# Beer Bitterness Measurement Using Mach-Zehnder Interferometer

1st João Victor Calderano
*Department of Circuits*
*Federal University of Juiz de Fora*
Juiz de Fora, Brazil

2nd Renato Luiz Faraco Filho
*Department of Circuits*
*Federal University of Juiz de Fora*
Juiz de Fora, Brazil

3rd Felipe Barino
*Department of Circuits*
*Federal University of Juiz de Fora*
Juiz de Fora, Brazil

4th Alexandre Bessa dos Santos
*Department of Circuits*
*Federal University of Juiz de Fora*
Juiz de Fora, Brazil

***Abstract*—This article introduces an innovative optical fiber sensor designed for the assessment of beer bitterness. The sensor utilizes a Mach-Zehnder interferometer (MZI) incorporating two long-period fiber gratings (LPFGs). Leveraging the sensitivity of the LPFGs to the refractive index of the surrounding medium, the sensor detects variations corresponding to the concentration of iso-$\alpha$-acids responsible for the bitterness in beer. Employing a two-point on-line self-calibrating procedure, the sensor estimates the bitterness of unknown samples by comparing them with reference samples of known bitterness.**

***Index Terms*—optical fiber sensor, food quality, bitterness, bitterness measurement**

## I. Introduction

Over the last decades, with large-scale production and the industrial maturing, new techniques related to automation, decision-making, traceability and quality monitoring have been developed [1]–[3]. Food industry has changed significantly, especially considering the quality and sanitation monitoring [4]. However, some areas of food control have not developed as expected and conventional methods are still required. Those methods can be time-consuming, arduous and dangerous. For instance, the bitterness of beer demands the use of arduous and time-consuming methodology. Presently, measuring beer bitterness involves transporting a beer sample to a laboratory where its absorbance of ultraviolet light is analyzed and scaled to the International Bitterness Unit (IBU). The process involves extracting an acidified beer solution into isooctane, followed by measuring absorbance at 275nm, as this wavelength offers the highest absorbance for elements contributing to beer bitterness [5].

This paper introduces an innovative approach for assessing the bitterness of beers.

Ambev, CNPq, Fapemig, Capes e Inerge

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## II. Methodology

The instrumentation setup was composed of the proposed optical fiber sensor, a plug-and-play interrogator system developed for this application, an aquarium with a drain system and a 3d-printed plastic to support and stabilize the sensor at the aquarium. This setup is shown in Figure 1.

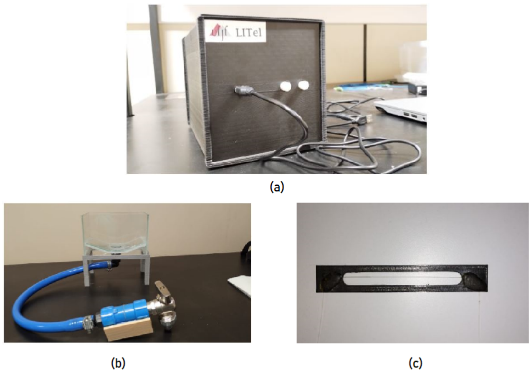


Fig. 1. (a) Interrogator; (b) Aquarium with drain system; (c) Glued sensor in support.

The MZI was manufactured using two Long Period Fiber Grating sensor (LPFGs) in series. Theses LPFGs ware arc induced with 500 ± 1 µm period and spaced by 15±1mm section of bare fiber.

We employed MZI fringe positioning for quantifying the bitterness of beer. Real-time processing of the optical spectrum obtained through the OSA involved the following steps: Savitzky-Golay zero-phase filtering for smoothing purposes; Fringe's dip was identified through derivative-based local minima detection during dip finding; To determine the resonant wavelength, $\lambda_{res}$ of the dips, we fitted a modified Lorenztian function to the resonante fit.

Before data acquirement, the beer sample must be prepared. This process involves the placement of this sample in a container containing one drop of octane per 100 ml of beer. Posteriorly, this container must be gently shaken. This procedure is very important so there is no bubble and foam formation in the sensor.

Our sensor proposal incorporates a two-point on-line self-calibrating procedure. The process, represented in Figure 3, involves presenting the sensor with a sample of low bitterness, followed by the sample under measurement, and concluding with a sample of high bitterness. Resonant dips and trace curves corresponding to $\lambda_{res}$ and bitterness are recorded for all three samples. The blind sample can be identified by appling triangulation.

