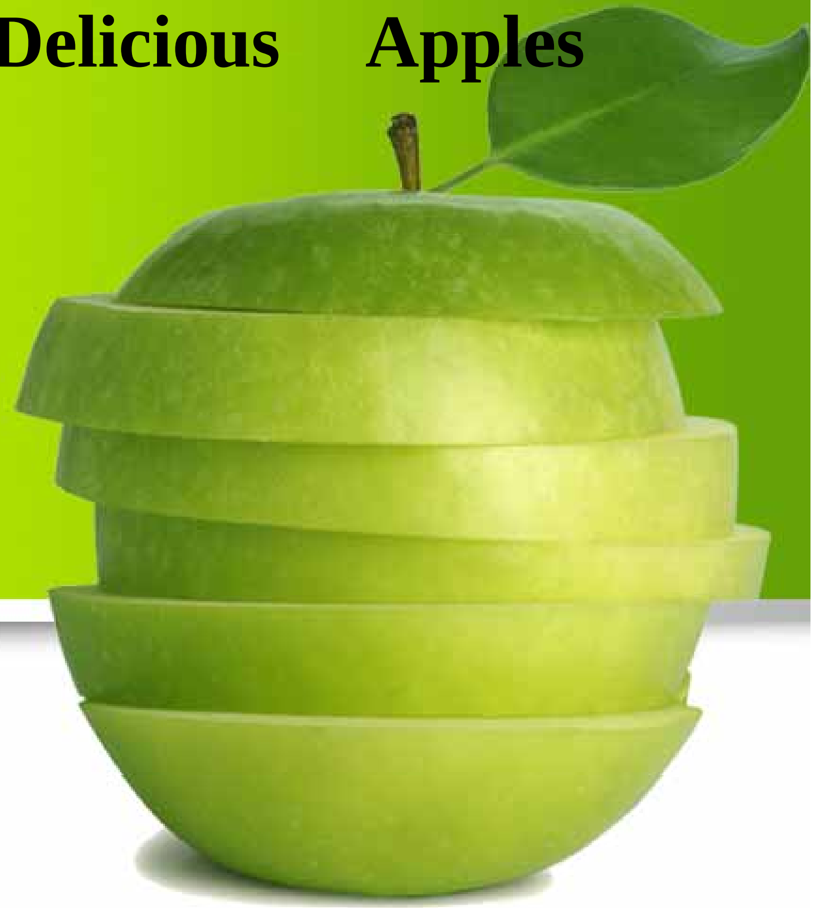
Department of Biomechatronic Engineering
National Ilan University, Taiwan

Automated Detection of Mechanically Induced Bruise Areas in Golden Delicious Apples Using Fluorescence Imagery

Yi-Chich Chiu Mu-Te Chen
Xing-Liang Chou Tony E. Grift



Introduction

The fruit will sustain certain mechanical injuries during marketing processes.

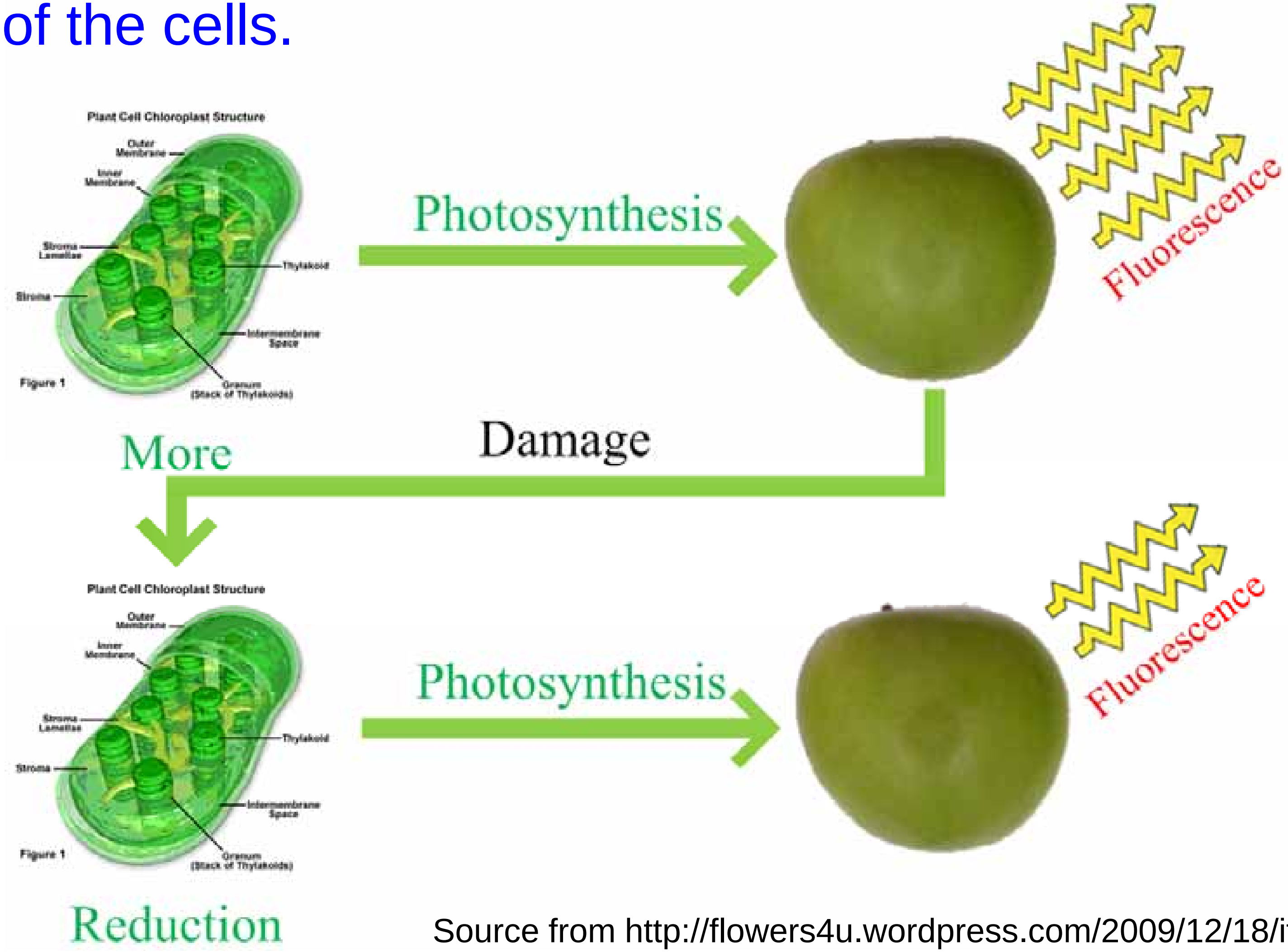
Fruit tissues, which contain large amounts of chlorophyll, are susceptible to damage from mechanical impact.

These injuries may induce bruises and cause quality degradation.

Photos from
http://www.alfalahimpex.net/products.html
http://www.goodfruit.com/Good-Fruit-Grower/October-2007/Why-apples-bruise/
http://www.teara.govt.nz/en/farming-in-the-economy/9/1/2
http://blog.xuite.net/erichu1014/catdad/20082230

Introduction (Cond.)

This mechanical impact damage has an effect on photosynthetic activity, which in turn reduces the fluorescence of the cells.



The reduced fluorescence can be detected using machine vision, which allows for removal of the damaged fruits in an automated fashion.

Source from http://flowers4u.wordpress.com/2009/12/18/its-complicated-being-green/

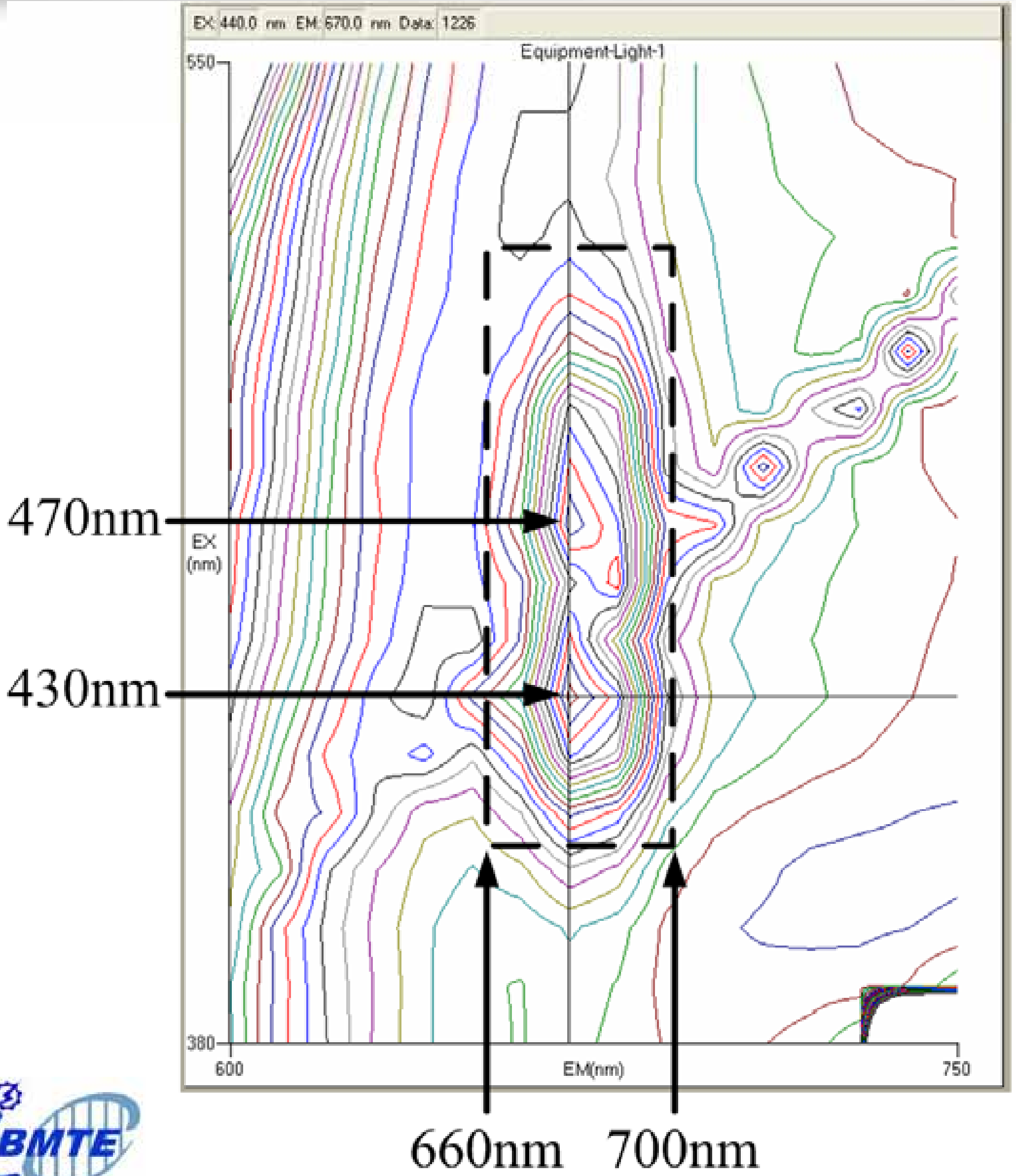
Objectives

- Develop a method allowing precise impacts on apples to produce the bruise
- Use chlorophyll fluorescence images for the automatic detection of fruit bruise areas in Golden Delicious apples
- To design an on-line, non-destructive apple bruise inspection system

Materials and Methods

- Using the 3D Scan spectrum function of fluorescence spectrophotometer (Hitachi, F4500), to analyze of fluorescence spectrum performance of Golden Delicious apples.

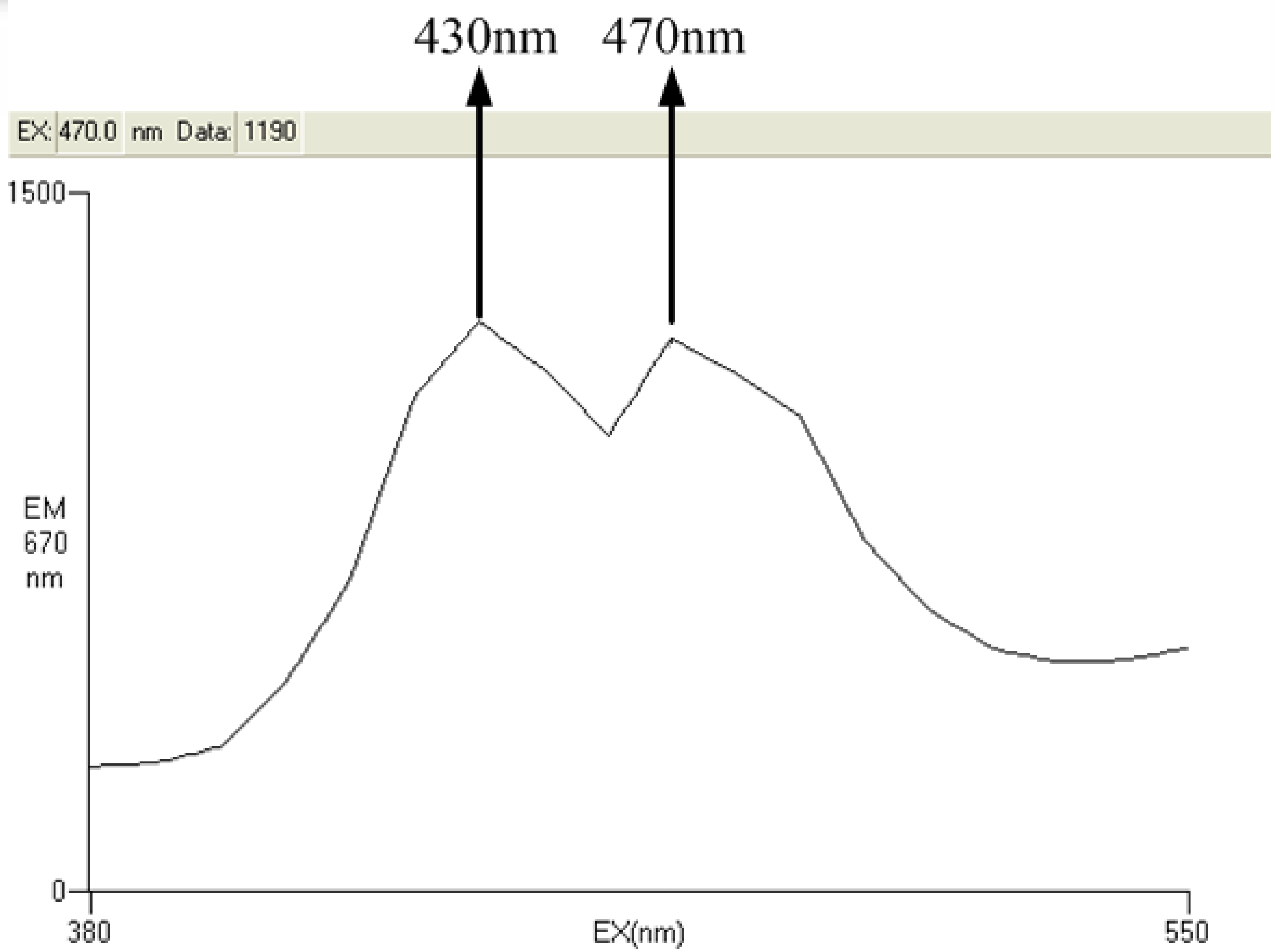
Materials and Methods (Cond.)



