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Numerical Processing Techniques for the Detection and Analysis of Biospeckle Activity

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***Abstract*—Conservation of cultivated fruits is a crucial concern in industry due to its physical damages during preservation and transportation. This paper reports a non-invasive, low cost and real time method termed laser biospeckle technique for supervising mechanical damages in horticultural specimens. The formation of biospeckle is based on the optical phenomenon of interference generated by a coherent light while interacting with biological material or dynamic systems. The present study considers fruits as a scattering media producing time varying speckle fluctuations in the imaging field due to its underlying biological progressions. Temporal biospeckle frames are developed by illuminating artificially damaged fruit sample with low power He-Ne laser, recorded by means of CMOS camera with a pixel size of 220µm and saved in computer as digital images. The present work employs three numerical processing methods namely inertia moment, spatial–temporal speckle correlation and generalized differences to extract data from biospeckle images.**

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***Index Terms*—Biospeckle activity, Generalized Difference,horticulture,Inertia Moment, Spatial and temporal speckle correlation.**

I. INTRODUCTION

Fruits and vegetables can be easily damaged in harvest and post-harvest period due to their poor handling. These impairments that occur all through preprocessing, transportation, storage, and packing can affect the quality of the fruits as well as their market price. Damages may be splits, punctures or bruises subject to the physico-mechanical properties of fruits. Fruits once damaged decay rapidly as a result of the degradation of tissue, intra-cellular water extraction, oxidation of phenolic compounds etc. The quality of fruits and vegetables expires with time since it is a biological organism where many chemical and physical processes occur constantly [1]. Nowadays non-destructive investigation techniques have been of great importance in the evaluation of fruits and vegetables based on the assessment of their physical, mechanical and optical properties. Optical methods have been playing an essential role in this field due to miniaturization, portability, robustness, low cost and high accuracy of their device construction. Laser biospeckle method is considered to be an emerging optical technique for non-destructive measurement of fruits and vegetables. When an optically rough surface of a sample is illuminated with a coherent laser light, the scattered waves from the surface interferes and forms a statistical interference pattern called speckles [2]. The speckle pattern developed from a biologically active specimen is termed as bio-speckle pattern or dynamic speckle pattern [3]. Dynamic speckle is a totally complicated phenomena and it occurs due to the underlying biological as well as physical activity of bio samples. The mentioned biological progressions mainly associate with cytoplasmic streaming, organelle movement, cell growth and division, while the physical processes include diffusion and Brownian motion [4]. Some recent studies have been revealed that biological process is predominant for biospeckle activity of the fruits [5]. The study of the temporary evolution of the bio speckle patterns can be carried out using numerical and graphical approaches. Numerical analysis methods include Inertia Moment [6, 7], Absolute Values of Difference [8, 9] etc. whereas methods such as Generalized Difference [10] and Fujii method [11] give the activity maps of biological activity.

In the present context, apple and orange fruit samples are examined before and after inflicting bruising mechanical damages. Fruits are illuminated with a low power He-Ne laser and the scattered light is recorded using CMOS camera. The temporal biospeckle patterns thus grabbed are processed using various statistical as well as image processing techniques to study the effects of mechanical impacts on fruits. Local disturbances produced on the surface immediately after the damage gives increased activity and falls below the normal values after a few days. The settling time of increased local activity can be calculated from cross correlation measurements. Inertia moment of co-occurrence matrix also shows gradual decrease of high activity in the bruised region and low activity in the non-bruised region. In order to understand the spatial distribution of activity few days after the damage, generalized difference methods is applied.

II. THEORY OF BIOSPECKLE PROCESSING

The following sub-sections briefly describe the method employed for the numerical analysis of biospeckle activity.

