2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 131619931

A Preliminary Study of Helmholtz Resonant for Measurement of Watermelon Volume

Huarui, Chen[1]; Huirong, Xu*[1]; Xiuqin,Rao[1]; Kondo, Naoshi[2];Junqi, Bao[1];

1.Zhejiang University, Hangzhou,Zhejiang,China.

2. Kyoto University, Kyoto, Japan.

* Corresponding author, E-mail: hrxu@zju.edu.cn

Written for presentation at the

2013 ASABE Annual International Meeting

Sponsored by ASABE

Kansas City, Missouri

July 21 – 24, 2013

Abstract. Fruit volume and density are vital features for fruit quality. In a Helmholtz resonant system the resonant frequency was found having a close relationship with the effective volume of the resonator. The objective of this study was to develop a watermelon volume measurement system using the Helmholtz resonant principle. A device consisting of a signal generator, an amplifier, a loudspeaker, a resonator, a microphone, a data acquisition module and a data analysis software was designed and tested. To evaluate the performance of the system, 65 watermelons from native orchard were used. Single-factor tests and orthogonal tests showed that the optimal factor of the watermelon volume measurement system was 6 s of data-acquisition time, 280 mm of distance between microphone to resonator port opening and 100 mm of height between loudspeaker to resonator port opening. The volumes of watermelons were estimated using this system based on the model formula between the resonant frequency and the volume of the resonator chamber with watermelon inside, and the actual volumes of watermelons were measured by water-filling method sequentially. The determination coefficients R^2 for the calibration sets (47 watermelons) and validation sets (18 watermelons) were 0.9655 and 0.9568, respectively. It was confirmed that the Helmholtz resonance showed great potential in measuring the volume of watermelon and the following study could reach to density prediction and watermelon internal quality evaluation.

Keywords. *Helmholtz resonant, watermelon, volume, fast and non-destructive measurement*

Introduction

Fruit volume is one of the important quality indices for agricultural products. It could be used for prediction of optimum harvest time (Hahn and Sanchez, 2000), output (Mitchell, 1986), finding the relationship between fruit expansion rate with internal defect (Ngouajio et al., 2003). Also, pattern wrapper based on the volume make it convenient for setting and transporting (Moreda et al., 2007).

It has always been a challenge to obtaining fast and accurate volumetric measurements. There are two traditional methods for measuring volume, the gas displacement method and the liquid displacement method based on Archimedes principle. The liquid displacement method is a simple and easy way, but agricultural products or foodstuffs may be damaged by their filling into liquid. The gas displacement method does not damage food seriously. But both two methods require quite a long time (Nishizu et al., 2001).

Over the past few decades, different electronic systems have been developed for non-destructive determination of volume. Optical ring sensor system developed by Gall (1997) can be used to estimate the volume of fruits moving at high speed, up to 2 m/s when measuring elongated products such as cucumber or zucchini (Moreda, 2004), with a root mean square error (RMSE) of 26 ml and a root mean square error of prediction (RMSEP) of 5.8% for volume estimates of zucchini. Kato (1997) devised an electric method for measuring watermelon volume based on the fundamental relationship between the capacitance of concentric double spheres and the radius of the inner sphere. This method yielded a RMSE of 26 ml, and a RMSEP of 0.4% with no orientation. Jarimopas (2005) made an improvement of the system and found the best orientation of each fruit, which obtained a result for watermelons with an average error of 1.24%, large cucumbers with an average error of 4.56%, wax gourds with an average error of 3.28% and guava with an average error of 3.19%. Also, there are other techniques such as machine vision (Blasco et al. 2003, Hryniewicz et al, 2005), magnetic resonance imaging (Andaur et al., 2004), artificial retina (Kanali et al., 1998), microwave (De Waal et al., 1988).