Fluorescent characteristic spectrum of chlorophyll

The excited spectrum region has strong fluorescence emission spectrum at about 430nm and 470nm, the emission spectrum is at 660nm~ 700nm. There is a large fluorescence release amount at about 670 nm.

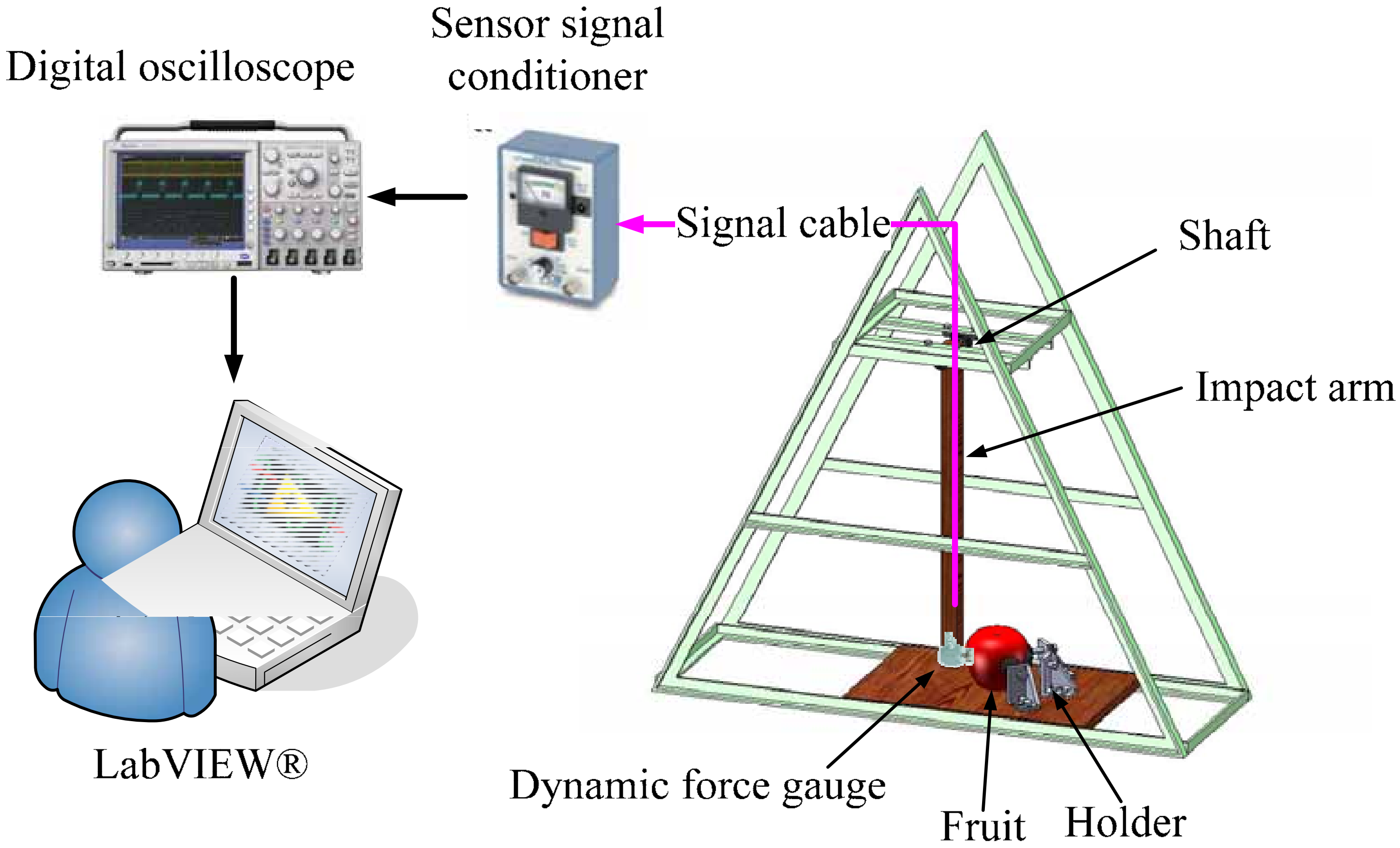
Materials and Methods (Cond.)



The 670nm emission spectrum intensity of apple in 380-550nm section of excited spectrum (Blue light waveband).

Materials and Methods (Cond.)

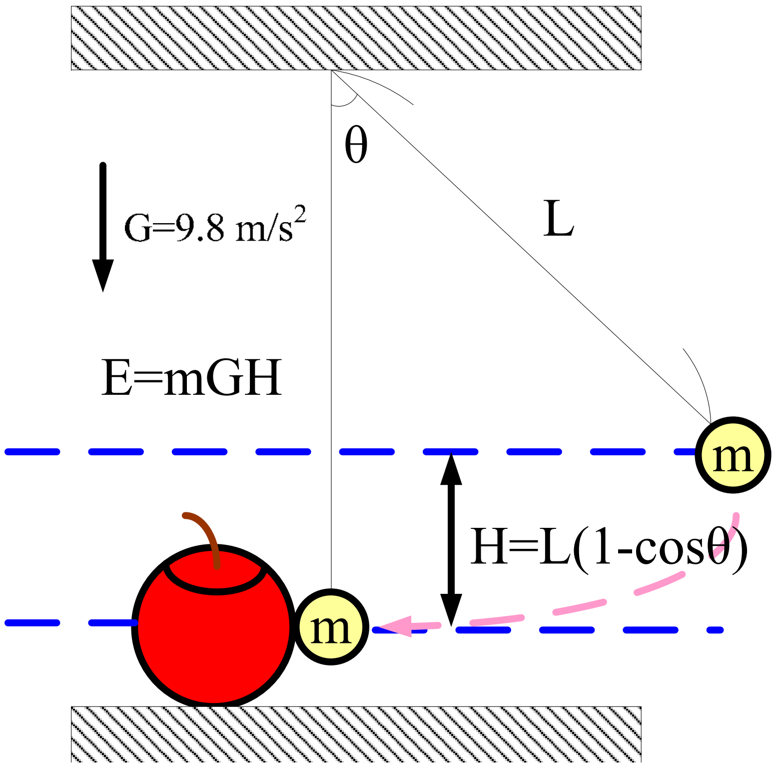
- Develop a fruit bruise making device to control the impact force that creates apple bruises.



PCB PIEZOTRONICS® ICP Force Sensor, 208C02

Materials and Methods (Cond.)

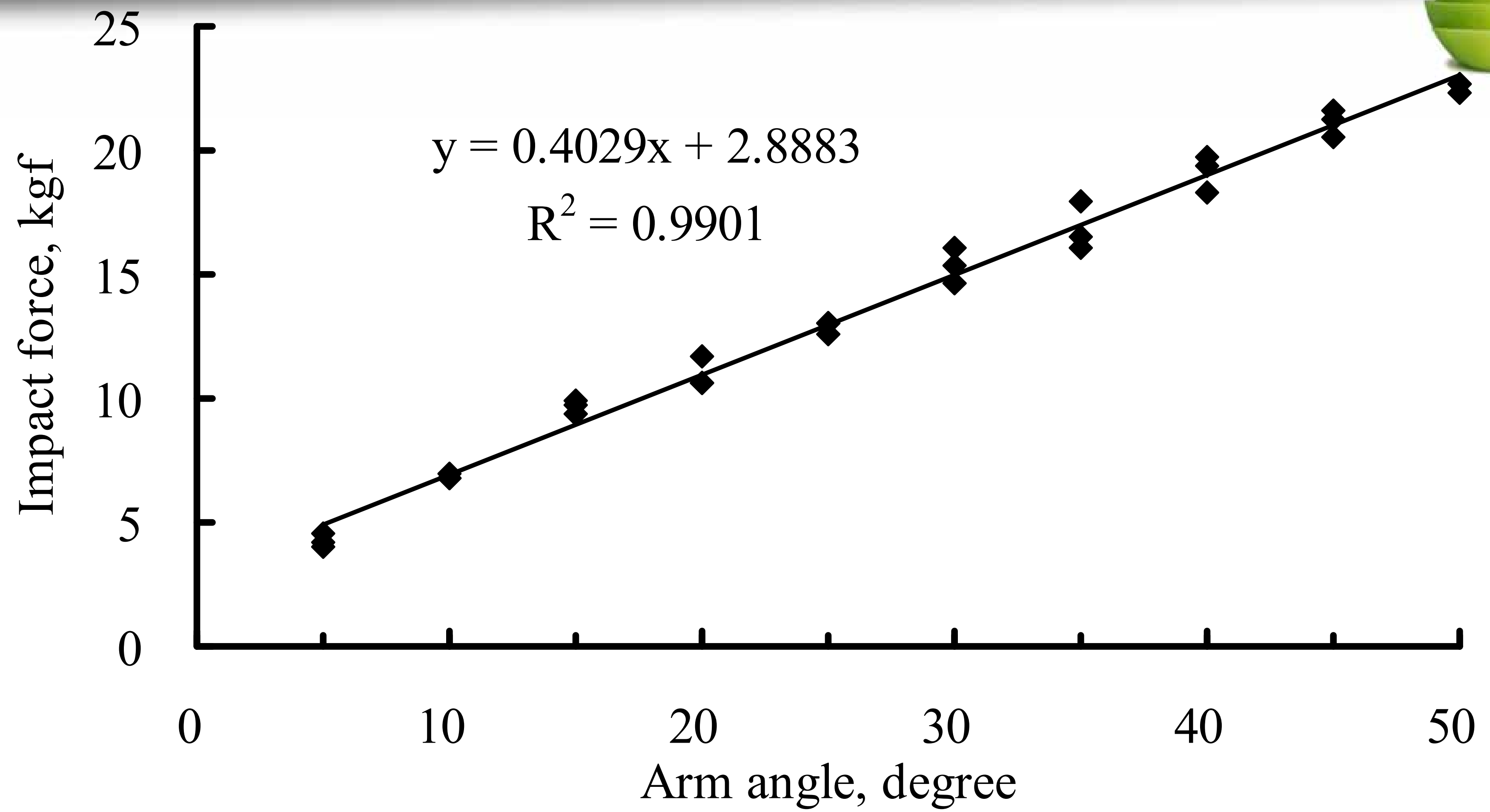
The impact energy is controlled according to the reciprocal transformation between potential energy and kinetic energy of the energy conservation law



$$E = mGH = E_e + E_i + E_f + \varepsilon$$

E: Impact energy of impact pendulum
m: Equivalent mass of pendulum
G: Value of gravity acceleration
H: Vertical distance between pendulum release point and fruit impact point = L (1-cosθ)
E_e: The energy transferred to the pendulum from the fruit as an elastic body in the impact process.
E_i: The energy absorbed by viscous body of fruit in the impact process
E_f: The energy released from friction of pendulum in the impact process
ε: Error in experiment (e.g. error resulted from operator's experience)
L: Pendulum length
θ: Free release angle of pendulum

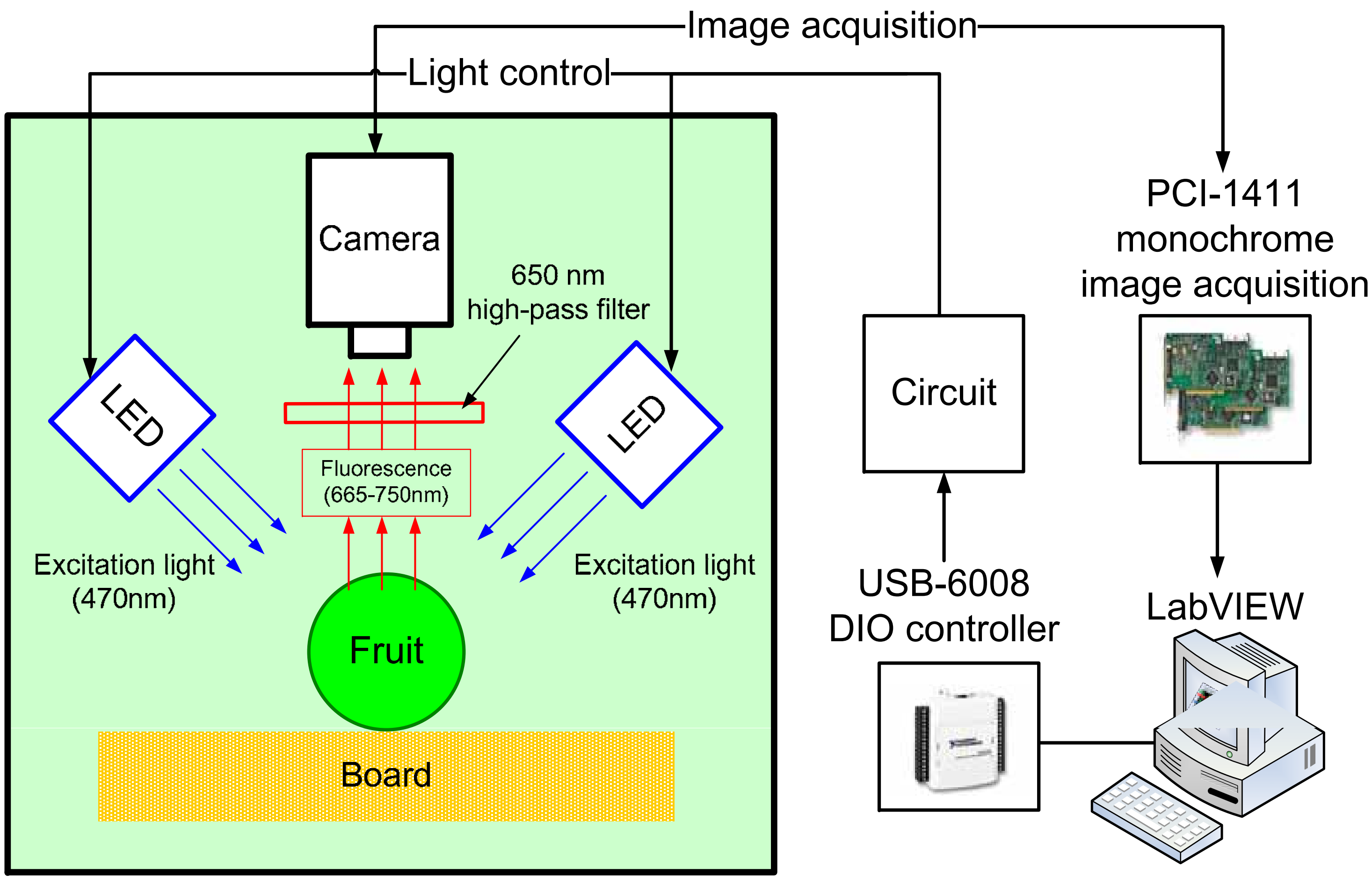
Materials and Methods (Cond.)