A. *Moment of Inertia of co-occurrence matrix*

This three-step method contains the formation of time history of speckle pattern (THSP), generation of co-occurrence matrix and the computation of inertia moment. The study of temporal evolution of dynamic speckle phenomenon using Inertia Moment was first proposed byOulamara. In this method, 512 sequential images of the biospeckle pattern and with a pixel resolution of 512 × 512 are grabbed initially using a digital camera. A specific

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column (for example, the middle column) is selected from each of them a new image is then made by arranging them vertically side by side, the chosen column extracted from the successive patterns. The resultant 512 ×512 composite image thus constructed is called the Time History of the Speckle Pattern (THSP). Its rows represent different points on the illuminated sample and the columns their intensity in every sampled instant. In THSP, the evolution of the sample appears as intensity fluctuations in the horizontal direction. For low activity where time variations of the speckle patterns are slow THSP shows horizontally elongated shapes and for high activity it looks like ordinary speckle pattern, as the horizontal intensity variations are fast. The THSP images are further analyzed using the inertia moment (IM) of co-occurrence matrix which expresses the number of the transitions of each THSP pixel with respect to its immediate neighbor. In biospeckle analysis, co-occurrence matrix formation is regarded as an intermediary step to obtain the Inertia Moment (IM) of a sample. Statistically the co-occurrence matrix (M_{co}) is expressed by the equation (1)

$$M_{co} = \lfloor N_{ij} \rfloor \tag{1}$$

where, N_{ij} denotes the number of occurrences of an intensity value i, followed by an intensity value j to move through rows or columns of the time history .Horizontal lines without intensity variations indicates the absence of activity and the equivalent co-occurrence matrix has only diagonal entries. For higher activity the M_{co} entries appears to be spread around diagonal and the extent of spreading been taken as the measure of the activity.

To get quantitative measurement from this matrix, it is essential to normalize it. This is achieved by dividing each row of this matrix by the number of times that the first grey level appeared. The summation of the components in each row then equals to 1.

Normalized M_{co} is expressed as

$$M = \frac{N_{ij}}{\sum_j N_{ij}} \tag{2}$$

Quantitative measurement of the spread of Mco is called Inertia Moment (IM). It is measured as the sum of the product of the pixel value of Mco and square of its distance from the principal diagonal.

$$MI = \sum_{ij} (M - I)^2 \tag{3}$$

The diagonal entries do not contribute to MI and the entries far away from the diagonal heavily contribute as it is multiplied by the square of the diagonal distance. Hence the measure of MI represents the activity of the biospeckle.

B. 2D cross correlation

Two dimensional cross correlation is a tool to estimate the degree of correlation between images. The method has several advantages over the inertia moment technique. It ispossible to get fast and continuous correlation data over a short interval of time.To assess the degree of correlation between the extracted images of the same size, 2D cross correlation has done over the images.

Cross correlation coefficient C is computed as

$$C = \frac{\sum_m \sum_n \left(A_{mn} - \bar{A}\right)\left(B_{mn} - \bar{B}\right)}{\sqrt{\left(\left(\sum_m \sum_n \left(A_{mn} - \bar{A}\right)^2\right)\left(\sum_m \sum_n \left(B_{mn} - \bar{B}\right)^2\right)\right)}} \tag{4}$$

Where A, $\bar{A}$, B and $\bar{B}$ represents image matrices and their corresponding mean values. For zero activity the cross correlation gives maximum correlation between images and for high activity, correlation value approaches zero.

C. Generalized Difference

Generalized difference methods are employed when the spatial distribution of activity is not uniform over the sample surface. In the activity image obtained, inactive regions appear dark and active regions appear comparatively bright.

$$I_{i,j} = \sum_k \sum_l \left| I_k(i,j) - I_{k+l}(i,j) \right| \tag{5}$$

Where k and l are indices spanning all the possible numbers of the registered images. All possible differences between all the different frames are added in absolute value for each point in the image, thus comparing all the images of all available time scales.

III. EXPERIMENTAL DETAILS

The experimental setup for the evaluation of biospeckle assessment is presented in the fig 1. The setup makes use of a He-Ne laser (18mW), a neutral density filter, a spatial filter assembly, CMOS camera and a Desktop computer.

