DEVELOPMENT OF AN ULTRASONIC DEVICE FOR QUALITY EVALUATION OF YOGURT

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Abstract:

In this article a possibility of application of the ultrasonic non-contact method for assessing the quality of yogurt was researched. A prediction assessment was made by an ultrasound based on four parameters – pH, conductivity, fat content, and viscosity. An ultrasonic device was developed to determine the parameters of yoghurt by modified ultrasound sensor available commercially. In order to obtain data for post-processing, a software application was designed for recognizing the ultrasonic signal through the image processing and analysis techniques.
The developed algorithms and procedures were applied to determine the distance between the object and the sensor, whereby basic physico-chemical parameters of yogurt could be predicted with the lowest relative error. The working distance was 35 cm for the considered system. The survey results show that the parameters fat content, pH, conductivity, and viscosity of yogurt could be predicted by the proposed system for contactless measurement with accuracy of 94-97%.

1 Introduction

Quality and safety of the dairy products is a daily problem that constantly requires their registration and testing. For this purpose, variety of contact and contactless methods can be used allowing automation of these activities.
The contact methods have a significant drawback that measured on immersion of the measuring probe in the product in which they can introduce microorganisms from the environment [1]. The disadvantages are important too. The contact methods have significant disadvantages of measurement which is a prerequisite for seeking suitable contactless methods for evaluation of the key quality indicators of yogurt. Such techniques are optical, gas, ultrasound [2].
More universal applications [3, 4] have found ultrasonic sensors that are applied to assess the quality of dairy products at all stages of production and acceptance of raw milk, pasteurization, ripening, tracking of the fermentation, control of the final product and storage.
The non-contact ultrasonic method, which is based on the effect of reflection or transition, is one of the ways for the diagnosis of sour-milk products. They are used in the conventional non-destructive methods for evaluating the quality of the product [5]. At modern stage, multisensory systems are used [6].
The ultrasonic methods offer some advantages over non-contact methods such as optical impedance. These methods are easily applied directly to the production line, they are non-destructive, allow

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quickly obtained measurement results, the possibility of automation of process measurement or control, and correction in the work of aggregates associated with the production of yogurt [7].

Table 1 is an overview of the more popular publications related to the evaluation of basic quality indicators of yogurt fermentation. It evaluates the physical and chemical properties of the product. Presented are the defining characteristics of the product, the frequency of the used ultrasonic transducer, the method for processing of the collected data, and accuracy of the reported results. For example, the method of measuring includes the apparatus used, the value to be measured, number of measured samples, and a method for the result processing.

More often methods for presenting measurement data with ultrasound are the amplitude and speed of the signal. Fewer publications are related to the performance of the ultrasonic signal in the form of features as Wavelet coefficients, phase difference, coefficients of attenuation. In the considered publications, the method of correlation between parameters or features is mainly used, and it presents the signal of physical or chemical parameter of a product used as a reference. To a lesser extent the use of classification procedures in this type of analysis is advocated upon. The results are often presented with nonparametric methods and mainly focused on assessing the possibility of application of ultrasound measurements to test the quality of yogurt.

The **aim** of this article is to assess the possibilities of prediction of some physico-chemical parameters of yogurt with an ultrasound sensor.

Table 1. Applications of analytical ultrasound for the quality of yogurt evaluation

Determined parameters of the product	Frequency of the transmitter, kHz	Measured variable	Method for data processing	Presentation of results	Reference
Monitoring process of fermentation and protein determination	5000-15000	Speed of the signal	Comparative analysis with previous studies	Non-parametric comparative analysis	[7]
Monitoring process of fermentation	3700	Phase difference	Comparative analysis with previous studies	Non-parametric comparative analysis	[8]
Determination of fat content	40	Wavelet coefficients	Use of classifier	Classification error 3.6-15.47	[9]
No data	40	No data	No data	Presentation of the scheme of measurement system	[5]
Monitoring process of fermentation	5000	Amplitude of the signal	Correlation with pH	Non-parametric comparative analysis	[10]
Monitoring process of fermentation	1000	Amplitude and speed of the signal	Correlation with pH	Non-parametric comparative analysis	[11]
Monitoring process of fermentation	5000	Attenuation coefficient and speed of the signal	Correlation with pH	Non-parametric comparative analysis	[12]

2 Materials and methods

For the purpose of this study, 40 yogurts were used that were produced according to BNS 12:2010 (Bulgarian national standards) [13], commercially available. The measurement conditions were: temperature 20-22°C; relative humidity 49-51%. An assessment was made of prediction by ultrasound on 4 parameters – pH, conductivity, fat content, and the viscosity. To determine actual value of parameters the following measurement methods were used:

