Development of the Device for Optimal Harvesting of Longkong (*Lansium domesticum* Corr.) Fruit-clusters Using Physics Technique

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ชื่อวิทยานิพนธ์	การพัฒนาเครื่องมือ เพื่อหาช่วงเวลาที่เหมาะสม ในการเก็บเกี่ยวผลลองกอง ด้วยเทคนิคทางฟิสิกส์
ผู้เขียน	นางพวงทิพย์ แก้วทับทิม
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บทคัดย่อ

ในการกำหนดระยะที่เหมาะสมที่สุดสำหรับเก็บเกี่ยวช่อลองกองนั้น ผู้วิจัยได้ใช้ค่าสเปกตรัมของผลช่อลองกองและโปรแกรม Computer Program for Color Analysis of Longkong Fruits (CPCAL) พบว่า ค่าสีน้ำเงินของภาพที่ถ่ายด้วยกล้องดิจิตอล โดยมีแสงจากหลอด LED สีแดง เป็นตัวชี้วัดที่แม่นยำที่สุด นอกจากนี้ผู้วิจัยได้ประยุกต์ข้อมูลเพื่อใช้ในการพัฒนาลองกองคัลเลอร์มิเตอร์ (LCM) สำหรับการใช้งานอย่างกว้างขวาง

ทำการถ่ายภาพผลลองกองที่สวนทุกๆวัน ในช่วงการเจริญเติบโตของผลลองกองตั้งแต่ผลลองกองยังอ่อนอยู่จนกระทั่งสุกมาก โดยใช้กล้องดิจิตอล และแหล่งกำเนิดแสงสีแดง และ สีเขียว การเปลี่ยนแปลงของสีพื้นฐาน 3 สี (สีแดง สีเขียว และสีน้ำเงิน) ในภาพถ่ายจะถูกวิเคราะห์ด้วย Computer Program for Color Analysis of Longkong Fruits (CPCAL) ที่ได้พัฒนาขึ้นมา จากนั้นจะเปรียบเทียบผลกับค่าอัตราส่วนของปริมาณของของแข็งที่ละลายทั้งหมด ต่อปริมาณกรด (TSS: TA) ในผลลองกอง พบว่า สเปกตรัมสีน้ำเงินจากการใช้หลอด LED สีแดง (Br) จะเป็นสัดส่วนผกผันกับอัตราการสุกของผลลองกอง ผลจากการวิเคราะห์สามารถสรุปได้ว่าช่วงเวลาที่เหมาะสมที่ชาวสวนลองกองควรตัดช่อลองกอง จะอยู่ในช่วงวันที่ 96 ± 8 นับจากวันที่ลองกองดอกแรกบาน ซึ่งมีค่าระดับสีน้ำเงินต่อพิกเซลอยู่ในช่วง 8.67 – 2.39 ถ้าตัดลองกองในช่วงที่ระดับสีน้ำเงินต่อพิกเซลมีค่าอยู่ระหว่าง 8.67-5.53 จะได้ลองกองที่มีช่อผลสวยงาม มีรสชาติหวานอมเปรี้ยว เหมาะสำหรับตัดไปขายในระยะไกล แต่ถ้าตัดลองกองในช่วงที่มีค่าระดับสีน้ำเงินต่อพิกเซลอยู่ระหว่าง 5.54 – 2.39 จะได้ลองกองที่มีรสชาติหอม หวาน เหมาะสำหรับนำไปขายในระยะใกล้ๆ ระดับสีน้ำเงินต่อพิกเซลมีค่าลดลง 0.45/วัน ซึ่งสามารถนำไปใช้ในการคาดคะเนวันตัดล่วงหน้าได้

เนื่องจากวิธีการที่ได้กล่าวมาแล้วข้างต้น เป็นวิธีการที่ซับซ้อนและใช้เวลามาก ผู้วิจัยจึงได้พัฒนาเครื่องมือเรียกว่า "ลองกองคัลเลอร์มิเตอร์" เพื่อใช้ในการกำหนดดัชนีการเก็บเกี่ยวลองกองโดยการวัดหน่วยสีผิวของผลลองกองซึ่งประกอบด้วยค่าของสีแดง ค่าของสีเขียว และค่าของสีน้ำเงินแล้วนำมาเปรียบเทียบค่าความแม่นยำ กับอัตราส่วนของของแข็งที่ละลายได้ในของเหลวต่อกรด

(TSS:TA) ของลองกอง พบว่า ค่าของสีแดงมีการเปลี่ยนแปลงที่สอดคล้องกับการเปลี่ยนแปลงของค่า TSS:TA มากที่สุด โดยที่ค่า TSS:TA มีการเปลี่ยนแปลงที่รวดเร็วอยู่สองช่วง ดังนั้นจึงแบ่งระยะเก็บเกี่ยวเป็นสองระยะ ช่วงแรกเมื่อลองกองมีอายุได้ 91 วัน นับจากวันที่ดอกแรกของช่อบาน ช่วงนี้หน่วยสีแดงมีค่าเป็น 60 ค่านี้เหมาะสำหรับเป็นดัชนีเริ่มเก็บเกี่ยวช่อลองกองเพื่อการส่งออกไปขายในระยะไกล จะได้ลองกองที่มีช่อสวยงาม ผลลองกองติดกับก้านช่ออย่างหนาแน่น รสชาติหวานอมเปรี้ยว ระยะที่สองค่า TSS:TA เมื่อลองกองมีอายุได้ 96 วัน ช่วงนี้หน่วยสีแดงมีค่าเป็น 67 ค่านี้เหมาะจะเป็นดัชนีในการเก็บเกี่ยวช่อลองกอง เพื่อขายในระยะใกล้ๆสวน จะได้ลองกองที่สุกมากและมีรสชาติหอมหวาน นอกจากนี้ยังพบว่าค่าของหน่วยสีแดงมีค่าเพิ่มขึ้น 1.4 /วัน ใช้สำหรับกำหนดวันเก็บเกี่ยวลองกองล่วงหน้า ลองกองคัลเลอร์มิเตอร์เป็นเครื่องมือที่เหมาะสำหรับกำหนดระยะเก็บเกี่ยวของลองกอง เนื่องจาก LCM เป็นเครื่องมือวัดลองกองชนิดแรก มีประสิทธิภาพ ใช้ง่าย ราคาไม่แพง

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ABSTRACT

In determining the most exact time for optimal harvest of Longkong fruit-clusters, the spectral reflectance of ripening fruit-clusters and the designed Computer Program for Color Analysis of Longkong Fruits (CPCAL) were used to find out that the blue value of Longkong skin rind photographed with a digital camera and red LED light source was the best indicator for determining harvest time. Furthermore, the researcher could develop Longkong Color Meter (LCM) for practical application.

During the growth of the fruit-clusters from immaturity to over-ripe phase selected Longkong fruit-clusters at an orchard were photographed daily with a digital camera and red and green LED bulbs as light sources. The changes in the three basic colors i.e. red, green, and blue in the photographs were analyzed with CPCAL. The obtained results were then compared with the total soluble solids per total acidity (TSS :TA). It was found that the Br value was inversely proportional to ripeness of Longkong fruits. The investigations suggested that the appropriate time to harvest Longkong should be 96 ± 8 days after the first flower of the fruit-cluster bloomed when the Br value was in the range of 8.67 – 2.39. When the fruit-cluster was cut while the Br value was in the range of 8.67 – 5.53, the fruits tasted sweet and sour and still formed a firm cluster suitable for a long distance shipment. But when the Br value was in the range of 5.52 – 2.39, the fruits had the right taste to be sold in local areas. In addition, the researcher found that the Br value decreased at the rate of 0.45 degree per day. This finding makes it possible for growers to plan their exact harvest days.

Because the above procedure was complicated and time consuming, the researcher developed the LCM to measure the red, green, and blue values in the skin rind of Longkong and validated its reliability with TSS : TA method. The experiment showed that with LCM the red value was most linearly related with the fruits' TSS : TA. The increase of the red value changed markedly

at the age of days 91 and 96 when the red values were of 60 and 67, respectively. This correspondence was a clue for 2 proper stages in harvesting Longkong: the first for a distant shipment on day 91 when the fruits tasted sweet and sour, and the second for local markets on day 96 when the fruits had the best flavor and fragrance. The finding that the rate of red value increased 1.4 degree per day also helped confirm the exact harvest days. Because LCM, which is the first device of its kind, is efficient in application, easy to use, and inexpensive, it can be a handy device for Longong growers in determining the proper harvest time of Longkong.

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Pungtip Kaewtubtim

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Longkong (*Lansium domesticum Corr.*) is an important economic fresh fruit of Thailand with a net income of about 15,600 baht per rai for an average yield of 488 kg per rai. [1]. It is one of several distinct forms of the species *L. domesticum* which includes Langsat, Duku and Duku Langsat [2]. Longkong trees of a medium height are native to Malaysia, Thailand and Indonesia [3]. The major states of Malaysia where Longkong is cultivated are Kelantan, Trengganu, Johor, Pahang and Kedah [2]. Longkong growing in Thailand is believed to have started in Narathiwat province [2]. The trees also grow on the east coast of Thailand and in the Uttaradit province in the North. Longkong is eaten fresh as a source of carbohydrate, protein, calcium, phosphorus, iron and vitamin C [4].

Problems in Longkong growing include (1) growers' lack of technical knowledge, (2) improper use of chemicals, and (3) unpredictable market price. Therefore growers need help from relevant agencies in the form of technical advice and training in order to apply their knowledge efficiently [1]. As for Longkong export, a major problem is the difficulty in separating immature fruits from mature fruits. Even experienced sorters can hardly prevent a significant proportion of immature fruits in their sale at the beginning of harvest season. When immature or unevenly ripe fruits do not have good flavor and fragrance, buyers are distrustful of the produce and this often pushes the price down.

Since non climacteric fruits can only be stored for 3-5 days at ambient temperature (25-30 ºC) and lower temperature may cause a freeze-burn, Longkong cannot be transported in cold storage to distant markets.

1.2 Literature review

1.2.1 The generality of Longkong fruits

Longkong (*Lansium domesticum Corr.)* has almost seedless fruits with a brittle skin and the size of 30 to 60 mm in diameter. There are 15 - 25 fruits per a Longkong inflorescence. The skin of young fruits is pale green and, when ripe, turns yellow with some brown spots while its sap is no longer sticky. The green seed is covered with white translucent pulp. During ripening period, astringency in the pulp declines while sugar increases six folds. The skin bruises very easily leading to brown discoloration [5].

1.2.2 The development of the Longkong flower

The Longkong tree bears flowers on 1-8 inflorescences arising from floral cushions on main branches. Each inflorescence is 15-20 cm long bearing 20-50 hermaphrodite flowers measuring about 6 mm across, which develop into nearly spherically shaped fruits [2].

1.2.3 The development of Longkong fruits

The yellow fruits are round or egg-shaped with a diameter of 2-4 cm. They grow densely in the form of fruit-clusters. Most seeds are polyembryonic, producing up to 5 seedlings per seed [2].

Some critical physiology-chemical characteristics of Longkong fruits during their growth have been studied [2]. It is known that their TSS:TA increases during fruit growth and the acid content decreases in the final phase of ripening, namely during maturation [6].

