Ubiquitous Computing: Final Project

Automated monitoring of beer brewing with smart outputs

Aims, Motivation & Background

This project's goal is to assist beer brewers by engineering a smart capable system to monitor environmental variables. Gathered variables indicate positive or negative brewing conditions through the lifetime of a fermentation, which is analysed and transformed into either digital or physical user notifications.

Brewing any type of alcoholic drink is a time-consuming task that requires constant monitoring. There are many contaminants that can cause a batch of beer to either stop fermenting, taste awful, or over-ferment. Without regular manual measurements and observation, the risk of these increase.

There exist many different types of smart brewing equipment currently out on the market, such as the MiniBrew (MiniBrew, 2020). These systems focus on automation of the product and are presented in their own encapsulated ecosystem with premade fermentation juice.

Additionally, there has also been several papers on beer and ethanol fermentation monitoring with off the shelf sensors (S. Piermarini, 2011). Focusing on the application of sensors to collect specific data from fermentation processes, not the post-processing and output of generated from that data which is this project's focus.

The system this project intends to create is one that could be modified for any usage, industrial or home, and used as a basis blueprint for future systems. That produces consistent outputs that could be interpreted by other systems using a common standard If This Then That (IFTTT) or a web-based Application Programming Interface (API).

Sensor Construction & Data Collection

The proposed system utilises a Raspberry Pi over that of an Arduino microcontroller. This is more than sufficient for the project's needs but allows for future iterations and expansion.

The sensors selected for this project were chosen to monitor both variables that would affect the fermentation process, and those that were a result of the process itself. Influencing factors that were monitored included movement, light, colour spectrum. Observational factors included pressure and C02 density. Additional considerations for sensors that would monitor the environment were also considered.

Environmental monitoring:

Light levels of the setup environment were monitored using both the **Flora UV Index Sensor – Si1145** and the **Photo Resistor Module KY-018.** This is due to the detrimental effect of light on certain recipes, often requiring an opaque vessel. As the exact light frequencies which are the cause of detriment is unknown, the system monitors both ultraviolet and visible light.

As the fermentation process requires a stationary vessel to allow the undesired sediment to separate out of the liquid and settle on the bottom, the project includes a **SunFounder – MPU6050** to record both gyroscopic and accelerometer data to ensure the vessel remains motionless.

The ambient temperature is also monitored as this has a large effect on the process. However, as there is temperature monitoring in the barometer module (detailed below), our design was revised to omit an additional external thermometer.

Miscellaneous environmental monitoring:

The **SunFounder - Raindrop Sensor** was included in our sensor collection to monitor the process in the absence of the user. This example was chosen due to the common error on behalf of novice brewers: allowing the process to run out of control, resulting in the vessel overflowing. The raindrop sensor modifies its resistance based on the moisture in contact with the board, therefore located externally the system can interpret this contact and produce output for the user.

Production variables:

The main output of the fermentation process is C02 as the yeast converts sugar to alcohol. The project utilises the **SunFounder - MQ-2 Gas Sensor** and **SunFounder – Barometer** to monitor these. The MQ-2 measures the level of oxygen in an atmosphere. As the level of oxygen dropped in the sealed vessel, the assumption can be made that the increasing C02 levels was the source of oxygen levels dropping.

The barometer was used to monitor pressure in the vessel. Once the vessel was sealed pressure would rise until enough to push past a bubble lock. Producing a cyclic rise and fall of pressure. The collected data was used to monitor the progress and speed of fermentation. The barometer also contained a thermometer which was opted to replace the need to include an additional module.

The **BH1745 Luminance and Colour Sensor Breakout** was included in the project, as this would allow the monitoring of changes in the colour of the liquid throughout fermentation. This meant the system could record the change in sediment that was yet to crash out of solution; this sensor required the use of a transparent vessel to operate.

Construction of sensor setup:

Original plans for construction involved sensors being directly inserted into the walls of the fermentation vessel. This requires lots of engineering effort to ensure no fluid would meet the sensors during the filling and emptying procedures. There was also a risk of a runaway reaction causing similar issues. To circumvent these issues, an additional chamber was designed and created to be positioned between the vessel and the bubble lock, containing the barometer and the gas sensors. The other sensors were affixed to the outside of the vessel, the colour sensor approximately halfway down and the lux, UV and gyroscope around the base of the additional chamber.

Limitations of design choices:

One of the main variables to monitor was the gravity of the liquid (Ethanol percentage), which would be indicative of how close to completion the process was. This proved to be unachievable through multiple design iterations; each suggested sensor setup proving to be either impractical or not fit for purpose. To work around this problem in the time available, the proposed solution was to manually monitor the values. This did not work due to vision being obstructed by foam from the reaction.

There was also possibility of issues with colour sensor to get any clear readings. The system had to use the sensor’s built in LED to illuminate the vessel contents, thereby reducing the efficacy of light sensors. This could be mitigated in future iterations by programming the LED to turn on only for data collection.

The barometer's integrated thermometer in placement of any additional thermometer was problematic due to the proximity within the chamber to the gas sensor. Complications caused by the gas sensor, which produces a high temperature to operate, were not foreseen and resulted in skewing of temperature readings. To mitigate this, periodic manual readings of the vessel wall were taken using a handheld infrared thermometer.

The major drawback of this build however was the inability to obtain an air-tight seal with the construction materials available under current circumstances. Unlike the anticipated rise-and-fall of pressure caused by the escaping gas passing through the bubble lock, It was found that the CO_2 was seeping out through the cracks in the chamber's construction. Multiple attempts were made to ensure a good seal but ultimately none were successful with the tools on hand. Pressure would build to a point, enough to dissolve CO_2 into the water of the bubble lock, but any excess would leak out instead of moving past the water in the lock.

Data Collection:

Data was collected into a Json formatted file, meaning the data can be imported into other applications with little hassle for the end user. There were three runs collected, 2 good and one 'bad' run, the bad run was contaminated with sanitizer. Each run was produced using turbo yeast to speed up the time for data collection. This is suitable for a prototype but data needs to be collected with normal yeast for an actual MVP.

Data Processing & Interpretation

The current version of the data interpreter is written in python. It extracts and converts data in the file into suitable arrays for graphing and processing. Using MatPlotLib the raw data is converted into line plot charts for comparison between runs; as seen in figures 5 through 21 in the appendix section.

Looking at the raw data plots, there does not seem to be any specific patterns or overlaps that correlate the good and bad health of the fermentation. This is compounded by the issues with sensors failing during data collection, so only all sensors collected on the first run, subsequent runs have data missing or inconsistent. However, domain knowledge tells us that following the lines for temperature and pressure, it can be observed to slowly increase over time in the two good fermentation collections. The pressure is observed to fall during the bad fermentation test, where sanitizer was left in the container before fermentation; this simulates someone not rinsing the container properly after cleaning, which is a common problem in home brewing.