Recently, a new and high precision noninvasive technique for the volume measurement using Helmholtz resonant was proposed. In a Helmholtz resonant system the resonant frequency was found having a close relationship with the effective volume of the resonator. Ohnishi et al (2008) combined electronic scale and Helmholtz resonance method to measure the density of kiwifruit. They got a result of the coefficient of determination (R^2) of 0.9254, the standard error of prediction (SEP) of 0.0019 g/cm^3. Webster (2010) developed a Helmholtz resonator to study the volume measurement of solids, liquids, and particulate samples, and gave two methods: the resonant hunting technique and the Q profile shifting technique to improve the accuracy of the system.

The objective of this study was to develop a volume measurement system using the Helmholtz resonant principle. As this emerging and primary technique mainly focused on small size samples in the preceding study, this paper explores the Helmholtz resonant for middle and large size agro-products.

Principle of Helmholtz Resonance

A chamber with a narrow port opening will resonate at a natural frequency when the air in the port is excited - a phenomenon known and exploited for thousands of years to make musical instruments (Fig.1.). The German physicist Hermann von Helmholtz (1821-1894) established the relationship of the resonant frequency to the volume of the chamber and the size of the port (Helmholtz, 1877).

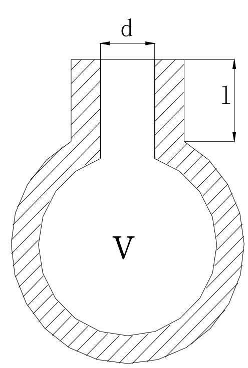

Fig.1. Simple ideal resonator

Helmholtz established the following equation to describe the resonant frequency of a chamber as Equation (1):

$$f_0 = \frac{C}{2\pi}\sqrt{\frac{S}{V\,(l + l_e)}} \tag{1}$$

where:f_0 is the resonant frequency of the chamber (Hz),

C is the velocity of sound in air,

d is the diametre of the port,

S is the cross-sectional area of the port,

V is the static volume of the chamber

And l+l_e is the transmission length of the sound in the port, where l is the actual length of the port and l_e is the compensation value. As the sound does not transmitt in a distance of port length due to air density, Webster (2010) gives the lengthe extension term, Equation (2).

$$l_e = 0.6r + \frac{8}{3\pi} r \quad (2)$$

Where r is the radius of the port.

When there is an object in the chamber, the resonant frequency will be changed as Equation (3).

$$f_P = \frac{C}{2\pi} \sqrt{\frac{S}{(V - W)(l + l_e)}} \quad (3)$$

Where f_p is the resonant frequency of the chamber with the object in.

W is the volume of the object.

As it is hard to measure the actural l_e, we always combine equation (1) and (3) to get the volume of the object in the chamber:

$$W = V\left(1 - \left(\frac{f_0}{f_P}\right)^2\right) \quad (4)$$

It can be seen that Equation (4) could eliminate the uncertain compensation value l_e and sound velocity C , which could minimise the varaible temprature effect on the measure accuracy.

Design of Helmholtz Resonant System

A watermelon volume detection system was designed using Helmholtz resonant theory. The main part consisted of a signal generator, an amplifier, a loudspeaker, a resonator, a microphone, a data acquisition module and a data analysis software, as shown in Fig.2.

Resonator

The resonator was made of three parts, chamber, port, and bottom (Fig.2.). The chamber and bottom were separated so that the watermelon could be put into the resonator. After laying the watermelon on the bottom of the chamber, a screw was used to roll them up. Any air leaks between the two parts could cause variability in the resonant frequency, thus the chamber and bottom were O-ringed to have them sealed. There is a salver fixed on the bottom so that the watermelon could not move when going up. All parts were made of clear stainless steel to reduce varying of temperature on the volume of the chamber and the noise around.

Microphones

Two prepolarised microphones (INV 9206, China Orient Institute of Noise & Vibration) of a frequency range from 20 Hz to 20 kHz with a sensitivity of 50 Mv/Pa were used to collect sound information. Microphone A spaced 280 mm from port opening, and Microphone B was placed near the loudspeaker. This allowed comparison of each position when collecting information.