1.2.4 Factors and conditions

The Longkong fruits can be harvested at about 16 weeks after the bloom of the first flower. At this point, the fruit size reaches about 25-35 mm diameter with skin color changing from green to yellow or greyish yellow and pulp becoming translucent and sweet. The mature fruits without latex on skin will yield to pressure [2]. Studies on suitable harvesting stages of Longkong show that the cluster have to be harvested when more than 75% of the fruits in the cluster reach maturity (i.e., the fruits are fully expanded and have a yellow skin) [7]. Studies on fruit development carried out from Apr. to Sep. 1982 showed that over 95% of fruits had 5 carpals. The curve showing growth from fruit set until maturity was sigmoidal, and the growth period lasted 14 weeks. During the 13 weeks the fruit shape is spherical global and changes to spherical a week later. The rind thickness increased after fruit set until week 9, then decreased gradually until maturity. The percentage of the total soluble solids (TSS) in the fruit juice increased gradually until week 14 with a maximum of 17%. The titration acidity (TA) decreased down to 1% in week 15. The TSS:TA ratio in week 15 was 18.1. Harvesting is recommended during weeks 14 -16 after fruit set [8]. Fruit yellowing (FY) is the stage at which all Longkong fruits in a fruit-cluster have a yellowish-green pericarp. Longkong harvested 4, 7, 10 and 14 days after the FY stage were observed for quality changes after being stored for 5 days under ambient conditions. Results from this experiment suggested that Longkong fruits could be harvested as early as at 4 days after FY (6-8 fruits in a bunch exhibited a shade of green on their skin, while the rest were yellow) if the fruit would have to be stored for a long period of time. The color of pericarp from all stages of ripeness changed to brownish-yellow after 5 days of storage. Fruit firmness decreases 2-folds after storage. The amount of TSS in fruits harvested on days 4 and 7 after FY increased during storage while the TA in fruit from all stages of ripeness decreased, which resulted in an increase in the TSS:TA ratio. The fruit harvested at an early stage of ripeness attained acceptable sweetness after 5 days of storage under ambient conditions [9]. Rattanawong reported that the optimal harvesting was when Longkong ripened about 80% because the fruits tasted sweet and sour and were strong enough for distant shipments. The following standard indicators should be considered to determine the optimal harvest of Longkong fruits: 1) age of fruits since first blossom until ripe phase taking about 180-200 days; 2) color of Longkong rind changing from yellow into dark yellow; 3) fruits at the end of inflorescence being soft and sweet; 4) pulp having a clear color [10]. Puntuwanit reported the following indicators for optimal harvest: age of Longkong since the first flower blossom until the harvest time about 12-13 weeks; pulp being white clear; TSS ranging 17-19% and TA 0.7 - 0.8 %; the rind of fruits having light-colored yellow [11]. Nakwirot and Sriwattanaworachai reported that the TSS increased during fruit growth and TA content decreased during the maturation [6].

However, all the above methods for determining the appropriate harvest time of Longkong are either subjective or destructive and inconsistent and wasteful. Therefore, nondestructive and objective methods for estimating maturity are needed.

1.2.5 Nondestructive methods for estimating maturity

Schreiber and coworkers checked chlorophyll used in photosynthesizing Longkong fruits because chlorophyll can be used to imply the old - young level of fruits [12]. Kawan reported that sugar in peaches and mandarin oranges were analyzed by a near-infrared (NIR) spectroscope. This method is quite popular because it can analyze the content of elements accurately. However, it is time-consuming, complicated, and expensive to measure and calculate. Also, uncertainty may occur due to the variation of size, and the geometrically asymmetric shape of Longkong fruits[13]. Saranwong and coworkers reported that they had successfully developed a technique for harvesting ripening mango fruits using an NIR spectroscope [14].

1.3 OBJECTIVES

1.3.1 To study the optimal harvesting time of Longong fruits by measuring the spectral reflectance of their fruit rind.

1.3.2 To develop a simple, accurate, time saving and nondestructive device for ripening evaluation of Longkong fruits.

CHAPTER 2

THEORIES

2.1 Color Theory

The capacity of an organism or machine to differentiate objects based on the wavelengths or frequencies of the light they reflect or emit is known as color vision. The nervous system obtains color by comparing the reactions to light from several kinds of cone photoreceptors in the eye, which are sensitive to various portions of the visible spectrum [15].

Color deriving from the light spectrum, light energy distribution against wavelength, interacts in the eye with the spectral sensitivities of the light receptors. Based on physical properties such as light absorption, reflection, or emission spectra, categories and physical specifications of color are also related to objects, materials, light sources, etc.

Usually, only features of the light composition detectable by humans are included; thereby objectively connecting the psychological phenomenon of color with its physical specification. As perception of color emanates from the sensitivity of different types of cone cells in the retina to dissimilar parts of the spectrum, colors are probably defined and quantified by the degree they stimulate these cells to. However, these physical or psychological quantifications of color do not completely explain the psychophysical perception of color appearance.

Light is emitted by most light sources at various wavelengths. A source's spectrum is a distribution which gives its intensity at individual wavelength. The color sensation in each direction is determined by the spectrum of light which arrives at the eye from a given direction. Nevertheless, many more possible spectral combinations than color sensations exist. In fact, a color may formally be defined as a class of spectra giving rise to the same color sensation despite wide variation among different species, and even among individuals of the same species.

The color of an object is subject to both physics and perception. Under physical consideration, it can be said that surfaces have the color of the light which reflects off them. This depends on the spectrum of incident illumination, the reflectance spectrum of the surface, and possibly on the lighting and viewing angles. However, it is not only the reflected light spectrum that a viewer's perception of the object color depends on, there is also a host of contextual clues, where an object's color is likely to be perceived as relatively constant; in other words, not influenced by the lighting spectrum, viewing angle, etc. This effect is known as 'color constancy'.

Primary colors are sets of colors which are able to be combined in order to make 'gamut', a useful range of colors. For human applications, three primary colors often used include red, green and blue. Red and similar colors, evoked by light which predominantly consists of the light wavelengths, range of 625-750 nm, are visible to human. Whereas infrared or below red, which has longer wavelengths, is invisible to human. The perception of green is evoked by light with a spectrum dominated by energy with the wavelength of around 520-570 nm, while the energy with the wavelength of roughly 440-490 nm makes blue [16].

2.2 Measurement Intensity of Light

Photometry is the science dealing with the measurement of visible light, or wavelengths from 390 to 770 nanometers, depending on the use of different references. The measurement of the entire optical spectrum, consisting of ultraviolet, visible and infrared light, is known as radiometry. Ranges of light's wavelengths are from 0.005 microns to 4000 microns.

In the discussion of light measurement, we need to understand flux, illumination, intensity and luminance. We must also consider what is going to be monitored and how we can make accurate measurement in order to decide the principal quantities involved in photometry and radiometry.

Photometry and radiometry are related; in that, both deal with light energy or flux. Visible light energy, known as luminous flux, is measured in lumens, while radiant light energy – radiant flux – is measured in watts. Wavelengths of luminous flux range from 390 to 770 nanometers, whereas those of radiant flux cover all optical spectrums, namely ultraviolet, visible and infrared wavelengths.

Luminous flux and radiant flux are connected in terms of a wavelength factor developed by the Commissioner Internationale de'Clairage (CIE) in France in 1724. The photopic eye response curve, developed from a sample of the population under daylight conditions, represents an average eye. Wavelength related to relative luminosity or visual response by the curve is called the luminosity function. The maximum efficiency of the average eye to see best is at 555 nanometers, and 680 lumens per watt is its conversion factor. Wavelengths other than 555 nanometers, but within the visible range, must be converted to the luminosity function in accordance with the CIE spectral response curve. Test equipment used in photometry, therefore, must employ sensors suitable for the CIE curve.

Terms related to the science of photometry are as follows.

Candela (cd) : The basic unit of luminous intensity or flux per unit solid angle.

Lumen (lm) : The basic unit of luminous flux, equal to one candela (cd) of flux generated by a source point into a solid angle of one steradian.

Luminous Energy (Q_V) : The generic term for luminous flux.

Luminous Flux (ϕ_V) : The photometric measurement for luminous energy with lumen (lm) as the SI unit.

Luminous Intensity (I_V) : The luminous flux measurement per unit solid angle from a point source with the candela (cd) as the SI unit, and lumens per steradian (lm/sr) as the unit of luminous intensity is [17].

2.3 Light Detector

A light detector refers to anything responding to light energy. However, to be of value, the detector must change the light energy into another useful form of energy.

2.3.1 Natural Light Detectors

Since objects will convert sunlight to heat, everything is, in a broad sense, a light detector. However, it does not mean that almost all the objects are particularly beneficial as detectors as they offer a small amount of details about the light's characteristics or the medium which the light comes through. What we probably like to know are the direction which the light comes from, the light's intensity as well as its wavelength or colors, all of which are difficult to decide from the object's temperature.

2.3.2 Detectors

The most commonly used detectors in optoelectronic controls perhaps are the photovolataic detectors which use the PN junction effects of semiconductor materials and are divided into several classes of commercially available devices. The photodiode, the simplest

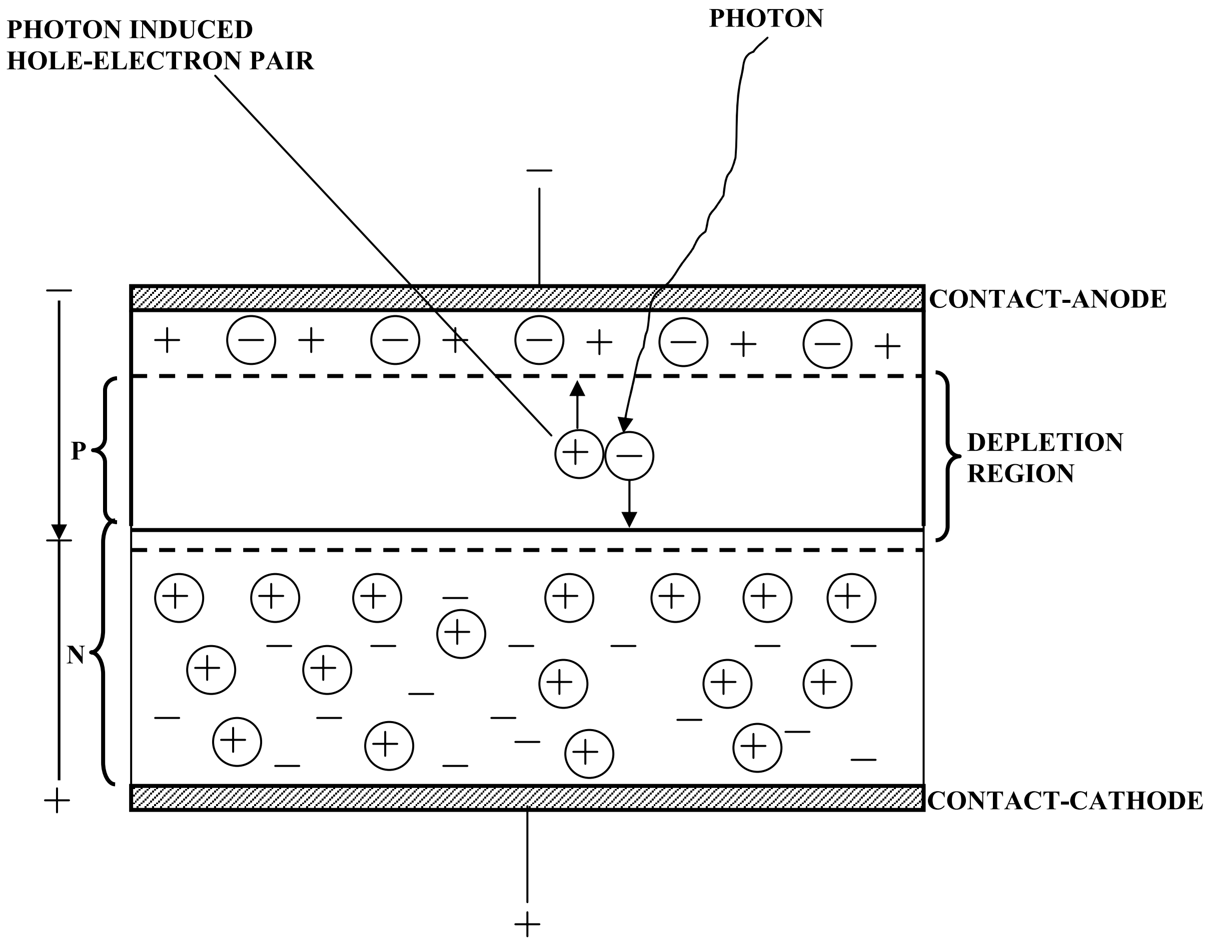


Figure 2.1 Reverse Biased PN Junction

form, is the building block which photo transistors, photo FETs (Photo Field-Effect Transistors), photo SCTs (Photo Silicon-Controlled Rectifiers), photo TRIACs (Photo Silicon-Controlled