Measurement of active acidity (pH). The active acidity is determined by the concentration of hydrogen ions and is expressed in pH units. It is determined by pH meter. Measurements were performed with pH-meter „Hanna pH 211“. Hanna pH 211 is a microprocessor measuring instrument of pH and temperature. The device measures the potential and concentration and reduction of oxidation in the mV range. The measurement of pH occures with a compensation of the temperature automatically or manually via a temperature sensor HI 7669/2W. The device has a large LCD display showing the measurement in a pH or mV and temperature simultaneously with graphical symbols. Calibration is done showing the necessary steps on the monitor.

Measurement of electrical conductivity. The portable digital conductivity meter DM750 is intended for automatic measurement of electrical conductivity of solutions using a two-electrode scheme of measurement. The apparatus is used for measuring the electrical conductivity of aqueous solutions of salts, acids, and bases. It features indicator display with 3 1/2 digit 13mm LCD. The unit power is provided by a 9V battery power. The measuring range is 0-200mS. The main measurement error is <1-5% of the range.

Measurement of viscosity. Dynamic viscosity (Pa.s) was measured by rotating viscometer Rheotest-2.1.

Determination of a fat content. The fat content of the yogurt is defined as a well prepared sample weighing precisely 50g, with 50ml of distilled water added and mixed well. The fat content of the sample was determined by the Gerber method as in raw milk. A sulfuric acid is used with a density of 1,820 amyl alcohol and buterometers for cow's milk. Before and after centrifugation, the butirometers were placed in a water bath at 65ºC for 5min. The reporting is done immediately after the second tempering. The fat content of the yogurt is obtained as reported on the scale of the butirometer fat multiplied by 2.

Obtaining ultrasonic signal. Figure 1 presents a schematic view of the system for receiving and processing the ultrasonic signal.