Data Acquisition Module

A NI-4431 Data Acquisition (DAQ) module (National Instruments, USA) was used to connect microphones and computer. The module consists of four analog input channels for reading from microphones with a single analog output. The four analog input channels simultaneously acquire at rates from 2 to 102.4 kS/s. In addition, each channel includes built-in antialiasing filters that automatically adjust to the sampling rate.

Software

A user friendly windows 07 based software, “Data Acquisition & Signal Processing” (DASP, China Orient Institute of Noise & Vibration), was used for the control of the process and the register of data, providing an easy output to be used with Microsoft Excel. The acoustic signal “time versus intensity” was got first, then a Fast Fourier Transform (FFT) was performed to determine the frequency spectrum. Sampling at 2560 HZ for 8192 points results in a resolution for the FFT spectrum of 0.3125 Hz.

Pink noise

Pink noise consists of random frequencies of equal power. By using pink noise as the driving frequency, the resonant frequency could be observed as a peak in the frequency domain. In the preliminary test chirps were used as the driving frequency, but the resonant frequency could be easily masked by the chirps. In later experiment, pink noise was applied to isolate the resonant frequency.

Support Structure

A loudspeaker with a power of 150 W was installed at the top of the resonance port. The amplifier, DAQ and computer were placed on the operation console.

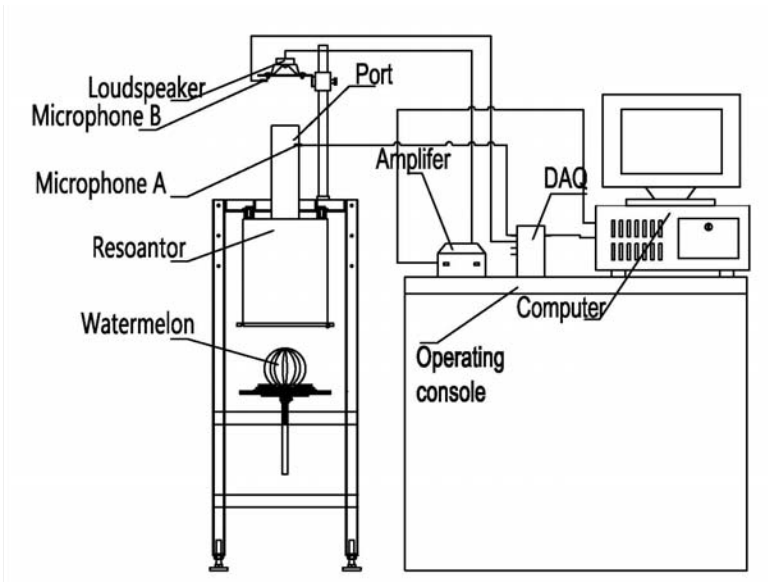

Fig.2. Schematic diagram of the measurement system

Materials and Methods

Firstly, we investigated the suitable position of microphone and loudspeaker and the sampling time. In this fundamental experiment single-factor tests were conducted. Six levels of microphone position (h, the distance between microphone to port opening) and seven levels of loudspeaker position (H, the height between loudspeaker to port opening) and six levels of data acquisition time (t) were shown as Table 1. At each level one experiment was conducted. There are three assessment criteria: whether the resonant frequency is prominent in the frequency domain, the repeatability and stability of three repetitive testing. After the single-factor tests, orthogonal test was conducted to find the suitable combination of the three factors.

Table 1. Factors and levels in single-factor tests

Factors	Levels
h (mm)	130,160,190,220,250,280
H (mm)	40,60,80,100,120,140,160
T (s)	2,4,6,8,10,12

h-the distance between microphone to port opening; H-the height between loudspeaker to port opening; t-data acquisition time

An amount of 65 “Kylin” watermelons grown by farmers in the areas of Yuhang district, Hangzhou, China and harvested in May, 2013, 40-50 d after flowering were used for this study. For each measurement, fruit samples were placed at room temperature for 24 h for equilibration to reduce the effect on the prediction accuracy by the temperature, then cleaned and numbered before signal acquisition.

