Ullage level monitoring model using sensors inside and outside the system in the fino-style winemaking aging process

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Abstract. Manual control of wine production possibly can be ineffective, considering in a winery there could be more than one parameter quality control with many tanks or barrels produced at the same time. In the aging process of Fino-style winemaking, the ullage must be maintained at a constant level. Considering the existing barrels and tanks, space is needed to place the sensor to collect data with the best result possible. In the case of sensor placement inside the system, an ultrasonic sensor is used by acquiring the time data needed to receive the signal emitted from the sensor. Whereas in the case of sensor placement outside the system, a microphone is being used to acquire sound frequency data generated from hitting wine cask with solenoids in a sample time of 100ms. Based on the latest research, the two sensors can be used to acquire ullage data from casks. However, for long-term use of an ullage monitoring system, it is recommended to use the inside one, although it is more expensive, the simple working principle and easier maintenance making it unlikely to hire experts only for dealing with the sensor nodes.

1. Introduction
One of the problems of fermentation and the aging process on wine industries is the manual work of controlling the wine using chemical and human-sensory sampling. This kind of control method consumes much of the winemaker's time, energy, and cost [1]. Manual control of wine production possibly can be ineffective, considering in a winery there could be more than one parameter quality control with many tanks or barrels produced at the same time.

Whereas, some parameters must be taken care of by the winemakers at the fermentation and aging process. For example in the aging process of Fino-style winemaking, the height of ullage ("ullage" may refer to (1) space between the wine and the bottom of the cork and (2) the evaporation of wine to the air space) must be maintained to a constant level [2]. In the other case, a set of relevant parameter used to monitor the process [3] one of them is temperature [4] depends on the variety of grapes and the wine-variety produced. Furthermore, risk on the stopping fermentation and growth of undesirable microorganisms also exists in the winemaking process [5]. Manual controlling may lead to oxidation each cask opening [6] and vulnerable to variations of measurement on each cask or barrel [1]. If these problems are not getting any attention from the winemakers, the quality of the wine will suffer [2], [6].

Monitoring systems using the electronic sensor-based for the wine industries has been developed with various methods. This monitoring system aims to be an answer to the problems stated before and mitigate manual-monitoring risks by acquiring data from tanks or barrels to provide reliable
information in real-time. Some of them are also featured with analytic tools, so the winemakers can manage to take a quick and right decision to maintain the ullage at a relatively constant level.

Data collection approach with the use of sensor nodes, considering existing barrels and tanks that widely used, leads to some compensations needed. One of that is the need for space to put the sensor node to acquire data with the best results possible. This paper will discuss the ullage monitoring of Fino-style winemaking aging process published on the two given paper using sensor node placement inside and outside the casks. The advantages and disadvantages of both methods also provided. This study aims to find out the best current method for acquiring ullage data with sensor nodes that can be applied to Fino-style wineries.

2. Methodology
In this study, there are two discussed experimental approaches researched that can be used to acquire the ullage data. The first one acquires the data with ultrasonic sensors placed inside the system and the other with a microphone that acquires sine wave values placed outside the system. The notable difference makes both have different working principles when applied to monitor the ullage. A closed cask that filled with wine in the Fino-style winemaking aging process is the definition of the system discussed below in this paper.

2.1. Placement inside the system
Monitoring device that used by the first approach placed the sensor nodes inside the system and named "Smart Cork" [2]. The ullage monitoring with Smart Cork uses an ultrasonic SRF08 sensor. Based on the datasheet, this sensor used to acquire data from 0,03m to 6m.

The SRF08 sensor working principle is by sending sound pulses towards an object, and then the sensor will receive an echo reflected by the object. While the sensor pulses the sound wave, the sensor will send HIGH signal feedback to the Data Acquisition Unit until the echo is received. With a timer, the Data Acquisition Unit will calculate the length of time the sensor sends a HIGH signal. Object distance calculated by dividing the time the sensor sends a HIGH signal with twice the speed of sound [7]. The SRF08 sensor also has a light sensor on the front of the module.

![Figure 1. Smart Cork [2].](image1)

![Figure 2. Hardware architecture of Smart Cork [2].](image2)
In Smart Cork research, cork was modified (Figure 1) to load sensor nodes inside the system [2]. These sensor nodes include two sensors that can acquire data on humidity, temperature, distance, and light intensity, as shown in Figure 2. An SD card is used to store data at the sensor node. This sensor node is also equipped with a real-time clock that only makes the sensor node fully functional every ten minutes. If this series of nodes is not fully functional or has completed an acquisition cycle until data transmission, then this series will be in deep sleep mode, as can be seen in Figure 4.

Figure 3. Firmware architecture of Smart Cork [2].

Figure 4. Data collection scheduling method [2]

The ultrasonic sensor data record on Smart Cork shows that the ullage has increased little by little over time. As shown in Figure 5, on 9 December, the level of ullage increased from 18.46 cm to 18.62 cm, and on 20 December, the level of ullage increased from 18.62 cm to 18.69 cm [2]. These small increases are in line with the characteristics of the Fino-style winemaking aging process, which continues to evaporate and release from the casks during the process, as stated in the introduction.