Relation between tilt angle of fruit impact arm and impact force peak value

Materials and Methods (Cond.)

- Using the fruit bruise detection system to capture the emissive chlorophyll fluorescence images.



Materials and Methods (Cond.)

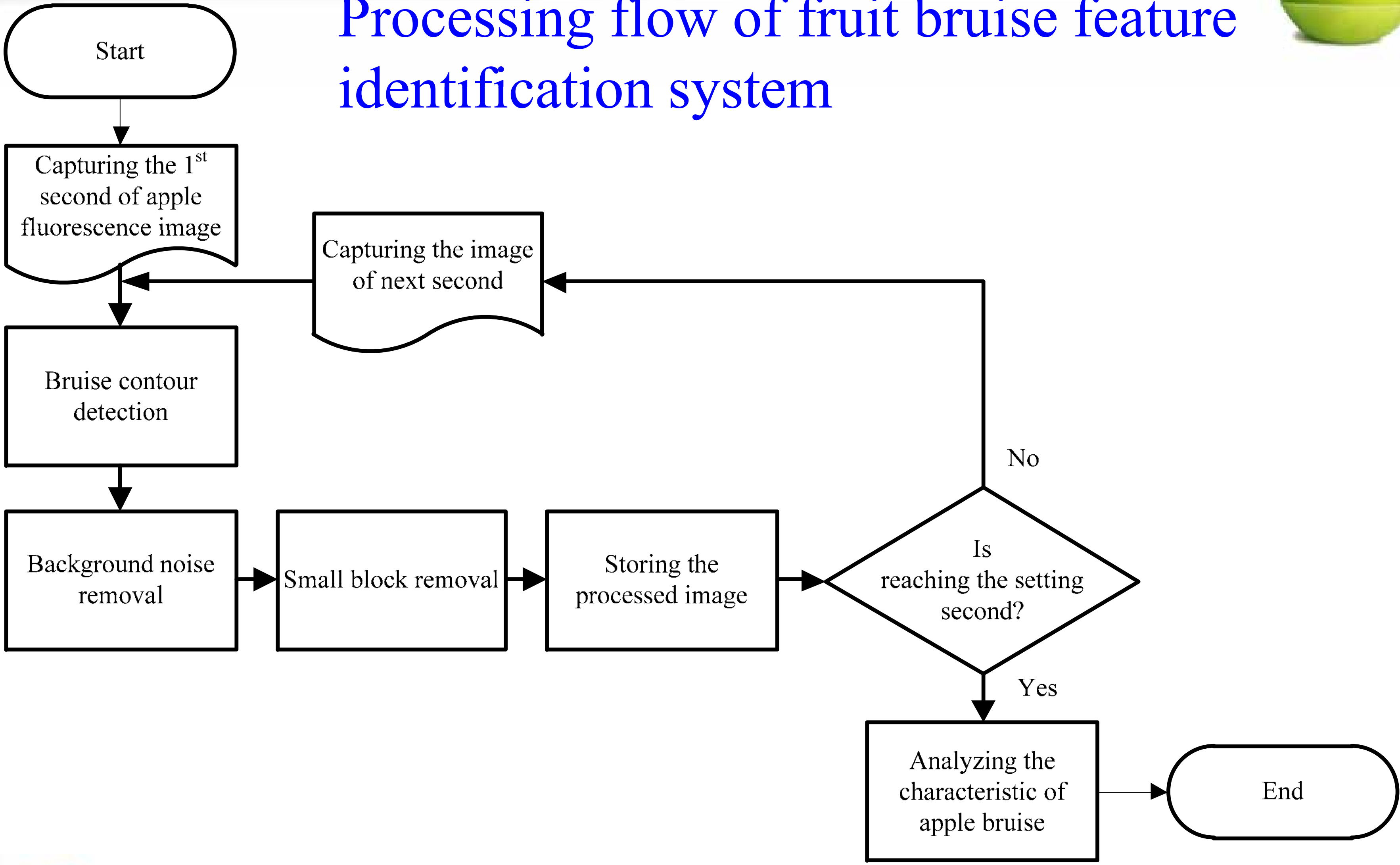
- The captured apple fluorescence images are processed and analyzed, and the apple bruise detection index is made to identify apples with bruises effectively.
- To measure the fluorescence intensity over time, a MATLAB program was developed which captured images every second.

Materials and Methods (Cond.)

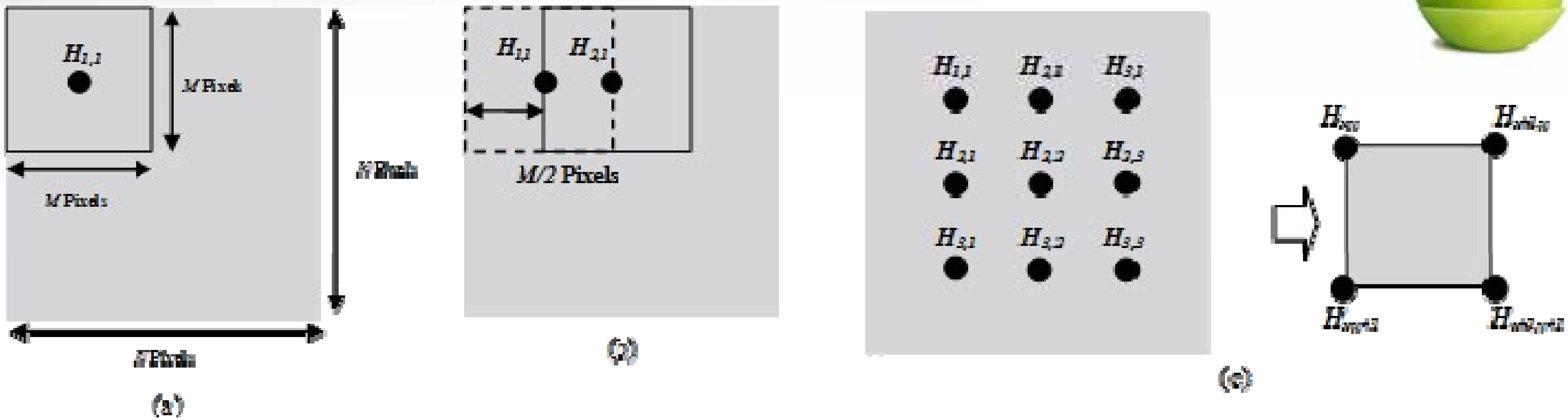
- Since the fluorescence intensity of the bruised area after impact is weaker than that of adjacent pixels, the bruise contour can be determined using an area adaptive binarization method.
- The edge of the bruise is not continuous, but contains noisy edges caused by varying illumination angles. To alleviate this problem a filter was applied that yields quasi continuous edges.

Materials and Methods (Cond.)

Processing flow of fruit bruise feature identification system

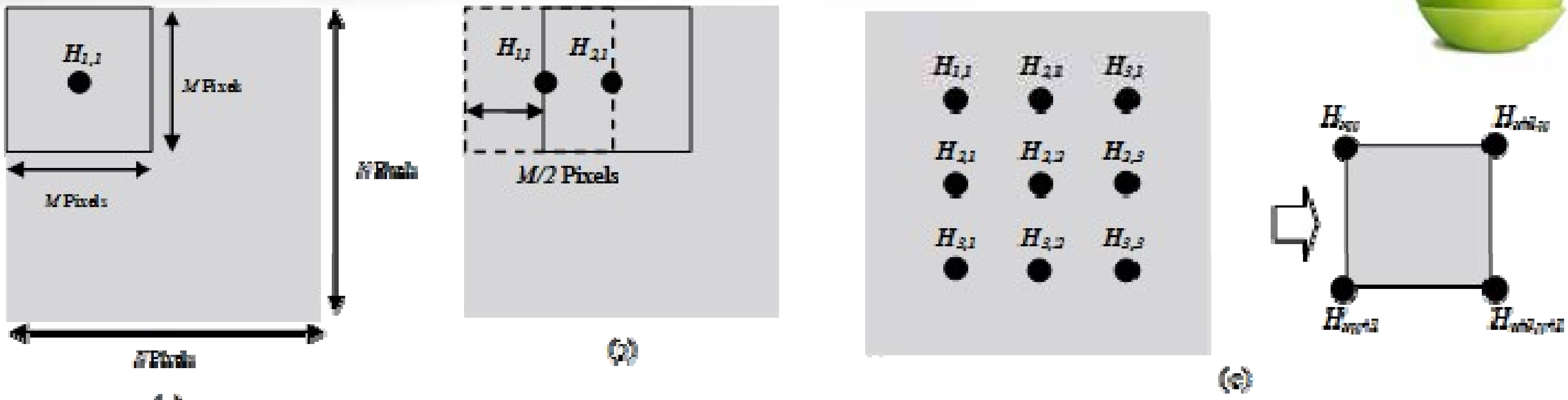


Bruise contour detection



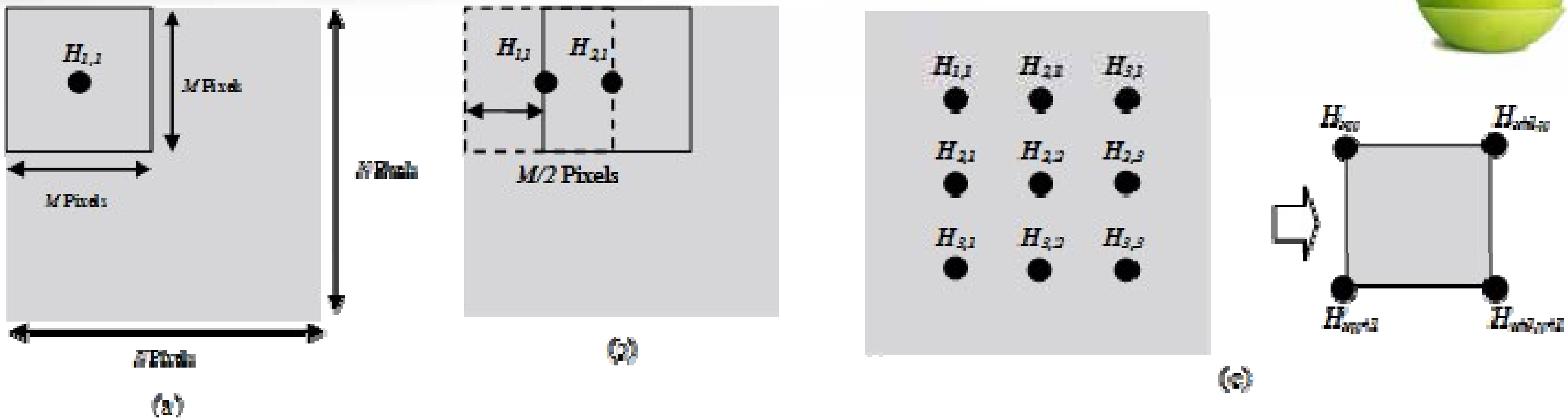
The original fluorescence image is plotted out as a masking window of M×M pixels, and the mean of pixels in this area is determined as the threshold value $H_{1,1}$, as shown in Figure (a).

Bruise contour detection (Cond.)



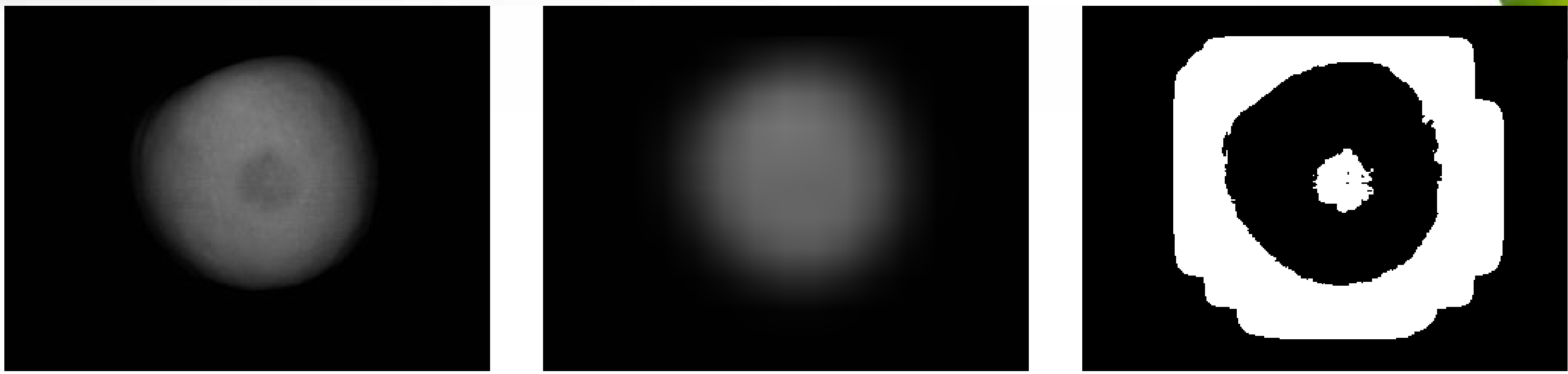
Shift to the right across M/2 pixels, and then repeat above step to get the second $H_{1,2}$ value (Fig. (b)). Similarly, scan M/2 pixels horizontally and vertically to calculate the corresponding $H_{x,y}$ values respectively. Therefore, the original fruit fluorescence image P(N, N) can obtain (2N/M)-1×(2N/M)-1 $H_{x,y}$ threshold values.

Bruise contour detection (Cond.)



The bilinear interpolation was used for adjacent four H-values ($H_{x,\ y}$, $H_{x+1,\ y}$, $H_{x,\ y+1}$ and $H_{x+1,\ y+1}$) to determine the adaptive threshold value $R_s(i, j)$ corresponding to M/2×M/2 area respectively.

Bruise contour detection (Cond.)



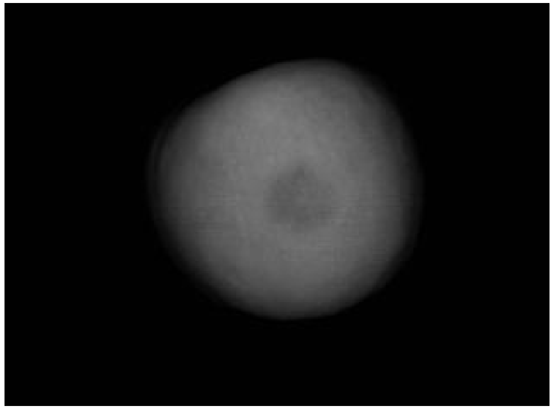
(a) *(b)* *(c)*

Compare the pixels P(i, j) of the original fruit fluorescence image (Fig. (a)) with the calculated adaptive threshold value $R_s(i, j)$ by using Eq. (1) (Fig. (b)), the pixels $P_{Label}(i, j)$ of the bruise area on the fruit can be detected, the result was shown in Fig. (c).

