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Nondestructive Firmness Detection in Agricultural Products by Power Spectrum Analysis of the Impact Force

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Introduction

Most varieties of agricultural products have nonunifom quality and nonuniform maturity at harvest. This quality difference may influence the consumer acceptance of the product. Thus postharvest quality sorting is required to supply reliable and uniform quality in the market place.

One of the product properties which could be used as a basis for nondestructive quality sorting is a firmness, because firmness is related to maturity and internal quality. For example, firmness of Sakurajima radish decreases as it has turns pithy, and firmness of pumpkin increases gradually as it becomes more matured. Thus, firmness can be used as a criterion for discriminating internal quality of Sakurajima radish and also for sorting pumpkins with different maturities.

At present, no commercial equipment exists for carrying out the nondestructive firmness sorting of large products such as pumpkins and Sakurajima radishes. However, the potentials for firmness sensing techniques have been investigated in the past for other products. Finney[6,7] studied and developed nondestructive techniques for evaluating the firmness of intact apples and peaches. He found that apples subjected to vibrational excitations displayed a series of resonant frequencies and that the second resonant frequency was associated with flexural vibrations, being strongly influenced by fruit size and firmness. He showed that fruit firmness was highly correlated with a stiffness coefficient, f^2m, Where f and m were the second resonant frequency and mass of the the fruit, respectively. An application of this technique to blueberry was made by Bower et al[2]. Yamamoto et al[12] developed a nondestructive technique for measuring textural quality of apples and watermelons based on the acoustic response They showed that the natural frequencies and firmness indices, expressed as functions of the natural frequency, mass, and density of the fruit, were significantly correlated with the fruit firmness. Further study using the pure compression model of vibration of an elastic sphere model was made by Armstrong et al[1].

Besides, Perry[10] developed a nondestructive firmness testing unit simultaneously applying low pressure air to small areas on opposite sides of peaches, to generate a non-bruising maturity indicating deformation. Mehlschau et al[9] developed a "deformmeter for nondestructive maturing detection for pears, based on the measurement of deformation derived from pressing two steel balls against the opposite sides of the fruit with a fixed force. Takao[11] developed HIT measurement apparatus for carrying out the nondestructive detecting of agricultural products.

These above mentioned methods could be used to indicate firmness for distinguishing immature and over mature fruits from those on the threshold of maturing. But the application of these techniques to an automatic sorting system was limited by the need for complicated fruit handling or the coupling of surface transducer. In addition, these techniques were not suitable for continuous operation.

Delwiche et ali[3-5], therefore, investigated the potential for using the impact force response as a method for firmness detection. Fruits were conveyed horizontally by belt at a fixed speed and were allowed to impact on a rigid surface at the belt discharge. Based on a shape analysis of the impact force curves, the fruits were separated into three firmness classes as they were rolling down along an inclined surface. Imou et al[8] analysed the impact forces of kiwifruit striking a rigid surface and found the fact that the firmness index obtained from the impact force and the other measurements were highly correlated with the firmness value measured by HIT-counter. These methods could be used to indicate firmness for small sized circular fruits but not for large size and nonglobular-shaped agricultural products such as pumpkins and Sakurajima radishes.

In this research, a firmness sorting method of impulse hammer type free from any limitation and orientation was proposed and the firmness index not depending on the impact velocity and mass of fruits was investigated.

Materials and Methods

1. Materials

Sakurajima radishes were harvested from the area of Sakurajima, Kagoshima Prefecture Japan. And pumpkins were harvested from the area of Kaseda Town, Kagoshima prefecture, Japan. After harvesting, the basic physical properties, such as mass, density, firmness, moisture contents, and impact force responses were measured immediately. Density was calculated by dividing the mass by the volume sample. Flesh firmness was destructively measured, using hand penetrometer with a circular cone of 12mm base diameter and 10mm length (MIKIYA KMH-51). And moisture contents of the radishes were measured, weighing the slices of samples by 100℃-24 hours method.