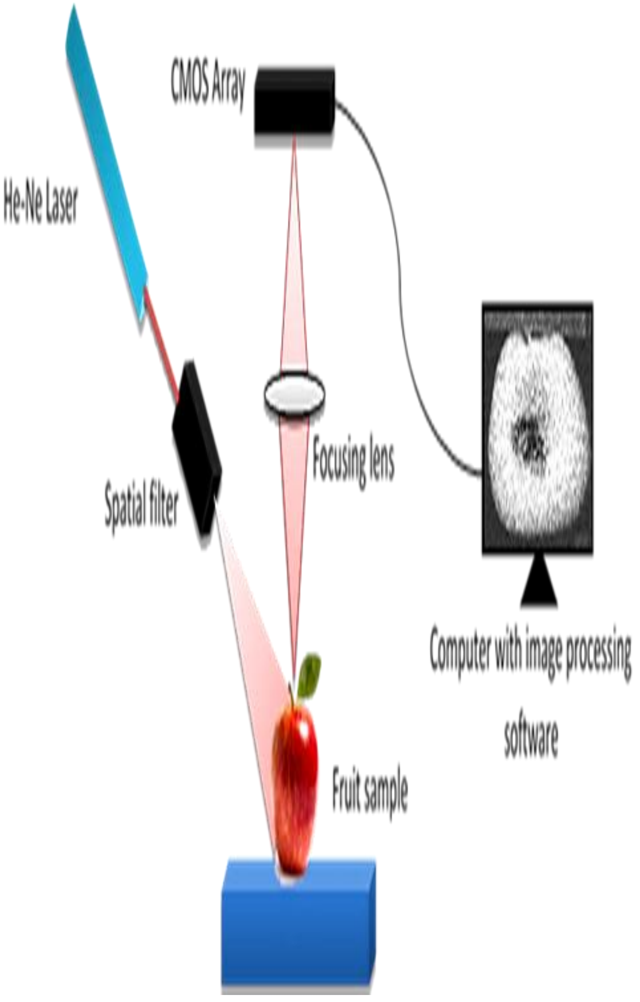

Fig 1

Biospeckle experimental setup

The spatial filter assembly is primarily encompasses a microscope objective lens and pinhole. It has three majorfunctions. The first function is to diverge the laser beam since microscope objective used is usually a double concave lens, the second is to eliminate noise on the patterns caused by the dust and scratches on the optics and the last function is to partially annihilate internal noise created in the laser cavity that travels along with the beam. The expanded and filtered laser beam emitted by the spatial filter assembly is utilized to illuminate the specimens and illumination intensity is kept constant throughout the measurements. Biospeckle images of size 512 ×512 are grabbed by using a CMOS array and a focusing lens arrangement. Then, the images are digitized and saved as files in a host computer with data acquisition software developed in MATLAB.

The apple fruit sample is mechanically bruised by applying pressure and its biospeckle pattern evolution are registered for a few minutes after the impact. The biospeckle signal activity of fruit sample is then studied using IM (Inertia Moment).The effects of damage after a few days later are observed as an activity map obtained through generalized difference method. The orange fruit sample is damaged by hitting with two mallets of different size in three different forces. The patterns of this specimen are analyzed by cross correlation method. Mechanical loading effects are also studied by applying three different loads on the orange.

IV. RESULTS AND DISCUSSIONS

Biospeckle patterns of the bruised and non-bruised areas of the apple are registered after a few minutes of impact. The temporal speckle evolutions are found to increase rapidly due to the disturbance in the cellular system and settled down slowly with time. The patterns are then processed to get THSP, co-occurrence matrix and Inertia moment. On visualizing THSP image thus created from bruised area compared to non- bruised one shows slightly greater speckled appearance in comparison with that of the non-bruised areas, clearly indicating increased biospeckle activity (fig 2). The corresponding co-occurrence matrix of the bruised area shown in fig 3 reveals more spread from the diagonal than that of the non-bruised area. The plot of Inertia moments depicted in fig 4 (b), clearly distinguishes between bruised and non-bruised zones quantitatively. Bruised area inertia moments gradually decreases to non-bruised moment values after few minutes, depending on the intensity of damage. The activity image of the bruised apple after a few days, obtained from generalized difference method is depicted in fig 4 (a). The bruised area is dark indicating very low activity due to dead cells and reduced bio-activity. The cross correlation plot of orange fruit sample impacted by a small mallet in three different forces is shown in fig 5 (a). The disturbance settling time has found to increase with increase in force of impact. Similar behavior obtained for the impacts of large mallet, but the settling time is more as the area of impact is more (Fig 5(b)).