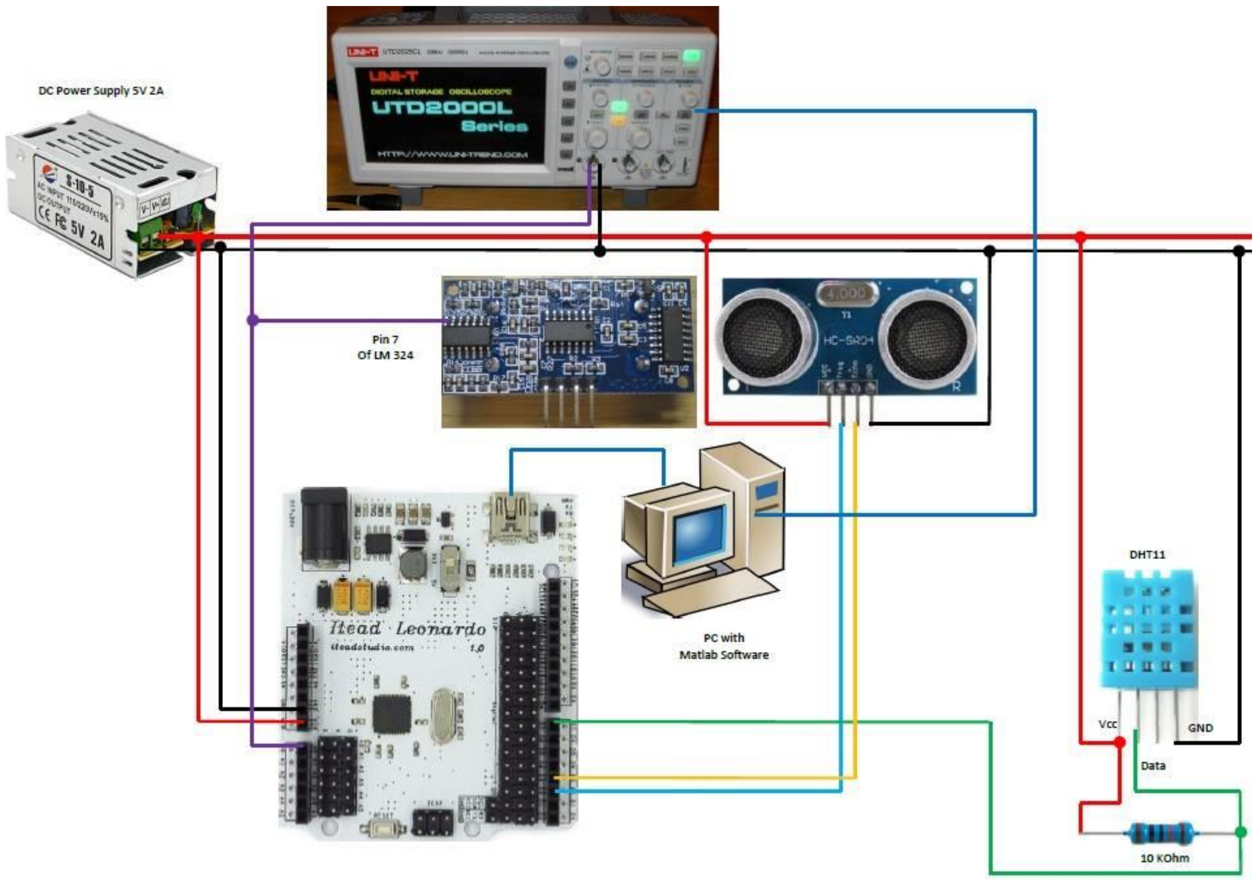


Figure 1. Principle schematic for the ultrasonic system.

An ultrasonic sensor HC-SR04 [14] is used. This sensor works with an ultrasonic signal with a frequency of 40 kHz and has a separate transmitter and receiver. The ultrasonic sensor management is performed by a single board computer Itead Leonardo through the digital pins D2 and D3, respectively to activate the sensor and read the echo signal. The signal from the receiver is amplified by the operational amplifier LM324. Pin 7 of this integrated circuit is connected to the analog input A0 of the single board computer and to the oscilloscope Uni-T UTD2025CL. The ultrasonic signal is displayed as analog data in the time domain on the screen of the oscilloscope. For calculation of temperature compensation a digital sensor for measurement of humidity is used as well as temperature DHT11 with pull-up resistor 10 KΩ, connected to the pin D7 of the single board computer. The power supply of the system is provided by the power supply 5V DC, 2A. All the devices are connected to a common minus.

The single-board computer Itead Leonardo uses the programming environment Arduino IDE and programming language C.

Detection of ultrasonic signal through techniques for image processing. The oscilloscope Uni-T UTD2025CL uses the software "Digital Storage Oscilloscope v.1.6". The software allows saving files in a binary file format on a personal computer, directly on the oscilloscope in the built-in memory or on a flash drive.

Data analysis. For data analysis the methods Partial least squares regression (PLSR) and Principal component regression (PCR) are used. The obtained model was evaluated by: coefficient of determination (R^2); root mean square error (RMSE), and the sum of squared errors (SSE). As a reference, these measurements were used fat content, conductivity, pH, and viscosity.

3 Results and discussion

Hardware and software tools developed. For the purpose of this work a laboratory equipment was set up to obtain ultrasonic characteristics of yogurt, as shown in Figure 2. The system consists of a developed ultrasound device with ultrasonic sensor, oscilloscope, and a personal computer with software.