Rectifiers Connected Head to Toe), and many photo sensitive integrated circuits are built upon. In Figure 2.1, a cross section of a reverse biased PN junction diode is illustrated. The deletion region of the PN junction functions as an insulation between the anode and cathode since neither free electrons nor holes are present in this region. A photon with energy equal to the energy gap is absorbed when entering the depletion region. Therefore, hole-electron pairs are formed due to this absorption. The hole-electron pair is separated and swept quickly out of the depletion region; the (-) portion of the pair will be transferred to the anode, and the (+) portion to the cathode. If the diode is biased as illustrated, a current flow through the reversed biased diode will be the result. If the hole-electron is made outside the depletion region, it will likely recombine, and there will not the production of photo current. So as to optimize the PN junction as a photodetector, the P region, therefore, ought to be as thin as possible to reduce the recombination probability. On the other hand, the thick depletion region is required to improve sensitivity. However, this thick depletion region causes the reduction in junction capacitance, which allows the photodiode to be capable of responding to rapid changes in high levels.

2.3.3 Selecting a Photo Detector

A light detector should include the following qualifications: enough sensitivity for the application, wavelength characteristic suitable for the source, effective cost, including initial cost, reliability and operating cost, ability to see light sources and electrically compatible with the rest of the system [18].

2.4 Light-Emitting Diode (LED)

A light-emitting diode (LED) refers to a semiconductor diode which emits incomplete narrow-spectrum light when it is electrically biased in the p-n junction’s forward direction, the effect of which is a form of electroluminescence. An LED is often a small area source and usually with additional optics added to the chip shaping its radiation pattern. The composition and condition of the semiconducting material used differently influence the color of emitted light into infrared, visible or near-ultraviolet. An LED can be utilized as a usual household light source.

An LED, similar to an ordinary diode, consists of a chip of impregnated or doped semiconducting material with impurities to create a p-n junction. Like in other diodes, current easily flows from the p-side (anode) to the n-side (cathode), but does not flow backwards. From electrodes flow charge-carriers-electrons and holes into the junction with different voltages. Meeting a hole, an electron falls into a lower energy level and allows energy to move in a photon form.

The band energy gap of the materials which form the p-n junction affects the wavelength and color of the light emitted. As indirect band gap materials, the electrons and holes, in silicon or germanium diodes, recombine by a non-radiative transition not producing any optical emission. On the other hand, the materials used for an LED have a direct band gap with energies corresponding to nearinfrared, visible or near-ultraviolet light.

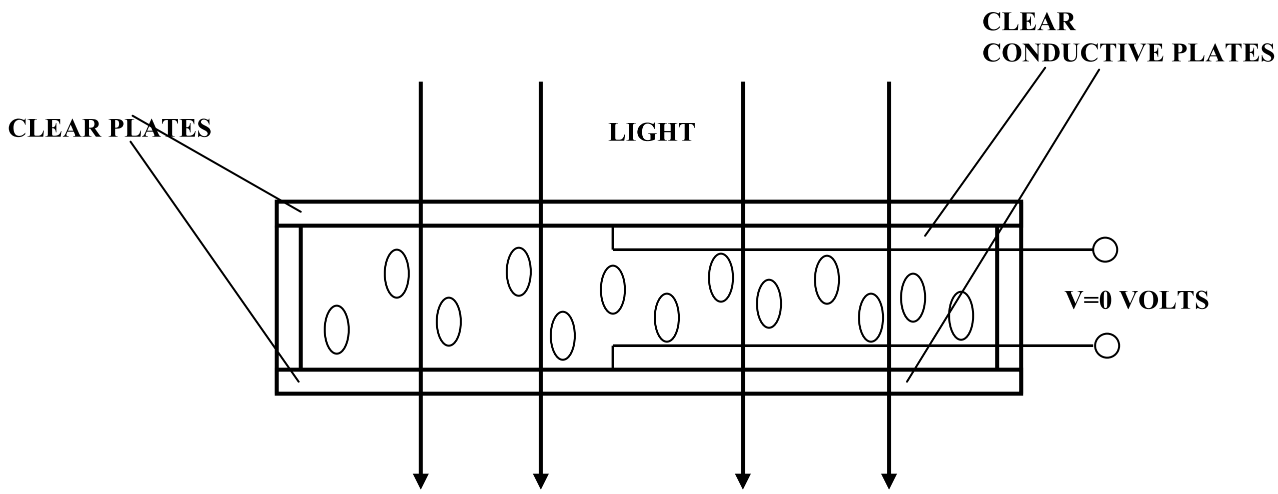
Added to existing red and green LEDs, blue LEDs can produce the impression of white light. This principle, however, is rarely used by white LEDs. In today's production, most white LEDs are based on an InGan-Gan structure, and emit blue light of wavelengths between 450 nm and 470 nm blue GaN. These Gan_based and InGaN-active-layer LEDs are usually covered by a yellowish phosphor coating made of cerium-doped yttrium aluminum garnet (Ce^{3+} : YAG) crystals having been powdered and bound in a type of viscous adhesive. The LED chip emits blue light which is partially changed into a complete broad spectrum with the center around 850 nm (yellow) by the Ce^{3+} : YAG. In fact, the single crystal form of Ce^{3+} : YAG is considered a scintillator rather than a phosphor. As the red and green receptors of the eye are stimulated by the yellow light, the combination of blue and yellow light produces the 'lunar white' shade [19].

2.5 Liquid Crystal Displays (LCD)

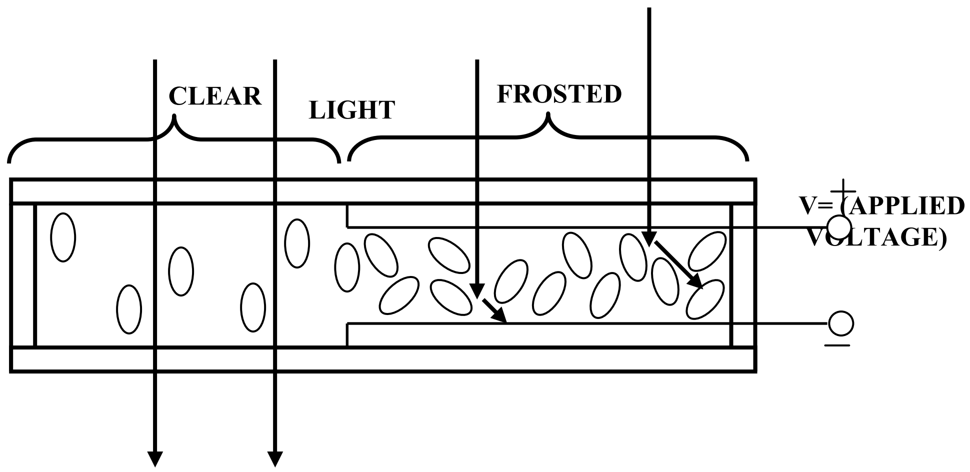
The liquid crystal display is a display type with unique features. Considering this as an optoelectronic display in some cases might be a misnomer as no light is emitted through this kind of display. On the other hand, the liquid crystal display merely employs the surrounding light to convey information. However, as light is a crucial ingredient, the displayed information is controlled by electrical bias. The display content is visually numeric and alphanumeric.

As a medium, the liquid crystal material is placed in a small space between two glass plates, a clear conducting material of which is arranged in a pattern on their inner surfaces. Without bias application to the plates, the liquid crystal molecules, demonstrated in oval shapes in Figure 2.2a, are oriented. The light, as a result, passes through the clear material which has a minimum of scattering. In contrast, with a bias utilization the crystals between the plates are disoriented. The light, therefore, is scattered and results in a frosted appearance as illustrated in Figure 2.2b. If a black plate is placed behind the display, it absorbs the passing-through light. As a result, the area with no bias becomes black to the viewer. The result of a visible contrast influenced by dissimilar reflectivity on the right and left sides of the display is shown in Figure 2.2b. If the biasing plates are properly arranged into segments or matrices, characters are able to be formed with the use of control circuitry similar to that of VLED displays.

The crucial benefit of the displays is their consumption of little power (a few microwatts) because of their production of no light and requirement for very low voltages in operation. With this result, their direct drive can be from almost any low voltage logic circuit, multifunction integrated circuit or microprocessor. The major disadvantages of the displays are that the ambient light must be present for the contrast recognition, and the temperature harmfully affects the performance. Low temperature on the one hand, slows the response time, but high temperature, on the other hand, can cause a loss of the scattering that the bias makes. The temperature performance in many applications is acceptable. Nevertheless, to see liquid crystal displays in darkness, ambient light must be supplied [18].



a. The oval shaped crystals are aligned so that most of the light passes through the display.



b. The light on the left of the display passes through while the light on the right is partially blocked by the randomly distributed crystals.

Figure 2.2 Liquid Crystal Display

2.6 Color Sensor

A sensor is a type of transducer. Most censors are electrical or electronic. Direct-indicating sensors, like a mercury thermometer, are human-readable. A thermocouple is an example of sensors which must be used with an indicator or display.

The TAOS TCS230A is a small, highly integrated color sensing device in a clear plastic 8-pin SOIC package. Its functions like analog frequency are to report the amount of shortwave (blue), mediumwave (green), longwave (red) and wideband (white) optical power incident onto the device. Moreover, it can also be employed in various color sensing applications. For instance, it details the concepts and calculations involved in color sensing by using the TCS230 programmable color light-to-frequency converter, which combines configurable silicon photodiodes and a current-to-frequency converter on single monolithic CMOS integrated circuit. It brings out a square wave (50% duty cycle) with frequency directly proportional to irradiance or light intensity. The frequency of full-scale output can be measured by one of the three prepared values through a couple of control input pins. Both digital inputs and outputs allow direct interface to a microcontroller or other logic circuitry.