Feature extraction was performed on the data sets to explore the additional axis for correlations that might help our system outputs. The feature's listed in figures 22 to 24, show the rate of change over 8-minute period to the pressure inside the container. Figures 25 to 27 show the rate of change of temperature in Celsius over 8-minute periods.

The feature graphs shed more light on the fermentation process than the raw data graphs. Showing the healthy fermentations having more positive climbs in pressure, and stable temperatures over time. The unhealthy fermentation has a graph that show major negative spikes in pressure, and very unstable temperatures.

System Outputs & User Feedback

The system that's proposed will have a multitude of outputs, through a mobile application and a open API, that can alert user's of the system when data collected is showing potential or current issues with the fermentation.

The proposed thresholds and their outputs are:

- User receives toast alert on phone/web for temperature error:
    - Temperature too high or cold, outside of 32-35ºC.
    - Large temperature fluctuation of more than 2ºC.
- User receives toast alert on phone/web for light exposure:
    - Where UV is above 50, Visible and IR is above 500.
- User receives toast alert on phone/web for Pressure issues:
    - Pressure rate falls consistently over five 8 minute periods (negative values).
    - Data is inconsistent to set thresholds for pressure when brewing, need ambient air pressure data too to make this decision, as it will be based on the difference between inside and out.
- Text alert and alarm buzz for pressure drop to ambient pressure (broken container).
- Text alert and alarm buzz for Spillage warning when the raindrop or water level sensor changes at all.
- App estimates from current pressure and alcohol levels the time left till completion in main User UI.
- App alerts via toast notification and alarm buzz that the fermentation is completed.
    - Close to estimated time and ABV reading is within range set.
    - Error and alert when either time and ABV have over or undershot.

Conclusion

This project challenged us, in designing the apparatus to collect accurate data, and then parsing that data into results and other forms of data that could be used to create a system. The prototype was not a success entirely due to reasons out of the project's control or risk factors. Sensors failing and not being able to find replacements in time, and the subsequent supermarket shortages only allowed a limited fermentation.

But the data collected shows promise of being able to threshold a couple of outputs that would be useful to a user. Opening avenues for continued experimentation and exploration of this topic. The outcome produced does not achieve the initial goal, but it does make several steps forward and proves that the system is possible.

Appendix

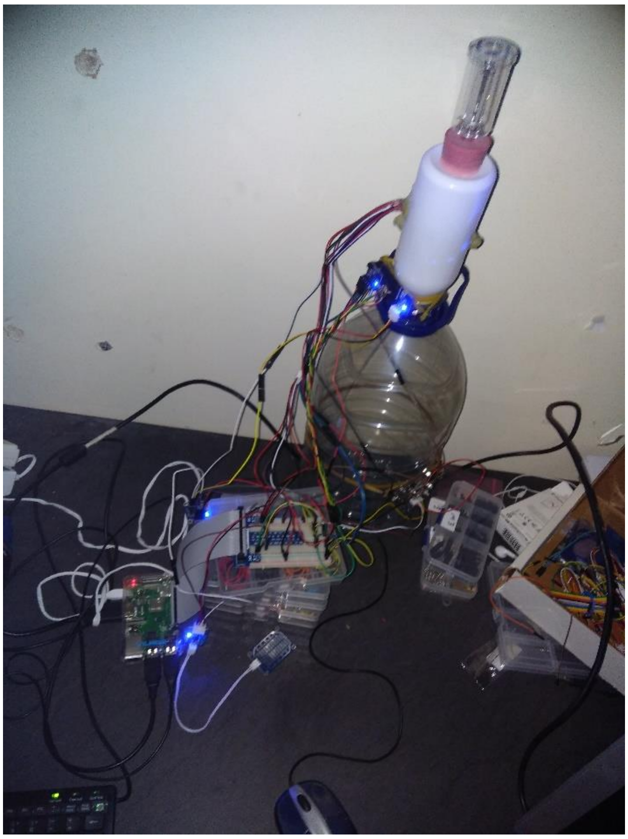

Figure 1 Complete prototype build

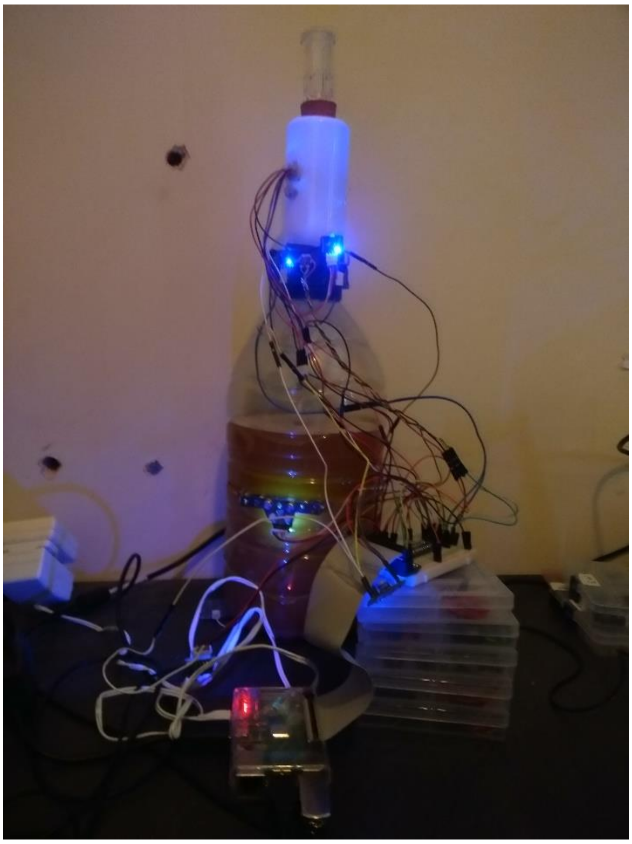

Figure 2 Prototype in use

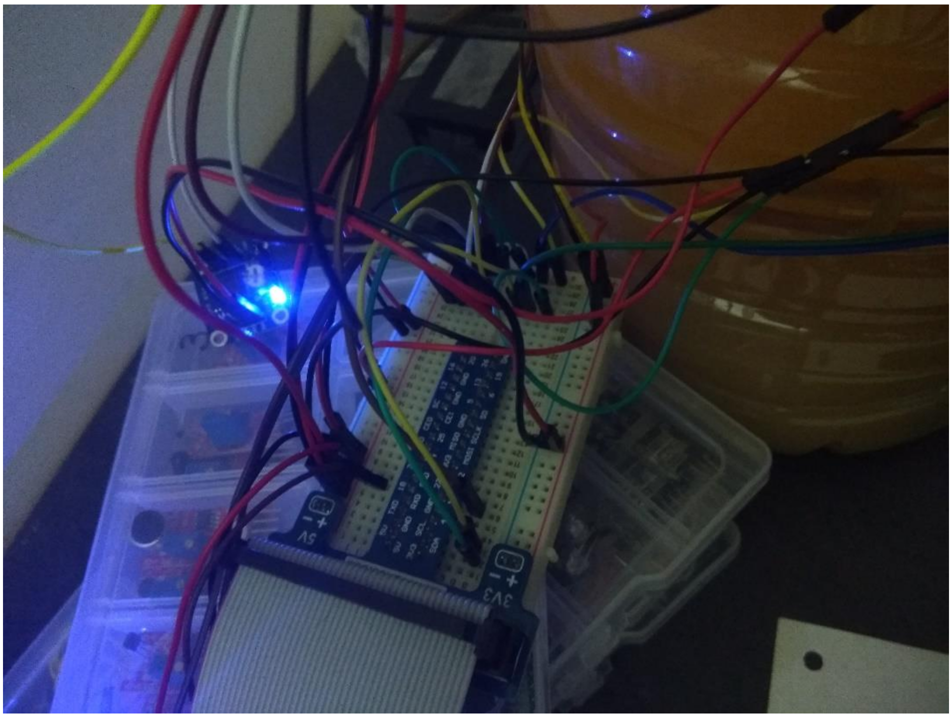

Figure 3 Pinout breadboard between raspberry pi and sensors

Figure 4 Sensors inside the sensing module.