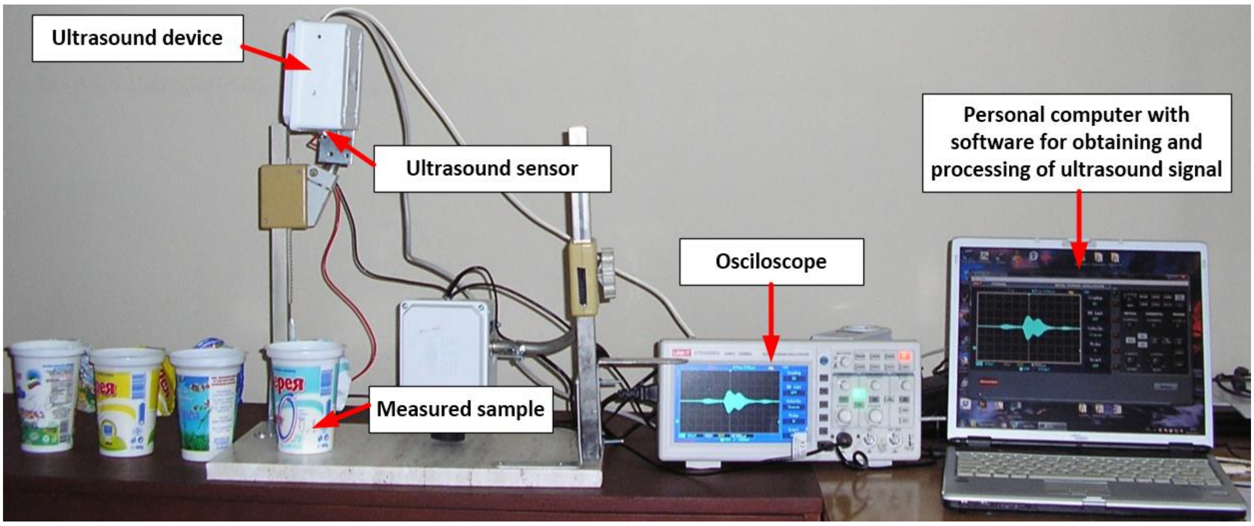


Figure 2. System for obtaining an ultrasound signal of a yogurt – general view.

A pseudo code of the algorithm for managing and reading the sensors is shown in Table 2. For the sensor DHT11 library dht11.h was used. Two intervals were used – for the sensor DHT11, 1000ms, shorter intervals of request for the device can lead to its damage; for the sensor HC-SR04 the interval is 5 ms. A pin "trig" for 10 ms has been activated in the ultrasonic sensor, and then the length of the pulse received on the echo pins can be read.

A distance in cm is determined by dividing the pulse width with 58. The distance from the ultrasonic sensor to the observed object has to be greater than its dead zone. It is determined with diameter's square of the piezo-ceramic plate- four times the wavelength. This parameter is specified by the manufacturer of the sensor. The aim is to avoid working with the spherical waves. The maximum distance of an object from the sensor is determined by the minimum signal/noise ratio [15]. The known literature and the Internet sources have published results and software for recording the readings of oscilloscopes from a series UT. The new results from the current UTD series are not available because these devices use a different protocol for communication with the PC via USB interface.

A program was developed in Matlab environment in order to obtain values of the ultrasonic signal through the techniques for image processing. Similar programs have been developed in Matlab for recognition of the indication of oscilloscopes, without connection to a personal computer via a screen capture of the oscilloscope with a camera using the techniques for pattern recognition [16]. The disadvantage of that approach is that five separate functions (files) are used for processing and it requires eight steps by the user to obtain the final result.

Table 2. Pseudo code of algorithm for receiving and processing of data from the sensors

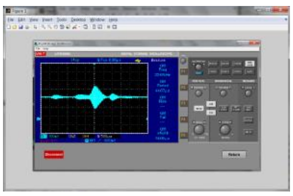
Stage	Content	Description
A	Loading of the library	*<dht11.h>*
B	Defining the inputs and outputs of single board computer	Pin 7 Sensor DHT11; //input Pin 3 for activating signal sensor HC-SR04; // output Pin 2 of the echo signal from the sensor HC-SR04; // input
C	Define the interval	For reading and processing data from DHT11, 1000 ms; Reading and processing of HC-SR04, 5 ms;
D	Initial settings	Set the speed of data transfer to a PC via serial port 9600 bits/s; *while (! Serial) {; // Wait for connection to a serial port*
E	The main program	F-M stages are repeated continuously
F	Program for the management and reading of the sensor for humidity and temperature DHT11	*unsigned long currentMillis = millis();* *if (currentMillis – previousMillis1 >= interval1){* *previousMillis1 = currentMillis;* *int err;* *temp, humi;* *if((err=dht11.read(humi, temp))==0)* *else { Displaying the number of error }*
G	Program for the management and reading of the ultrasonic sensor	*if (currentMillis - previousMillis2 >= interval2){* *previousMillis2 = currentMillis;* *activation of the pin 3 to 2 ms;* *activation of the pin 2 for 10 ms;* *distance=pulseIn(ECHOPIN, HIGH); // calculating the distance in cm* *distance=distance/58;* *s1=analogRead(A0); // reading of analog input A0* *v1=s1*(5.0/1023.0); // conversion of analog values from interval 0-1023 to voltage 0-5V}*
H	Output of data via serial port	Output values for temperature, humidity, distance and voltage via serial port

Table 3 presents the algorithm for receiving and recording the values of the ultrasonic signal in Matlab. The user has to perform two operations - to record a screenshot of the program screen in the clipboard that works with the oscilloscope and to launch a function in Matlab for image processing and receiving data of the ultrasound signal. The experience has shown that in presenting the image S_{HSV} color components have separated signal and undisplayed axes and other objects in the image that would prevent the recognition. Figure 3 presents in a graphical form stages of the work of the proposed algorithm. Signals are displayed on the screen of the oscilloscope with settings 100 mV/div and 500μs/div. After the conversion to HSV color model processed S_{HSV} color components which clearly observe the resulting signal with the removed objects below 1000 pixels. The processing time is 33.033±0.796s.

