Multidiszciplináris tudományok, 12. kötet. (2022) 4 sz. pp. 25-33 **https://doi.org/10.35925/j.multi.2022.4.3**

AUTOMATED FERMENTATION CONTROL

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Abstract

Although wine consumption has a considerable tradition in Hungary, beer has been consumed in larger quantities in recent years, which increased the imports and the large-scale domestic production. The brewing process involves the fermentation of beer. There are two types of fermentation technologies, namely lower and upper fermentation. The fermentation process can be monitored and automated. Fully automated systems are quite expensive. Monitoring solutions also help improve the process, but are not the most effective solutions. This paper aim is to present a self-made automated fermentation control based on an existing monitoring system.

Keywords: *beer, fermentation, control, automation*

1. Introduction

Although wine consumption has a considerable tradition in Hungary, beer has been consumed in larger quantities in recent years, which increased the imports and the large-scale domestic production. The domestic offer is complemented by breweries producing small-scale, handcrafted products that live their renaissance. The average weekly beer consumption of Hungarians aged 15 and older was 2.6 liters in 2019. (KSH, 2021)

The hot breweries that form the first phase of brewing are followed by a second phase called fermentation. Beer fermentation is the metabolism of the brewer's yeast. There are two types of fermentation technologies, namely lower and upper fermentation. (czechminibreweries.com; Vogel, 2015; Kunze, 1983)

The style of bottom fermentation includes lower fermentation beers using the yeast Saccharomyces uvarum. Most of the world's production is lower-fermented beers, including the Czech Pilsner. The lower yeast fermentation is performed at a temperature of 6-12 °C and lasts for 6-12 days. The beer is kept at a low temperature for at least a month, which ensures, among other things, the dispersion of sulfur compounds formed during primary fermentation. (czechminibreweries.com; Vogel, 2015; Kunze, 1983)

The beer fermentation style based on top fermentation includes all beers that have used the yeast Saccharomyces pastorianus. This style includes beers such as Ale, Porter, Stout, Altbier, Trappist or Wheat Beer. The upper fermentation process is carried out at a temperature of 15-24 °C and usually takes 3-9 days. In most cases, activated carbon on the surface of the beer, together with yeast, raises the rise in carbon dioxide. This is why these beers are called fermented beers. The primary fermentation of these beers usually lasts for three weeks, in some cases for several months. Higher fermentation temperatures cause more flowering in the final beer. The beers fermented on top have a variety of flavors and often find exotic aromas (cloves, bananas, greps, etc.), although the brewery did not add such ingredients to the beer. All this is caused by the top fermentation. (czechminibreweries.com; Vogel, 2015; Kunze, 1983)

There are solutions for monitoring and fully automating the fermentation process. Fully automated systems are quite expensive, a brief summary of which is given in the next section. Next, an own automated system built on a monitoring device is presented.

2. Literature review

There are many automated fermentation systems available on the market. An example is Lianyungang Hechang Machinery Co 's PLC controlled automatic liquid strain fermenter system. The system including HMI touch screen, with PLC control system, can record production data, with storage function, and is also capable of intervention. Fermentation tanks are hundreds liter stainless steel containers, with liner for food grade grinding mirrors. (chinaloadingarm.com)

The BrewMonitor System, from Precision Fermentation, is a real-time, end-to-end fermentation monitoring and analysis solution, that is purpose-built to enable brewers to increase quality and profitability through greatly enhanced fermentation-process control.

The features in BrewMonitor System 2.5 definitively address two of the most critical aspects of brewing quality assurance. The first is faster access to the most crucial day-to-day fermentation data. The second is automating the transformation of raw data into actionable fermentation insights, this simplifies the intervention. (precisionfermentation.com; Popky, 2021)

Independent craft beer start-up Hi Sign Brewing also has its own totally automated brew system, which include fermentation system. During fermentation, the yeast will break down sugars into alcohol and CO_2. Rate of fermentation and flavors produced by the yeast vary greatly in different temperatures. Hi Sign uses a temperature probe in all fermentation tanks and a valve to control the chill power going in to the tank. Together they work just like a thermostat in a house. This ensures the temperature during fermentation is the same, yielding consistent fermentation times and flavors. The current Siemens set up at Hi Sign consists of a single industrial computer, an AS410-5H controller, two racks of ET200S I/O, a Scalance Switch, Sinamics G120 Drives and Sipart PS2 valve positioners. The PCS 7 software includes OS single station with AS/OS engineering and advanced process graphics. (grainfather.com)

3. New solution

The following section presents a new solution, which is simple, inexpensive and builds on an already exist monitoring system.