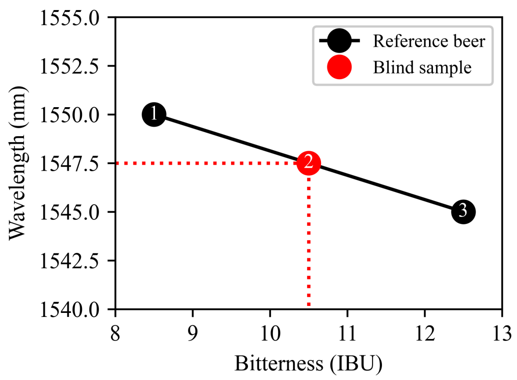


Fig. 2. Two-points Calibration.

All of our measurements were compared with measurements conducted in the laboratory. These measurements are given in International Bitterness Unit (IBU). We tested 8 different beer samples, across three and five times per day. At the factory, with more reliable reference samples and blind sample check, we evaluated sensor bias.

## III. Results

The measurements were taken under different temperature conditions, at 22 and 6.5 degrees Celsius. The experiment was conducted under laboratory conditions and several samples were used with different bitterness values. As mentioned before, these measurements were compared with the real bitterness of its samples. All measurements values is shown in Table 1.

TABLE I
Measurements Following Methodology

| *Sample* | *Prop. (IBU)* | *Lab. (IBU)* | *Temp. (°C)* |
|---|---|---|---|
| Sample-1 | 8.4 $\pm$0.1 | 8.693 $\pm$ 0.5 | 22 |
| Sample-2 | 9.2 $\pm$0.17 | 9.434 $\pm$ 0.5 | 22 |
| Sample-3 | 9.3 $\pm$0.0 | 9.433 $\pm$ 0.5 | 6.5 |
| Sample-4 | 10.5 $\pm$0.22 | 10.403 $\pm$ 0.5 | 6.5 |
| Sample-5 | 8.9 $\pm$0.26 | 9.291 $\pm$ 0.5 | 6.5 |
| Sample-6 | 9.8 $\pm$0.3 | 9.519 $\pm$ 0.5 | 6.5 |

Analysing Table I, notice that the proposal sensor indicates a maximum error of $0.391 \pm 0.26$ IBU, a minimum error smaller than 0.1 IBU (0.097 IBU), a avarage error of 0.238 IBU and a MSE of 0.066.

In a first moment, the sample preparation guidelines was not respected, resulting unacceptable results, as idicates Table II, Sample-7. Other experiment was conducted not respecting the progressive graduation of bitterness of beers to calibrate the measument instrument, the results is shown in Table II, Sample 8.

TABLE II
Measurements not Following Methodology

| *Sample* | *Prop. (IBU)* | *Lab. (IBU)* | *Temp. (°C)* |
|---|---|---|---|
| Sample-7 | 10.4 $\pm$0.38 | 9.433 $\pm$0.5 | 22 |
| Sample-8 | 8.1 $\pm$0.5 | 12.17 $\pm$0.5 | 22 |

## Conclusions

This paper presents a novel application for optical fiber sensors. A Mach-Zehnder interferometer and the use of two-point calibration was applied to measure the bitterness of beers. This calibration method proves to be very efficient, especially for tests conducted under laboratory conditions, as it avoids problems related to the variation of the calibration curve slope over time and cross-sensitivity, as we can see by analysing the sample temperature in Table I.

Results obtained in experiments conducted under the conditions mentioned in the Methodology section were satisfactory. Experiments following the protocol to avoid foam formation and proper calibration showed a maximum error of $0.391 \pm 0.26$ IBU IBU.

## References


[1] H. Lasi, P. Fettke, H.-G. Kemper, T. Feld, and M. Hoffmann, “Industrie 4.0,” WIRTSCHAFTSINFORMATIK, vol. 56, no. 4, pp. 261–264, Aug. 2014, doi: 10.1007/s11576-014-0424-4.

[2] J. K. Zhou, Taigang Liu, and Lifeng Zhou, “Industry 4.0: Towards future industrial opportunities and challenges,” in 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), IEEE, Aug. 2015, pp. 2147–2152. doi: 10.1109/FSKD.2015.7382284

[3] H. Cañas, J. Mula, M. Díaz-Madroñero, and F. Campuzano-Bolarín, “Implementing Industry 4.0 principles,” Comput Ind Eng, vol. 158, p. 107379, Aug. 2021, doi: 10.1016/j.cie.2021.107379.

[4] Ihegwuagu Nnemeka Edith and Emeje Martins Ochubiojo (2012). Food Quality Control: History, Present and Future, Scientific, Health and Social Aspects of the Food Industry, Dr. Benjamin Valdez (Ed.), ISBN: 978-953- 307-916-5, InTech, Available from: http://www.intechopen.com/books/scientific-health-and-social-aspects-ofthe-food-industry/food-quality-control-history-present-and-future

[5] Bishop, L. R. (1964). THE MEASUREMENT OF BITTERNESS IN BEERS. Journal of the Institute of Brewing, 70(6), 489–497. https://doi.org/10.1002/j.2050-0416.1964.tb06354.x