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Complementing Digital Image Analysis and Laser Distance Meter in Beer Foam Stability Determination

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Abstract: The aim of this research is to investigate the possibility of applying a laser distance meter (LDM) as a complementary measurement method to image analysis during beer foam stability monitoring. The basic optical property of foam, i.e., its high reflectivity, is the main reason for using LDM. LDM measurements provide relatively precise information on foam height, even in the presence of lacing, and provide information as to when foam is no longer visible on the surface of the beer. Sixteen different commercially available lager beers were subjected to analysis. A camera and LDM display recorded the foam behavior; the LDM display which was placed close to the monitored beer glass. Measurements obtained by the image analysis of videos provided by the visual camera were comparable to those obtained independently by LDM. However, due to lacing, image analysis could not accurately detect foam disappearance. On the other hand, LDM measurements accurately detected the moment of foam disappearance since the measurements would have significantly higher values due to multiple reflections in the glass.

Keywords: image analysis; laser distance meter; beer foam

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1. Introduction

Foam stability and retention is an important indicator of beer quality and freshness. Beer foam stability is expressed as a change of foam height over a certain period. Brewing industries are devoted to producing stabile and retentive foam head since many consumers like to see a big and rich head of foam in a glass. Different for every beer type, beer foam can also result in the lacy pattern at the bottom of the finished beer, known as lacing or cling, especially appreciated in Belgian beers [1]. Foam quality is described by several characteristics such as stability, retention, viscosity, whiteness, bubble size, density [2] and many research papers specifically describe, quantify and monitor foam stability via different methods [3–25]. Foam stability is a result of many factors. Some of them include foam-positive proteins (Z, LTP1, hordein fragments), hop acids, non-starch polysaccharides and metal ions, while lipids and high ethanol levels reduce foam stability [2,26].

Recent scientific advances in image analysis methods have led to the popularization of this method and its ubiquitous application in different fields. Image analysis methods display several setbacks such as camera focusing as well as light reflection off the surface and within the beer glass [25]. This demands that the measuring set-up has to be done under controlled directional light conditions which entail lower illuminance values and automated focusing. In beer foam monitoring via image analysis, an additional setback exists as a result of foam lacing or clinging, which makes it impossible to detect the actual level of foam [27].

In our previous research [27], the use of a RGB camera in foam assessment was portrayed as a low-maintenance, cheap and easy method that requires minimal input from the employees and is applicable in every laboratory. However, if applied alone, it gives inaccurate results when foam lacing is present. With the introduction of a 3D camera [27], the problem of lacing is no longer present, but the automated image analysis method based on the analysis of RGB video images and 3D data for accurate detection of the foam height becomes more complex for everyday usage. The proposed solution identifies the necessity to have two cameras and led to two related analyses being conducted. In order to simplify the procedure of obtaining accurate foam height data from the measurements provided by the 3D camera, it was necessary to replace it with an accurate available device whose output data could be detected by an existing recognition system based on an RGB camera. Previous knowledge of working with solids has imposed the laser distance meter (LDM) as a logical solution. Using one RGB camera and one software [27], it is possible to measure the height of the foam and recognize the measured value on the LDM display by image analysis of the recorded video. For a given frame in the region of interest, color segmentation by filtering thresholding in HSV color space was used to generate a binary image. By performing morphological operations of erosion followed by dilation on the binary image, the average height of foam is measured as well as the value on LDM using optical character recognition.

The initial assumption based on a high level of foam reflectivity did not include the possibility of laser beam penetration into the foam, which proved to be the biggest problem in measurement accuracy. What has proven to be crucial to complete this research is that LDM detects the moment of foam disappearance. Another identified challenge was the inability to recognize digits on the LDM display using optical character recognition, due to the refreshing of the display giving the camera unreadable data.

The aim of this paper was to assess the applicability of a non-invasive, objective, and affordable image analysis method based on one RGB camera and LDM measurements under real conditions, in order to monitor and valorize the foam stability of lager beers.