2. Apparatus and Methods

Schematic diagram for the experimental apparatus is shown in Fig 1. Pendulum device was used in the striking part of the experimental apparatus. Striking velocity could be changed by chaining the falling angle of the pendulum. The striker was made of a rigid sphere hammer ($R=7$mm). And force transducer (RION PH-51) was mounted in the striking sphere hammer. The leg length of pendulum was 35 cm and its total mass was 205g. THe fulcrum of the pendulum could be easily changed up and down so that it was very easy to make the striker tap on the point of equator of each sample.

Samples were kept on the flat plate of pendulum device and the pendulum with a hammer was allowed to tap on the point of equator of the samples from its predefind angle. The impact signals were measured by force transducer held in pendulum. The transducer output was amplified through charge amplifier (RION NM-27) and was routed first to a FFT analyzer (ONO SOKKI CF-920S) and then to a microcomputer (NEC PC-9801). The FFT analyzer contained an AD converter capable of running at high speed. It also stored the resulting data in the internal memory and processed the data into a format usable for the computer.

3. Power spectrum analysis of the impact forces

The frequency spectrum of a non-periodic impact signal can be obtained from the time-frequency domain relationships expressed by the Fourier transform.

$$F(j\omega)=\int_{-\infty}^{\infty} f(t)e^{-j\omega t}\,dt \qquad (1)$$

Concerning arbitrary signals, for example an impact signal, this Fourier transform can be calculated most effectively by a fast Fourier transform algorithm. These algorithm are disposed by FFT analyzer. The transformation of the impact force sequence f(n) is given by

$$F(k)=\sum_{n=0}^{N-1} f(n)e^{-j2\pi kn/N} \qquad (2)$$

where

F(k) is the transformed force,

N is the length of the imput sequence,

n is the time index,

k is the frequency index.

From the above mentioned expression, it was ascertained that the impact signal was expressed with amplitudes at a series of frequencies. The amplitudes at various frequencies of power spectrum were used to determine the firmness of kiwifruit[4] But the amplitudes were sensitive to the impact velocity. In order to reduce affect of impact velocity, the following ratios of the amplitudes at the various frequencies in the power spectrum produced by the FFT analyzer were considered to be the criteria for determining the firmness of fruits.

$$C_{(k+1/k)}=\frac{F_{(k+1)}}{F_{(k)}} \qquad (3)$$

where k=0,50,100,···,450.

The relationships between there characteristics $C_{(k+1/k)}$ and fruit parameters (flesh firmness, density, mass, moisture contents) were discussed.

