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# Non-destructive prediction of apple firmness during storage based on dynamic speckle patterns

**B. Jamshidi[1*]- A. Arefi[2]- S. Minaei[3]**

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## Introduction

In recent years, the determination of firmness as an important quality attribute of apple fruits has been widely noticed. Common methods for firmness measurement are destructive and cannot be applied in sorting lines. Therefore, development of a non-destructive, simple, fast, and the low-cost determination technique of firmness is imperative. Dynamic speckle patterns (DSP) or bio speckle imaging as a new optical technique has been recently noticed for non-destructive quality assessment of food and agricultural products. In this research, the feasibility of using this technique was investigated for non-destructive prediction of firmness in intact apples during five months of cold storage.

## Materials and Methods

During the harvest season, in 2013, a total of 540 'Red Delicious' apples were obtained from a local orchard in Oshnaviyeh, Iran. The apples with similar color and shape were collected from several trees in the same place. The samples were stored under cold conditions for five months. Five experiments were carried out; the first experiment was done immediately after harvesting and other tests were performed during storage time, i.e. 30, 60, 120, and 150 days after harvesting date. In each experiment, the samples were illuminated by two laser diodes at the wavelengths of 680 nm and 780 nm, separately. DSP images of each fruit were acquired using a CCD camera. Then, time history of the speckle pattern (THSP) was created for each sample. After taking images, reference measurements were carried out for each sample to determine its firmness. Quantification of DSP activity was done using the statistical features of inertia moment (IM) and the absolute value of differences (AVD) extracted from the THSP images. Moreover, features of the images were extracted based on texture and wavelet transform. Finally, artificial neural network (ANN) models were developed for prediction of apple firmness based on image's information obtained from the wavelengths of 680 nm and 780 nm, and the reference measurements. The 60, 15, and 25 percent of total samples were randomly used for calibration, cross-validation, and test validation sets, respectively. The correlation coefficient between measured and predicted values of the firmness and also the standard error of prediction (SEP) were calculated to compare the performance of the different ANN models.

## Results and Discussion

After one month of the storage, apples lost about 15 percent of their initial firmness.The softening process continued and the firmness index dropped to 48.05 N (a total decrease of 42%). A significant difference was observed among the mean values of the firmness belong to the different storage times. In first and second months of the storage, a negative linear relationship was observed between DSP activity and the firmness. The lowest value of IM was observed for apples belonged to the harvesting date. DSP activity suddenly increased after 30 days of the storage. This ascending trend continued and reached to its maximum value on the 60th days of the storage. It was noted that DSP activity is significantly affected by the chlorophyll absorption during this period. Moreover, DSP activity at the wavelength of 680 nm was more than that at 780 nm. After two months of the storage, a significant decrease in DSP activity was observed for both wavelengths of 680 nm and 780 nm. The main reason for this phenomenon came back to changes in carbohydrates. During this ripping period, starch,

1- Assistant Professor, Agricultural Engineering Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran
2- Ph.D. Graduated Student, Mechanics of Biosystems Department, Urmia University, Urmia, Iran
3- Associate Professor, Mechanics of Biosystems Department, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran
(*- Corresponding Author Email: b.jamshidi@areeo.ac.ir)

which plays a main role in backscattering phenomenon is converted into simpler carbohydrates and it causes an increase in soluble solid contents and a decrease in the number of scattering centers. After developing the ANN models, the correlation coefficient of the prediction ($r_p$) for different topologies was ranged from 0.74-0.81 and 0.81-0.83 for the wavelengths of 680 nm and 780 nm, respectively. Moreover, standard error of prediction (SEP) was between 8.4-9 N and 8.1-8.7 N for the wavelengths of 680 nm and 780 nm, respectively. The achieved results may be more attractive when they are compared with obtained results using multispectral/hyperspectral scattering imaging, as expensive and rather complicate techniques for non-destructive firmness assessment in apple fruits.

## Conclusions

It was concluded that dynamic speckle patterns (DSP) or bio speckle imaging could be a simple, low-cost and appropriate technique for non-destructive prediction of firmness in intact apples during storage.

**Keywords:** Bio speckle imaging, Dynamic speckle patterns, Laser, Non-destructive, Wavelet