2. Materials and Methods

Sixteen samples of commercially available light lager beers packaged in brown/green glass bottles (0.5 L) underwent analysis using the methods described below. Ten were domestic beers and six others were foreign (Germany, Czech Republic, Denmark, Slovenia and Holland). Beer samples were held at room temperature (23 °C) for two days, in order to reduce the influence of temperature fluctuations, as can been seen from Figure 1.

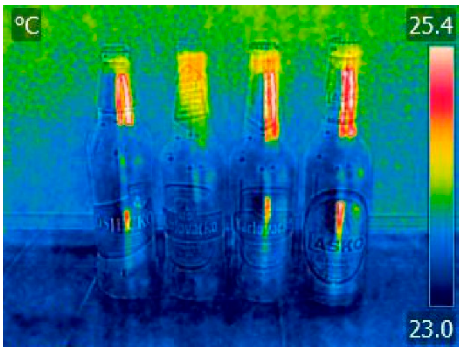


Figure 1. Infrared thermographic recordings of samples.

Glasses (0.5 L; generic brand, model Lilith, h = 185 mm, Ø = 0.75 mm) were washed, and degreased then rinsed in demineralized water and dried. All the glasses were identical and left to cool down at room temperature prior to analysis, which can be seen from Figure 2. Values of the thermogram legend are set by the infrared thermal camera, according to the registered radiation.

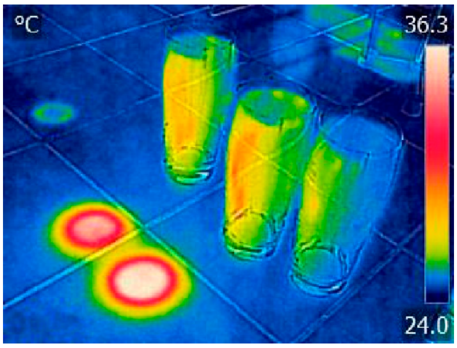


Figure 2. Infrared thermographic recordings of glasses.

For each experiment, beer was hand-poured according to [28], and as described in Nyarko et al. [27].

Figure 3 shows the experimental setup used in data collection. The basic idea was to develop a complementary method that could provide information about foam stability in cases when foam lacing obstructs visual information for the RGB camera.

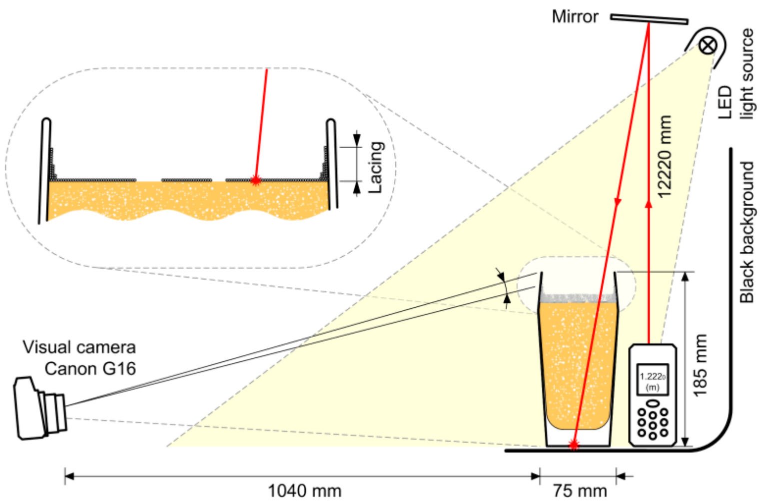


Figure 3. Experimental setup.

The optical characteristic of foam to reflect 88% of light (Table 1) [29] led to the idea that LDM could be employed in this research.

Table 1. Reflectivity of certain materials according to [29].