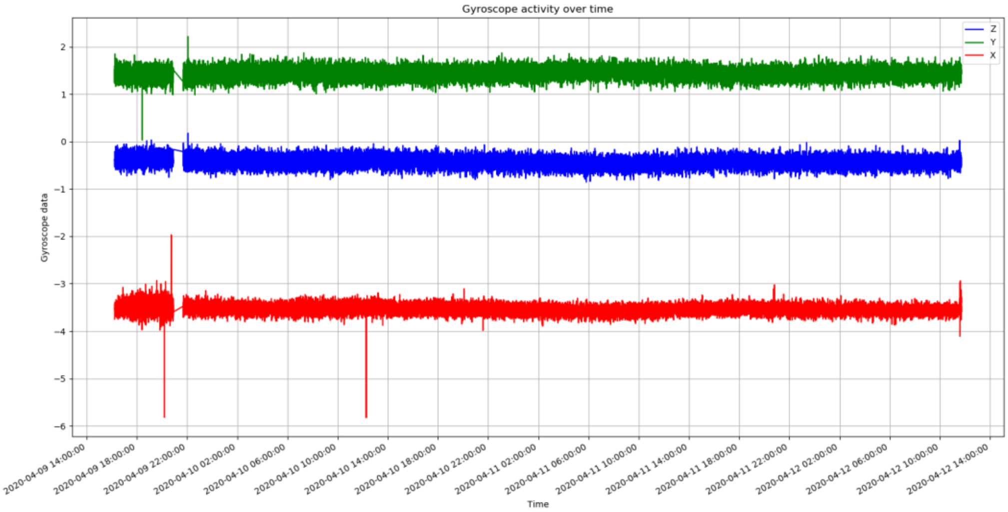

Figure 5 Gyroscope data in run 1

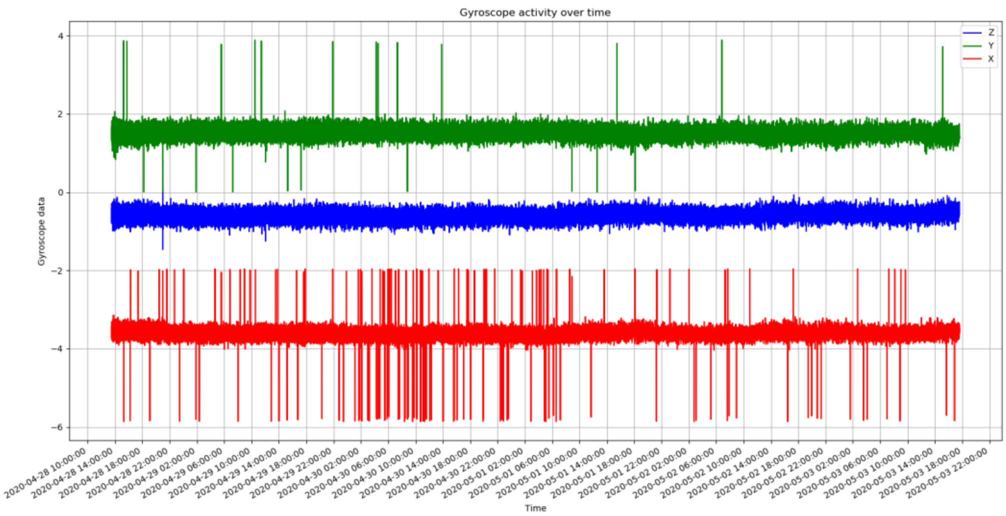

Figure 6 Gyroscope data in run 2

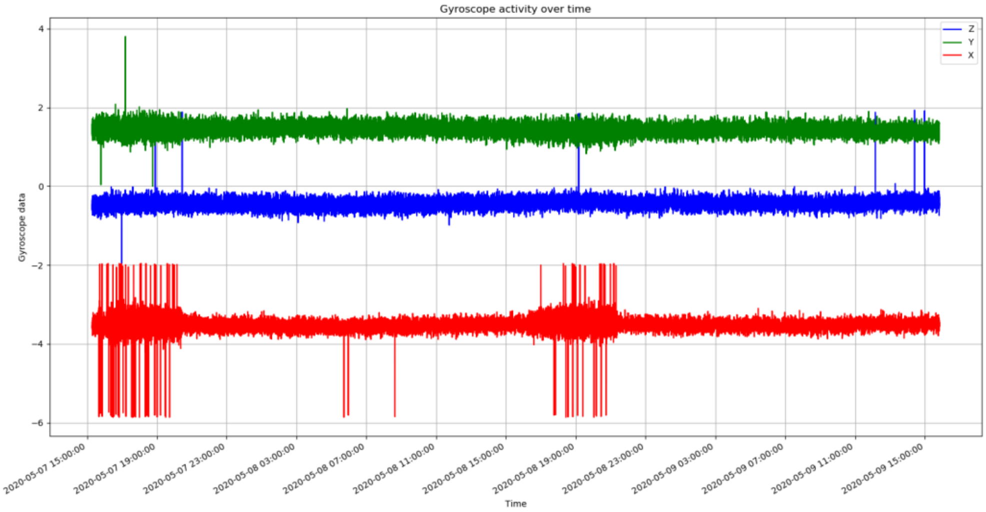

Figure 7 Gyroscope data in run 3

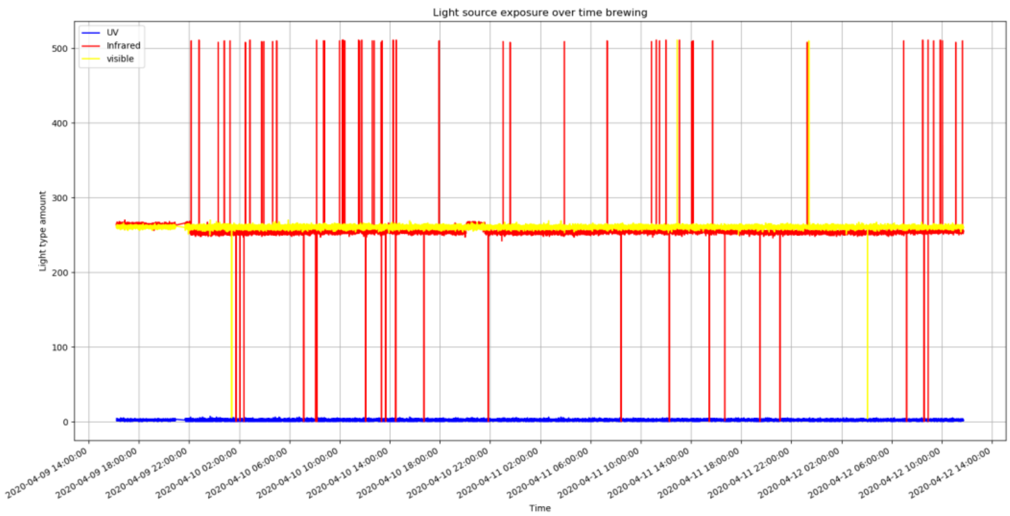

Figure 8 Light source monitoring in run 1

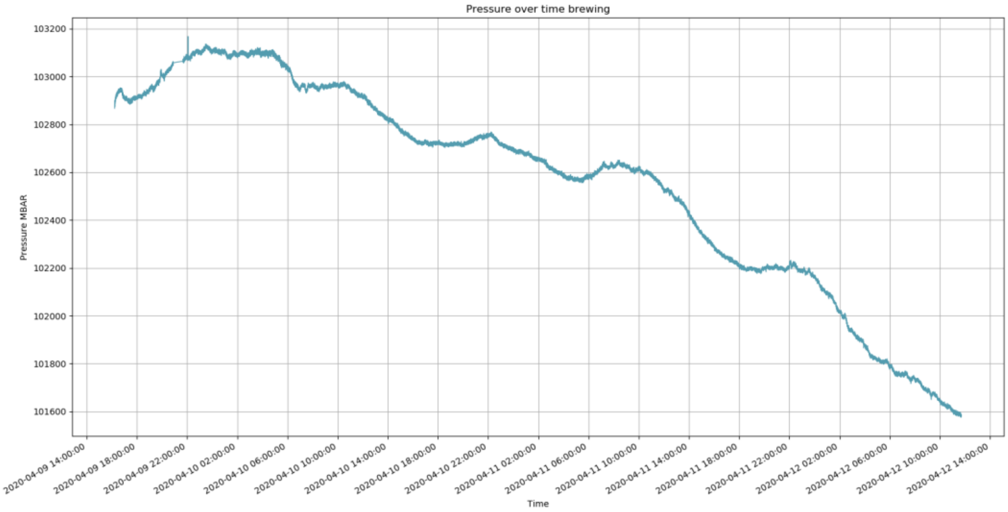