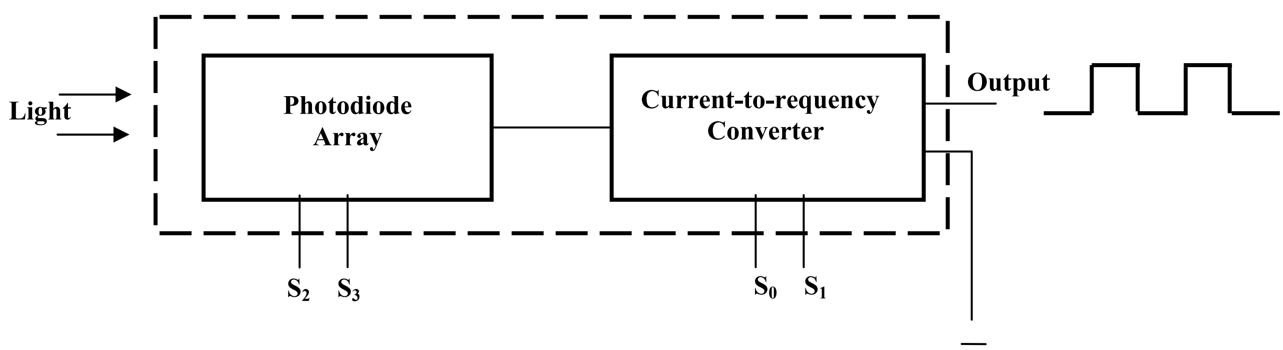


Figure 2.3 Functional Block Diagram

The light-to-frequency converter reads an 8 x 8 array of photodiodes (120 um x 120 um in size and on 144-um centers). Each group of sixteen photodiodes separately contains blue filters, green filters, red filters and clear with no filters. These four colors of photodiodes are employed to reduce the influence of non-uniformity of incident irradiance. All sixteen photodiodes of the same color are joined together in parallel to photodiode of the device (pin-selectable) which is used during the operation [20].

2.7 Microchip PIC16F877 Microcontroller

A microcontroller is a compact stand alone computer for application control. A whole processor, memory and the I/O interfaces on a single piece of silicon assists in economizing time to read and write to external devices.

There are five reasons why microcontrollers are incorporated in control systems.

1. Cost: Microcontrollers with the supplementary circuit components is much cheaper than a computer with an analog and digital I/O.

2. Size and Weight: In comparison with computers, microcontrollers are compact and light.

3. Simple Applications: Microcontrollers are suitable for applications that require very few number of I/O with the small code, no extended amount of memory, and only a simple LCD display as a user interface.

4. Reliability: Microcontrollers hardly encounter failure owing to its simpler architecture than that of a computer.

5. Speed: Microcontrollers run much faster than a computer as all of the components are located on a single piece of silicon.

PIC16F877 is one of the most commonly used microcontrollers, especially in automotive, industrial, appliances and consumer applications. Its block diagram is described as follows.

The important features of PIC16F877 are high performance RISC CPU. There are only 35 single word instructions to learn. Except for program branches, all single cycle instructions consist of DC-20 MHz clock input, DC-200 ns instruction cycle, up to 8K x 14 words of FLASH Program Memory, up to 368 x 8 bytes of Data Memory (RAM), up to 256 x 8 bytes of EEPROM Data Memory, pinout compatible to the PIC16C73B/74B/76/77, interrupt capability (up to 14 sources), eight level deep hardware stack, direct, indirect and relative addressing modes, Power-on Reset (POR), Power-up Timer (PWRT) and Oscillator Start-up Timer (OST), Watchdog Timer (WDT), with its own on-chip RC oscillator for reliable operation, programmable code protection, power saving SLEEP mode, selectable oscillator options, low power, high speed CMOS FLASH/EEPROM technology, fully static design, In-Circuit Serial Programming (ICSP) via two pins, processor read/write access to program memory, wide operating voltage with 2.0V to 5.5V range, high Sink/Source Current of 25 mA, commercial, industrial and extended temperature ranges and low-power consumption [21].

CHAPTER 3

MATERIALS AND METHODS (SECTION 1)

In order to test the hypothesis about the correlation between the harvest time of Longkong fruit clusters, the change of their rind color, and the TSS:TA ratio, an analysis was conducted. A digital camera with red and green LED light sources was used to take photographs to study the spectral reflectance of ripening Longkong fruit-clusters which was then compared with the the TSS : TA.

3.1 The analysis of the TSS:TA of Longkong fruits

3.1.1 Materials

1) Hand Refractometer
2) White cloth
3) Sodium hydroxide solution
4) Phenolphthalein
5) Sample Blender
6) Tags

3.1.2 Methods

1) Selecting and tagging the budding fruit-clusters and recording the date for the first bud blossom.
2) Analysing the TSS of Longkong fruits by using a hand refractometer. Longkong pulp samples were crushed into tiny pieces by a machine blender. Their juice was filtered through thin white cloth.
3) Titrating the juice by adding a few drops of 1% phenolphthalein and sodium hydroxide solution.
4) Computing the TSS : TA each day after taking Longkong photographs.

3.2 A study of the spectral reflectance of ripening Longkong fruits

3.2.1 Materials

1) materials for making Light Control Box
2) red and green LED bulbs, 120 each
3) 12 volt battery
4) Cannon digital camera with Power Shot A20 at 480 × 640 pixel
5) white future board

3.2.2 Methods

1) Building up the Light Control Box (LCB) to keep external light out
2) Installing red and green LED bulbs inside the LCB as light sources (Appendix A-1)
3) Wiring the 12 volt battery on the LCB for power supply (Appendix A-2)
4) Fixing an A4 white future board behind the selected Longkong fruit-cluster (Appendix A-3)

5) Covering the fruit cluster with the LCB

6) Taking 8 photographs of each cluster with each LED light source (Appendix A-4 a)

3.3 Color analysis from images of Longkong fruits

Digital LCB photographes were analysed by using Computer Program For Color Analysis of Longkong Fruits (CPCAL). From each photograph 5 - 8 areas were selected to represent each studied Longkong fruit-cluster (Appendix A-4b). The program will analyse the value of each of the three colors (R, G, and B) in each pixel of each circled area. After that the total value of each color in all pixels of the cluster was calculated and averaged out. The same analysis was conducted for photographs taken with different light sources. The process is illustrated in Figure 3.1.

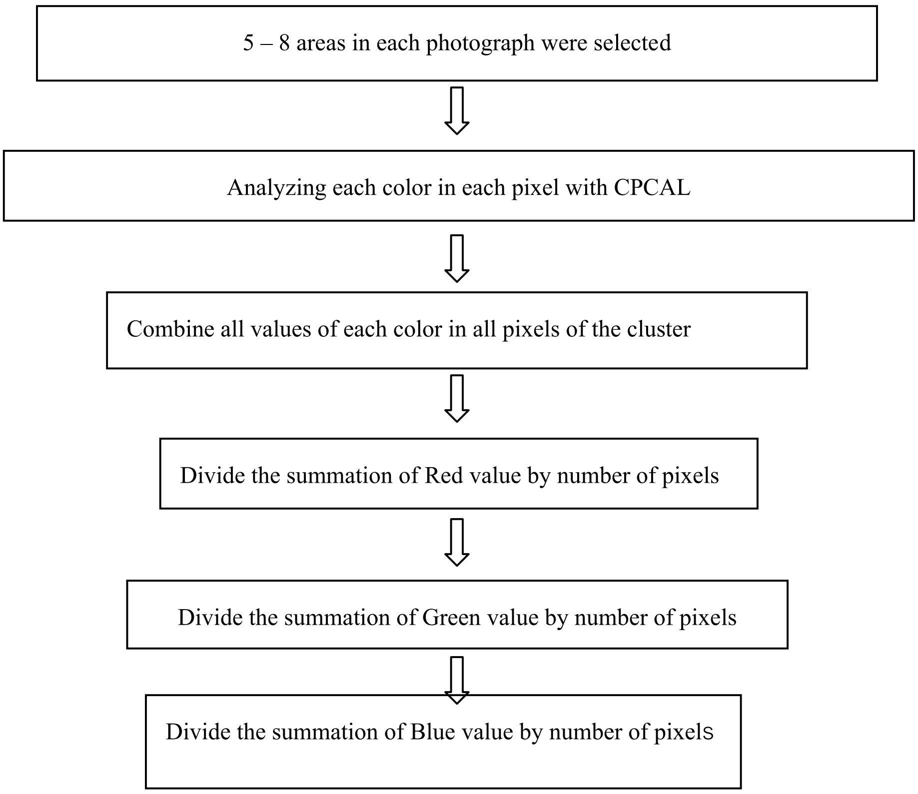


Figure 3.1 The procedure for RGB spectrum analysis of Longkong

CHAPTER 4

RESULTS AND DISCUSSIONS (SECTION 1)

The TSS : TA was investigated with respect to the spectral reflectance of ripening fruit-clusters while the ripeness was analysed from images of those fruits taken by a digital camera incorporated with red and green LED bulbs. The obtained data was used to specify the relationship between the TSS : TA of the fruits and the visible and measured color shift of the fruits' skin throughout the ripening process.

4.1 The TSS : TA

The average TSS:TA ratio derived from the analysis of 4 sets of Longkong fruit-clusters from day 65 after the first blossom of the inflorescence until day 105 is shown in Table 4.1.

Table 4.1 The TSS : TA content of Longkong fruit performed in 4 sets as shown.

Age (day)	Set 1	Set 2	Set 3	Set 4	TSS:TA
65	3.25				3.25
68			2.87		2.87
69	3.56		3.17		3.37
70			2.81		2.81
72			3.40		3.40
73	3.83		3.44		3.63

Table 4.1 (Continued)

74			2.97		2.97
75	3.22				3.22
76			3.67		3.67
77	2.58				2.58
79	3.29		3.14		3.21
80			5.11		5.11
81	3.9				3.90
82			2.45		2.45
83	6.02				6.02
84	5.51		4.98		6.26
85	8.66	3.41		6.69	6.25
86	8.85	6.95	3.41	7.69	6.97
87	8.46	3.05		11.83	7.78
88	9.38		4.22	7.94	7.18
89	9.90	3.04	3.41	14.70	7.76
90			6.95	14.82	10.89
91	13.32	2.81	3.05	8.75	6.98
92	13.72		5.25	20.75	13.24
93	11.48	9.79		20.06	13.78
94	12.43		12.01	19.44	14.63
95	17.14	13.36		24.51	18.34
96	18.10		16.76	20.21	18.36
97	18.23	11.76		24.49	18.16
98	20.31		16.98		18.64
99	20.59	15.58		21.23	19.13

Table 4.1 (Continued)

100	18.14		18.56	23.71	20.13
101	23.14	20.61			21.88
102	19.68	23.61	19.91		21.07
103	21.24	19.80		25.48	22.15
104		19.75	26.40		23.08
105		23.60			23.60

Figure 4.1 shows the TSS:TA against the age since the first blossom of flower buds. The curve was quadratic, equivalent to the equation $y=0.0192x^2 - 2.6964x + 97.283$ with a reliability (R^2) of 0.9599**.** The graph was divided into two parts: the first for the period of days 64 - 82, when the TSS:TA was quite low and constant; the second for that after day 82, when the TSS:TA increased linearly versus time.