A pink noise was made using a computer, which had professional audio software that could generate the pink noise. The signal was amplified with the amplifier and applied to the loudspeaker. The DSAP software in the computer set off the two microphones to pick up the sound signal in resonator and the loudspeaker, respectively. The data was recorded and analyzed using FFT to obtain the Helmholtz resonant frequency. The volume of the chamber could be obtained according to the principle of the Helmholtz resonance mentioned above.

Correspondingly, the actual volume of the watermelon was detected by water filling method shown as the Fig.3. V_0 is a certain volume in a barrel with height h. After putting the watermelon in the barrel, pouring V_1 volume of water in the barrel until reach the same height h, V_0-V_1 is the actual volume of the watermelon.

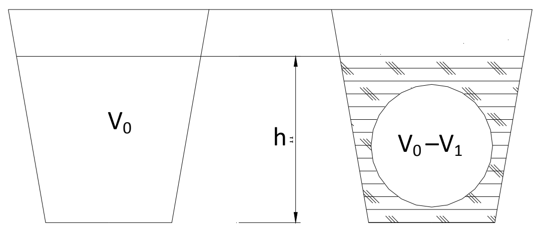

Fig.3. Schematic plot of Water filling method

Results and Discussion

Single-factor tests

From the experiment's results we found that the factor H did not seem to have a significant influence on the results, however, the factors h and t affected the resonant frequency prominence in the frequency domain. When h was lower than 220 mm, or t was less than 4 s there were other interference peak overlapping the resonant frequency. Thus, we conducted the orthogonal test to find the optimal combination of the three factors.

Orthogonal test

Orthogonal designing of three factors (h, H, t) at three levels was applied for obtaining optimal combination, which was shown in Table 2. The h should be longer than 220 mm and less than the whole port length 300 mm and t should be longer than 4 s.

Table 2. Factors and levels in orthogonal test

level	(A) h (mm)	(B) H (mm)	(C) t (s)
1	220	80	6
2	250	100	8
3	280	120	10

h-the distance between microphone to port opening; H-the height between loudspeaker to port opening; t-data acquisition time

Table 3 gave the results of orthogonal test. As shown in Table 3, the influence to the measured volume decreased in the order: C > A > B according to the *R* (range) values. Data acquisition time was found to be the most important determinant of the volume due to the maximum *R* value. However, the result showed that the longer acquisition time did not show a good outcome. These results indicated that the optimal combination was 6 s of data acquisition time, 280 mm of distance between microphone to port opening, and 100 mm of height between loudspeaker to port opening.

Table 3. Orthogonal test scheme and analysis of test results

Test number	A	B	C	Measured volume(mL)
1	1	1	1	※
2	1	2	2	6206
3	1	3	3	6252
4	2	1	2	※
5	2	2	3	6275
6	2	3	1	6298
7	3	1	3	※
8	3	2	1	6411
9	3	3	2	6206
K1	12458[a]	※	12709	
K2	12573	18892	12412	
K3	12617	18756	12527	
k1	6229[b]	※	6354.5	
k2	6286	6297	6206	
k3	6308	6252	6286	
R	80[c]	45	148	
Factor(most-least)			CAB	
Optimal level			A3B2C1	

[a] $K_i^A = \sum the$ amount of predicted volumes at A_i

[b] $k_i^A = K_i^A / 3$

[c] $R_i^A = \max \{K_i^A\} - \min \{K_i^A\}$

※ **Resonant frequency is a not prominent in the frequency domain**

Volume detection

Frequency spectrum plots for each microphone were illustrated in Fig.4. Fig. 4a was the recorded sound signal after FFT transform obtained by microphone A, which showed the reacting Helmholtz resonance in resonator. Fig.4b was the recorded signal after FFT transform obtained by microphone B, which showed the reacting of loudspeaker. A significant difference between the sound signal obtained by each microphone was seen from the Fig.4, which implied that the Helmholtz resonance obviously different from the driven frequency. Also, the resonant frequency was prominent among the other peaks in the spectrum that greatly corresponding to the find of Nishizu et al (2001).