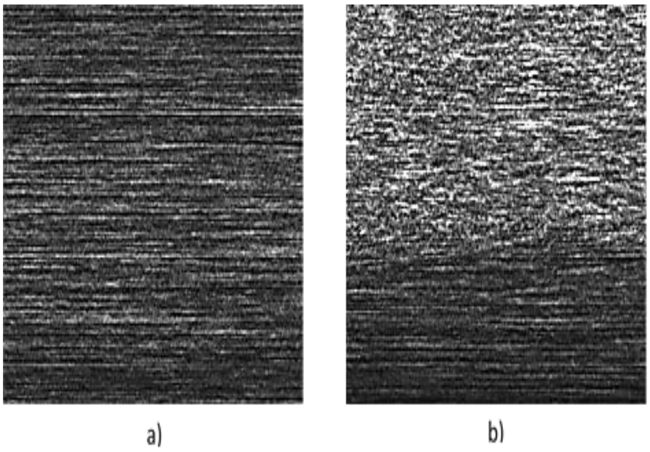

Fig 2
THSP images of a) non-bruised area and b) bruised area

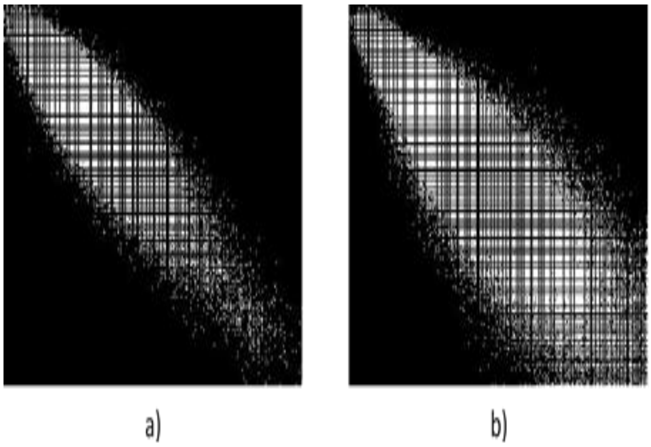

Fig 3
Co-occurrence matrix of a) non-bruised area and b) bruised area

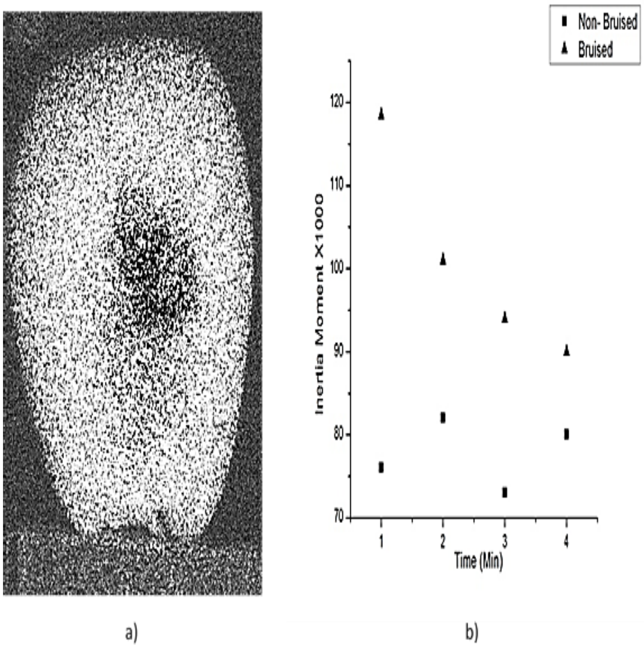

Fig 4

a) Activity image of bruised apple after a few days, obtained from generalized difference b) Inertia moment of bruised and non-bruised region of apple immediately after impact

For the big mallet impact the disturbance spread on the fruit surface is clearly visible in the graph as a decrease in correlation immediately after the impact. Three different mechanical loads are applied to the orange sample and the correlation change is depicted in fig 5(c).