Material	Reflectivity
White paper	up to 100%
Newspaper with print	69
Dimension lumber	94
Snow	80–90
White masonry	85
Concrete, smooth	24
Beer foam	88

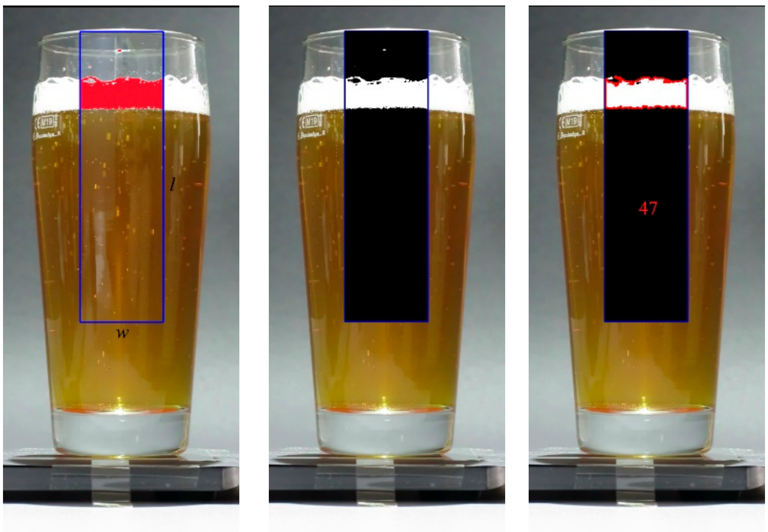
2.1. Image Analysis of Video

The automated image analysis procedure described and used in [27] for measuring foam height from recorded RGB videos was implemented in this paper as well. A brief description of the procedure is described herein.

Video recordings, with a frame rate of 30 fps, were taken of each beer sample over a 5 min period using a Canon G16 RGB camera(Canon PowerShot G16; Ota City, Tokyo, Japan). Determining the height of beer foam using image analysis was performed using seven steps (Figure 4):

1. A region of interest (ROI) of known width (w) and height (l) for a given frame of the recorded video is defined. It is imperative the whole height of the foam and part of the beer is covered by the ROI since all the next steps are performed only on this ROI.
2. The ROI is color segmented in HSV color space by thresholding using previously defined lower and upper values of the foam color in the HSV color space.
3. A binary image of the thresholded ROI in HSV color space is generated.
4. Morphological operations of erosion followed by dilation are performed on the binary image to eliminate small white noises or artifacts that appear in the image.
5. The largest contour on the binary image is determined. This contour marks the boundary of the foam/head.
6. The area (A) of the region enclosed by the largest contour is determined.
7. The average height (h) of the beer foam in pixels is then determined using Equation (1):

$$h = A/w. \tag{1}$$



(**a**) (**b**) (**c**)

Figure 4. Estimation of foam height from image. (**a**) Region of interest (ROI) of known width (w) and height (l) is initially defined for the image. The ROI is thresholded in HSV color space. The pixels satisfying the threshold are marked in red. (**b**) Binary image of ROI thresholded in HSV color is generated. (**c**) Morphological operations of erosion followed by dilation performed on binary image to remove artifacts. The largest contour (marked in red) is found.

The average height of the beer foam in mm can be obtained using the conversion 1 mm = 6.6 px.

The procedure was implemented in the Python programming language [30] using the OpenCV library v.3.4.2 [31]. Since the beer glass is always located in the same position, the algorithm can be run in either offline or online mode in order to automate the process of determining the beer foam height. In this paper, the height of foam was determined from the recorded videos (offline mode). Every 10 s, 5 consecutive frames were taken and the height of foam determined for each frame. The average height in pixels for these 5 measurements was taken to represent the height of foam every 10 s.

2.2. Measurement Using a Laser Distance Meter

To measure the decrease in foam height, a BOSCH GLM 80 Laser Distance Meter (Bosch, Gerlingen-Schillerhöhe, Germany) with an available option to search for maximal and minimal value was used (Figure 5). This option enabled the measurement of foam height decrease during a 5 min interval with a frequency of 1 Hz. This was also recorded by the aforementioned RGB camera in video format. As shown in Figure 3, the LDM measured the distance to the top of the foam head by reflecting off a mirror placed above the beer glass. Hence, with time, the decrease in foam height is measured as an increase in distance by the LDM.

