipment and sanitation in the winery and performing it if needed
- Assisting in processing barrels and tanks.
- Performing minor barrel repairs if necessary and monitoring the quality of the barrels.
- Participating in the writing, refining, and updating of winery procedures as needed

6. Utility of the wine production management system.

The presented system was created with great care for the employee's life and thriving vineyard production. Our system is not only used to create the finest quality beverages, but its other objective is to make it easier every day in the winery and help workers in their most challenging tasks [31, 32]. Fundamental in the presented system is the control menu for the regular worker. It enables steering of the temperatures, showing the actual temperature and the proper temperature for the actual progress of fermentation, but more importantly, the system will not allow us to change the temperature to values that can affect the quality of the wine. The system can handle fermentation and aging, notifying when any tank needs action, e.g., sugar contamination is too low or any of the values received by sensors is out of the accepted range.

The Wine Production Management System applies to ordinary employees and provides many possibilities for senior employees, managers, and office workers. By storing all historical data and presenting them with a graph with selectable time frames, senior employees can even determine how to improve some of the production elements or the quality of beverages. There are many

more ways sensor data can increase winery efficiency and revenue. Another feature comes from storing historical data – especially for office work. All records show the exact amount of resources used for every tank or type of wine made. With all this information available, wineries can now determine which production sector most resources are used. It can recalculate additional costs and, equally important, reduce the required paperwork. In standard cases, when workers do paperwork, all missing resources and produced beverages must be checked manually. The Wine Production Management System can summarize all products used in the specified period and print the results for the user.

7. Conclusions

Implementing a wine production management system in a winery significantly impacts many aspects of the winery. Implementing management software will make employee jobs more accessible and more effective. Additionally, it is an excellent investment in the future: It improves the quality of the wine, decreases the production time, and helps to manage all the papers. There is no need to use Excel or any production documentation.

The problem with introducing this system may be the reluctance or uncertainty of people who are professionally engaged in wine production and do not have much contact with advanced technology. These people may claim that traditional methods are the best. Another challenge is to train employees to use the system; the system should be as intuitive as possible.

With the presented system, the winery can develop itself more efficiently, gather more knowledge of what happens with its product, etc. The Wine Production Management System covers many criteria that vineyards consider. Our system provides a secure, easy-to-use, clean, and fast interface on any system – available on mobile, website, or desktop applications.

Nevertheless, our system may still cover a lot more. We aim to add data and manufacture more beverages such as beer, champagne, fizz, cider, or more potent liquids. Another possibility of development is to deliver intelligent tools that help fermenting and aging processes and prepare resources in the crushing and pressing production phase. Possible features for the crushing phase may be sensors that press fruits with the proper strength and time. For the harvest phase, our system will have infrastructure in plants in wine fields to check moisture and growth percentage and automatically manage grapevine watering.

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