Figure 9 Pressure data from run 1

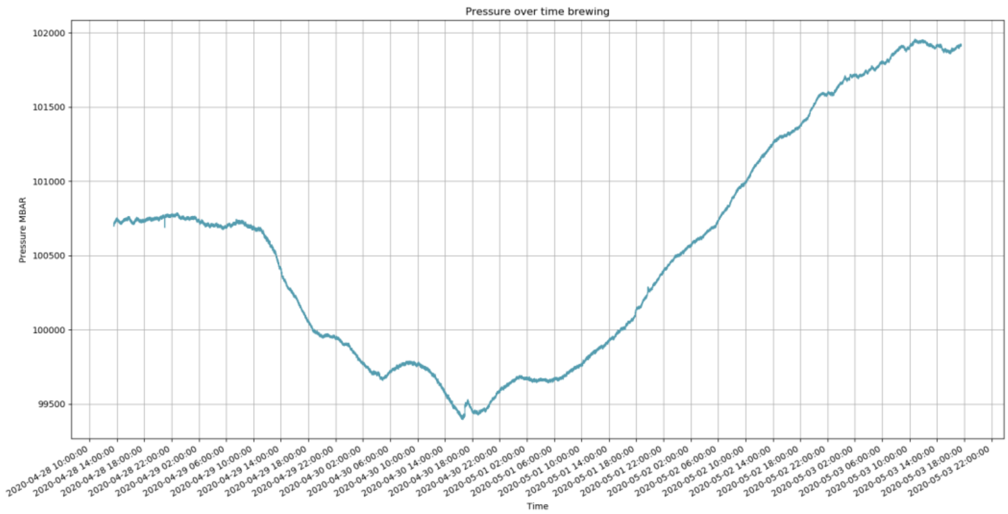

Figure 10 Pressure data from run 2

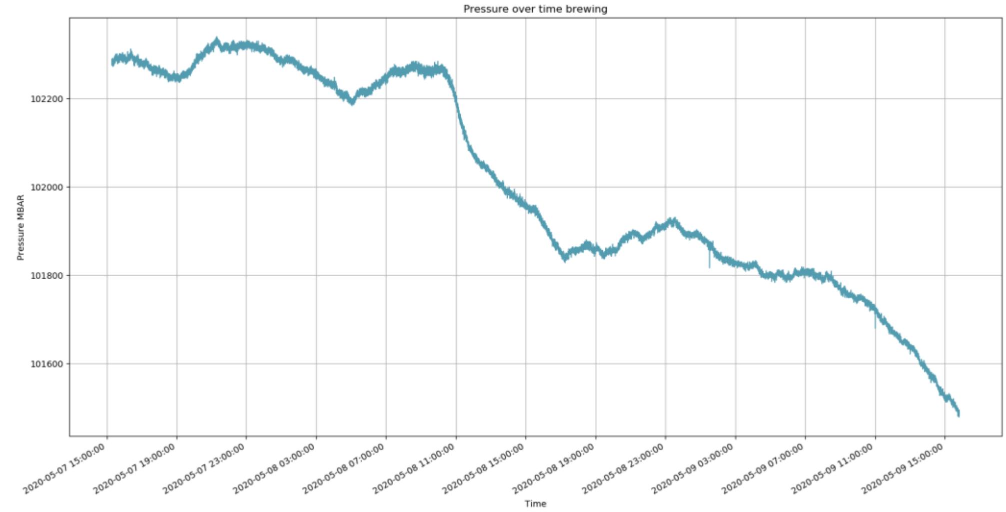

Figure 11 Pressure data from run 3

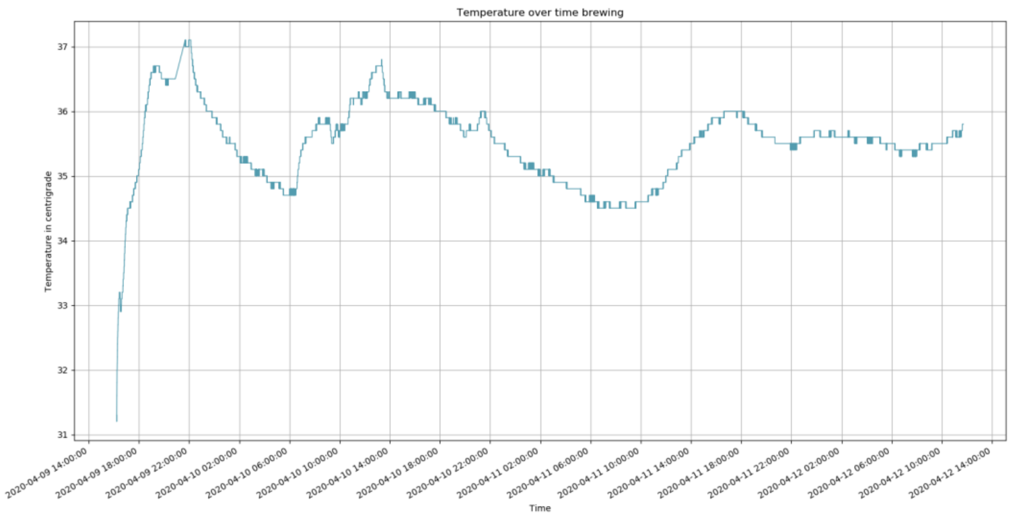

Figure 12 Temperature data from run 1

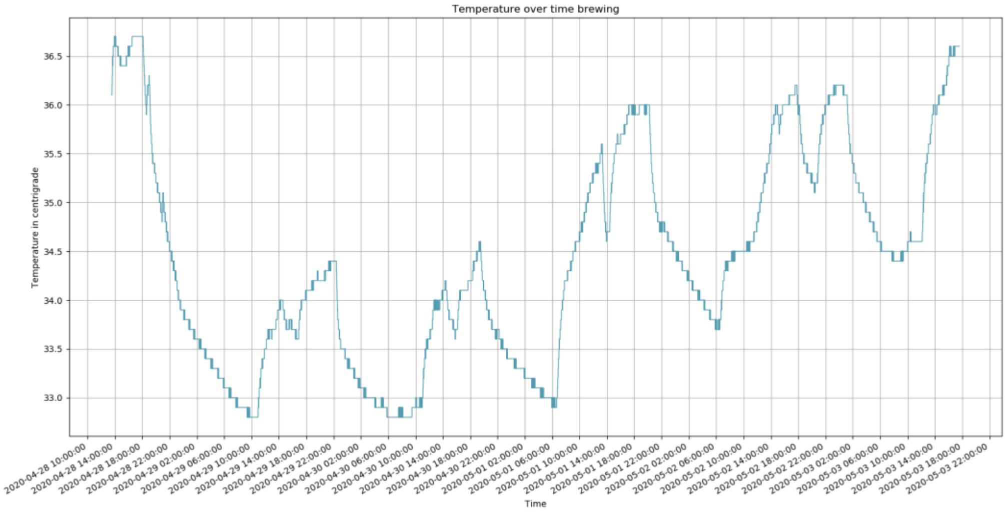

Figure 13 Temperature data from run 2