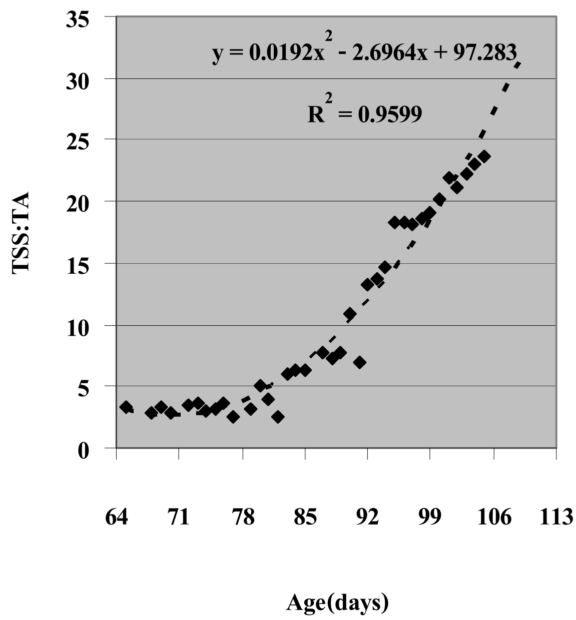


Figure 4.1 The correlation between the Longkong age and its TSS:TA.

4.2 The spectral reflectance of ripening Longkong fruit-clusters

To determine the appropriate harvest time of Longkong fruit-clusters, the spectral reflectance was investigated from images taken by a digital camera incorporated with red and green LED bulbs. Every day, selected Longkong fruit-clusters at an orchard were photographed, starting from immature phase to the over-ripe phase. The changes in the three basic colors, i.e. red, green and blue, of the images were measured with a specially developed Computer Program for Color Analysis of Longkong Fruits (CPCAL) as shown in Table 4.2.

Table 4.2 Result of color value per pixel in images of Longkong, analysed by means of the CPCAL software.

Age (days)	**Rg**	**Gg**	**Bg**	**Rr**	**Gr**	**Br**
70	10.40	11.10	8.60	15.80	8.00	9.40
71	13.80	14.61	9.83	17.58	9.00	10.55
73	19.10	20.50	14.70	28.50	10.10	18.40
74	11.21	13.04	8.88	16.12	7.99	9.93
75	17.10	18.52	14.33	25.33	10.93	17.40
76	15.85	17.55	11.90	23.80	9.60	13.47
77	13.93	19.30	10.65	22.50	8.42	12.06
78	15.49	17.16	13.31	23.49	9.66	14.66
79	13.94	16.44	9.57	23.12	8.75	10.98
80	17.83	22.93	12.73	29.69	8.83	14.02
81	18.37	22.49	12.57	35.24	8.42	14.28
82	18.55	24.40	11.00	32.92	7.68	12.86
83	24.44	33.85	11.99	51.53	6.29	13.57

Table 4.2 (Continued)

84	18.77	24.81	12.14	36.03	7.38	13.44
85	27.30	40.78	9.61	69.78	4.55	10.12
86	18.84	27.13	13.63	27.94	8.62	11.72
87	30.63	39.83	11.30	69.59	7.61	10.99
88	21.36	36.73	8.51	65.70	4.80	6.31
89	27.80	38.77	6.44	59.76	9.40	9.06
90	31.04	49.01	5.37	75.73	10.29	5.63
91	31.06	43.01	7.67	73.91	7.81	8.35
92	37.26	59.14	7.75	105.71	5.72	8.96
93	31.41	47.29	7.57	95.76	6.92	6.17
94	24.17	50.79	4.36	100. 54	1.18	5.94
95	30.03	44.31	6.05	101.69	0.26	3.60
96	24.94	42.52	6.27	92.57	0.50	2.63
97	32.81	44.51	6.08	97.97	0.14	3.81
98	25.42	40.98	7.49	92.55	0.48	5.00
99	25.88	49.16	5.40	103	0.02	2.07
100	30.83	42.05	8.06	98.34	0.18	5.15
101	19.82	34.00	7.65	85.02	0.41	2.58
102	19.53	29.46	8.29	82.96	0.38	2.38
103	26.84	58.30	2.88	117.73	0.08	0.98
104	19.66	39.01	5.12	96.07	0.09	0.87
105	24.00	44.36	4.40	101.31	0.22	1.43
106	27.79	50.24	4.35	115.00	0.24	3.60
107	23.32	52.58	3.60	116.09	0.00	0.48
108	28.97	45.45	5.88	105.75	0.00	2.43
109	24.82	37.04	8.13	98.67	0.00	1.94

Note : Rg, Gg and Bg are the average Red, Green and Blue color values per pixel of 30 Longkong fruit-clusters illuminated by the Green LED light source, while Rr, Gr and Br are the average Red, Green and Blue color values per pixel of the same clusters illuminated by the Red LED light source.

The resulting color values per pixel from experiments in various conditions as shown in Table 4.2 were analysed by plotting each color value per pixel versus the age in days as shown in Figures 4.2 - 4.7. For further analysis, multi correlations between the color value per pixel versus age (days) and versus the TSS : TA were plotted together as shown in Figures 4.8, 4.9 and 4.10.

Figure 4.2 shows the relationship between age (days) of Longkong fruits since the first flower bud blossomed against the average Rg value of the fruit's skin when photographs were taken with the green LED light source. The resulting equation was $y = -0.0271x^2 + 5.2061x – 222.85$, with R^2 of 0.6066. The graph shows how the average Rg value varied with the Longkong fruit age. The red value per pixel reached its maximum level of 28 on day 96. After that the red value declined due to the change of the skin towards a brown color.

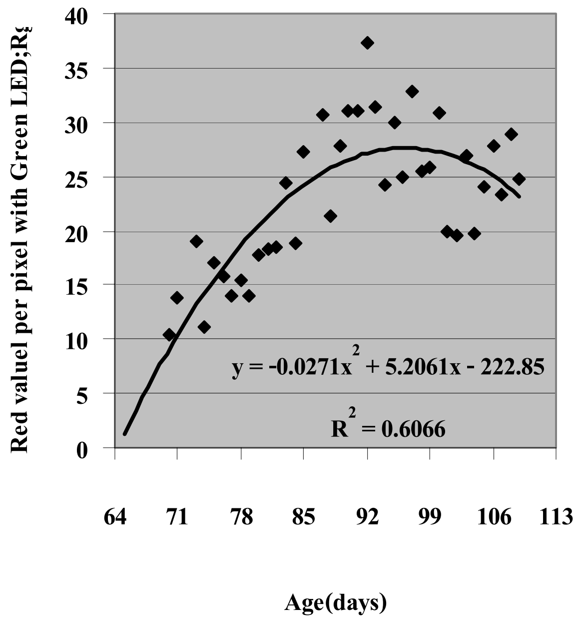


Figure 4.2 The change of the Rg value against the age of the fruits using the Green LED.

Figure 4.3 shows the relationship between age (days) of Longkong fruits since the first bud blossom against the average Gg value when photographs were taken with green LED light source. The graph equation was $y = -0.039x^2 + 7.9435x - 358.37$ with R^2 of 0.7511. The graph indicates that the green value reached its maximum value of 45 on day 100. After that the green value started to decline.

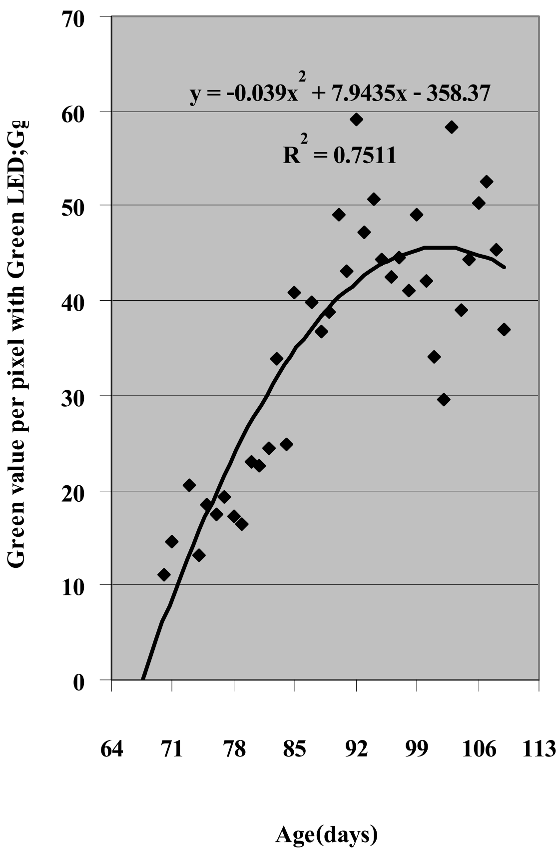


Figure 4.3 The change of the Gg value against the age of the fruits using the Green LED.

Figure 4.4 shows the relationship between age (days) of Longkong fruits since the first bud blossomed against the average Bg value of photographs taken with the green LED light source. The graph shows a linear decline with a negative slope : y = -0.2061x + 26.992, with R^2 of 0.5905.

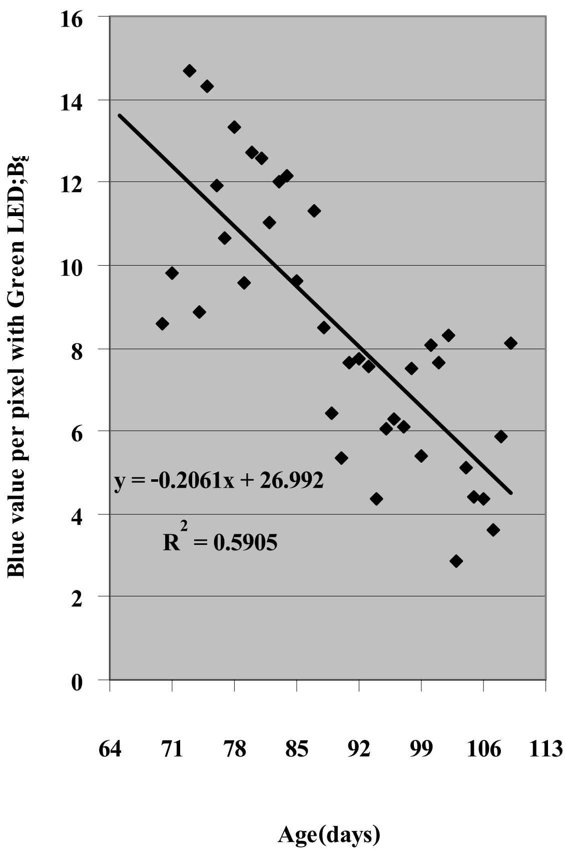


Figure 4.4 The change of the Bg value against the age of the fruits using the Green LED.

Figure 4.5 shows the relationship between age (days) of Longkong fruits since the first bud blossomed against the average Rr value of photographs taken with the red LED light source. The graph is linear with y = 2.805x – 184.08, and its R^2 is 0.8734.