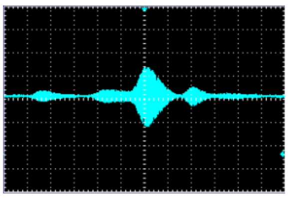
Physico-chemical parameters' predictions of yogurt by ultrasonic characteristics. Here it was aimed at non-destructive to be expressed, with accuracy of at least 95% to identify problems with the product that are to be subjected to analysis by an authorized laboratory. Using the reference data obtained from the laboratory measurements, it is possible to determine the relationship between the ultrasound characteristics of the examined products and their properties pH, conductivity, viscosity, fat content.

Table 3. An algorithm for recognition of the ultrasonic signal

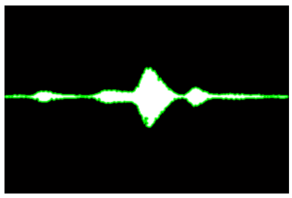
Stage	Content	Description
A	Save the image in clipboard	By keyboard shortcut Ctrl-Alt+PrtScr
B	Loading image from clipboard into the workspace of Matlab	Used is the function *imclipboard*
C	Separation of Region of Interest	By the function *imcrop* is separated the screen area with the signal
D	Converting of the image in HSV color model	For further processing is used SHSV color component of the image
E	Filtering the image, removing small objects and filling the holes	The image is filtered with a filter of the type Disk; By the command *bwareaopen* are cleared all of the objects with area under 1000 pixels; By the command *imfill* are filled holes in the contour of the ultrasonic signal;
F	Separation of the contour of the object	By the functions *bwtraceboundary* and *flipud* are obtained the upper and lower half of the contour
G	Obtaining unique values in the vector of contour coordinates	By the function unique
H	Removing the vertical points on the right side of the contour	*if length(ad)<length(be)* *be=be(:,1:length(ad))* *else if length(ad)>length(be)* *ad=ad(:,1:length(be))* *end* *end*
I	Scaling	Determine the number of pixels for V/dev и μs/dev
J	Combining the data and obtaining vectors for a time and voltage	*combinedSize1 = max(size(ax, 2), size(bx, 2)) * 2;* *comb1 = NaN(1,combinedSize);* *comb1(1:2:size(ax,2)*2) = ax;* *comb1(2:2:size(bx,2)*2) = bx;*
K	Recording the resulting vector in a file	The data obtained are stored in *.mat file



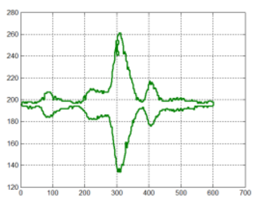
a) Loading of the image from clipboard



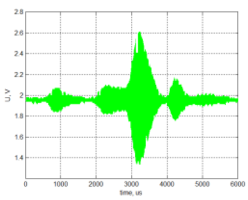
b) Separation of region with signal



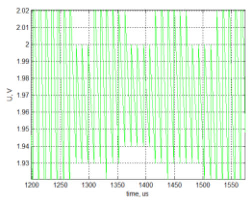
c) Recognition of region with signal



d) Separation of the signal



e) Removing of non-informative data



f) Scaling, visualization and storing of the data

Figure 3. Stages of ultrasound signal recognition.

Experimentally, the required number of latent variables for prediction were determined. 95% of the data can be described by 2 latent variables, and 100% by 3. In practice, methods are sought after suitable to reduce the amount of data. From this point, two latent variables were used.

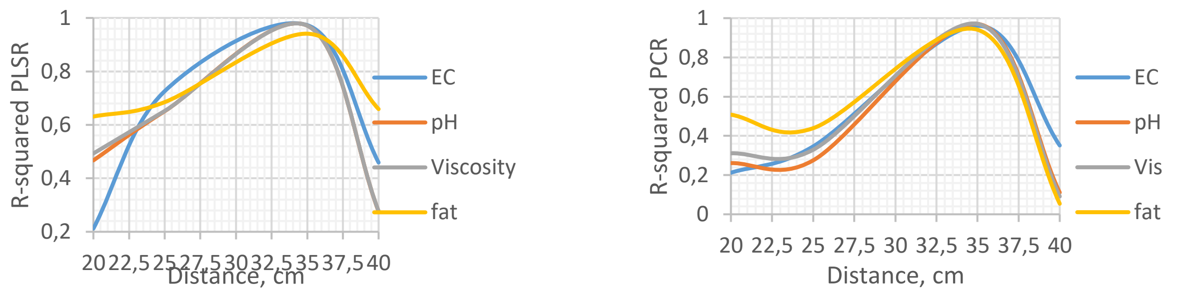
A distance was determined for obtaining ultrasonic characteristics using two components. Table 4 shows the results using the method PLSR, and Table 5 shows the method for PCR. There is a tendency in SSE and RMSE at 35 cm of distance that they are with the smallest values 5-30% for both tested methods. Data of the coefficient R^2 is presented for research methods graphically in Figure 4. It is seen that the maximum value for the coefficient is obtained from the distance 35 cm.