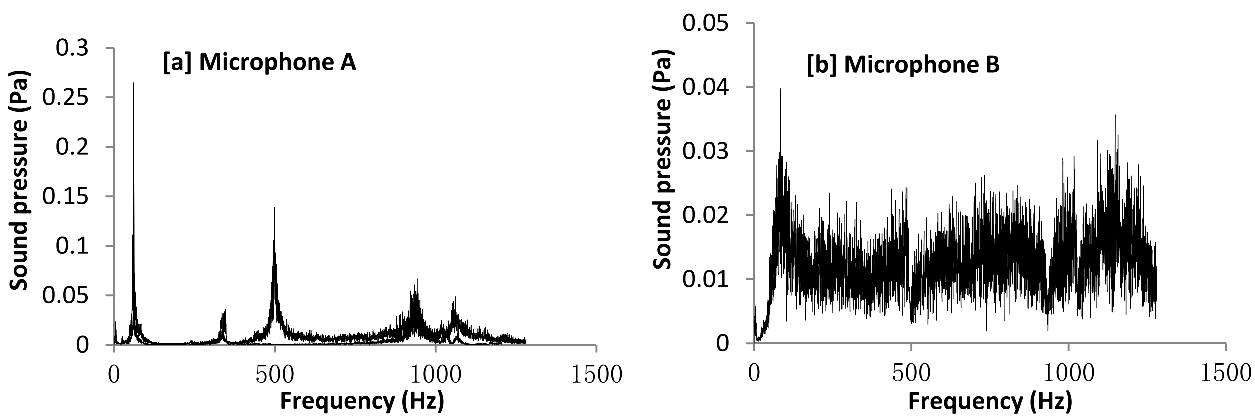

Fig. 4. Frequency spectrum plots of microphone A and B

Fig.5 gave a typical comparison of three size watermelons. As shown in Fig.5, the resonance frequency rose with the increasing of the volume of the watermelon, which was best corresponded to the Equation (3) that the resonant frequency would rose when the object's volume increased in the chamber. This was because that the effective volume in the chamber decreased as the increasing of object's volume, and the sound vibrated in a much smaller space which led to a more significant vibration.