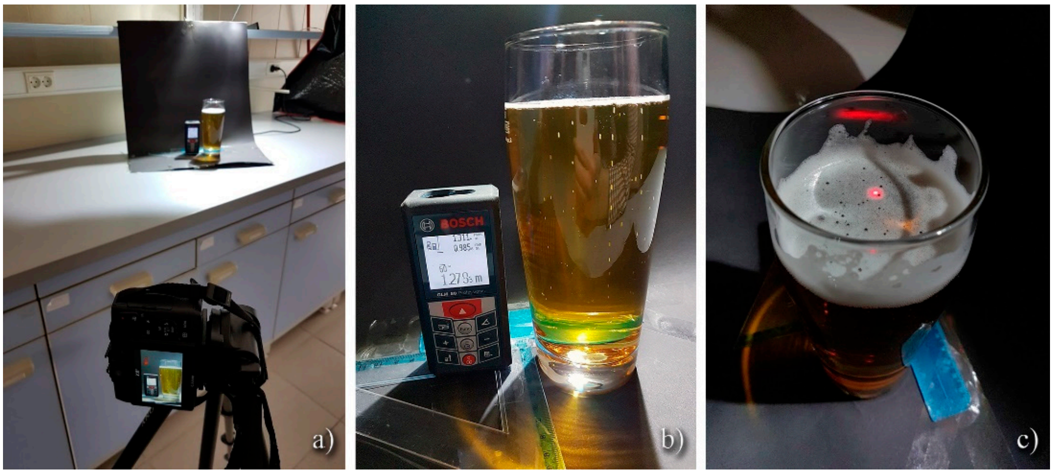


Figure 5. Photos of experimental setup: (**a**) general setup; (**b**) LDM and a sample; (**c**) laser dot on the beer foam.

We initially considered automating the readings from the LDM using optical character recognition on each video frame. However, this idea was dropped due to the erratic changes on LDM display during image sampling, as can be seen in Figure 6.

Figure 6. Changes of measured values recorded on BOSCH GLM 80 LDM for five consecutive frames of the RGB video.

3. Results and Discussion

RGB video recordings were obtained for 16 samples (denoted by S01 . . . S16), each lasting 5 min. Using the image analysis procedures described in Section 2.1, the estimated height (in mm) was obtained from the RGB video every 10 s. The results of the measurements are displayed in Table 2.

Table 2. Height (mm) of foam determined by performing image analysis on RGB videos of 16 beer samples.

	Sample															
Time	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**
0	39	58	60	48	37	42	48	49	25	17	48	62	46	43	18	15
10	35	54	57	42	32	38	43	45	23	10	45	57	43	38	12	11
20	31	50	57	37	28	35	40	42	20	8	45	55	41	34	10	8
30	28	47	56	33	24	32	39	40	17	5	44	54	39	29	8	6
40	25	44	55	30	22	30	36	37	15	4	43	51	36	26	7	5
50	21	41	52	26	20	28	34	35	13	2	43	49	34	23	6	4
60	19	39	50	24	18	26	33	33	11	2	31	48	31	20	5	4
70	17	37	48	21	16	24	31	30	11	-	35	47	31	18	4	3
80	15	35	47	19	15	23	29	28	9	-	34	46	30	16	4	3
90	13	32	40	17	14	22	27	26	8	-	26	42	30	15	4	3
100	12	30	41	15	13	22	26	25	8	-	24	39	29	13	3	3
110	10	28	40	14	12	22	24	24	8	-	21	38	29	12	3	-
120	10	25	39	13	11	22	24	26	8	-	14	36	28	11	3	-
130	9	23	28	12	10	22	23	23	7	-	13	33	28	11	3	-
140	8	21	36	12	10	21	23	23	7	-	13	31	28	10	3	-
150	8	19	35	11	9	22	23	23	7	-	13	26	28	9	3	-
160	7	17	34	11	8	21	23	25	7	-	13	25	28	8	3	-
170	6	15	32	10	8	21	23	23	7	-	13	24	25	8	-	-
180	6	14	25	10	8	21	22	23	7	-	12	24	23	7	-	-
190	5	14	29	10	7	21	23	23	7	-	12	24	21	7	-	-
200	5	13	30	10	7	21	22	22	6	-	13	24	22	6	-	-
210	5	12	29	9	7	20	23	22	6	-	12	23	21	6	-	-
220	4	11	28	9	7	20	22	22	6	-	12	24	20	6	-	-
230	4	10	26	8	6	20	22	22	6	-	12	23	21	6	-	-
240	4	10	25	8	6	20	23	22	6	-	12	23	23	5	-	-
250	4	9	24	8	6	20	22	22	6	-	12	22	21	5	-	-
260	4	9	19	7	6	20	22	22	6	-	12	22	21	5	-	-
270	4	8	22	7	6	17	22	22	-	-	12	22	22	5	-	-
280	4	8	21	7	6	20	22	22	-	-	12	20	21	5	-	-
290	4	7	20	6	6	19	22	22	-	-	11	20	21	5	-	-
300	4	7	14	6	5	20	22	22	-	-	12	20	21	5	-	-