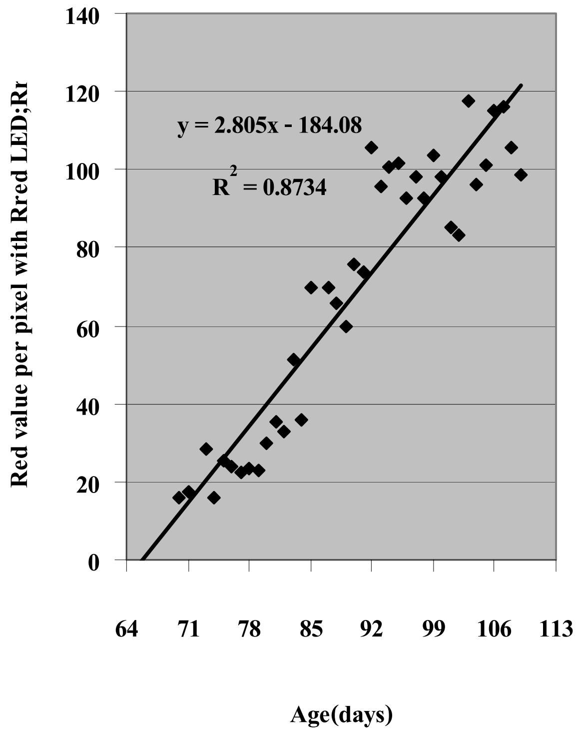


Figure 4.5 The change of the Rr value against the age of the fruits using the red LED.

Figure 4.6 shows the relationship between age (days) of Longkong fruits since the first bud blossomed against the average Gr value of photographs taken with the red LED as a light source. The graph had the equation $y = -0.0035x^2 + 0.3159x + 5.2133$, and has R^2 of 0.7865. This graph decreased rapidly as the time reached day 92. At this stage the Longkong skin rind color changed into yellow.

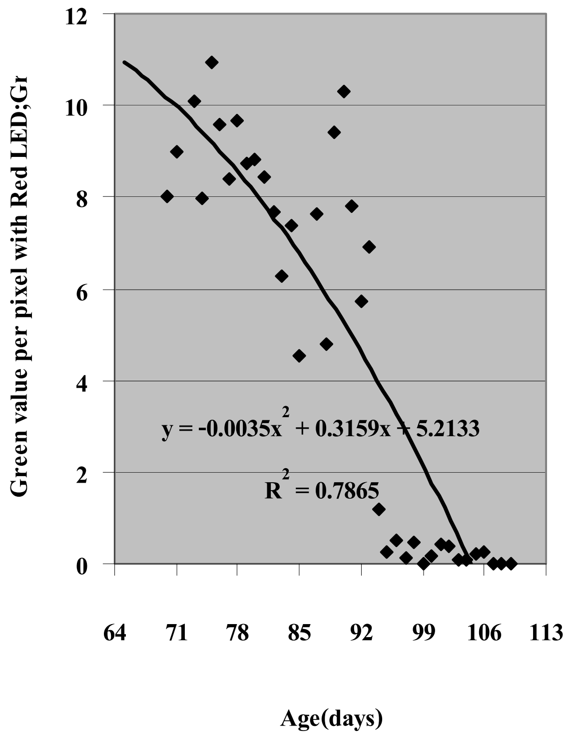


Figure 4.6 The change of the Gr value against the age of the fruit using the red LED.

Figure 4.7 shows the relationship between age (days) of Longkong fruits since the first bud blossomed and the average Br value when photographs were taken with the red LED light source. The graph was linear with y = - 0.3885x + 42.764 and has R^2 of 0.7829. It showed that the blue color value of Longkong skin decreased when the color of Longkong skin rind changed into yellow and the linear change continued when the fruit was over- ripe.

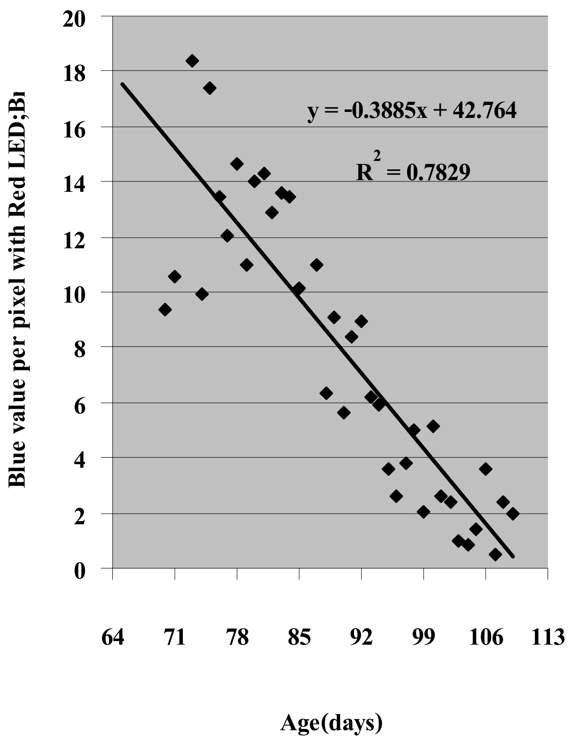


Figure 4.7 The change of the Br value against the age of the fruit using the red LED.

Figure 4.8 shows correlations between the age (days) of Longkong fruits since the first bud blossomed and the TSS : TA and the average Bg value. Both linear correlations, namely Age vs Bg and Age vs TSS : TA, showed the equation of y = - 0.2319x + 29.516 with R^2 equal to 0.4661. This graph shows that the intersection point between the age vs Bg and age vs TSS :TA was on day 93 since the first Longkong flower bud blossomed. If the deviation for the main indicators, namely the age (days), TSS : TA, and Bg, is taken into account, the figures for optimal harvest of Longkong clusters should be 93 ± 9, 14.5 ± 7, and 8 ± 3 respectively.

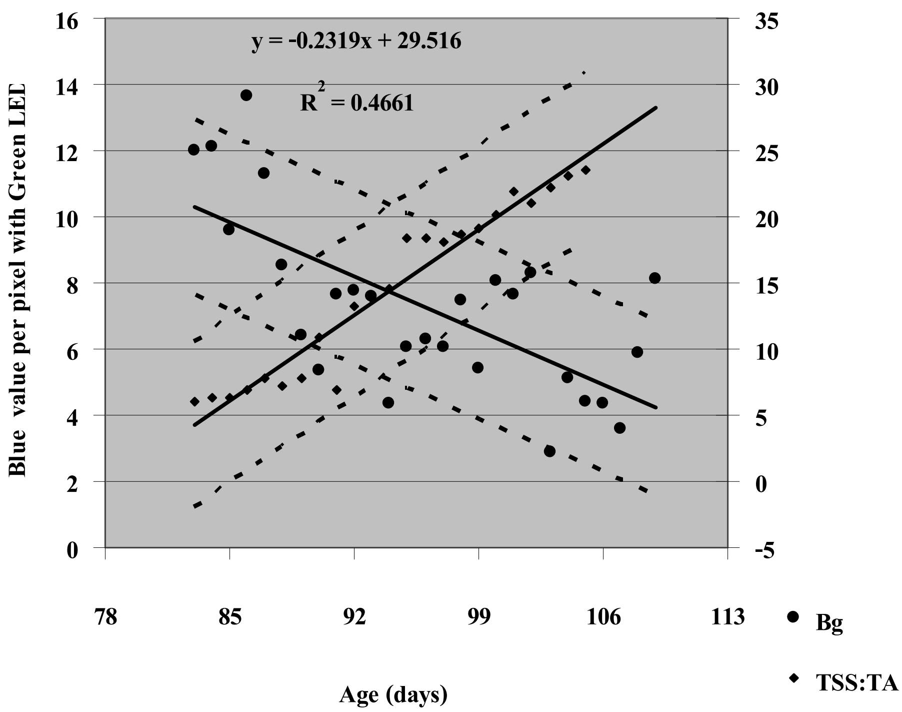


Figure 4.8 Multi correlations between age (days) and the Bg value and the TSS: TA of photographs taken with the green LED light source.

Figure 4.9 shows correlations between the age (days) of Longkong fruits since the first bud blossomed and the TSS :TA and the Gr value of photographs taken with the red LED light source. Both linear correlations, namely age vs Gr and age vs TSS : TA showed the equation of y = -0.3752x + 39.113 with R^2 of 0.6592.At the cross sectional point between the linear graphs of age vs Gr and age vs TSS : TA was the Longkong age on day 95 since the first bud blossom. If the deviation for the main indicators, namely the age (days), TSS : TA and Gr, is taken into account, the figures for optimal harvest of Longkong clusters should be day 95±8, 16±7, and 3.4±4, respectively.

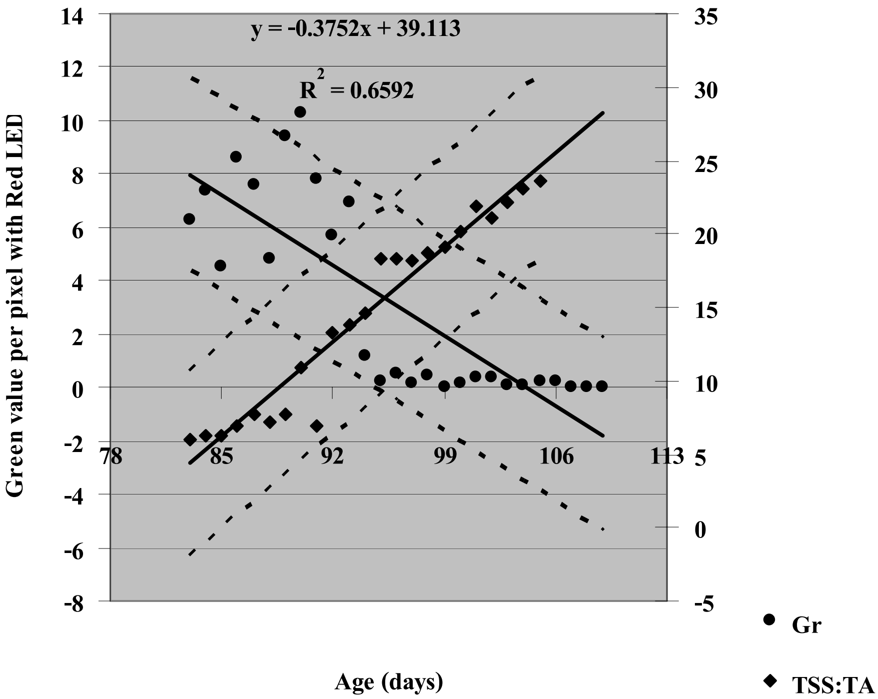


Figure 4.9 Multi correlation between age (days) and the Gr value and the TSS: TA of photographs taken with the red LED light source

Figure 4.10 shows correlations between the age (days) of Longkong fruit since the first bud blossomed and the TSS :TA and the Br value of photographs taken with the red LED as a light source. Both linear correlations of age vs Br and age vs TSS : TA showed the equation of $y = -0.4483x + 48.565$ with R^2 of 0.8089. At the cross sectional point between the linear graphs of age vs Br and age vs TSS : TA was on day 96 since the first bud blossomed. If the deviation for the main indicators, namely the age (days), TSS : TA , and Br, is taken into acacount, the figures for optimal harvest of Longkong clusters should be 96±7 days, 16.29±6.44, and 5.53±3.14, respectively.