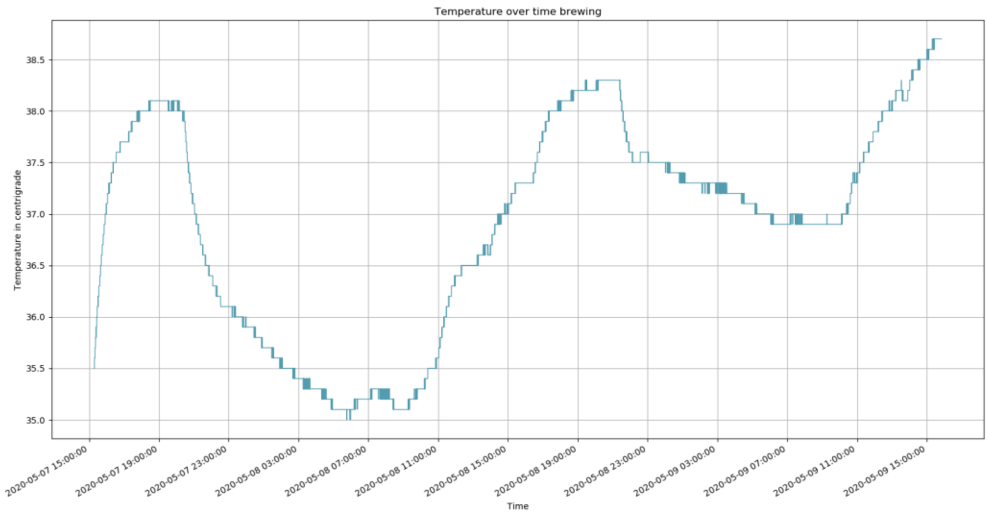

Figure 14 Temperature data from run 3

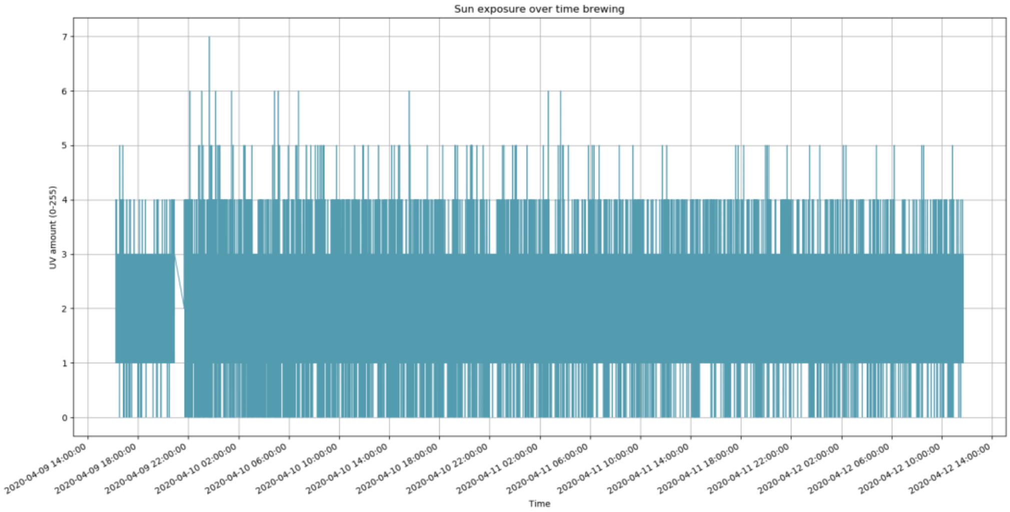

Figure 15 UV data from run 1

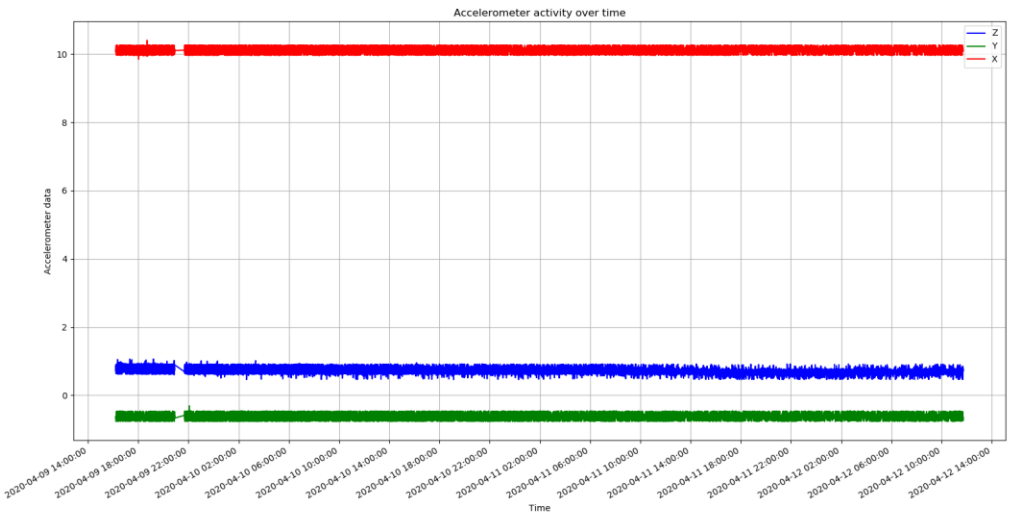

Figure 16 Accelerometer data from run 1

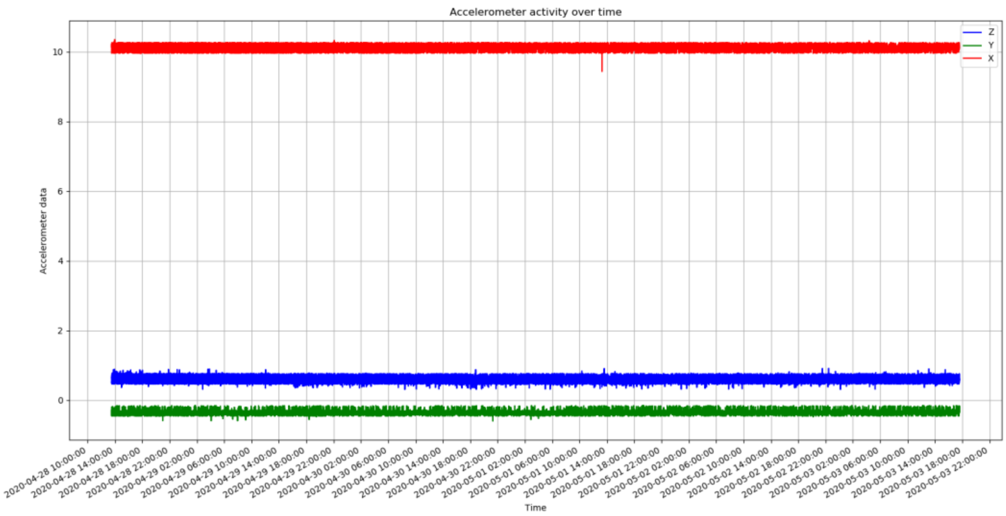

Figure 17 Accelerometer data from run 2

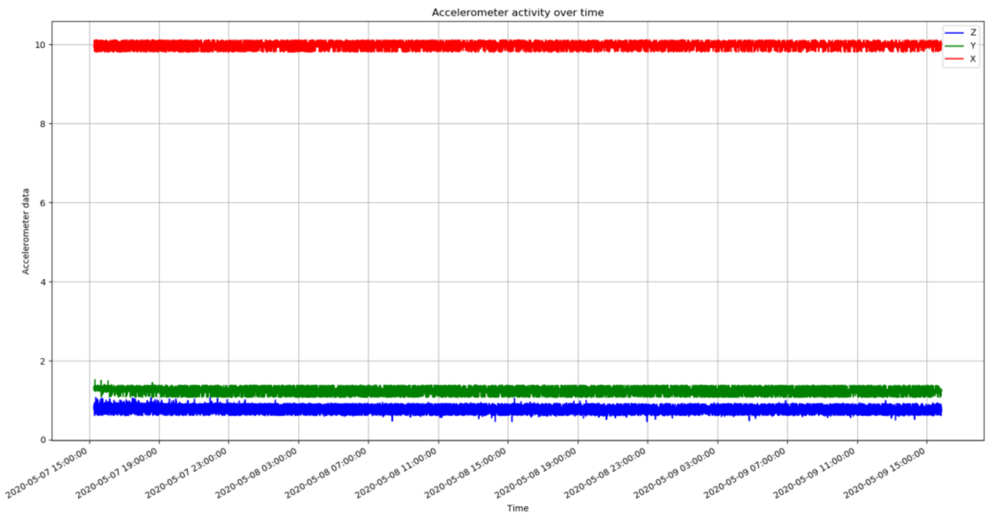