The sign "-" in the table indicates that measurements were stopped due to the foam's disappearance.

Figure 7 shows foam height (mm) obtained by performing image analysis on RGB images. Table 3 shows values of foam height recorded by LDM.

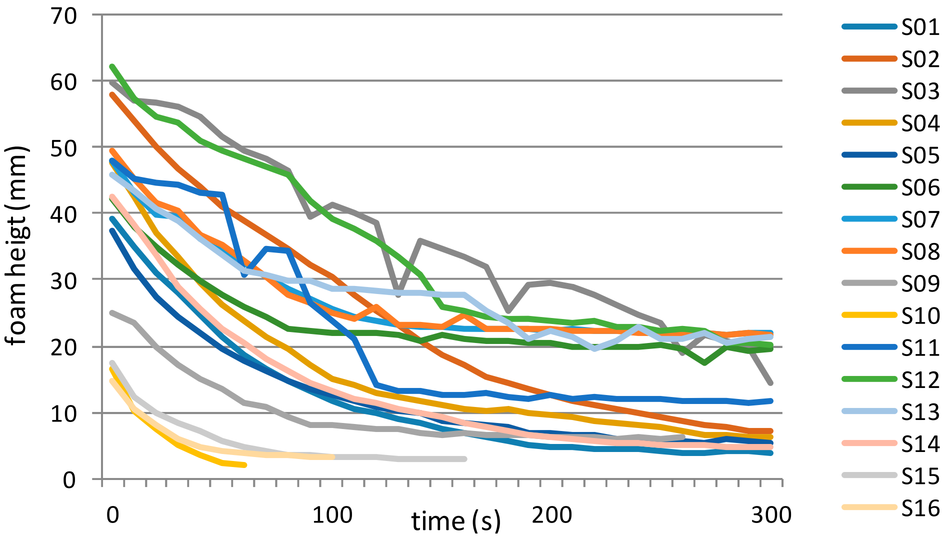


Figure 7. Graphic representation of the foam height determined by performing image analysis on RGB videos.

Table 3. Height (mm) of foam of 16 beer samples determined by laser distance meter.

	Sample															
Time	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**
0	32	51	51	40	30	34	39	45	12	6	43	55	38	37	6	6
10	29	49	50	37	26	33	39	41	12	4	39	54	35	33	5	5
20	25	46	49	33	23	30	37	39	9	2	37	51	33	30	4	3
30	18	45	50	30	17	29	36	36	10	2	34	49	30	27	3	4
40	18	43	48	27	15	28	33	34	9	3	31	45	27	21	3	**10**
50	15	40	47	25	14	26	31	32	7	**−211**	28	44	24	21	**7**	**12**
60	15	39	46	21	10	22	29	31	7	**−212**	26	42	23	18	**21**	**25**
70	12	37	44	19	10	21	27	28	5	-	23	39	20	16	**25**	**−210**
80	10	34	42	17	9	19	24	27	5	-	21	37	17	14	**−236**	**−210**
90	7	32	41	15	9	16	22	25	4	-	18	31	16	11	**−244**	**−204**
100	9	29	39	12	6	13	19	22	3	-	17	29	14	9	**−217**	**−205**
110	7	26	36	12	6	12	17	20	4	-	14	26	11	6	**−220**	-
120	4	25	34	9	5	10	15	18	6	-	12	23	10	7	**−223**	-
130	5	23	32	7	4	9	13	16	5	-	11	20	8	6	**−226**	-
140	3	21	30	8	3	10	12	14	7	-	7	18	7	5	**−247**	-
150	3	19	29	7	4	8	11	12	8	-	6	16	5	4	**−261**	-
160	2	16	28	6	4	7	9	10	9	-	6	14	4	4	**32**	-
170	4	14	27	6	4	7	8	9	**15**	-	5	12	4	4	-	-
180	4	13	25	5	5	6	6	9	**−213**	-	5	11	3	5	-	-
190	4	12	23	5	4	5	7	8	**−213**	-	5	9	3	4	-	-
200	4	12	24	4	5	5	6	6	**−213**	-	12	8	2	4	-	-
210	3	10	21	4	6	4	5	5	**−213**	-	7	8	3	5	-	-
220	4	9	21	4	6	4	3	5	**−213**	-	7	6	2	5	-	-
230	4	7	20	5	**21**	4	3	5	**42**	-	**−205**	5	3	4	-	-
240	5	7	20	4	**−183**	3	3	5	**−212**	-	**11**	5	3	4	-	-
250	4	6	19	5	**−183**	3	2	4	**−211**	-	**7**	5	3	4	-	-

