

Prediction of Watermelon Consumer Acceptability based on Vibration Response Spectrum

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Abstract—It is difficult to judge ripeness by outward characteristics such as size or external color. In this paper a non-destructive method was studied to determine watermelon (Crimson Sweet) quality. Responses of samples to excitation vibrations were detected using laser Doppler vibrometry (LDV) technology. Phase shift between input and output vibrations were extracted overall frequency range. First and second were derived using frequency response spectrums. After nondestructive tests, watermelons were sensory evaluated. So the samples were graded in a range of ripeness based on overall acceptability (total desired traits consumers). Regression models were developed to predict quality using obtained results and sample mass. The determination coefficients of the calibration and cross validation models were 0.89 and 0.71 respectively. This study demonstrated feasibility of information which is derived vibration response curves for predicting fruit quality. The vibration response of watermelon using the LDV method is measured without direct contact; it is accurate and timely, which could result in significant advantage for classifying watermelons based on consumer opinions.

Keywords—Laser Doppler vibrometry, Phase shift, Overall acceptability, Regression model, Resonance frequency, Watermelon

I. INTRODUCTION

WATERMELON is a popular fruit and it has different properties and applications. According to FAO statistics published in 2008, Iran has been ranked third among watermelon producing countries. Nondestructive quality determination of watermelons has been a challenge for its customers since it has different structure from the other fruits. The subjective methods are usually based on appearance or sound caused by slap. Both are not reliable because these methods are prone to human factor errors. Researchers have studied different objective methods to evaluate watermelon quality: acoustic and dynamic technology [1]-[3]-[7]-[15]-[22], electrical and magnetic technology [8]-[14], X-ray and computed tomography [21], and near infrared (NIR) spectroscopy [5]-[6]-[16].

In this paper Laser Doppler Vibrometry (LDV) technology is used to detect overall quality of watermelon. In recent years using LDV has been studied by researchers as a new

nondestructive technique to test the quality of some fruits. Muramatsu did comparison between the use of accelerometer and LDV to measure the firmness of some varieties of apple, pear, kiwi and citrus. Their results of measurements carried out using the LDV expressed more accurate than the accelerometer results [10]. In addition, Muramatsu evaluated the texture and ripeness of some varieties of kiwi, peach and pears. They excited samples at different stages of ripeness, by the sine wave with frequencies from 5 to 2000 Hz and the vibration responses at top point of the fruit were measured by LDV. Then the phase shift between input and output signals was compared with the data obtained from the method of force-displacement. A significant relationship between these two methods obtained in 1200 and 1600 Hz excitation frequencies. The ability of the LDV technique for detection of internal defects of some citrus varieties was approved [11]. Muramatsu also used the method to conduct some tests and determine fruit texture changes during the ripeness. This technique was used for persimmon, apple and kiwi. In the range of 1,200 to 1,600 Hz, phase shift as a function of the ripeness significantly changed. They also found resonance frequency for all fruit under test was a function of the ripeness [12]. Terasaki used LDV to assess properties of kiwifruit at different stages of ripeness. They considered two factors $S = f_n = 2^2 m^{2/3}$ and $\eta = (f_2 - f_1) / f_{n=2}$ where $f_{n=2}$: second peak resonance frequency, m : mass of fruit and f_2 and f_1 are frequencies determined at 3 dB below peak resonance. The relationship between S as elasticity index and firmness of kiwifruit was significantly high. η also showed a good correlation with soluble solids content [20]. The potential of measuring the vibration response with a laser vibrometer was explored in plums by Bengtsson. Phase shifts at selected frequencies were highly correlated to postharvest storage time, plum weight, plum length and plum width [2]. Murayama conducted research on ripeness by the LDV in which pears harvested at different times and in different periods of storage were tested. Results showed that correlation coefficients between firmness and elasticity index were significantly high [13]. Taniwaki also conducted a separate investigation to review the trend of change in elasticity index figures from the melon, persimmon and pear after harvest period. The second resonance frequency of sample was obtained using LDV. The samples were evaluated by panelists' senses considering features such as appearance, sweetness, firmness and etc. (each separately). The overall acceptability was sensory evaluated by subjective scoring. High correlation between the elasticity index and the mentioned properties were observed [17]-[18]-[19]. The main objective of present study is establishing a relation among

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parameters measured by LDV and watermelon consumers' opinion using multiple linear regression models.