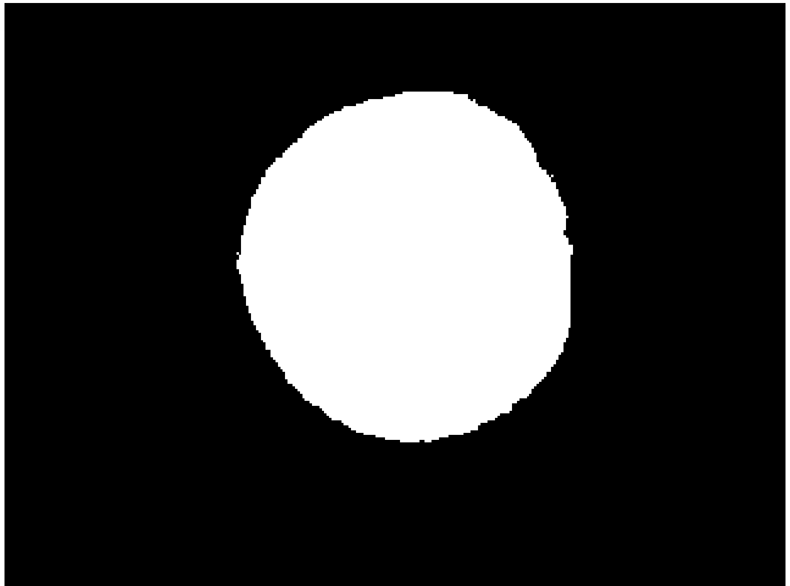
$$P_{Label}(i, j) = \begin{cases} 1, P(i, j) \leq R_s(i, j) \\ 0, otherwise \end{cases} \qquad (1)$$

Background noise removal

- In the fruit bruise fluorescence detection system, the light source is directed towards the centre of the apple, so the fluorescence excited around the contour is vague.
- To determine the proper threshold value for binarization, the Ostu method (the method of Maximum Between-cluster Variance, MBV) was employed (Ostu, 1979).
- This method removed noise outside the apple contour from the local adaptive binarization image produced earlier.

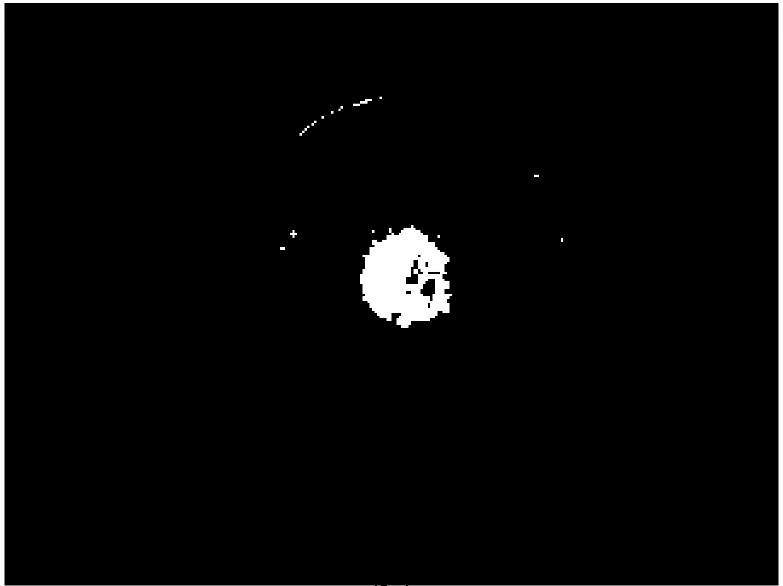


Background noise removal (Cond.)



(a)

(a).



(b)

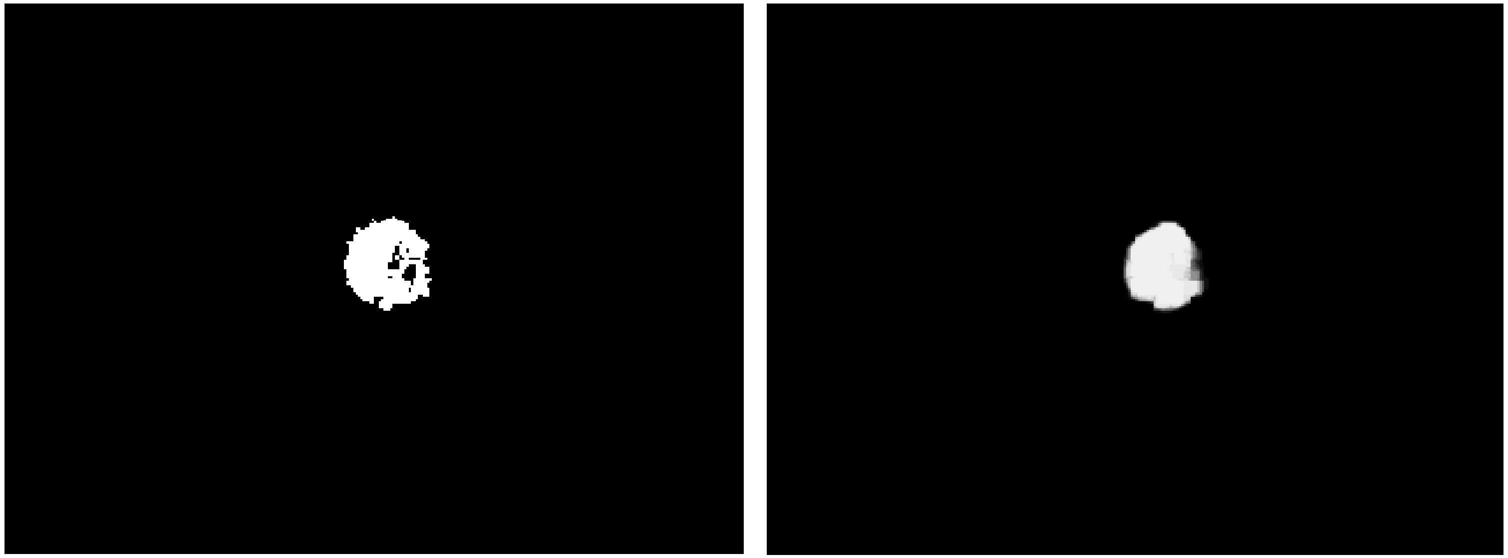
(b).

(a). Apple contour identification

(b). Image of apple bruise obtained after background noise removal.

Small block removal

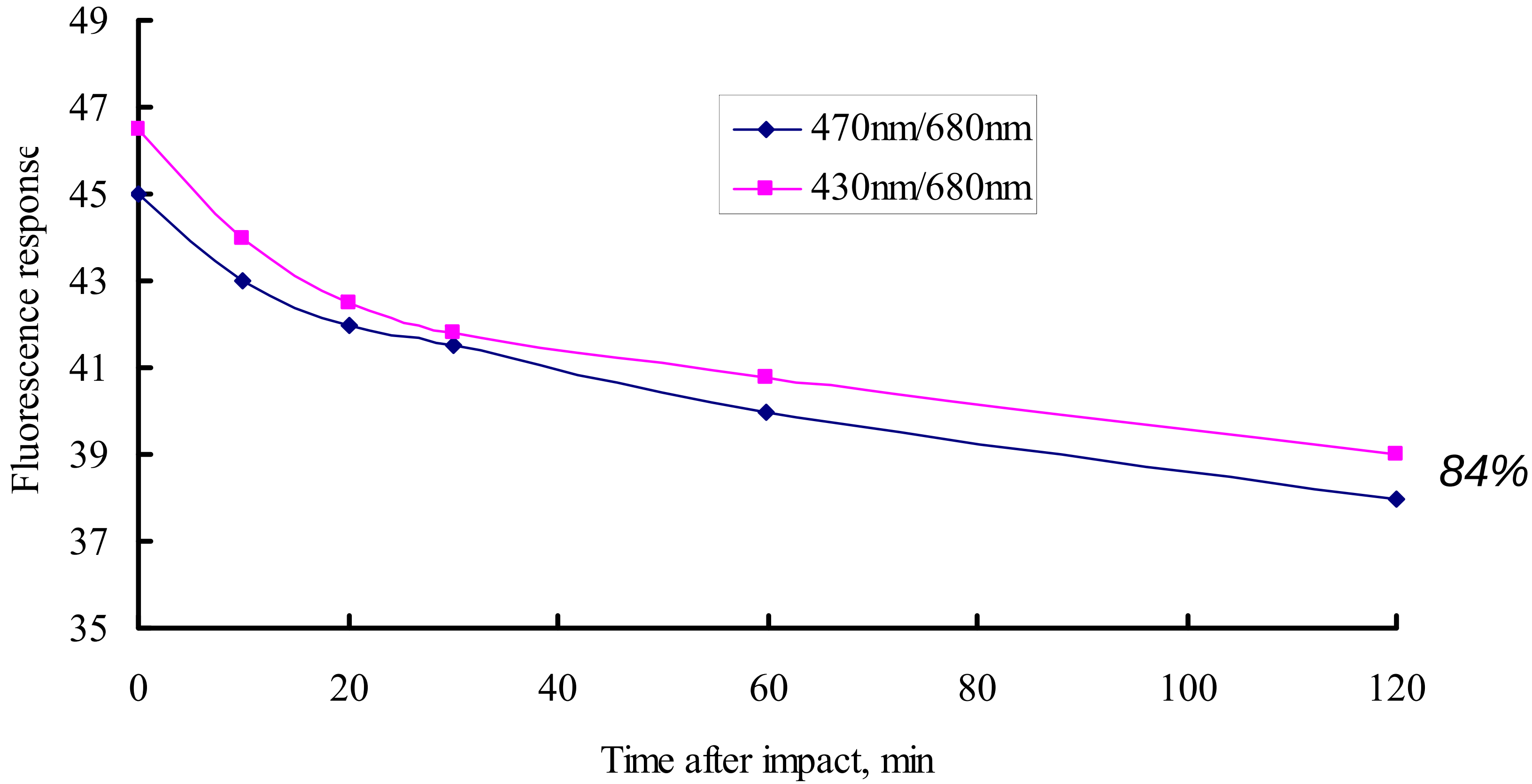
- A 'size filter' was employed which discarded connected noisy pixel blocks smaller than an arbitrary size.



(a) (b)

Results and Discussion

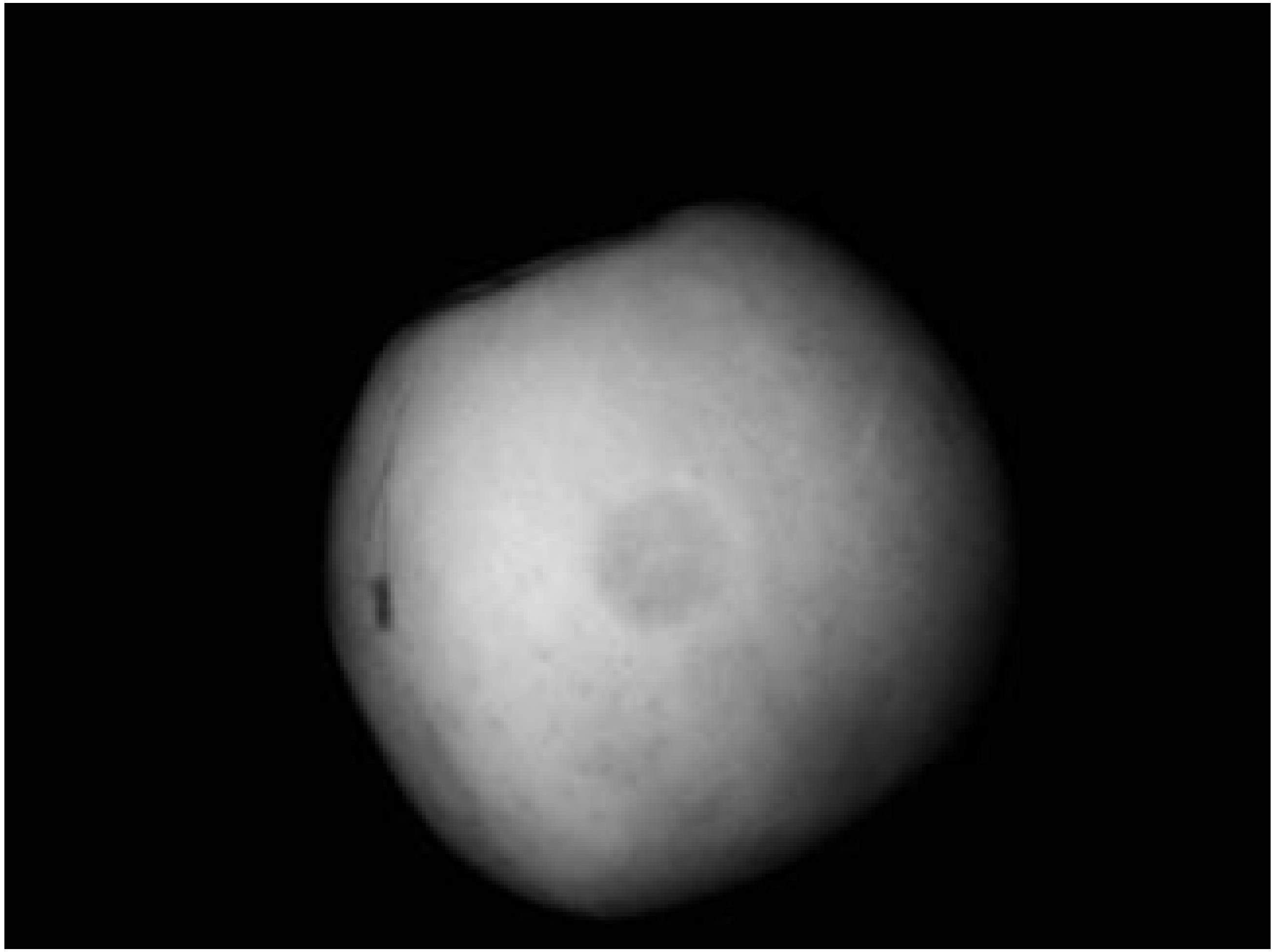
The fluorescence release amount of bruise detected by spectrophotometer of Hitachi, F4500



Time-varying decrease in fluorescence release amount of apple bruise after impact at 10.4kgf.