Table 3. *Cont.*

	Sample															
Time	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**
260	5	6	18	5	**−184**	2	2	3	**−213**	-	**15**	4	3	5	-	-
270	5	4	17	5	**−181**	3	2	2	-	-	**−216**	4	3	4	-	-
280	9	4	15	5	**−181**	2	2	2	-	-	**−200**	4	2	2	-	-
290	6	4	15	4	**−179**	1	2	2	-	-	**−202**	5	2	8	-	-
300	6	4	14	4	**−179**	1	2	2	-	-	**−202**	6	2	8	-	-

The bolded data indicate the errors in measurement due to reduction of foam layer or its complete disappearance which caused multiple reflections that resulted in unrealistic readings. The sign "-" in the table indicates that measurements were stopped due to the foam's disappearance.

Figure 8 shows foam height (mm) obtained by LDM measurements. Higher values of foam height are noticed when comparing data shown in Table 2 to that in Table 1. This is due to the fact that, despite having a high reflectivity of 88% (Table 1), the laser beam still penetrates the beer foam and reflects between the layers. At this stage, the properties of the foam, especially the size of the bubbles, contribute to the measurement error. Hence, laser measurement can only be used as an indicator of foam disappearance since the measured values are not precise and accurate. Figure 9 represents the difference between the measured values obtained by image analysis and LDM for the maximum height of beer foam measured at the start of the experiment (time = 0 s). A mean discrepancy value of 7.29 mm is obtained for all samples.

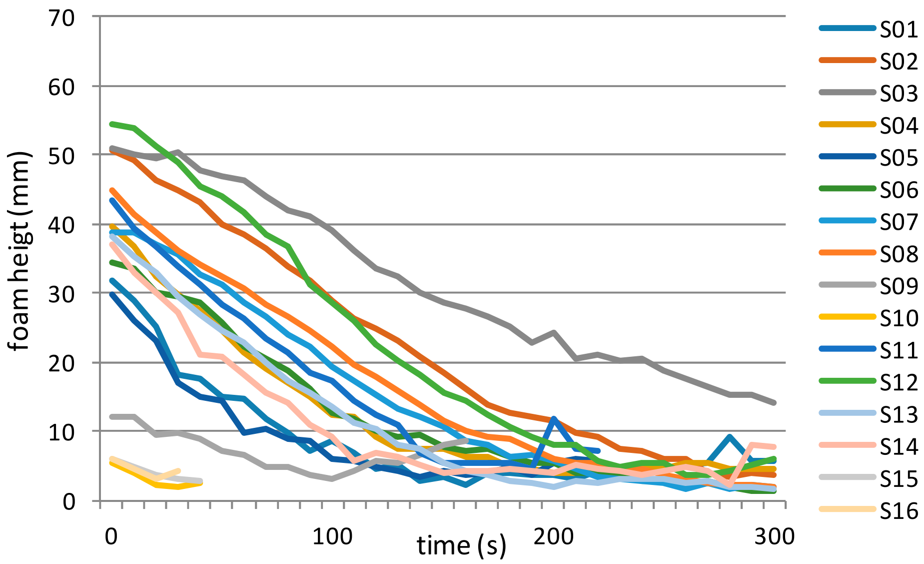


Figure 8. Graphic representation of the foam height determined by laser distance meter.