2.2. Placement outside the system
Monitoring device that used by the second approach placed the sensor nodes outside the system and named “Wine Note” [6]. Ullage monitoring with Wine Note uses a microphone as an audio sensor that
retrieves the sound frequency data. This audio sensor uses an Arduino microphone with characteristic frequency ranges from 50 Hz to 20 kHz.

Figure 6. Wine Note [6].

The Wine Note is placed on the surface of the wine cask. Wine Note works by striking the cask using a solenoid as a source of sound that will be received by the microphone as a sound sensor. When the cask is being hit, the resonant frequency produced by the cask is 200 Hz to 600 Hz. The sound produced by the cask then recorded for 100 ms to be processed later [6]. Signal processing uses Direct Fourier Transform (DFT), which is embedded in the NUCLEO board and stored inside the local drive while transmitted via LoRa. A cycle from data acquisition to data transmission is done once a day automatically at night, to minimize unwanted noise even though this sensor node is on a soundproof cover [6]. When the cycle is complete, the sensor node will become inactive until the next night cycle.

Figure 7. Frequency data record from Wine Note [6]

The data record using the Wine Note shows that the device can acquire frequency data from the recorded sound. Recorded data as shown in Figure 7. Estimating the wine volume in a cask is calculated with the fast maximization of concave functions by the dichotomy method. According to the calculation, this algorithm offers a low complexity, but there is still a limitation on the resolution [6].
In Figure 8, the increasing volume of wine in the cask will lower the frequency. Vice versa, the lower the volume of wine in the cask, the higher the frequency will increase.

3. Result and Discussion
The ullage control system of the aging process has a critical component that must be present in the device to find the space that is not filled with wine inside the cask. There are several aspects that we can compare between both sensor nodes either inside or outside the system. We can see the advantages and disadvantages of each sensor node from the comparison of both sensor nodes.

Table 1. Smart Cork and Wine Note comparisons.

| Parameter                          | Smart Cork [2]                                         | Wine Note [6]                                         |
|------------------------------------|--------------------------------------------------------|-------------------------------------------------------|
| Parameter unit                     | Sensor range to the wine in the cask                    | The frequency generated from the cask                 |
| Sensor’s measuring range           | Meter                                                  | Hertz or cubic meter                                  |
| Actual use                         | 0.03m to 6m                                            | 50Hz to 20kHz                                         |
| Working principle of data acquisition | The sensor will receive an echo reflected from the object (wine) | The frequency will be received by the sensor with a sample time of 100ms |
| Sensor placement                   | Inside the cask                                         | Outside the cask                                      |
| Power source                       | 5V power adaptor                                       | 9V alkaline battery lasts five years                  |
| Cost estimation                    | Around €166                                             | Around €50-€75                                        |
| Advantage(s)                       | Plug-and-play device and measurements can be operated simultaneously | No need to change anything from the system           |

These two devices can be used with the different sensors to determine the contents of wine in the casks. The different characteristics of the two sensors used to make each sensor nodes have advantages and disadvantages. In the case of sensor placement inside the system, the SRF08 sensor and an ultrasonic sensor is used to acquire the time data needed to receive the echo. Whereas in the case of sensor placement outside the system, a microphone is used to acquire sound frequency in a sample...
time of 100ms. The output data from the two sensors are then used to determine and help the winemaker maintain the ullage at a relatively constant level. The measurement range of these two sensors has met the specifications needed to acquire ullage data. As shown in table 1, the actual use of the two sensors is within a subset of the measurement range of the two sensors.

In terms of economic and user convenience, the two are in opposition to each other. Wine Note, with the sensor node placement outside the system offering a more affordable price, does not need to change anything from the system, and supported with an alkaline battery but has a lack of user convenience in operating because of the calibration curve is very dependent on wooden variety, the humidity, and the age of the cask used [6] which leads to the need of an expert on the setup and operation. In comparison, Smart Cork offers a plug-and-play device. However, because Smart Cork has two sensors and more features, the sensor node's price is higher than the Wine Note. The use of a power adapter on Smart Cork also has the consequence of having enough electrical port for all devices used. Also, Smart Cork has the advantage of acquiring data that can be done simultaneously if there is more than one cask in a production house, while the Wine Note will be more optimal if carried out in parallel to minimize unwanted noise from being acquired by the sensor.

4. Conclusion

The ullage monitoring system of the aging process in Fino-style winemaking can use sensors with placement inside the system such as SRF08 sensors or audio sensors to detect empty spaces or contents of the wine cask while placed outside the system. Both sensor nodes have fundamental differences in the type of data acquired, which leads to the ease of implementation for its users. Based on the results of both latest research that has been done, it is known that the ease of implementation of sensors with placement inside the system is better for the winemakers because with a simple working principle, hiring an expert is not needed to be able to implement the sensor nodes even though the costs incurred are more expensive at the first time use. Still, both sensor nodes still have plenty of room for improvement. This ullage control system is not only limited to wine processing with the Fino-style winemaking but can also be used by all wine processing that requires height as a parameter.

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