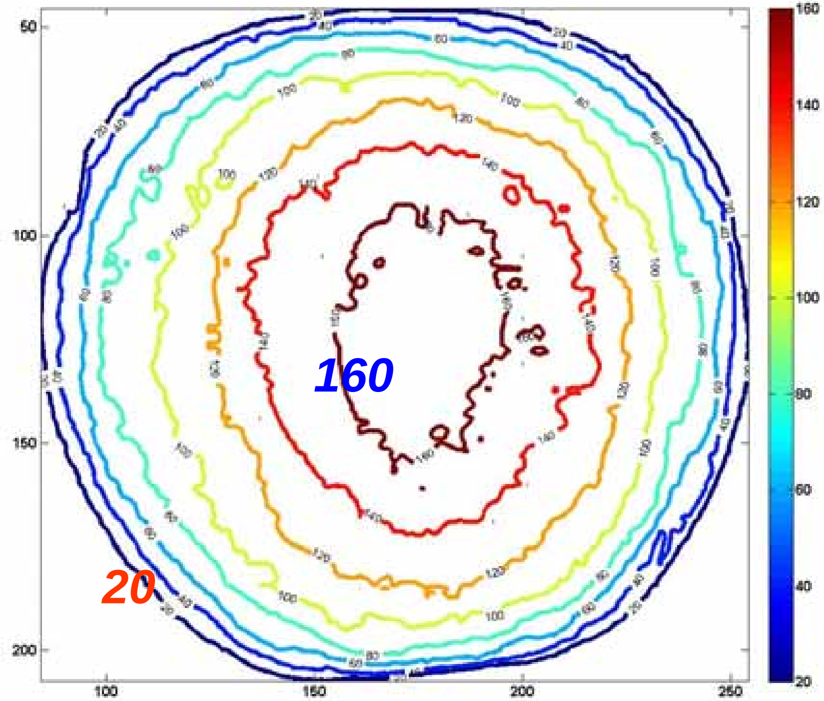
Results and Discussion

Fluorescent image of apple with bruise

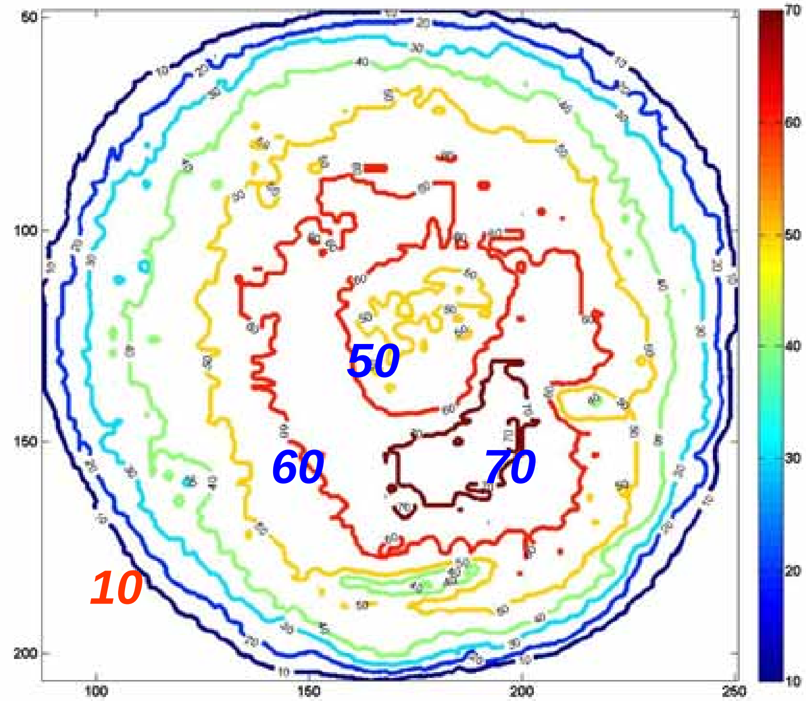


Results and Discussion

Fluorescent image intensity values of apple



without bruise



with bruise

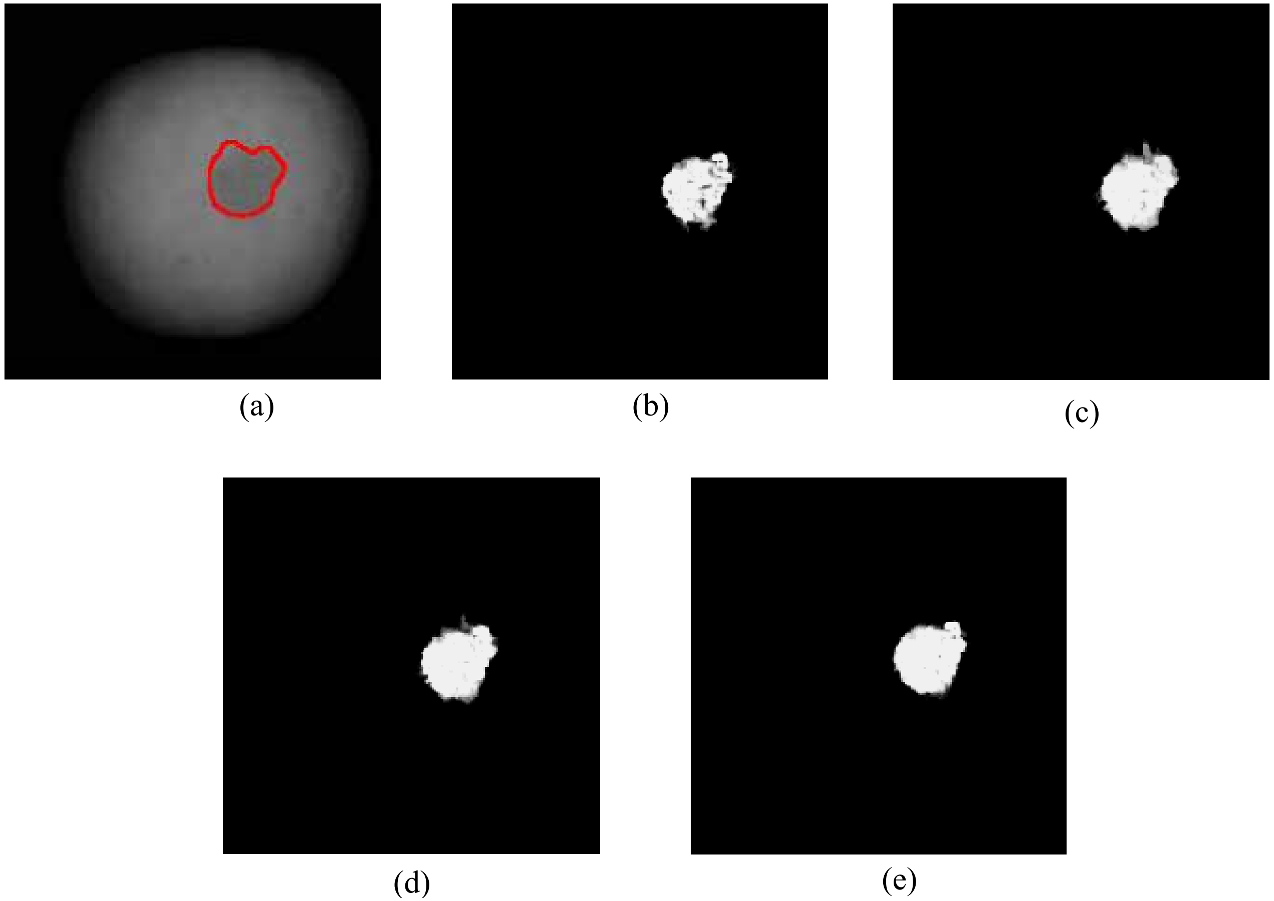
Detection and comparison of fruit bruise area

- This study adopted the bruise area of manually selected fluorescence image (AreaROI), the circled area as the standard of bruise area.
- Compared with the fruit bruise area automatically discriminated by the system (Areasys).
- The accuracy rate of bruise area judgment (AreaRate) was figured out by the Eq.

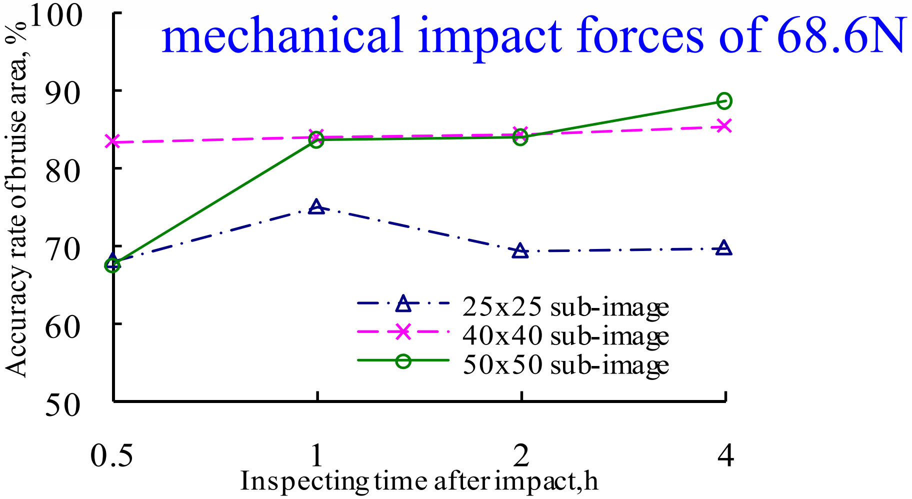
$$AraeRate(\%) = 1 - \frac{\left| Area_{sys} - Area_{ROI} \right|}{Area_{ROI}} \times 100\%$$

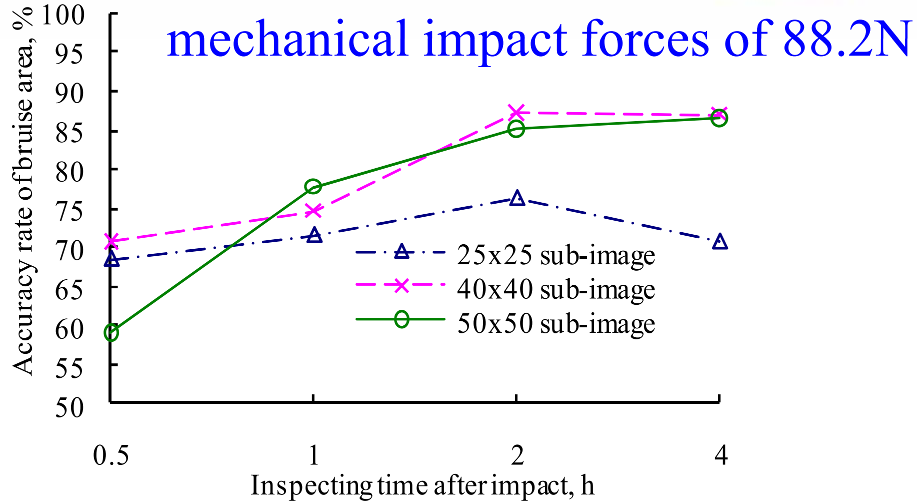
Detection and comparison of fruit bruise area

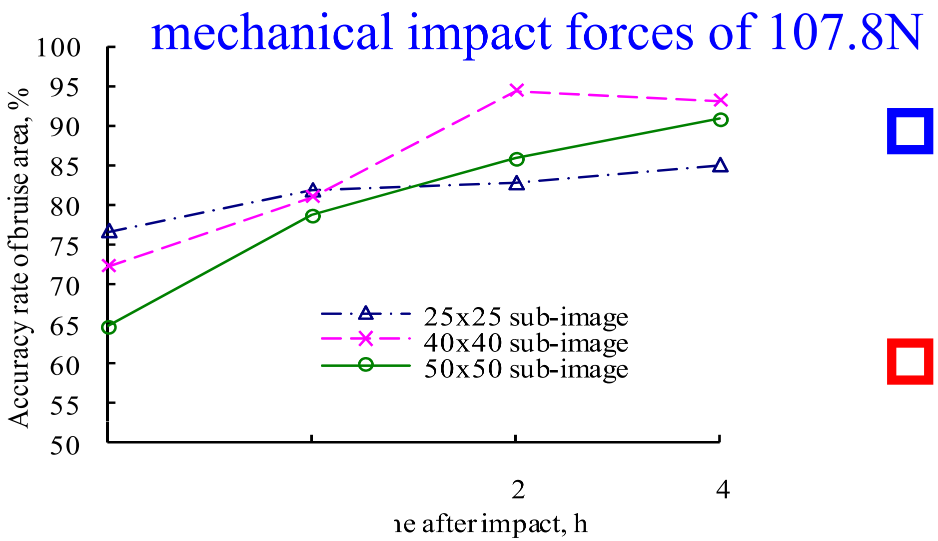
(a) manually circled ROI area; (b) 0.5 hour after impact; (c) 1 hour after impact; (d) 2 hours after impact; (e) 4 hours after impact.



