BREWNET: Intelligent cloud-connected sensors for economic small-scale process optimisation

The project provided small-scale craft brewers with a state of the art method to monitoring the fermentation stage of brewing to improve the efficiency of craft brewing. It succeeded in using ultrasonic and temperature measurements and machine learning within a cloud environment (see below) to predict the Alcohol by Volume percentage (ABV%) during fermentation. The project demonstrates that digital technologies can be employed to optimise manufacturing processes at low-cost and without the need for expensive onsite instrumentation and data specialists. This is especially relevant for SMEs, across the food and drink manufacturing sectors, where both cost and expertise in particular areas are often major challenges.
The project is the first to combine low-cost sensors and low power wireless networks to collect data during craft beer fermentation and use cloud based predictive analytics to estimate optimal fermentation end-point.

Taking craft brewers from…

The brewing of beer is based on fermentation, where yeast is added to wort (produced by mashing the grain with hot water) to convert sugar to alcohol. Fermentation is stopped when the beer has reached a specified alcohol content and the required flavour profile has developed. This is a critical step in brewing because fermentation is directly related to the beer’s quality. Large-scale brewers use techniques such as inline near-infrared (NIR) spectroscopy to measure alcohol content in real time. Such instrumentation is not a viable option for small-scale brewers as it is prohibitively expensive and requires trained operators.

Currently more than 2000 craft brewers within the UK continue using traditional methods of taking samples of beer from the fermenter, every 4 to 10 hours, to test the alcohol content using hydrometers. The difficulty is that fermentation is highly variable, depending on seasonal variations in the ingredients and natural fluctuations in temperature; samples are taken infrequently to avoid wasting effort and beer, but this reduces the usefulness of the tracking information and beer is nonetheless wasted. A sub-optimal fermentation also affects down-stream stages such as kegging and bottling. Ultimately, variation in the duration of fermentation introduces variations in the quality and flavour of the product, which can result in customers’ dissatisfaction.

Taking craft brewers to…

A series of challenges were tackled in meeting the project’s aims. These were:

**Data sensing and collection**

1. To develop an ultrasonic sensor, in a bespoke probe holder, to measure alcohol content in a small-scale (200 Litre) fermenters. No intervention is required in the fermenter once the probe is in position, as the analysed results give a direct measurement of the Alcohol by Volume percentage (ABV%).

2. To develop a sensing platform to receive data from the probe. This unique sensing platform can combine ultrasonic and temperature data and transmit these successfully via an IoT link (described in 3. below).
3. To investigate connectivity between the sensing platform and a cloud-connected gateway (IBM Bluemix and Watson IoT cloud platform) which can store and process data from the brewery.

Signals were sent between the brewery and the University of Nottingham via low power wireless networks. These were variously configured with transmission modules located at either indoor or outdoor locations.

**Data analytics and machine learning in the cloud**

4. Ultrasonic and temperature data were recorded from the brewery. Features extracted from the ultrasonic data correlated with the changes in alcohol content during fermentation. To obtain sufficient data to investigate machine learning techniques, fermentation experiments continued in the University of Nottingham laboratories. Artificial Neural Networks (ANN) and linear regression techniques were used to predict the Alcohol By Volume percentage (ABV%) from the ultrasonic results from 10 batches of the same beer. ANN techniques gave a better overall prediction. The error (RMSE below) between the actual and predicted values of ABV% decreased as more batches of beer were included in the machine learning.

![Graphs showing ABV% prediction vs. batches](image-url)
**Wider benefits**

There are clear benefits of the developed technology. Firstly, there is potentially an economic saving to Totally Brewed estimated as £500 per annum, which extrapolates to a saving of £414,000 across all UK craft breweries. The potential saving in utilities for UK craft breweries amounts to 120 million litres of water per annum, 86 million megawatt hours of energy per annum and 78 tonnes of carbon dioxide per annum. These savings are achieved by reducing over fermentation and eliminating the need to remove beer to measure the ABV% offline.

Additionally, introduction of these methods would facilitate compliance with future legislation which will compel craft brewers to provide information about the calorific content of their products. With more accurate predictions of when fermentation will complete, production scheduling will also be improved.

The project highlighted the challenge of obtaining sufficient data for successful machine learning. In a craft brewing context, the data needed comes from a process which takes place perhaps only eight times per year. The project thus suggests that these tools, based on machine learning, might be more readily applied in high volume or larger companies where data is not so limited, and also in one where the process is already more standardised, for example, for monitoring processes in dairy or bakery production processes.

**What next?**

A further project is underway in which the cloud-connected sensors are being developed into commercial prototypes (see below). Two avenues for future research are, firstly to work with additional local craft breweries to investigate how fermentation data can be monitored in a cloud framework, and secondly to trial the sensor technology in other brewing processes such as bottling, cleaning and mashing. We also aim to develop sensors for small-scale optimisation in other contexts, for example, in industrial biotechnology, dairy and alcohol distillation.

**Further funding achieved**

- **Funder:** EPSRC Impact Acceleration Account
- **Amount:** £10,750
- **Project title:** Brewnet sensor development
- **Timeframe:** 6 months