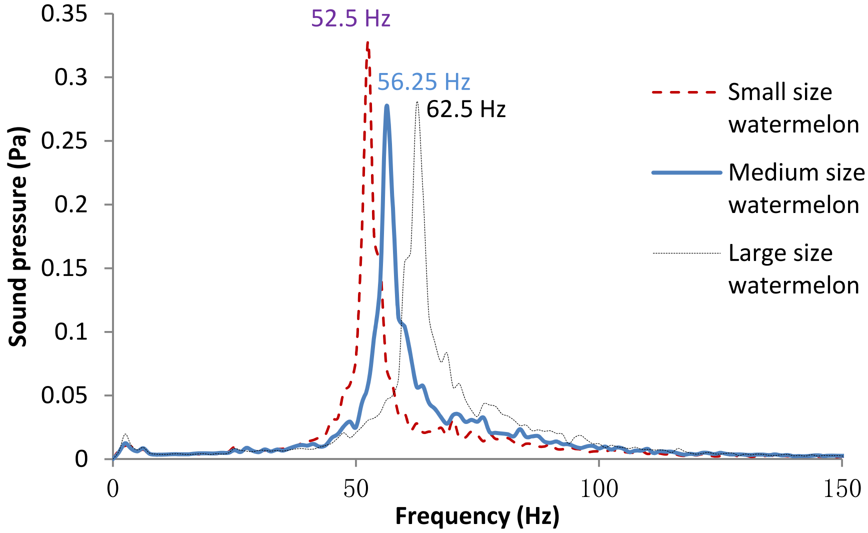

Fig. 5. Frequency spectrum plots of three size watermelons

The scatter plots of actual versus measured/predicted watermelon volume were shown in Fig.6. As can be seen from the figure, the R^2 for the calibration set (47 watermelons) and validation set (18 watermelons) were 0.9655 and 0.9568, respectively. It means that this measurement system has practically enough accuracy for volume measurement. To evaluate the performance of calibration model, the predicted volume (the volume calculated by the liner model), the standard error (the difference between actual volume and predicted volume) and relative error (the standard error dividing actual volume) were calculated. As shown in Table 4, the results showed that 72.2% of the samples were found to have a relative error lower than 7%. However, the predicted values had great discrepancy with the actual values. There are two reasons may lead to this result: firstly, the fundamental equation should be revised specific to the watermelon measurement system. Secondly, the water filling method to measure the actual volume had artificial operation and judgment errors as well.

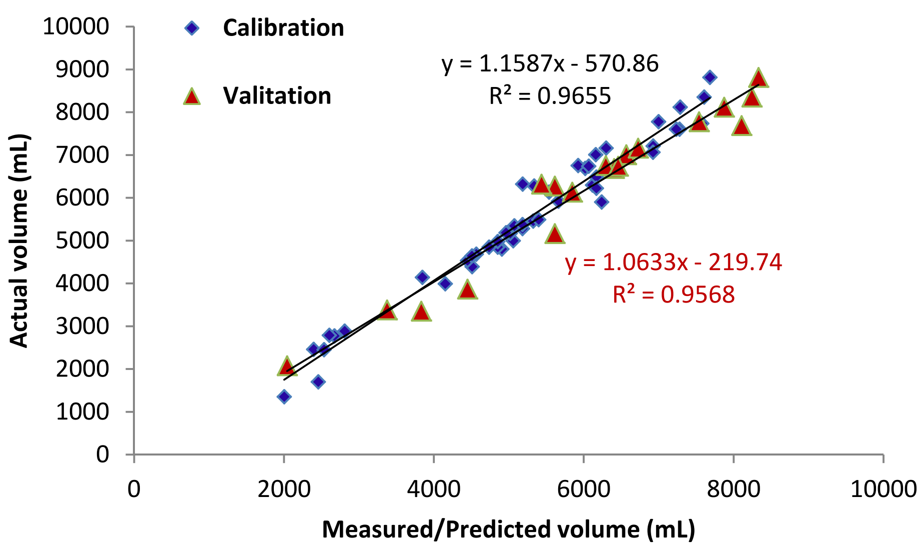

Fig. 6. Scatter plots of actual versus measured/predicted watermelon volume

Table 4. Prediction results for watermelon volume.

Sample number	Actual vol. (mL)	Predicted vol. (mL)	Standard error (mL)	Relative error
1	2076.68	2041.581	35.099	1.69%
2	3381.68	3375.080	6.600	0.20%
3	3869.68	4448.257	-578.577	-14.95%
4	3799.68	3831.945	-481.338	-14.37%
5	8813.68	8332.342	481.338	5.46%
6	8119.68	7873.171	246.509	3.04%
7	8354.68	8242.288	112.392	1.35%
8	7779.68	7538.069	241.611	3.11%
9	7689.68	8105.557	-415.877	-5.41%
10	7009.68	6566.986	442.694	6.32%
11	7159.68	6726.606	433.074	6.05%
12	6685.68	6404.886	280.794	4.20%
13	6754.68	6295.417	459.263	6.80%
14	6739.68	6459.198	280.482	4.16%
15	6134.68	5845.978	288.7019	4.71%
16	6275.68	5614.091	661.589	10.54%
17	6319.68	5436.928	882.752	13.97%
18	5165.68	5614.091	-448.411	-8.68%

Actual Vol -the volume detedted by water water-filling method
Predicted vol -the volume calculated by the liner model
Standard error -the difference bwtween Actual Vol and Predicted Vol
Relative error -the Standard error dividing Actual vol

Conclusion

The Helmholtz resonance technique was investigated to establish an effective method for measuring watermelon volume. The determination coefficients R^2 for the calibration and validation set were 0.9655 and 0.9568, respectively. A percentage of 72.2 of the samples were found to have a relative error lower than 7%. It was confirmed that the Helmholtz resonance was applicable in measuring volume of watermelon. In the further study, we should take temperature and sample position into consideration; also, we could further the study into density prediction and watermelon internal quality evaluation.