M-value choose

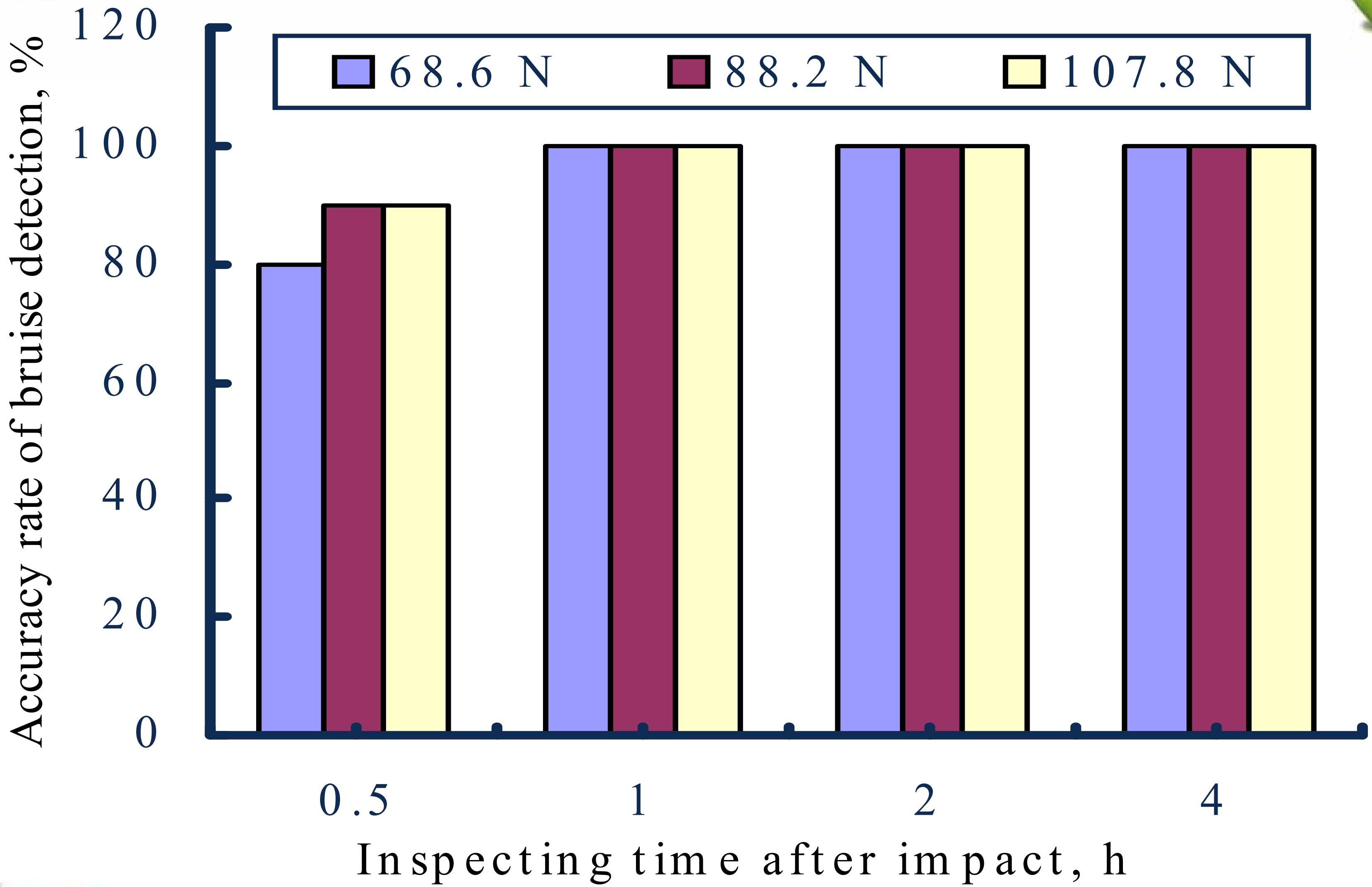






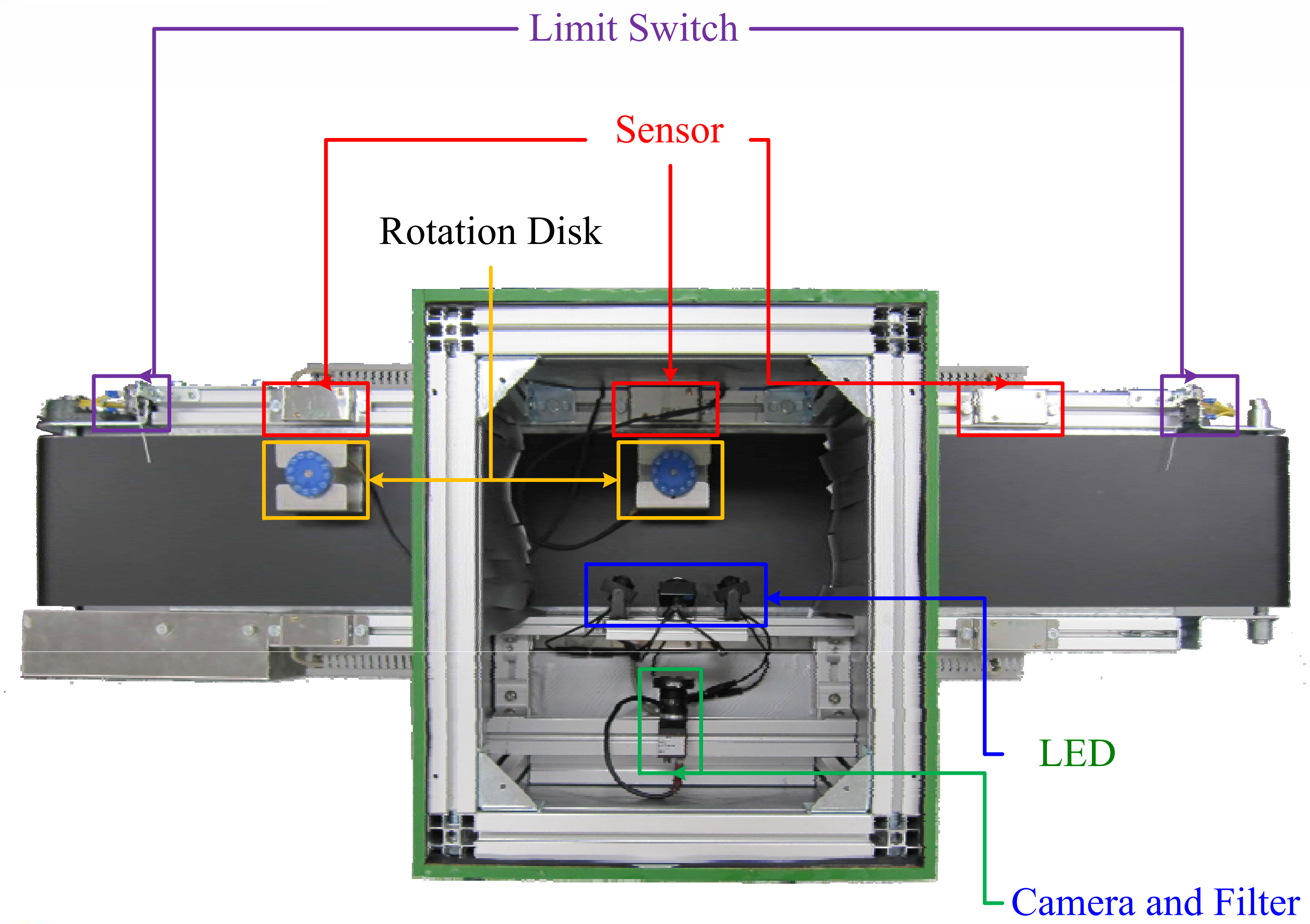
- Adopt three sizes of M-value mask to detect the accuracy rate of bruise area.
- Adopted M-value of 40 as the basis of judging the apple bruise area.