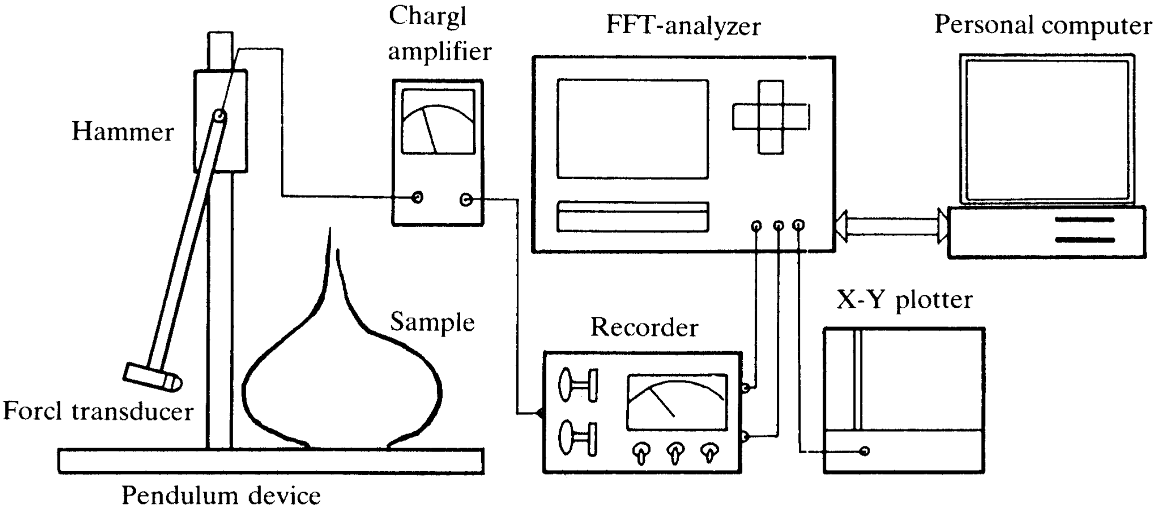

Fig. 1. Schematic diagram for experimental measurements

Results and Discussion

1. Power spectrum for different firmnesses in radish

The power spectra of the impact force of two Sakurajima radishes with low and high firmnesses are shown in Fig.2. where, the falling angle of the pendulum was fixed at 20 degrees, and the sampling interval, 0.039ms ; and a sequence length, 1024, giving a frequency increment of 25Hz respectively.

It could be seen that the amplitude of the power spectra of the impact force decreased in the 500Hz range, and that hard radish contained high frequency components less attenuated than those of soft fruits. Thus, the power spectrum of the impact force was one of the possible criteria for determining the firmness of Sakurajima radishes. If the affect of impact velocity on the power spectrum could be reduced, then the power spectrum of the impact force might be used for detecting firmness of radish.

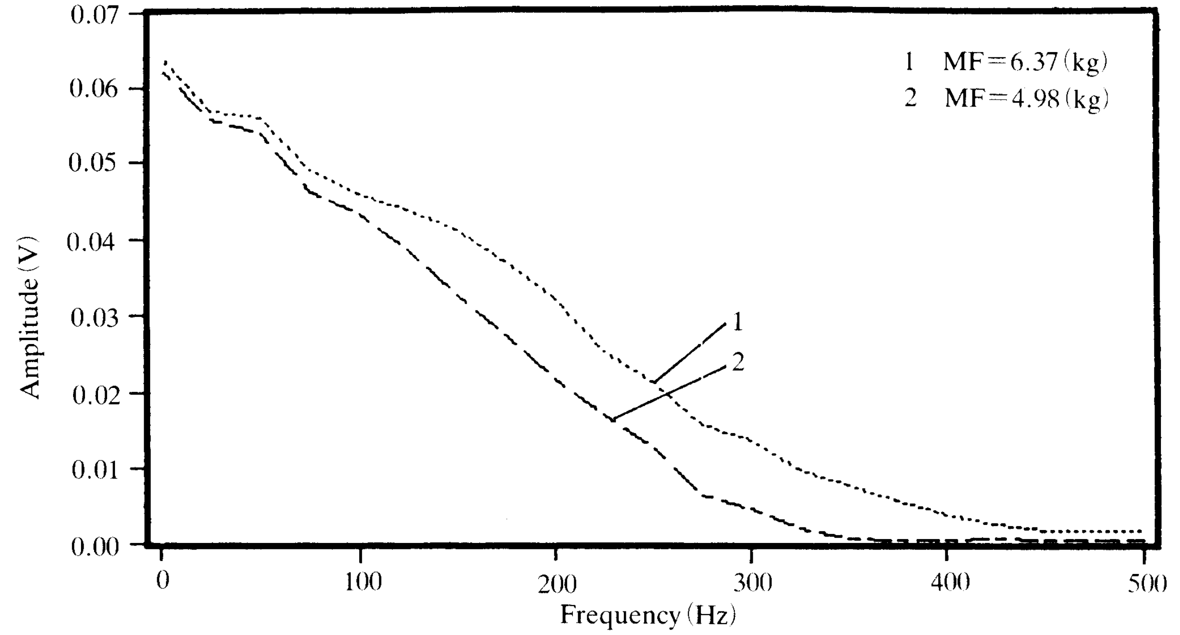

Fig. 2. Power spectra of impact signals for hard and soft Sakurajima radishes

2. Influence of the impact force

By changing the falling angle of the pendulum, the effect of the impact speed of hammer at contact on the ratio $C_{(300/250)}$ for Sakurajima radishes with different firmness is obtained as shown in Fig.3. It showed that the ratio $C_{(300/250)}$ of hard radish had higher value than that of the softer radish in all the falling angles of the pendulum. And the ratios increased when the falling angle of the pendulum increased from 5 degree to 15 degree. But in the regions between 15 degree and 30 degree, the ratio tended to remain constant.