3.1. Fermentation

The fermentation process is an important step of the brewing whereby the yeast converts the glucose of the wort to alcohol and carbon dioxide. An average fermentation holds up to 10-14 days, during this time the CO_2 tries to escape through the airlock and give us feedback on how the fermentation is at that moment. Should we need any precise information about the process, we have to use a hydrometer or a refractometer to get an exact SG number. SG is the Specific Gravity of a liquid, it is a dimensionless number that gives the density of one material compared to another. In this case, the gravity of the wort to the gravity of pure water compared. Pure water would have the SG of 1.000, while the usual wort at the beginning of the fermentation has the original gravity (OG) of 1.055. At the end of the process, the final gravity (FG) would be in the 1.0051.015 range. Nowadays, modern programs to help calculate these numbers are used. They are mostly correct and help us predict the end product from the raw materials. (bisonbrew.com)

Figure 1. *Example for a beer indiegrents*

To get a precise picture of our fermentation these values have to be measured and calculated, but the specific gravity has another important property. With the values OG and FG, our alcohol by volume (ABV) can be calculated which refers to the percentage of a liquid that is pure alcohol. The mathematical method comes from the chemical reaction:

$$ABV = 132.715 * (OG - FG) \tag{1}$$

3.2. Controlling the fermentation temperature

Controlling the fermentation temperature can make significant changes in the fermentation time and the quality of the end product. Every yeast has a temperature they work best in, but during the process, this temperature must be changed by right of the specific gravity. For example, a typical lager yeast likes to ferment between 7-13°C, but near the end of fermentation (about 10-15 gravity points left) the fermenter have to warmed to 18-20°C for some days, be called diacetyl rest.

Diacetyl is a common off-flavor, composed of two similarly flavored molecules(vicinal diketones and acetyl propionyl) that gives a buttery, butterscotch-like flavor to the beer. They are created by the yeast as a fermentation byproduct. At the end of the fermentation, when the yeast finished consuming all of the fermentable sugars, it starts to consume other energy sources like diacetyl. For this, it needs energy in the form of heat. (byo.com; tilthydrometer.com)

After the diacetyl rest, the lager-type beer needs a four-week lagering stage in the range of 1-3 °C, when it can reduce sulfur compounds and matures the flavor. The temperature change between 18 and 2 °C could shock and kill the yeast, the temperature should be gradually lower by 2-3°C every day until our goal reached.