II. MATERIALS AND METHOD

In this study forty watermelons were selected for the experiments. The variety of watermelons was Crimson Sweet which is one of the varieties for export from the Iran. It is nearly round with bright green and medium dark stripes.

The experimental setup has been presented in Fig.1 and 2. A fruit sample was placed on a shaker, and excited with random wave signals (frequencies, 0–1000Hz) generated and amplified using a computer and amplifier respectively. While the excitation signal was detected by accelerometer (Model Endevco 4397) installed on vibrational plate, the response of the fruit was optically sensed using a Laser Doppler Vibrometer (Model Ometron VH1000-D, Denmark).

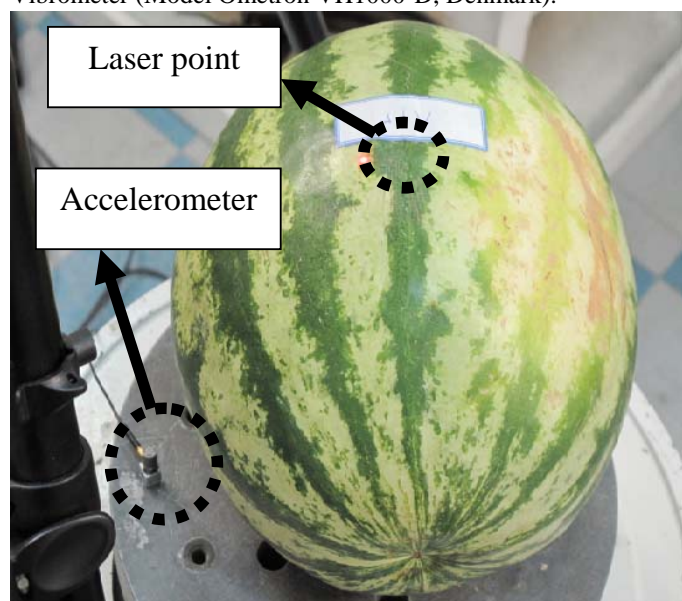


Fig. 1 Excitation signal was measured as input signal by accelerometer installed on shaker

Briefly laser beam from the LDV is directed to the upper surface of sample and the vibrations are measured from the Doppler shift of the reflected beam frequency due to the motion of the surface. Considering the response signals, the excitation signals and using FFT, the phase shift between the mentioned signals were extracted for entire frequency range. Vibrations transmission through the watermelons resulted in this phase shift. Using frequency response curves from the accelerometer and LDV system, the resonance frequencies of the first two vibrational modes were determined.

The frequencies of the phase shifts which had the highest correlation with color indicators were chosen.

After determining the vibration response of the samples and measuring their weight, they were cut at the midpoint. Then watermelons were sensory evaluated. Seventeen panelists graded the fruits in a range of ripeness in terms of overall acceptability (total desired traits consumers). The fruit ripeness indices were scored on a scale of 1–5 (1: unripe, 3: ripe, and 5: overripe).



Fig.2. LDV sensed response of the fruit in upper surface as output signal

Finally the correlation between LDV-test results and the consumer opinions was determined.

The chosen phase shift, frequency resonances and mass were used for making prediction model. This step was carried out using MATLAB (7.6.0 R2008a, The Math- Works Inc., USA)

To quantify the predictive ability of the models, the determination coefficient (R²) and root mean squared error (RMSE) were obtained. Leave-one-out cross validation was applied for validating models. This technique separates a single observation case from all cases as the validation data, and the remaining cases use for deriving predictive function. This procedure is repeated such that each observation in the sample is used once as the validation data.

III. RESULTS

By investigating the whole spectrum of phase shift between input and output vibrations, ten frequencies in which phase shift had better relation with watermelon quality were picked out. These are 52, 77, 96, 153, 242, 516, 541, 624, 821, 1071 Hz. In order to predict the overall acceptability of watermelon using phase shift, multiple linear regression models were presented whose general form is the following:

$$y = a_0 + \sum_{i=1}^{13} a_i x_i \quad (1)$$

Where

x1: Fruit mass (g)

x2: First resonance frequency (Hz)

x3: second resonance frequency (Hz)

x4: Phase shift in 52 Hz (radian)

x5: Phase shift in 77 Hz (radian)

- x6: Phase shift in 96 Hz (radian)
- x7: Phase shift in 153 Hz (radian)
- x8: Phase shift in 242 Hz (radian)
- x9: Phase shift in 516 Hz (radian)
- x10: Phase shift in 541 Hz (radian)
- x11: Phase shift in 624 Hz (radian)
- x12: Phase shift in 821 Hz (radian)
- x13: Phase shift in 1071 Hz (radian)
- y: overall acceptability (1: unripe to 5: overripe).