Analysis of fruit bruise detection rate



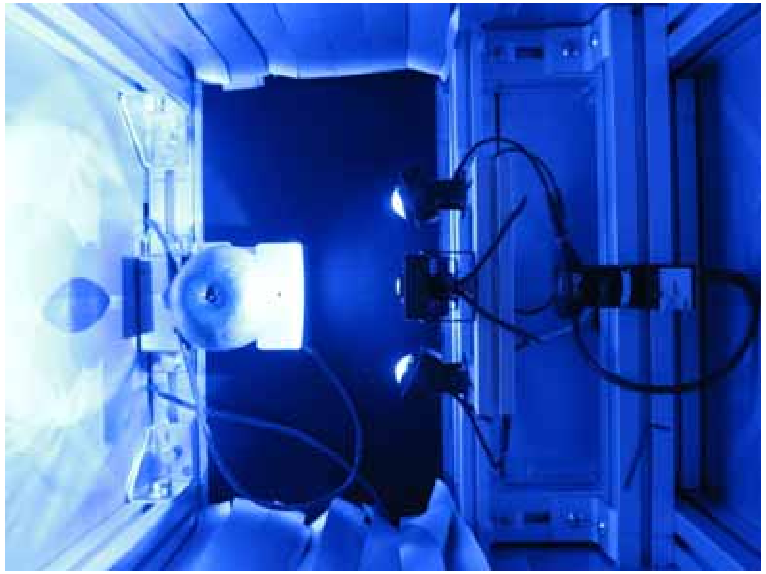
On-line inspection system

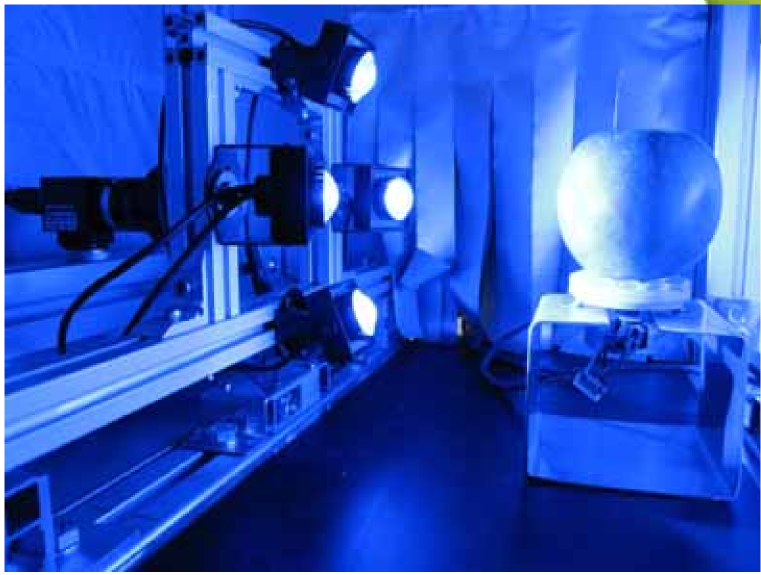
On-line inspection system

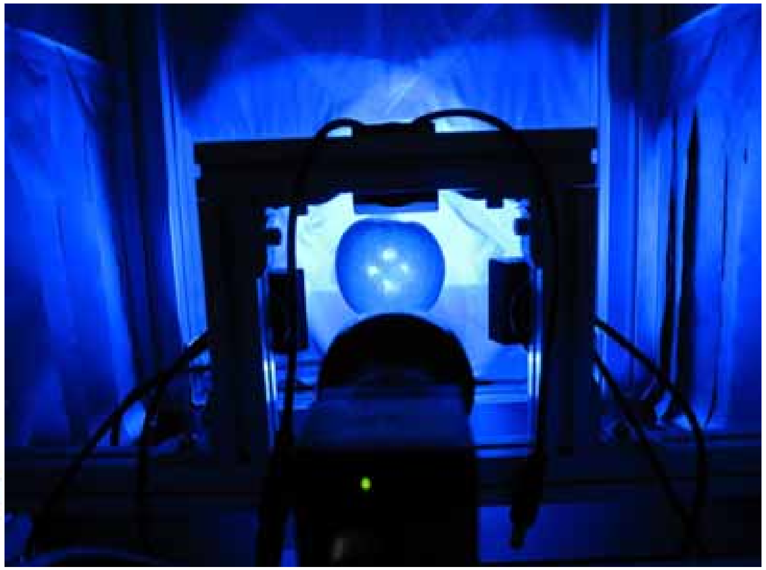


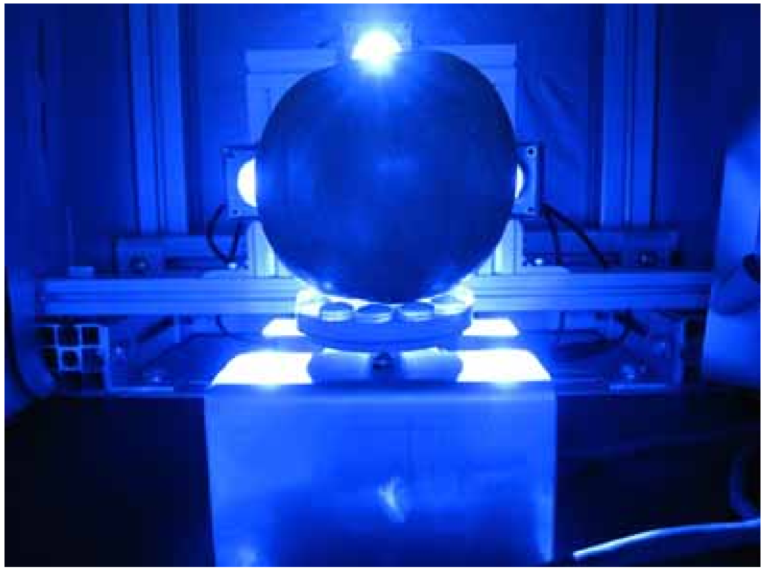
Fruit rotation disk

Image acquisition chamber

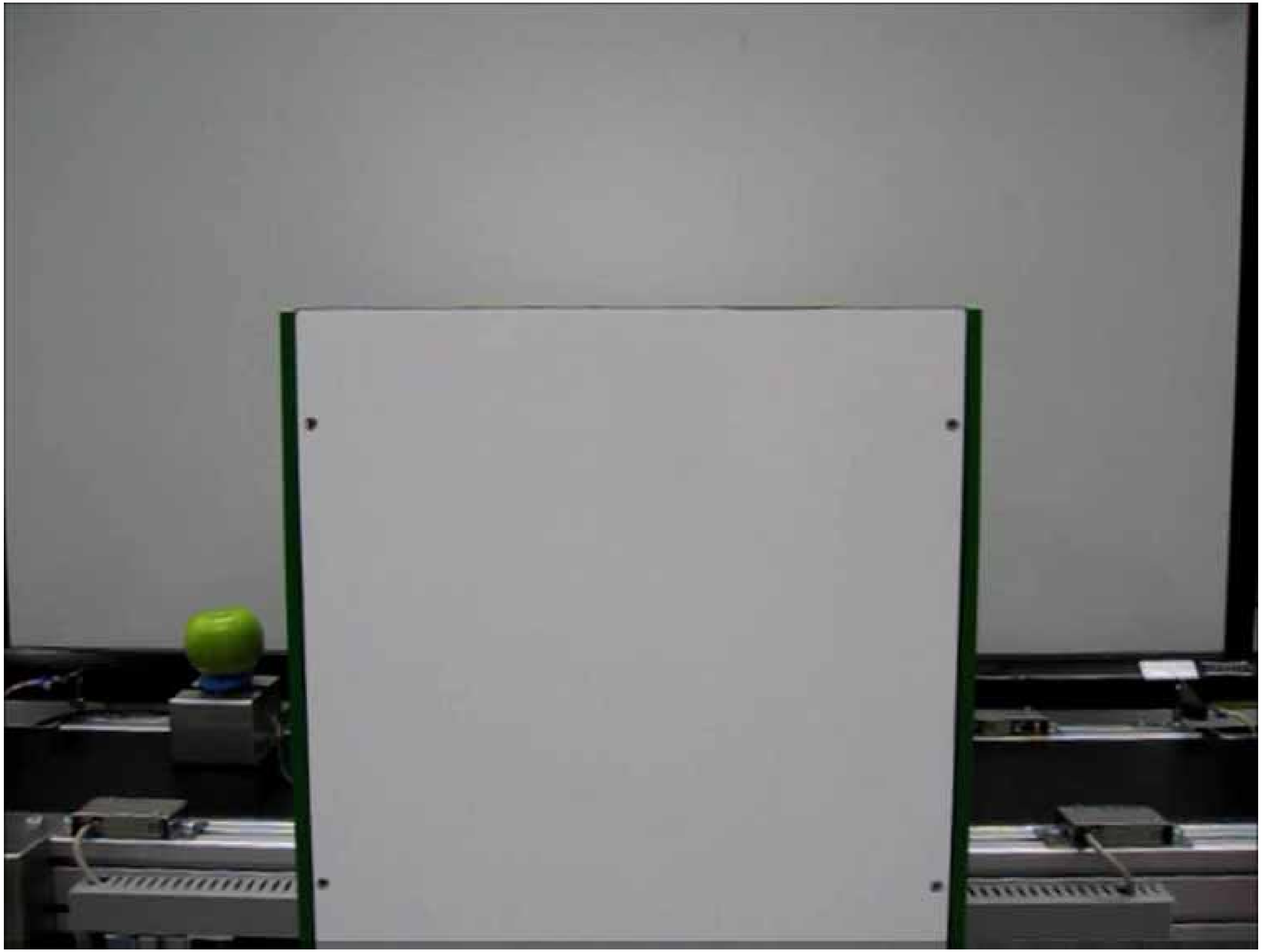








Video of image capture



Video of bruise detection

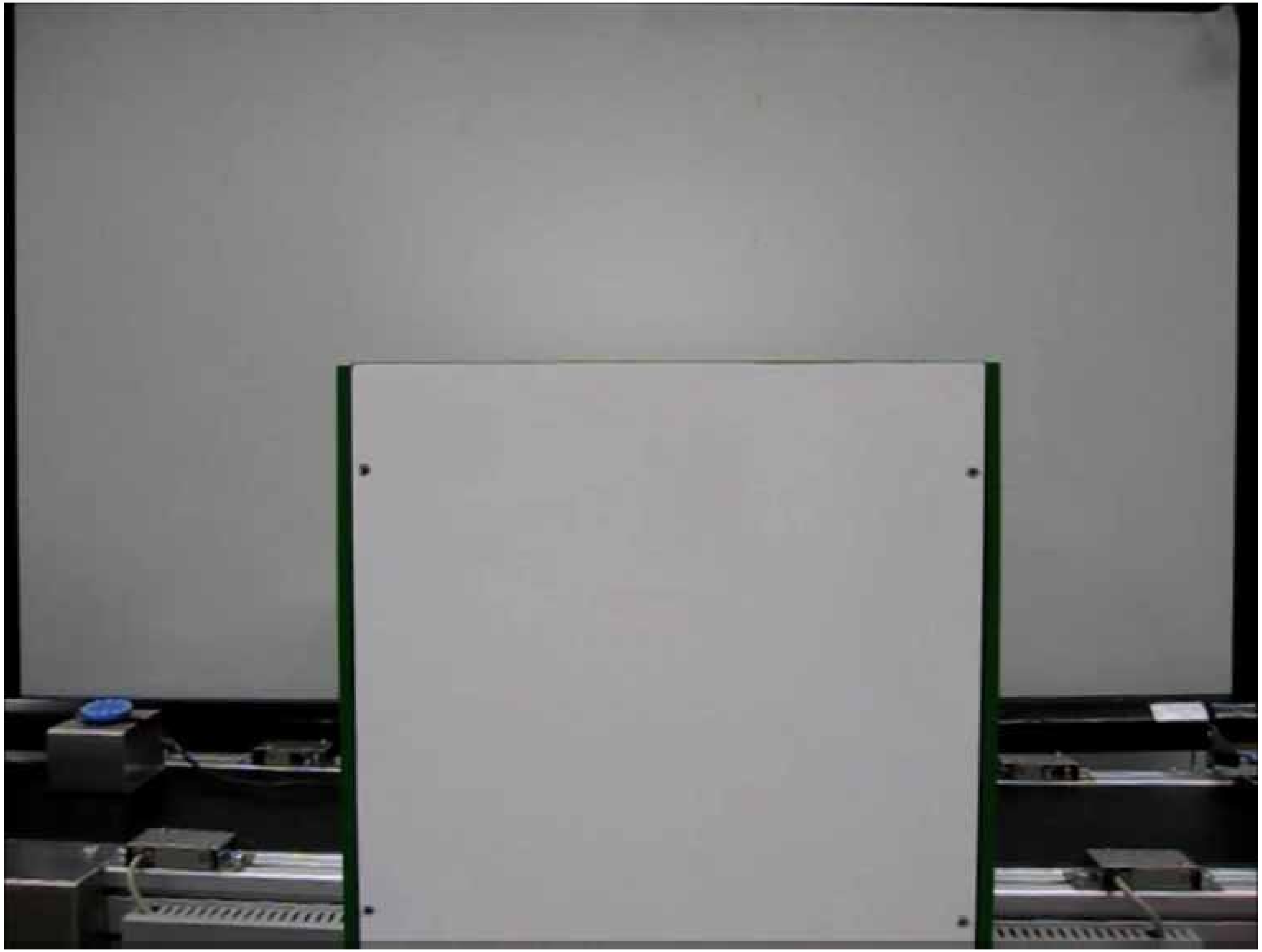
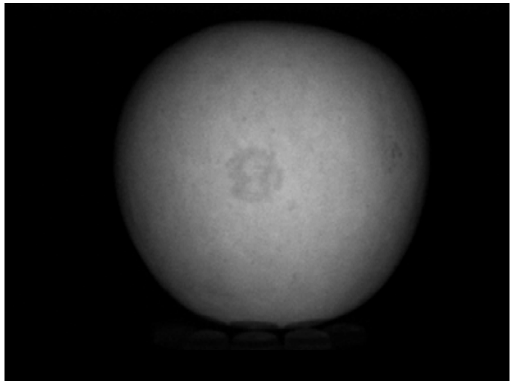
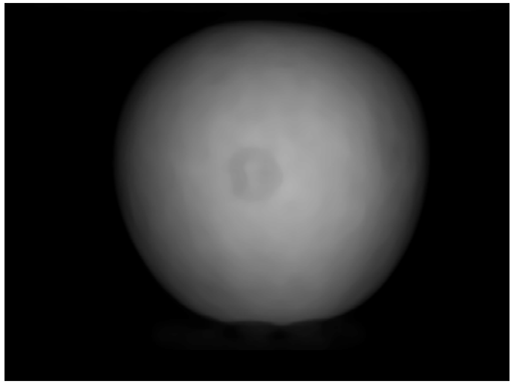


Image processing

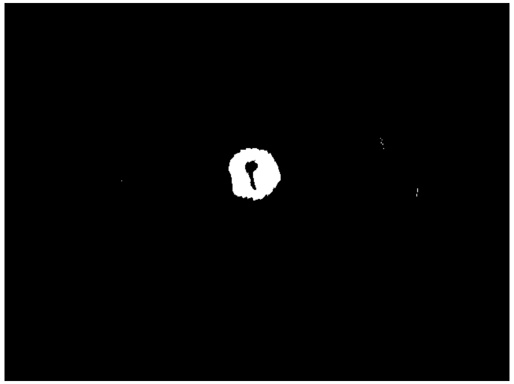


Fluorescence image

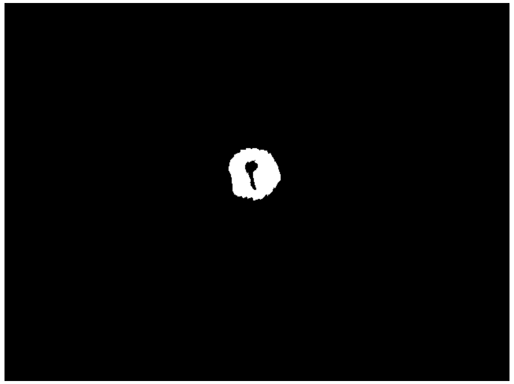


Filtering

Local adaptive threshold



Background removal



Noise and small block removal

Hole filling

Conclusions

- A fruit bruise making device has been developed to control the mechanical impact force that create apple bruise.
- A fruit bruise inspection system based on chlorophyll fluorescence images for quality control has been developed.

Conclusions (Cond.)

- Golden Delicious apples were impacted with forces of 68.6, 88.2 and 107.8 N. The bruise images were processed using local adaptive binarization and noise reduction, after which the features of the bruise area were highlighted by averaging these images.
- The results show that at 30 minutes after impact, the identification of bruises was 86.7% which raised to 100% after 1 hour.

Thank you for your attention!

National Ilan University, Taiwan

Effect on masking window of M-value

- M-value was set as three masking window sizes of 25, 40 and 50 in this test for further analysis.

- The calculation of fruit bruise area adopted in this study was for judging whether the $P_{Label}(i, j)$ values of all pixels of fruit images were greater than the threshold (threshold is set as 5 in this study).

Effect on masking window of M-value

- M-value was set as three masking window sizes of 25, 40 and 50 in this test for further analysis.
- The calculation of fruit bruise area adopted in this study was for judging whether the $P_{Label}(i, j)$ values of all pixels of fruit images were greater than the threshold (threshold is set as 5 in this study).
- if this pixel represented the fruit bruise point (Eq. 4), the pixel points of all bruises were accumulated as the system calculated fruit bruise area.

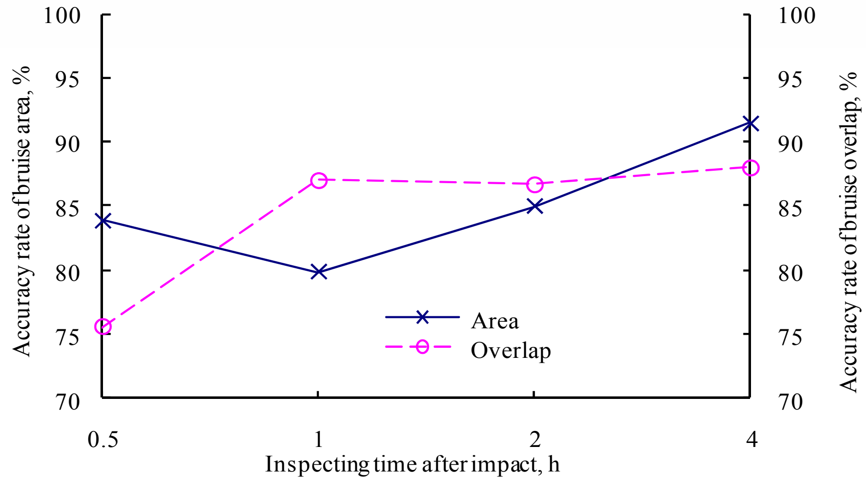
$$Pob_{sys}(i,j) = \begin{cases} 1, P_{Label}(i,j) > 5 \\ 0, otherwise \end{cases} \quad (4)$$

Analysis of overlap rate of apple bruise area

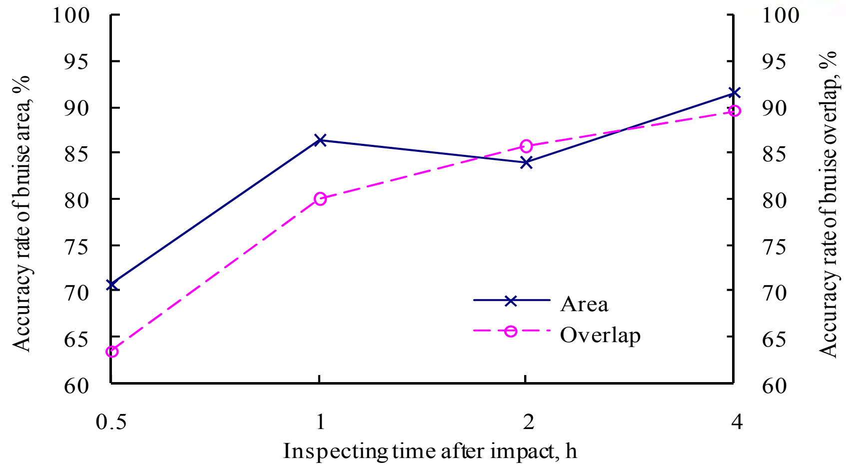
- This test used the bruise overlap rate for the analysis of bruise contour edge.
- The region of interest of manually circled fluorescence image was used as real fruit bruise contour PROI.
- compared with the bruise contour Psys automatically detected by the bruise feature identification system developed by this study.
- The bruise overlap region between them was calculated, so as to calculate the overlap rate of bruise area, the calculation method is shown in Eq. 7.

$$OverlapRate(\%) = \frac{P_{sys}(i,j) \cap P_{ROI}(i,j)}{P_{sys}(i,j) \cup P_{ROI}(i,j)} \times 100\% \qquad (7)$$

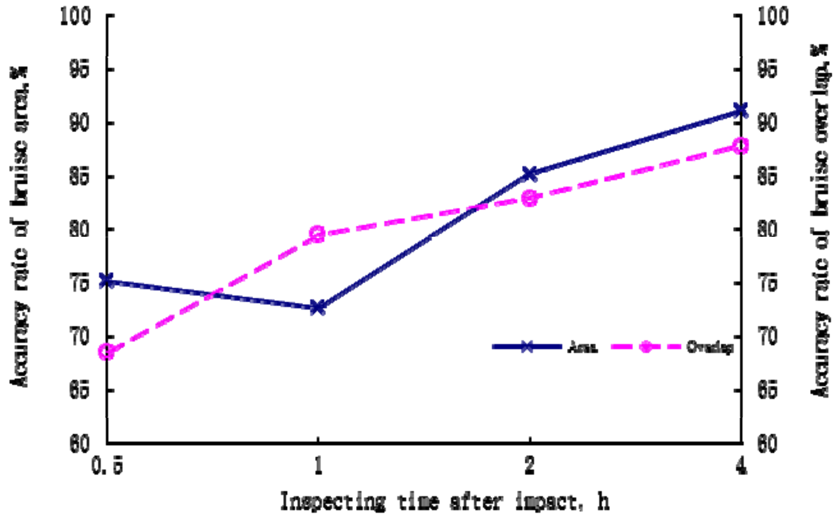
Analysis of overlap rate of apple bruise area



impact force parameters of 68.6 N

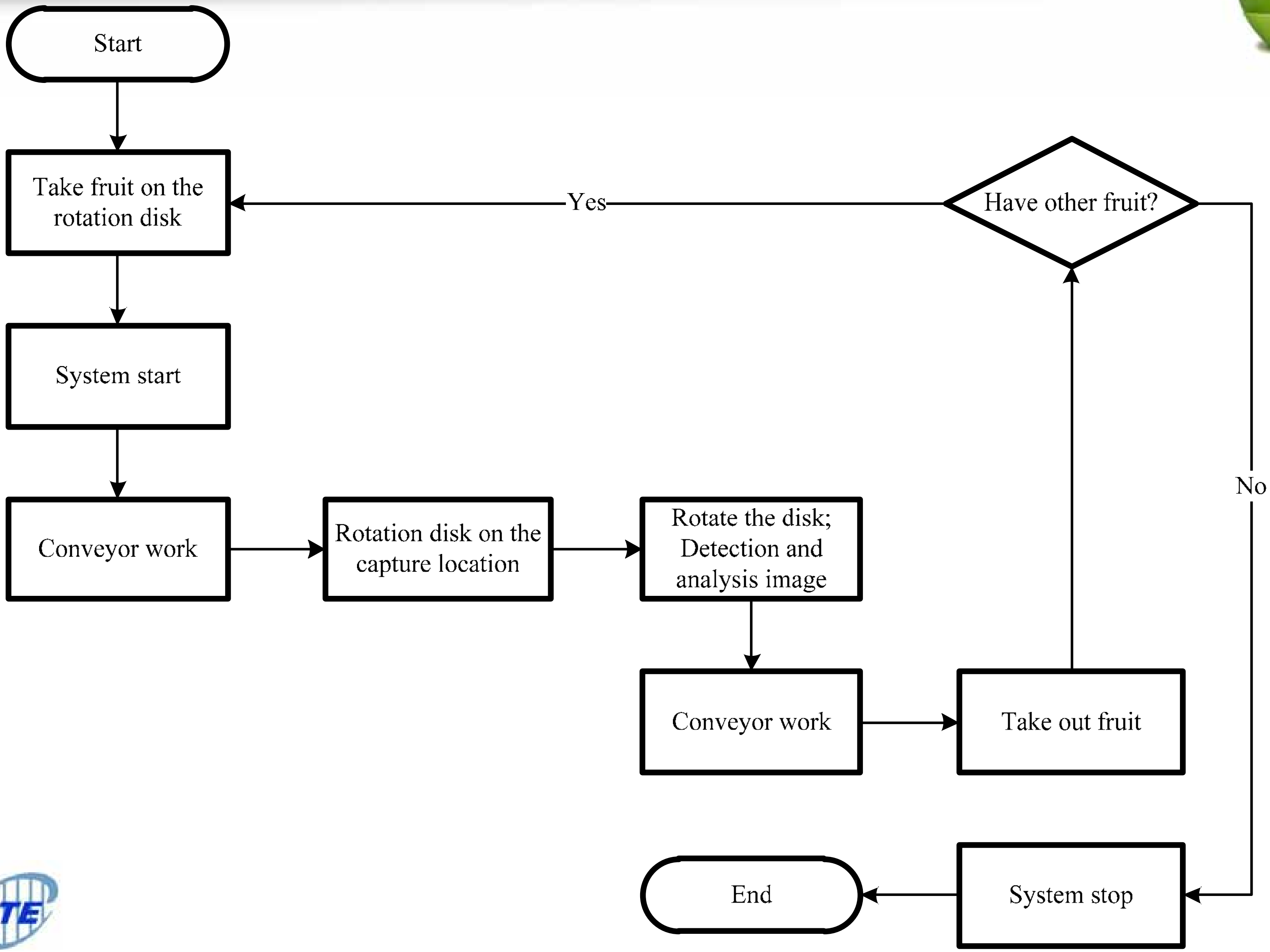


impact force parameters of 88.2 N



impact force parameters of 107.8 N

Processing flow of On-line inspection system



Conclusions

- This study has developed a detection method that applies specific impact forces to fruit to make fresh bruise and detects whether the fruit is bruised.