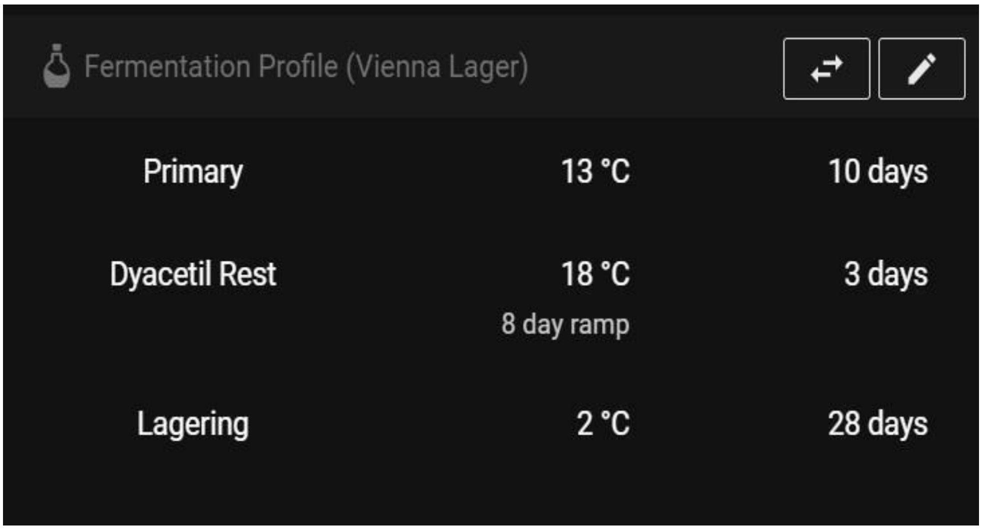

Figure 2. *Typical lager fermentation profil*

To automatize this long process, the analog measuring devices have to forgotten like hydrometers or thermometers and find a digitizable tool.

3.3. TILT Hydrometer

TILT is a floating digital hydrometer for measuring the temperature and specific gravity of something liquid during fermentation. It has a built-in temperature sensor and a gyroscope wherewith the TILT is able to perceive the angle of incidence and calculate the SG. The device works with a CR123A 3 V battery and should be changed every two years as suggested by the manufacturer.

Figure 3. *TILT Hydrometer*

The measured data comes out through Bluetooth Low Energy beacon communication protocol. BLE is a wireless personal area network technology developed by Apple and used for transmitting data over short distances. As the name indicates it has low energy requirements and ideal for applications to transfer small data packs periodic. The communication consists of advertisements, for example broadcast at regular interval by BLE devices via radio waves. This advertisement is a one-way communication method, the beacon devices that want to be discovered by the master can broadcast packets of data in set intervals. These data packets are meant to be collected by BLE master devices. The beacon standards recommend a 100ms broadcast interval because a broadcast more often allows for quicker discovery but uses more battery life. According to Apple, the advertised data consists of four pieces of information.

- UUID is a 16-byte string for distinguish a group of related beacons.
- Major is a 2-byte string used to differentiate a smaller subset of devices within the group.
- Minor is 2-byte string for identify individual beacon devices.
- Tx Power is a 1-byte string used to identify the distance between the master device and the beacon. (ibeacon.com)

In our situation the TILT Hydrometer transmits two data messages, the first is a response to a scan by a BLE beacon device, and the second data packet includes the specific gravity and the temperature.

```
> 04 3E 27 02 01 00 00 5A 09 9B 16 A3 04 1B 1A FF 4C 00 02 15
  A4 95 BB 10 C5 B1 4B 44 B5 12 13 70 F0 2D 74 DE 00 44 03 F8
  C5 C7
```

Figure 4. *Example for TILT Hydrometer data message (kvurd.com)*

This double message in Figure 4. contain the device data and the measured values, for our automatized project would like to used.

```
04: HCI Packet Type HCI Event
3E: LE Meta event
27: Parameter total length (39 octets)
02: LE Advertising report sub-event
01: Number of reports (1)
00: Event type connectable and scannable undirected advertising
00: Public address type
5A: address
09: address
9B: address
16: address
A3: address
04: address
1B: length of data field (27 octets)
1A: length of first advertising data (AD) structure (26)
FF: type of first AD structure - manufacturer specific data
4C: manufacturer ID - Apple iBeacon
00: manufacturer ID - Apple iBeacon
02: type (constant, defined by iBeacon spec)
15: length (constant, defined by iBeacon spec)
A4: device UUID
95: device UUID
BB: device UUID
10: device UUID
C5: device UUID
B1: device UUID
4B: device UUID
44: device UUID
B5: device UUID
12: device UUID
13: device UUID
70: device UUID
F0: device UUID
2D: device UUID
74: device UUID
DE: device UUID
00: major - temperature (in degrees fahrenheit)
44: major - temperature (in degress fahrenheit)
03: minor - specific gravity (x1000)
F8: minor - specific gravity (x1000)
C5: TX power in dBm
C7: RSSI in dBm
```

Figure 5. *TILT data format explanation (kvurd.com)*

The TILT as can be seen don't use the major and minor according to the apple recommendation, instead hiding the sensor data into them and give a unique identifier UUID for every Hydrometer. The temperature data is the major, a 16-bit unsigned integer, a hexadecimal number 0044, which is 68°F that is 20°C in Figure 5. The specific gravity x1000 at the place of the minor bytes is 1016, what is divided by 1000 is 1.016.