Figure 18 Accelerometer data from run 3

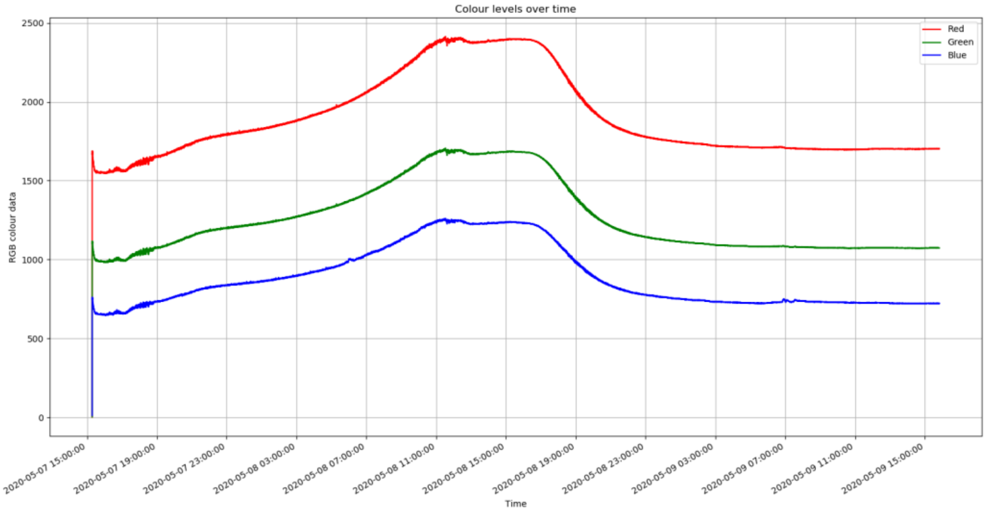

Figure 19 Colour sensor data from run 1

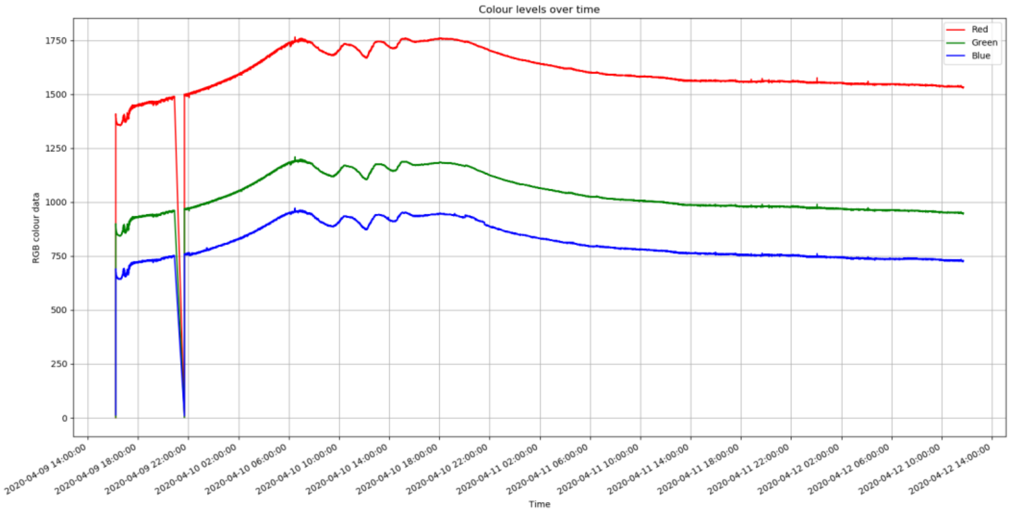

Figure 20 Colour sensor data from run 2

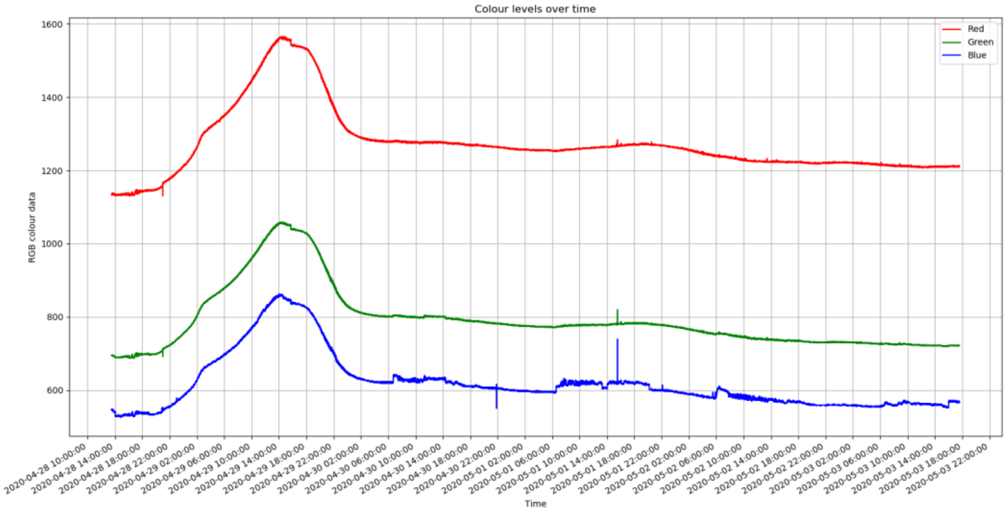

Figure 21 Colour sensor data from run 3

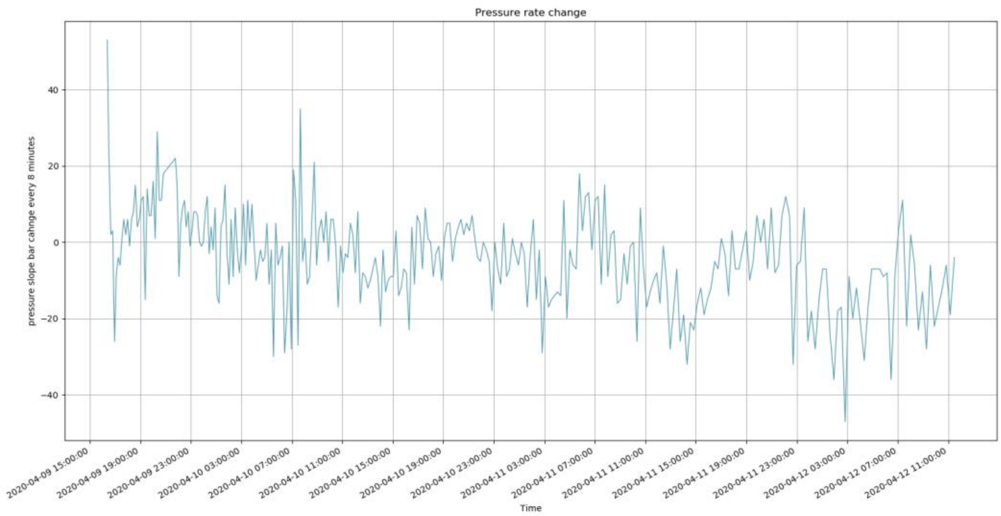