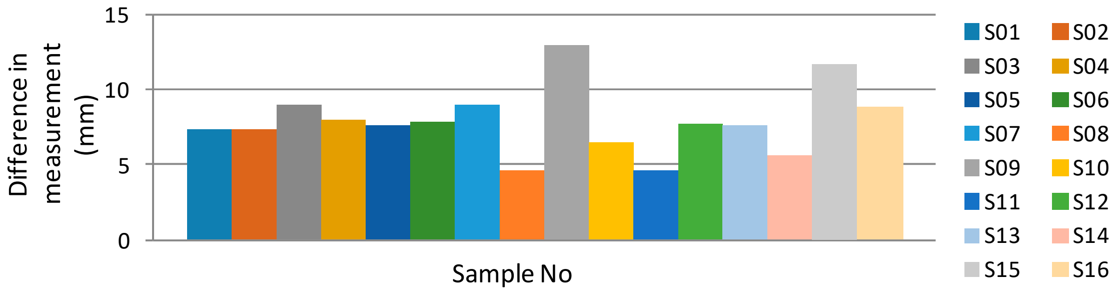


Figure 9. The difference between the measured values by image analysis and a laser distance meter for first measurement, i.e., maximum height of beer foam.

Based on the information from Tables 2 and 3 and by applying the algorithm shown in Figure 10, information about lacing, i.e., the time instance of disappearance of foam, can be obtained. In Figure 10, X denotes the sample measurement of foam height determined by image analysis, while Y denotes that determined by LDM. It should be noted that this procedure can be used in both online and offline measurement modes to determine when to end measurement. In this research case, offline analysis was performed. As mentioned earlier, a video lasting for 5 min (300 s) was taken of each beer sample. Starting with t = 0 s, measurements are performed every 10 s. Foam height is automatically determined via image analysis as previously described, while LDM measurements need to be determined manually. In order to synchronize LDM measurements with those obtained by image analysis, the same five consecutive frames used in image analyses are stored and the LDM measurements are read manually (Figure 6). The instant the current LDM measurement significantly differs from the previous measurement is an indication that the laser has fully penetrated the foam or the foam layer is significantly reduced (marked in bold in Table 3). At this point, the automated measurement procedure via image analyses is stopped and lacing can be denoted as the foam height determined by image analysis (X_n).

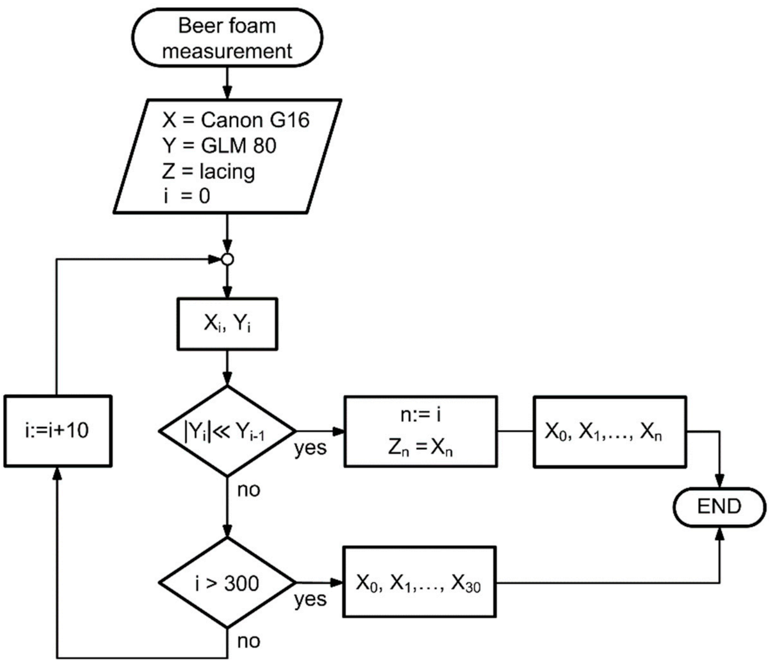


Figure 10. Algorithm used for beer foam analysis and determination of lacing.