3.4. Reading data with the STM32 microcontroller

For the message reading an STM32 Nucleo F411 development board and a X-Nucleo-IDB05A2 expansion board would like to used. The IDB05A2 is using a BlueNRG-M0 Bluetooth Low Energy processor module to accomplish connection with the TILT hydrometer.

Through SPI pins, the connection is established between the expansion board and the Nucleo board. The controller's code was written in C language using the open-source STM32 CUBE IDE platform, which was created specifically for STM32 microcontrollers.

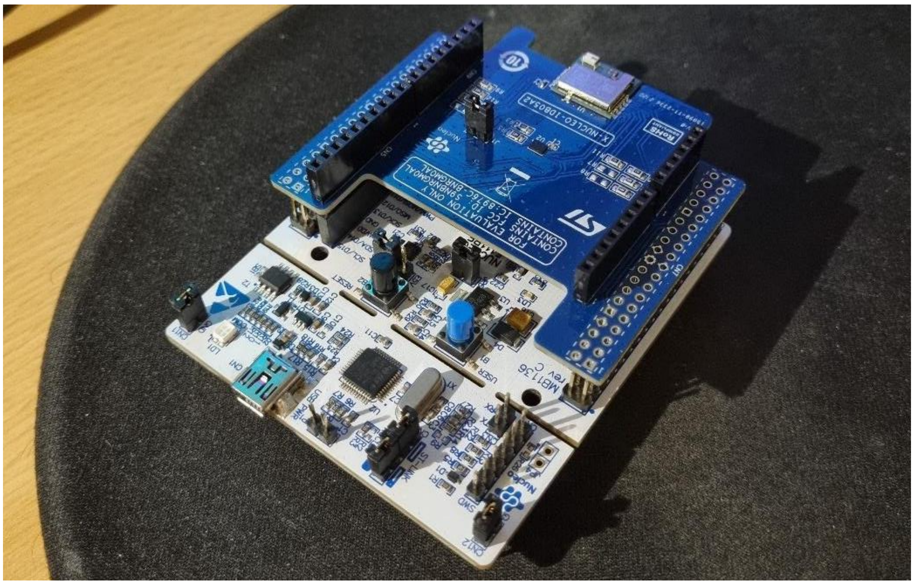

Figure 6. *NucleoF411 and IDB05A2*

The program is able to build a BLE beacon communication and reading the incoming measured data from the TILT using the X-Nucleo-BLE1 software package. Unlike conventional Bluetooth, BLE communication doesn't require pairing between the two devices. In our situation the TILT, also known as the slave device, broadcasts the information via the protocol and the master device, the microcontroller discovers the nearby BLE signals and identifies through the UUID. To test the BLE communication use a terminal program called the STM32 CubeMonitor-RF can be used, which is able to send commands to our controller in real time.

After the GAP (Generic access profile) and GATT (Generic attribute profile) initialization the microcontroller begins to scan with the ACI_GAP_START_GENERAL_CONNECTION_ ESTABLISH_PROC function. The following command is the HCI_LE_ADVERTISING_REPORT_EVENT, which is self-called by the program after a successful scanning. At last, the Meta Event sends our message to the terminal.