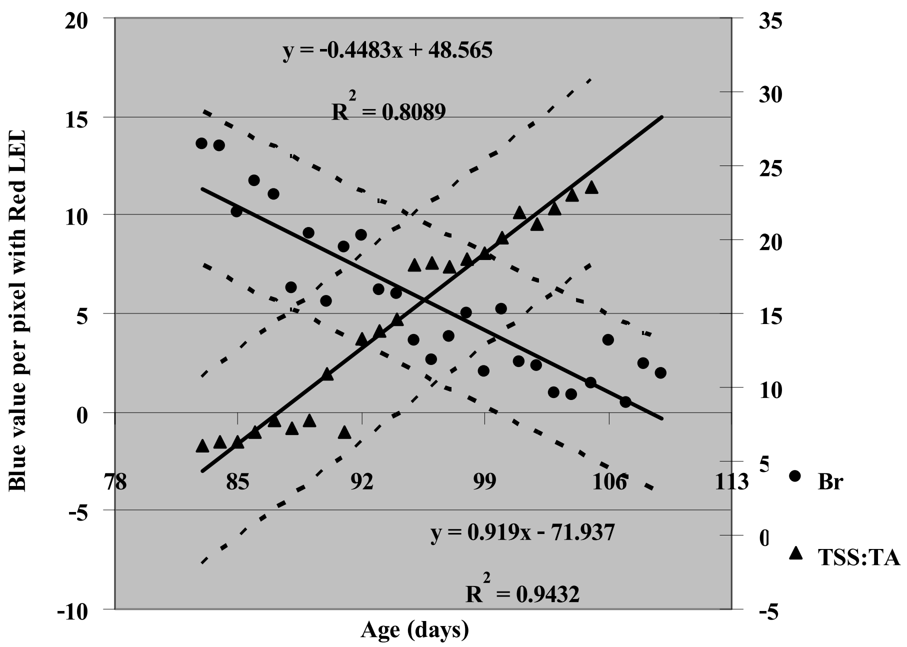


Figure 4.10 Multi correlations between age (days) and the Br value and the TSS :TA of photographs taken with the red LED light source.

The research result suggested that the graph in Figure 4.10 showing the correlation between age (days) and the Br value represented in the equation of y = - 0.4483x + 48.565 with R^2 =0.8089 and that between age and the TSS : TA represented in the equation of y = 0.919x – 71.937 with R^2 = 0.9432 should be used in calibrating the system. The period for optimal harvest should be day 96 $\pm$ 8 after the first bud flower of the fruit-cluster blossoms while the Blue value is in the range of 8.67 - 2.39. If a Longkong fruit-cluster is cut while the blue color value ranges between 8.67 - 5.53, the fruits will taste sweet and sour appropriate for a long distant shipment. When the blue color value ranges between 5.52 - 2.39, the fruits will have the best flavor and fragrance proper for sale in the local areas. In addition, it is also found that the Br value usually decreases at the rate of 0.45 per day. The developed technique will make it possible to plan the optimal harvest day.

The result shows that the optimal harvest time of Longkong fruit-clusters can be determined by measuring relevant changes in the three basic colors i.e. red, green and blue of the spectral reflectance images taken by the digital camera. However, to determine the appropriate harvest time of the Longkong fruit-clusters in the orchard, a simpler device must be developed.

CHAPTER 5

MATERIALS AND METHODS (SECTION 2)

Chapter 4 shows that the researcher was successful in identifying the Br value as the key indicator for determining the optimum harvest time of Longkong fruits with spectral reflectance technique. However, since the process was too complicated and time consuming for Longkong growers, the researcher tried to apply this discovery for general use by developing a simpler device based on the same spectral reflectance technique and called it Longkong Color Meter (LCM). Nevertheless, when the experiment was carried out, it was notable that the red value was the best indicator of the optimum harvest time of Longkong.

5.1 LCM development to determine the appropriate harvest time of Longkong fruit clusters

LCM consisted of two major parts connected with electric wiring: control box and sensor box. Both boxes were black inside.

5.1.1 Control Box

5.1.1.1 Equipment

1) black boxes	1 units
2) digital information LCD	1 piece
3) microcontroller PIC16F877	1 unit
4) 9-volt battery	1 unit

5) Electricity wire 1 unit

6) press button 2 units

5.1.1.2 Design Methods

1) A hole was made at the top of one side of the box to install LCD
2) A power switch was installed at the left bottom of this side
3) 2 press buttons were fixed on the right side of the power switch, one for "YES" button, one for "NO" button
4) The battery was connected to the power switch
5) The microcontroller was installed inside the box

5.1.2 Sensor Box

5.1.2.1 Equipment

1) LED 2 bulbs
2) sensor (TCS230) 1 unit
3) black PVC pipe 1 unit

5.1.2.2 Design Methods

1) The sensor TCS230 was fixed on the back side of the box

2) 2 light emitting diodes (LED) were installed on each side of the sensor TCS230 as light sources as shown in Figure 5.1(b).

3) A detector probe was made from the PVC pipe, having the length of 1.5 cm, diameter of 3.3 cm at its base, and 2 cm at the other end in order to have one light spot of the

beams from both light sources, to cover the sensor, and to fit well with a Longkong fruit, respectively as shown in Figure 5.1(c).

4) The probe in 3) was inserted into a hole in the front side of the box until the base well covered the sensor and the LED bulbs. The probe had to stay on the box tightly so that there would not be interference from external light.

5) The electric cord was wired to interface the control box and the sensor box.

Each number corresponds with the components stated below:

1) The major control box

2) LCD monitor

3) Power switch

4) YES button to enable the device

5) NO button to disable the device

6) Wiring circuit between control box and sensor box

7) The sensor box

8) Sensor TCS230 and 2 emitting diodes (LED) were installed in the black box.

9) Two light emitting diodes (LEDs) to generate light to shine on the Longkong surface.

10) detector probe.

11) Longkong fruits

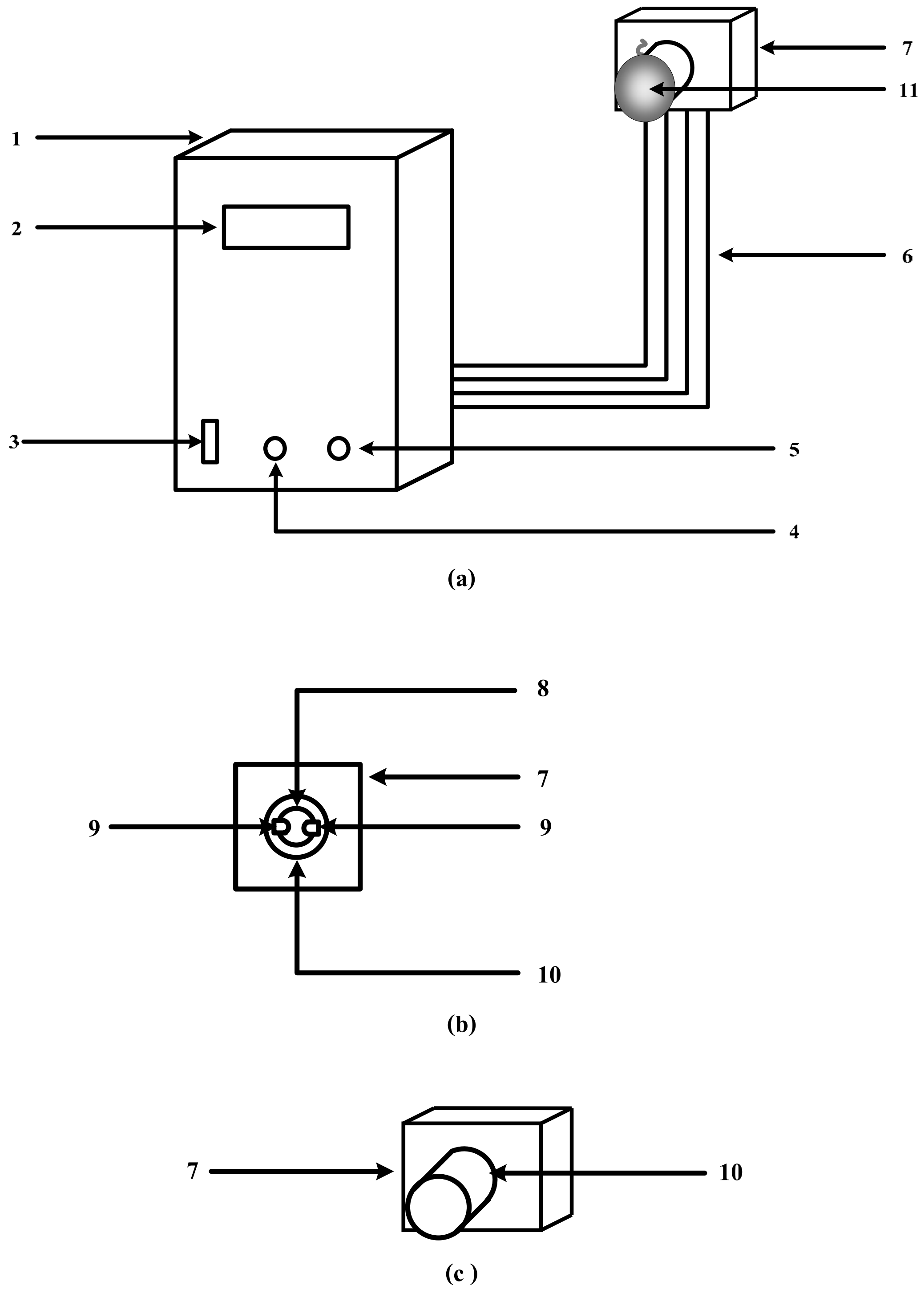


Figure 5.1 Configuration and major components of the LCM

5.2 The Operational Principles of the LCM

When the switch was turned on, the battery supplied the device with electric power. The microcontroller reset itself first in order to initialize the circuit by sending its current from gate RBO to B of the PNP Q BC547 transistor. The current flowed from gate C to gate E that enabled the LED1 and LED2 to illuminate. Resistors R6 and R7 of 330 ohms were connected in series to the circuit in order to control the current from battery to diodes. When they illuminated Longkong fruits with a white light from LED1 and LED2, the light shone on the photodiode array installed inside the TCS230 ICS. The sensor will convert the color brightness into a square wave signal with a 50% duty cycle. The frequency output is associated linearly with the color brightness of the light that shone on the TCS230 sensor. Gates S0 and S1 of IC TCS230 were connected to R1 and R2, respectively. Both states are set to be a positive logic in order to set the frequency output (fo) at level 100% while S2 and S3 were the signal gates to select photodiode filter in use. The output signal from IC converted the electrical signal into frequency signal and sent it out at the output gate number 6. This signal controlled the enable- and disable-output signal from gate OE while it is active for logic “0”. When the output signal is sent from the output gate of the TCS230 sensor to the microcontroller by its pass way via the RC2/CCP1 I/O port of the microcontroller of PIC16F887, the signal was evaluated and sent the output through port D and display by an LCD monitor when the “Yes” node insisted on the desirable value, gate RB6 was in the positive logic state. When the “Yes” node was pressed, the RB6 was grounded. This enabled the IC to recognize the referred value for further evaluation. The “No” node was used to recognize the undesirable value. In a normal state, the RB7 gate was in the positive logic. Whenever the “No” node was pressed, the RB7 was grounded. This enabled the IC to recognize the unwanted value and skip this step. The “Reset” node reset the whole circuit; in the normal state, the MCRL was at the positive logic. Whenever the “Reset” node was pressed, the instrument initialized the process. The VDD gate supplied the electrical potential to the IC while the VSS gate was grounded. CLKIN and CLKOUT gates were the clock signal to the PIC16F887. The result was displayed on LCD monitor through Port D of the IC at gate D4, D5, D6 and D7. The RS gate was controlled by the Reset node of PIC16F877 that enabled the device to initialize itself.