Figure 11 shows the information about lacing values for 16 samples analyzed in this research shown in Tables 2 and 3.

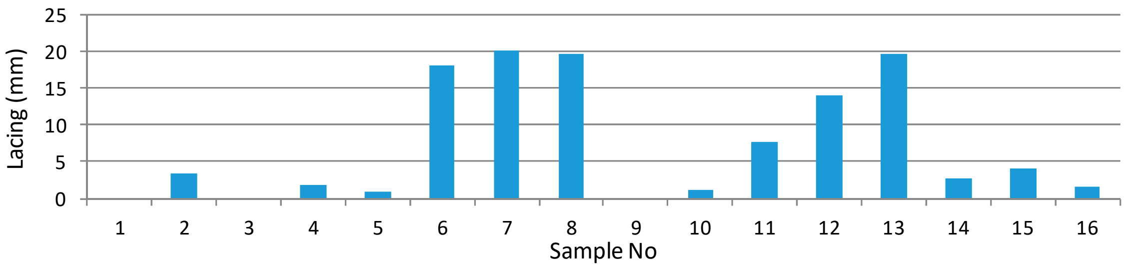


Figure 11. Lacing amount (mm) for individual samples.

By comparing the numerical values from Figure 11 and photos of the last phase of measurement (Figure 12), it can be concluded that the algorithm gave satisfactory results in all cases.

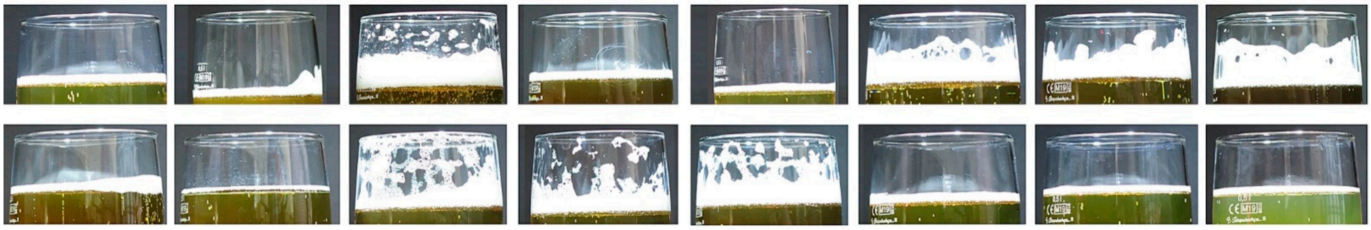


Figure 12. Photos of 16 samples in the last phase of measurement (the first row contains images from samples S01–S08, while the second row contains images from samples S09–S16).

4. Conclusions

Beer foam stability is easily affected by storage under unfavorable conditions (temperature fluctuations, UV light exposure). The novelty of this paper is the use of a laser distance meter combined with the application of digital image analysis in beer foam stability measurement. The basic hypothesis, however, was to rely on the laser distance meter to provide more precise measurements compared to that obtained by image analysis. The data obtained by laser distance meter turned out to be significantly lower than the expected values. This could be attributed to the multiple reflections between the foam (bubbles) layers. Nevertheless, the use of the laser distance meter clearly identifies the instant the foam disappears. With this knowledge, it can be determined whether the values obtained in measurements obtained by the implemented automated image analysis procedure are due to lacing or not. However, in order to truly corroborate this method, further examinations involving different beers (wheat, craft, black) with different foam characteristics should take place. The main characteristics of this method are affordability and precision in detection of foam disappearance, which cannot be recorded with the human eye. Moreover, with this method we actually tried to investigate whether the foam matrix can be detected and quantified via optical methods.

Since we depleted all optical methods, future aspects of this research include ultrasound application in foam stability detection and measurement. This could also transpire to be a cheap, precise and available detection method.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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