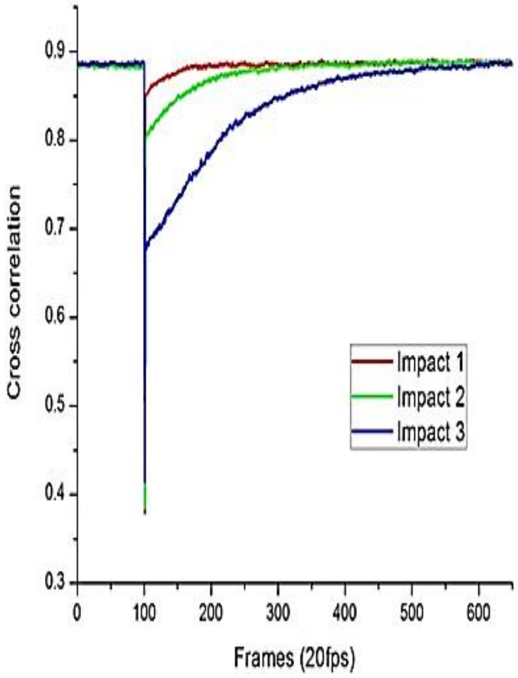

Fig 5(a)
Cross correlation measure of the orange immediately after small mallet impact

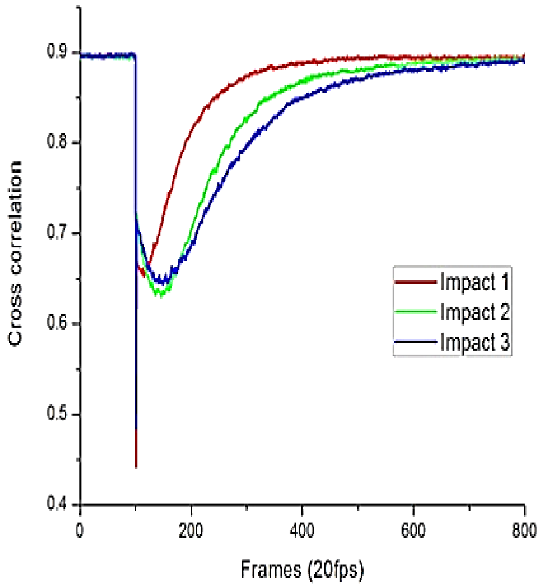

Fig 5(b)
Cross correlation measure of the orange immediately after large mallet impact

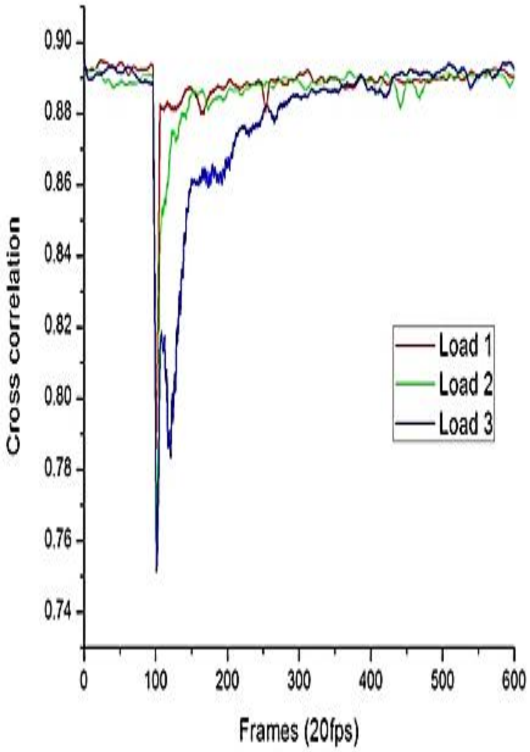

Fig 5(c)
Cross correlation measure of the orange immediately after loading impact

The graph shows impulsive reduction in correlation due to instantaneous increase of speckle activity and then gradually reduces to normal value.

V. CONCLUSION

Different types of mechanical damages in orange and apple has been studied using biospeckle technique with the help of statistical and image processing methods. Damaged areas can be identified from both inertia moment value and activity image of generalized difference. Cross correlation is also a useful method especially for continuous data plotting. All these methods with further improvements can be beneficial for farmers and fruit sellers to assure the quality of fruits by properly monitoring physical damages.

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