Using the same method, the same results could be obtained for the other characteristics $C_{(k+1/k)}$. And these patterns have been noted to be consistent over a number of trials. Therefore, the results showed that there was no influence of the falling angle of the pendulum from 15 degrees to 30 degree on the ratio $C_{(300/250)}$.

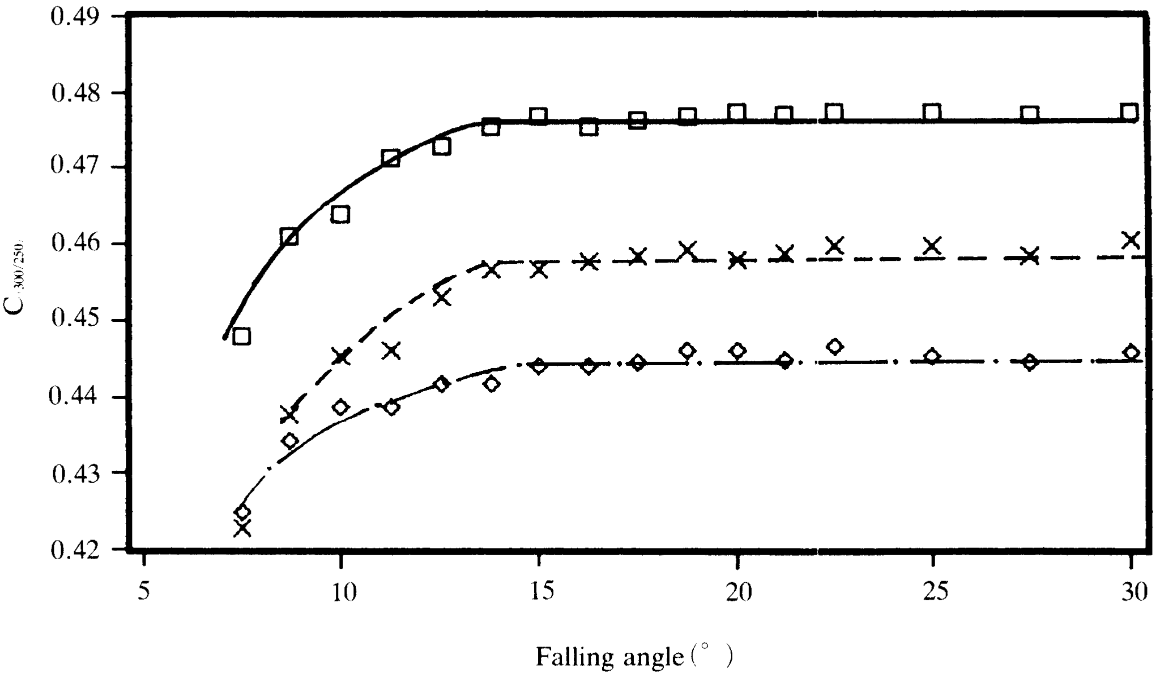

Fig. 3. Relationship between falling angles and the characteristics $C_{(300/250)}$ for three Sakurajima radishes with different firmnesses
□ MF=5.52(kg) × MF=5.41(kg) ◇ MF=5.35(kg)

3. Determination of firmness

Using ninety-four Sakurajima radishes, many measures were taken from the power spectra in order to relate them to the sample's properties. They included the ratios of the force magnitudes at 0,50,100,150,200,250,300,350,400 and 450Hz. A correlation matrix of the measures and the sample's properties are show in Table 1. The sample's firmness affected the ratio of the force magnitudes at various frequencies. And there was an excellent correlation between the ratio $C_{(300/250)}$ and the firmness, giving the correlation coefficient of 0.88. Besides, the sample's density also affects the ratio. A relatively high correlation coefficient between the ratio $C_{(300/250)}$ and the densities of samples.