- Developing a fruit bruise inspection system based on chlorophyll fluorescence images for quality control.

Conclusions (Cond.)

- Golden Delicious apples bruise images were processed using local binarization and noise reduction, after which the features of the bruise area were highlighted by averaging these images.

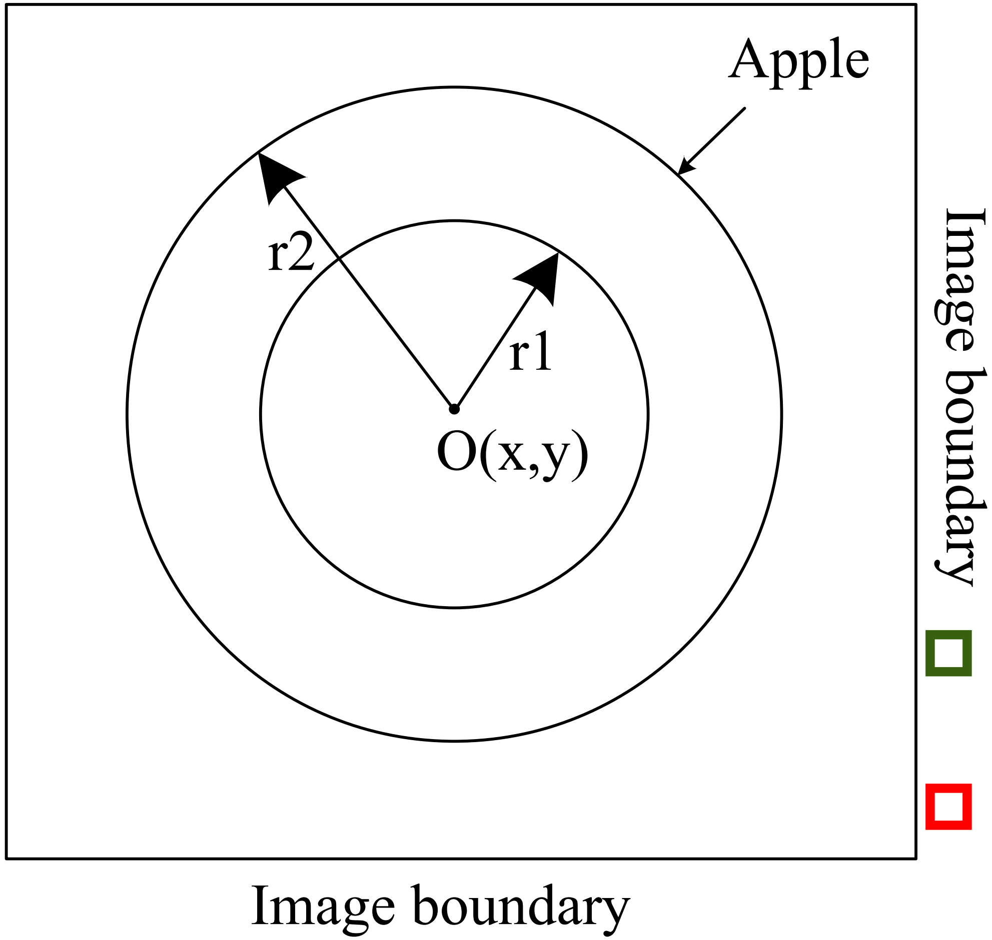
- The objective of the research was to determine the earliest point in time, at which the bruises could be detected with high accuracy.

Conclusions (Cond.)

- The results show that at 30 minutes after impact, the identification of bruises was 86.7% which raised to 100% after 1 hour.

- According to the relation between fruit bruise and the change in chlorophyll fluorescence discussed in this study, the visible and invisible fruit bruises can be identified and detected, and it can be used as the basis of developing online nondestructive fruit bruise detection system in the future.

Definition of bruise identification index



$$I_{R2\text{-}R1} = \sum_{t=1\,sec}^{60\,sec} \text{Region2} - \text{Region1}$$

- When an apple without bruise, $I_{R2\text{-}R1}$ shall be less than 0.
- On the contrary, when an apple with bruise, so that the $I_{R2\text{-}R1}$ will be greater than 0.
- The impact on apple can be judged according to this logic.

The calculation procedure follows

- Select an initial estimated threshold value T_i.

- Take T_i value as the demarcation, divide the image into two groups of pixels. G_1 represents all pixels with gray scale $\geq T_i$; G_2 represents all pixels with gray scale value $< T_i$.

- Calculate the mean gray scale value μ1 and μ2 of pixels in G1 and G2 areas separately.

- Determine the new threshold value by using Eq. 2.

$$T_{new} = \frac{\mu_1 + \mu_2}{2} \qquad (2)$$

The calculation procedure follows

- Determine whether the absolute difference values of T_i and T_{new} are converged less than the tolerance coefficient k_0, if it is acceptable, the final T_{new} is designated as the overall threshold value T_{all}; contrarily Ti shall be replaced by T_{new}, and Step 2 to Step 4 shall be repeated.

- Determine the apple bruise feature $P_{bruise}(i, j)$ by using Eq. 3.

$$P_{bruise}(i, j) = \begin{cases} 1, & P_{Label}(i, j) \geq T_{all} \\ 0, & otherwise \end{cases} \quad (3)$$

Small block removal

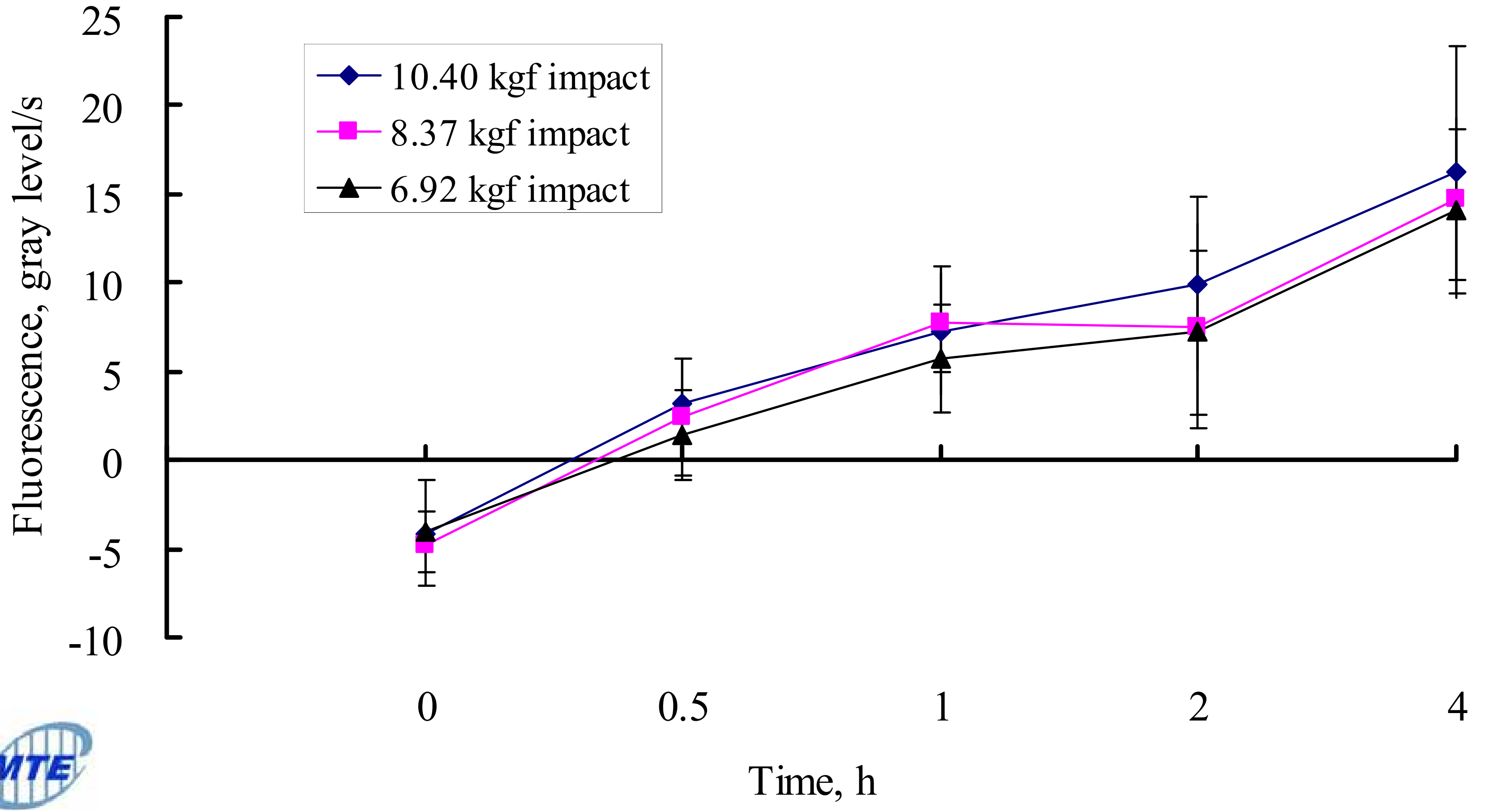
- The bruise area detection process is hampered by two effects being :

1. The individual images of the fluorescence emission contain noise inside the assumed bruised area.

2. The fluorescence emitted by a bruised area changes over time.

Results and Discussion (Cond.)

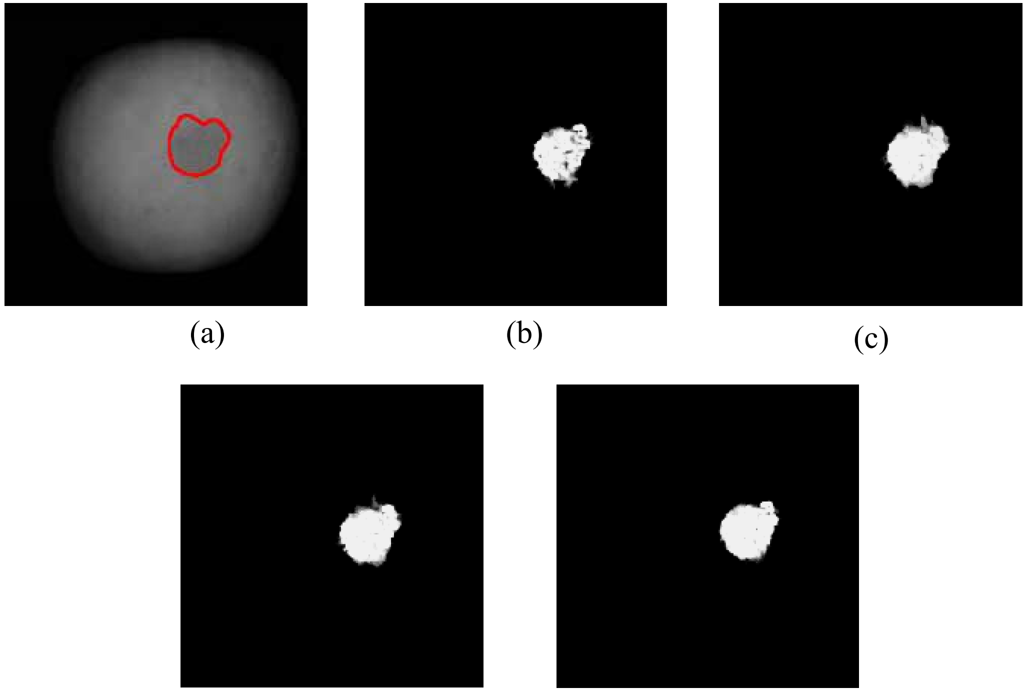
Apple bruise identification index I_{R2-R1} varying with time under different impact forces



Effect on masking window of M-value

$$Area_{sys} = \sum_{i=1, j=1}^{i=M, j=N} Pob_{sys}(i, j) \qquad (5)$$

$$AraeRate(\%) = 1 - \frac{\left| Area_{sys} - Area_{ROI} \right|}{Area_{ROI}} \times 100\% \qquad (6)$$

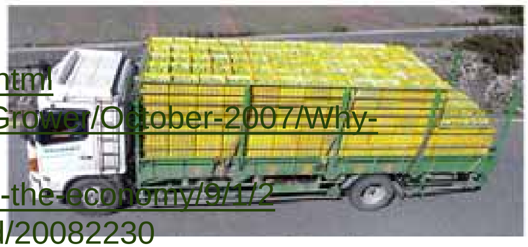


(a) (b) (c)

(d) (e)

Introduction

The fruit will sustain certain mechanical injuries during marketing processes.



Fruit tissues, which contain large amounts of chlorophyll, are susceptible to damage from mechanical impact.

These injuries may induce bruises and cause quality degradation.

http://www.alfalahimpex.net/products.html
http://www.goodfruit.com/Good-Fruit-Grower/October-2007/Why-apples-bruise/
http://www.teara.govt.nz/en/farming-in-the-economy/9/1/2
http://blog.xuite.net/erichu1014/catdad/20082230