Figure 22 Pressure rates from run 1

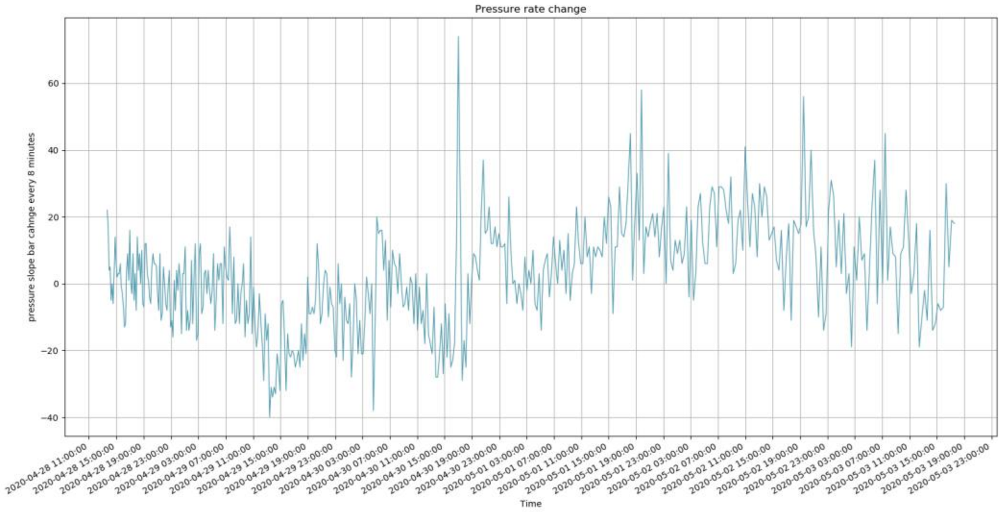

Figure 23 Pressure rates from run 2

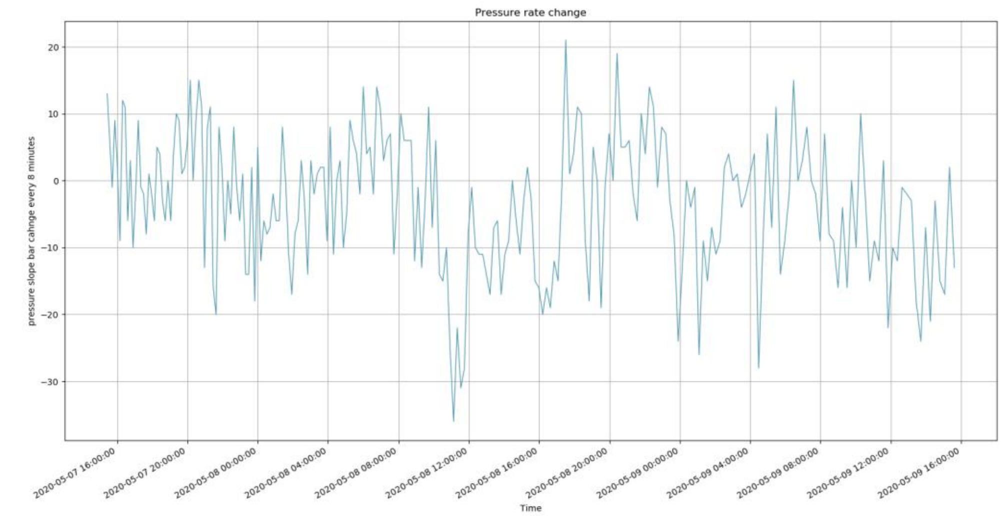

Figure 24 Pressure rates from run 3

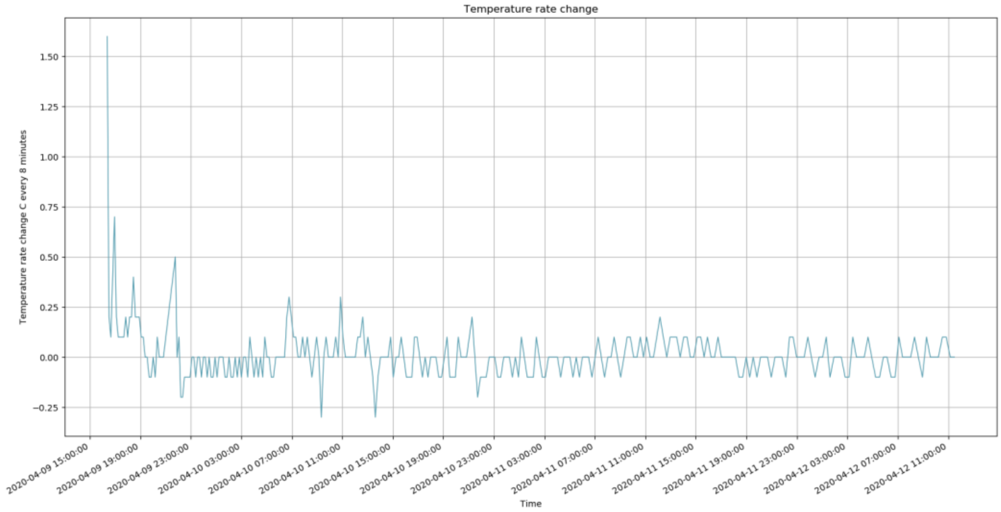

Figure 25 Temperature rates from run 1

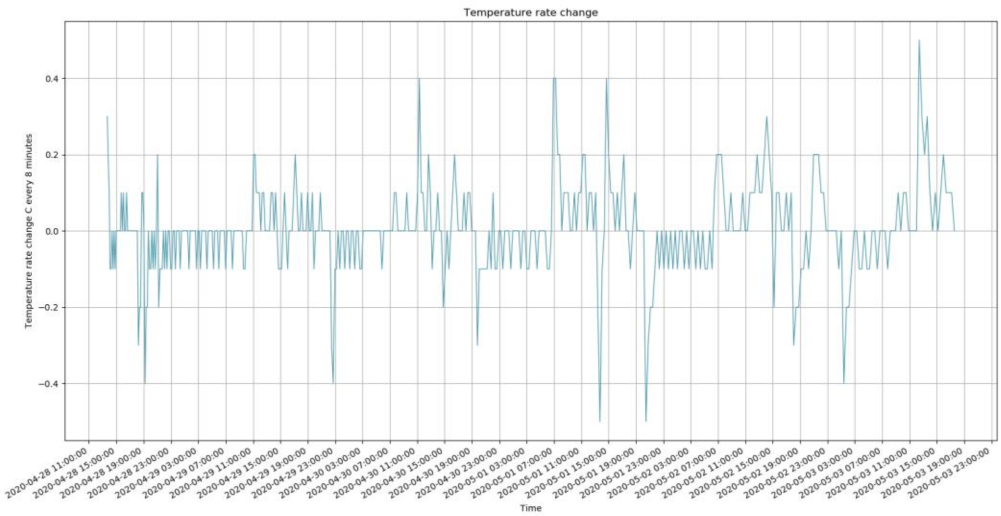

Figure 26 Temperature rates from run 2