Table 4. Amendment of the parameters of PLSR at different distance of measurement

Parameter / Distance, cm	**Prediction of conductivity**			**Prediction of pH**			**Prediction of viscosity**			**Prediction of the fat content**		
	R^2	SSE	RMSE	R^2	SSE	RMSE	R^2	SSE	RMSE	R^2	SSE	RMSE
20	0.212	0.091	0.213	0.467	0.042	0.146	0.493	0.313	0.395	0.631	1.571	0.886
25	0.726	0.686	0.586	0.651	0.039	0.139	0.652	0.284	0.377	0.685	1.457	0.854
35	0.973	0.576	0.537	0.971	0.005	0.049	0.971	0.035	0.133	0.941	0.381	0.436
40	0.459	0.856	0.654	0.276	0.034	0.131	0.277	0.251	0.354	0.659	1.515	0.871

Table 5. Amendment of the parameters of PCR at different distance of measurement

Parameter / Distance, cm	**Prediction of conductivity**			**Prediction of pH**			**Prediction of viscosity**			**Prediction of the fat content**		
	R^2	SSE	RMSE	R^2	SSE	RMSE	R^2	SSE	RMSE	R^2	SSE	RMSE
20	0.212	0.118	0.243	0.261	0.033	0.128	0.311	0.268	0.366	0.508	1.686	0.918
25	0.346	0.779	0.624	0.275	0.034	0.131	0.329	0.276	0.372	0.439	1.662	0.912
35	0.961	0.576	0.537	0.971	0.005	0.049	0.971	0.035	0.183	0.941	0.381	0.436
40	0.351	0.784	0.626	0.111	0.017	0.092	0.091	0.104	0.228	0.054	0.346	0.416



a) PLSR *b) PCR*

Figure 4. Results for coefficient R2 for research methods. EC – Electric conductivity; pH – Active acidity; Vis – Viscosity; fat – Fat content tages of ultrasound signal recognition.

The presented results demonstrate the possibility of indirect determining of the physico-chemical properties of yogurt using the ultrasonic characteristics. The creation of predictive models is provided to quantify different characteristics concerning the composition of the studied products. The values of the parameter fat content as specified in [17,18] are the values measured in the laboratory and those mentioned on the product packaging vary up to 5%. Ultrasonic techniques achieved the same results using both methods of prediction. Small values of the coefficient R^2=0.2-0.4 and higher values of errors SSE and RMSE (0.75-0.92) were obtained using other parameters such as carbohydrates, fiber, proteins, referred as a value on the package. This is a prerequisite for realization of the future research related to a precise determination of the values in the laboratory and evaluation of the possibility of predicting these parameters with the ultrasonic techniques.

Proposed is an electronic circuit of a system for contactless measurement of yogurt parameters, using modified ultrasonic distance sensor HC-SR04 which receives the ultrasound characteristics of the product. In comparison to the results published [5] and [9] the systems use more complex schematic to obtain ultrasonic characteristics of the product.

4 Conclusion

This article provides an overview of the advantages and disadvantages of the contact and contactless methods for assessing the quality of yogurt.

Proposed is an electronic circuit of a system for contactless measurement of yogurt parameters, by modified ultrasonic distance sensor HC-SR04, which receives the ultrasound characteristics of the product.

The proposed software solution using the image processing solves the problem of transferring data from oscilloscope to personal computer by the techniques for receiving, processing, and analysis of images. It has the advantage over the prior work -it requires a small number of operations to use the application by the user.

Experimentally, the distance between the object and the sensor was found, whereby it can be predicted with basic physicochemical parameters of yogurt with the smallest error. For the considered system that distance is 35 cm.

The survey results show that the parameters fat content, pH, conductivity, and viscosity of a yogurt could be predicted by the proposed system for contactless measurement with accuracy of 94-97%.

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