The coefficients of models for calculation of overall acceptability are showed in table 1.

TABLE I
NUMERICAL VALUES OF THE REGRESSION MODEL COEFFICIENTS

Coefficient	Unit	overall acceptability
a0	-	6.6183
a1	1/g	0.0002
a2	s	-0.1023
a3	s	0.0249
a4	1/radian	-0.1279
a5	1/radian	-0.0185
a6	1/radian	-3.7133
a7	1/radian	-0.3742
a8	1/radian	-0.0036
a9	1/radian	-0.0860
a10	1/radian	-0.3319
a11	1/radian	0.4476
a12	1/radian	-0.1098
a13	1/radian	0.0635

Table II shows performance of MLR models in prediction in terms of correlation coefficient and RMSE.

TABLE II
MLR MODELS FOR PREDICTING OVERALL ACCEPTABILITY OF WATERMELON

Acceptability	Calibration		Validation	
	R ²	RMSE	R ²	RMSE
	0.89	0.3459	0.71	0.5856

Actual and predicted values of consumer opinions were plotted in fig. 3 to visually evaluate the performance of the models.

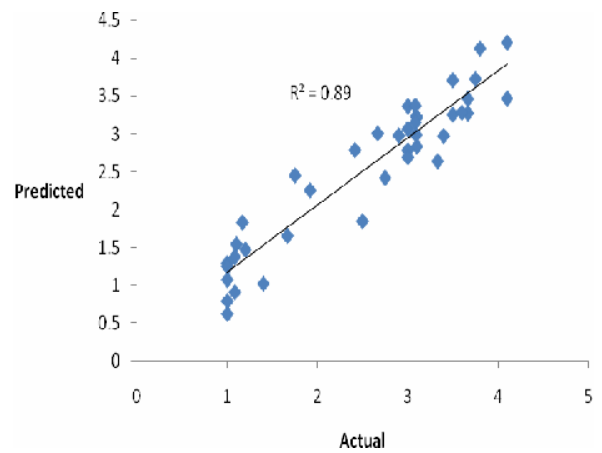


Fig. 3 Actual and predicted values for overall quality

IV. DISCUSSION

Vibration response was obtained ratio of imposed and perceived signals. It seems variations of total solvable solids, pigmentation in the cells and internal restructuring of watermelon during ripeness cause changes of modal properties derived vibration response such as resonance frequency and damping ratio as well as variations of phase difference between imposed and perceived signals on certain frequencies. Because of this phenomenon the first and second resonance frequencies and also their damping ratios as well as phase shifts can be used as variables in the watermelon ripeness modeling. Former studies with LDV which applied vibration response for other fruit considered only second resonance [13]-[17]-[18]-[19]-[20]. Meanwhile former studies which applied phase shift for other fruit usually considered it in predetermined frequencies for example the response was conventionally monitored at intervals of 400 Hz [11]. While here the best frequencies was selected instead of same those frequencies. Employing the panel test, the optimum quality range of watermelons depended on consumers' opinion can be achieved in terms of vibration response. Therefore after vibrations tests and predicting watermelon acceptability, distributors enable to separate fruits whose score are not in the optimum range of overall acceptability. In general the optimum range depends on customers' taste. Using LDV technology vibration response of watermelon is sensed without contact and in real-time that is a major advantage for industrial grading and sorting of watermelons. It is concluded present study demonstrates feasibility of laser vibrometry for predicting overall acceptability of fruit as an online contactless sensing method. There is also capability to investigate and develop nondestructive vibration -based methods for simultaneous analysis of other internal properties of watermelon like total soluble solid (TSS). It is obvious that buying a poor-quality watermelon, in comparison with other

fruits includes more financial loss. Diagnosing those watermelons in a bottleneck (like the main fruit and vegetable farms, ports and other terminals) and separate them, this could increase the consumer satisfaction, and providing a plan for using those products is conceivable. The results of this research can be used for developing a rapid sorting system for watermelon.

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