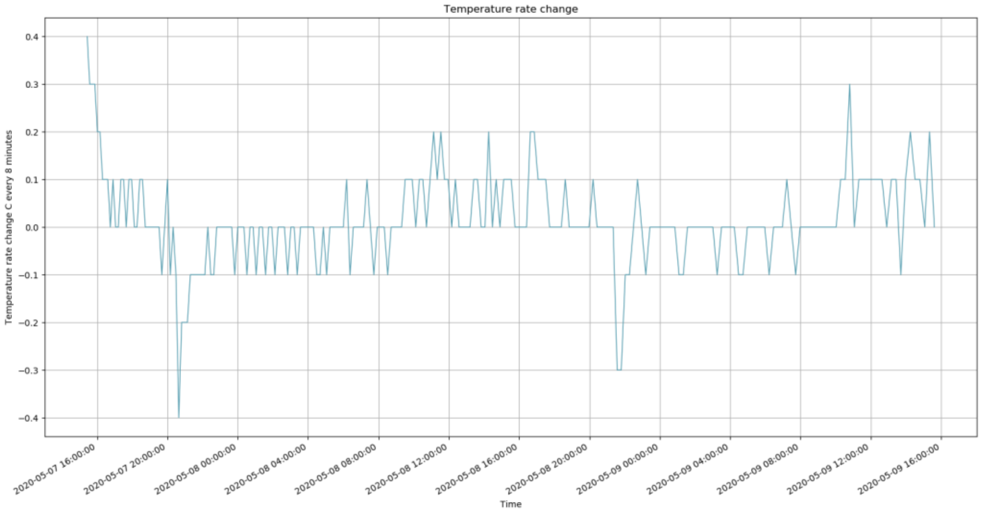

Figure 27 Temperature rates from run 3

References

MiniBrew, B., 2020. *MiniBrew | Brew & Tap fresh craft beer at home.* [Online]
Available at: https://www.minibrew.io/

S. Piermarini, G. V. M. E. M. S. G. P., 2011. Real time monitoring of alcoholic fermentation with low-cost. *Elsevier,* Issue 127, pp. 749-754.