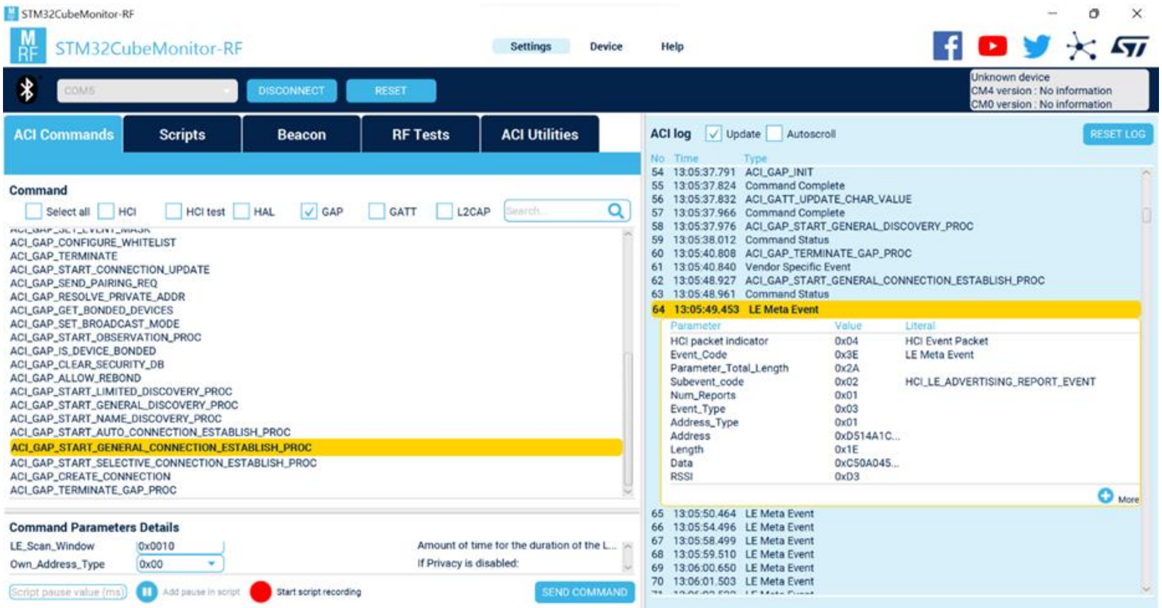

Figure 7. *Communication*

The raw data coming from the TILT is the following:

[0x04,0x3E,0x2A,0x02,0x01,0x03,0x01,0x1E,0xF8,0xC8,0xA1,0x14,0xD5,0x1E,0x02,0x01,0x04,0x1A,0xFF,0x4C,0x00,0x02,0x15,0xA4,0x95,0xBB,0x40,0xC5,0xB1,0x4B,0x44,0xB5,0x12,0x13,0x70,0xF0,0x2D,0x74,0xDE,0x00,0x52,0x04,0x0A,0xC5,0xD3] In this code the D5:14:A1:C8:F8:1E the Mac address of the TILT can be found, and the measured data is stored in the major and minor bytes.

The temperature data is stored in the major bytes. It is 27.7 °C converted from 82°F and 0x00,0x52 = 82 in decimal. The specific gravity creates the minor bytes. The minor bytes are 0x04,0x0A =1034, but after these bytes are divided by 1000, the received specific gravity is 1.034. Hereinafter, the microcontroller will process the data and control the fermentation temperature based on the programmed fermentation algorithm.

After receiving the measured data, a 5V 2-Channel 250V/10A will be used to relay module to control the temperature during the fermentation. Depending on the stage of fermentation, both relays can turn on and off a heater and cooling system. Hopefully this project can help the homebrewers make their brewing and fermentation system more professional.

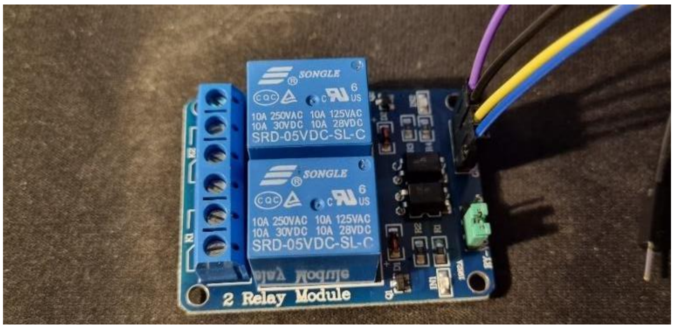

Figure 8. *5V Relay module*

4. Summary

The fermentation process of beer can be monitored and automated. Fully automated systems are quite expensive. Monitoring solutions also help improve the process, but are not the most effective solutions. In this article, our goal was to create a self-made automated fermentation control based on an existing monitoring system. The paper showed that using the TILT hydrometer, you can create your own cost-effective fermentation control.

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