The mass also affected the ratio, but the variation of the ratio with the mass of samples was indistinct. And hence, there was small affect of the sample's mass on the ratio of the force magnitudes at various frequencies.

A very poor correlationships of all ratios and the moisture contents of samples were shown in Table 1.And the moisture contents hardly affect the ratios.

There results given in Table 1 showed that the ratio $C_{(300/250)}$ was a suitable criterion for determining the firmness of those products, while it was a relatively suitable criterion for predicting the density of those products.

4. Determination of pumpkin's firmness

By the same method, the characteristic $C_{(300/250)}$ for pumpkins was obtained and a plot of the flesh firmness estimated by using the characteristic $C_{(300/250)}$, against the flesh firmness measured with a penetrometer, is shown in Fig.4. Comparison of the firmness values obtained by the characteristic $C_{(300/250)}$ and penetrometer showed that the two methods gave extremely close results, which showed that the method using make of the characteristic $C_{(300/250)}$ seemed to be also suitable for determining firmness of pumpkin.

Table 1 Matrix of correlation coefficients between Sakurajima radish's properties and the impact force characteristics

Ratio of amplitudes	Firmness	density	Mass	Moisture content
F(50/0)	−0.153	−0.011	0.315	0.001
F(100/50)	0.018	0.250	0.211	−0.022
F(150/100)	0.531	0.251	−0.367	−0.049
F(200/150)	0.672	0.590	−0.076	−0.032
F(250/200)	0.772	0.701	−0.160	−0.062
F(300/250)	0.886	0.692	−0.132	−0.028
F(350/300)	0.721	0.650	−0.109	−0.060
F(400/350)	0.599	0.642	−0.263	−0.012
F(450/400)	0.553	0.583	−0.149	−0.003

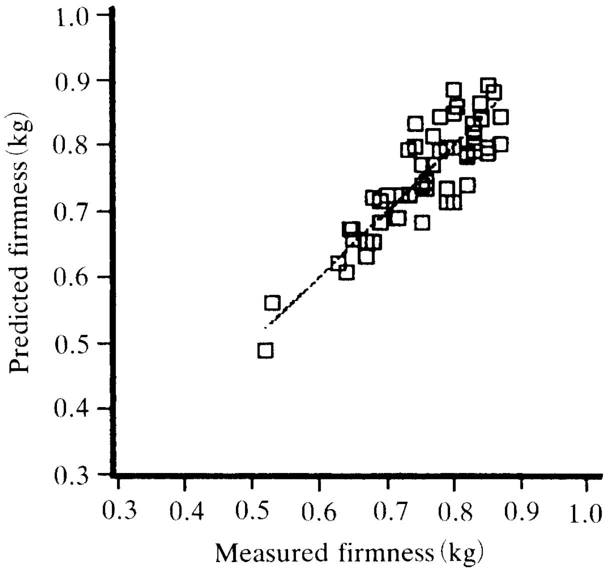

Fig. 4. Comparison of pumpkin's firmness predicted by the characteristics $C_{(300/250)}$ and those obtained by the penetrometer measurement.

Summary

In this research, power spectrum analysis of an impact force of samples was investigated as a possible means for a rapid firmness detection. The relationships of the sample's firmnesses and the ratios of the force magnitudes at the various frequencies were discussed, and new reliable criterion that was sensitive to firmness of samples but not sensitive to the variability in impact velocity was produced.

1).Higher frequency components were present while the sample was hard.

2).There were positive and negative correlation coefficients between the amplitudes at various frequencies in the power spectrum and the following items: firmness, density, mass, moisture contents.

3).There was little affect of the sample's mass and moisture contents on the ratio of the force magnitudes at various frequencies.

4).It was found that the index $F_{(300/250)}$ was a suitable criterion for determining firmness of

Sakurajima radishes and pumpkins, because it was highly correlated with penetrometer measurements of firmness and density of the samples, and of the independence of the impact force on impact velocity.

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