Acknowledgement

The authors gratefully acknowledge the financial support provided by the National 863 Project of China (No. 2012AA10A504).

References

Andaur, J.E., Guesalaga, A.R., Agosin, E.E., Guarini, M.W., Irarrázaval, P. 2004. Magnetic resonance imaging for nondestructive analysis of wine grapes. Journal of Agricultural and Food Chemistry. 52 (2): 165–170.

Blasco, J., Aleixos, N., Moltó, E. 2003. Machine vision system for automatic quality grading of fruit. Biosystems Engineering. 85 (4): 415-423.

De Waal, A. Mercer, S., Downing, B.J. 1988. On line fruit weighing using a 500 MHz waveguide chamber. IEEE Electronics Letters. 24 (4): 212–213.

Gall, H. 1997. A ring sensor system using a modified polar coordinate system to describe the shape of irregular objects. Measurement Science and Technology. 8(11), 1228–1235.

Hahn, F., Sanchez, S. 2000. Carrot volume evaluation using imaging algorithms. Journal of Agricultural Engineering Research. 75 (3): 243–249.

Hryniewicz, M., Sotome, I., Anthonis, J., Ramon, H., De Baerdemaeker, J. 2005. 3-D surface modeling with stereovision. In:

Hertog, M.L.A.T.M., Nicolaï, B.M., (Eds.), Proceedings of the 3rd International Symposium on Applications of Modeling as an Innovative Technology in the Agri-Food Chain; MODEL-IT 2005. ISHS Acta Horticulturae 674.

Jarimopas, B., Nunak, T., Nunak. N. 2005. Electronic device for measuring volume of selected fruit and vegetables. Postharvest Biology and Technology. 35(1): 25–31.

Kanali, C., Murase, H., Honami, N. 1998. Three-dimensional shape recognition using a charge-simulation method to process primary image features. Journal of Agricultural Engineering Research. 70 (2): 195–208.

Kato, K. 1997. Electrical density sorting and estimation of soluble solids content of watermelon. Journal of Agricultural Engineering Research. 67 (2): 161–170.

Ohnishi, K., Nishizu, T., Kondo,N., Goto, K., Maezawa, S., Nakano, K., Nakanishi, I. 2008. A consideration on afterripening management of kiwifruits based on relation between fruit density and sugar content. An ASABE Meeting Presentation, Paper Number:085226.

Mitchell, P.D. 1986. Pear fruit growth and the use of diameter to estimate fruit volume and weight. HortScience 21 (4): 1003–1005.

Moreda, G.P., Ortiz-Cañavate, J., García-Ramos, F.J., Ruiz-Altisent, M. 2007. Effect of orientation on the fruit on-line size determination performed by an optical ring sensor. Journal of Food Engineering. 81 (2): 388–398.

Moreda, G.P. 2004. Diseño y evaluación de un sistema para la determinación en línea del tamaño de frutas y hortalizas mediante la utilización de un anilloóptico. Ph. D. Dissertation. Universidad Politécnica de Madrid, Spain. (Design and assessment of a system for on-line size determination of fruits and vegetables, using an optical ring sensor).

Ngouajio, M., Kirk, W., Goldy, R. 2003. A simple model for rapid and nondestructive estimation of bell pepper fruit volume. HortScience. 38 (4): 509–511.

Nishizu, T., Ikeda, Y., Torikata, Y., Manmoto, S., Umehara, T., Mizukami. T. 2001. Automatic, continuous food volume measurement with a Helmholtz resonator. The CIGR Journal of Scientific Research and Development. Manuscript FP 01004. Vol. III.

Webster, E.S. 2010. The application of Helmholtz resonance to determination of the volume of solids, liquids and particulate matter. Ph. D. Dissertation. Massey University, Palmerston North New Zealand.