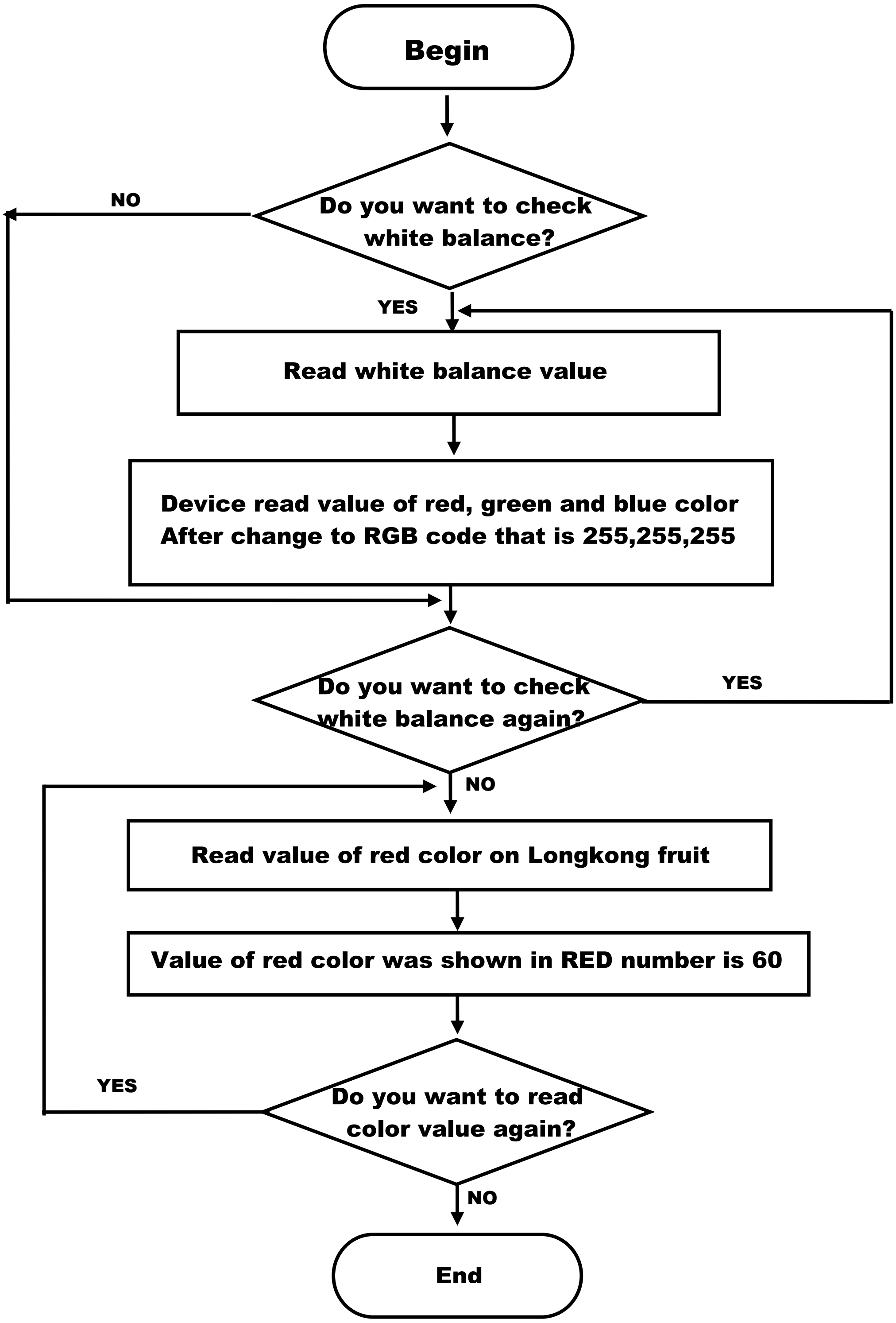


Figure 5.2 Flow chart diagram of the working process of the LCM

The R/W gate would read the data sent out from EN gate of PIC16F877 and displayed on LCD monitor through port D.

5.3 Operational method of the LCM

1) Tagging dates on the first Longkong bud blossom of each of 30 inflorescences
2) About 10 weeks after tagging the blossoms, identifying 6 selected fruits of different locations (upper, middle, and lower) in each cluster
3) Checking the LCM working status by pointing the meter's detector probe to white paper by pressing the power switch of the LCD monitor to display the question "Do you want to check white balance or not?"
4) Pressing "Yes" button so that the program would read the Red (R), Green (G) and blue (B) value. The result of the white balance check was displayed as the R, G and B values of 255, 255, 255, respectively. This showed that the device was working properly and ready to use.
5) Pressing "No." when the monitor displayed the question "Do you want to check the color balance again?"
6) Setting the device's detector probe to point to the skin surface of the selected Longkong fruit.
7) Covering both the LCM and the fruits with black cloth, to prevent the sunlight from interfering with the measurement.
8) Pressing the "Yes" button for the LED bulbs to illuminate the Longkong skin surface
9) Recording the R, G, and B values
10) Counterchecking the results with TSS : TA of a fruit of the same age
11) Repeating the process everyday until the observed fruit was overripe

CHAPTER 6

RESULTS AND DISCUSSIONS (SECTION 2)

The result of the first part of the research shows that the optimum harvest time of Longkong fruits can be determined with a digital camera incorporated with red and green LED light sources. But the process was complicated, slow, and in appropriate for Longkong growers. A new device was then developed. It comprises a detector probe, electronic circuits, and other accessories as described in Chapter 5.

The new device was validated by measuring the spectral reflectance of 30 Longkong fruit-clusters for their ripening during days 71 to 120. The red, green and blue value associated with their spectral reflectance were determined. Their TSS :TA was also determined at the same time. The results of red, green and blue value versus the TSS :TA is shown in Table 6.1.

Table 6.1 The correlation between red, green and blue value with TSS:TA and age(days) of Longkong clusters.

Age(days)	Red value	Green value	Blue value	TSS:TA
71	22.3	49.5	50.3	
72	23.8	47.5	47.9	1.22
73	24.7	46.3	46.9	
74	21.0	50.0	50.3	0.92
75	24.0	51.9	52.4	
76	22.0	16.6	16.7	0.85
77	25.3	33.5	33.6	0.84
78	21.6	40.6	41.0	

Table 6.1 (Continued)

79	27.2	15.0	15.0	1.21
80	28.4	64.9	64.9	1.13
81	25.0	52.2	52.5	
82	29.9	70.9	70.7	1.17
83	31.2	28.3	28.8	
84	34.3	49.8	62.8	1.60
85	37.2	55.6	55.0	
86	37.3	30.2	30.6	1.20
87	44.5	64.4	64.1	1.89
88	47.4	22.8	21.9	
89	51.2	93.0	92.2	2.61
90	53.1	92.2	93.5	
91	59.6	99.2	99.2	3.64
92	62.1	60.1	25.6	
93	63.2	61.9	62.0	4.11
94	65.9	40.4	62.5	
95	64.8	65.6	40.8	4.20
96	67.3	45.0	65.1	6.88
97	66.3	65.1	43.8	
98	70.0	44.1	67.0	7.06
99	69.3	54.2	44.5	
100	72.4	43.5	53.4	8.38
101	72.1	53.7	43.8	
102	74.2	44.3	53.8	7.44
103	74.9	57.1	44.4	

Table 6.1 (Continued)

104	74.6	44.6	57.2	7.77
105	70.6	53.7	43.9	
106	75.0	27.4	54.6	10.26
107	77.4	73.5	27.9	
108	74.0	127.9	71.7	9.27
109	82.8	102.3	166.2	
110	74.6	14.7	103.2	11.27
111	82.0	28.5	14.8	
112	75.4	47.4	28.8	11.07
113	80.6	126.4	47.1	
114	78.8	56.8	125.6	10.79
115	79.3	14.8	57.6	
116	73.0	130.9	15.3	
117	79.2	14.6	130.0	13.14
118	75.0	128.5	14.9	
119	79.1	121.1	127.0	12.01
120	80.0	131.6	128.3	

Figure 6.1, represents the correlation between age (days) versus the red spectral value of the selected Longkong fruit-clusters as found by the new designed device. The studied period covered days 70 - 120 after the first flower bud bloomed. The x-axis represents the age (days) while the y-axis represents the red value of Longkong fruit-clusters.

The result showed that the red value was quite stable when the Longkong fruit-cluster was 70 - 82 days old (Figure 6.1). The red value then increased exponentially during days 83 - 100. The red value seemed to show a plateau curve after day 100 onward for a period of time and started to decrease when the Longkong skin rind changed into brown color.

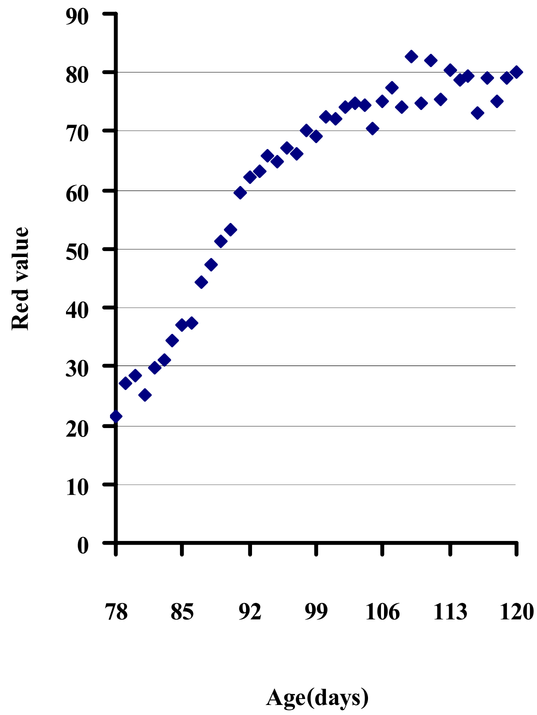


Figure 6.1 The correlation between age (days) versus the red value of the Longkong rind

Figure 6.2 shows that correlation between the Longkong age (days) versus the green value in the reflectance from the sample skin rind. The experiment covered days 70 - 120 after the first flower bud blossomed. The green value was in the range of 18 - 130 units. The correlation between the Longkong age and the green value could not be determined because the green value showed an irregular pattern.

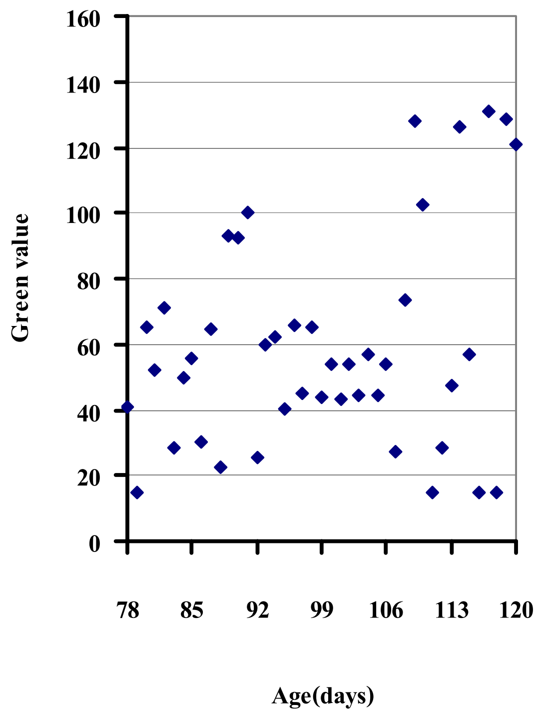


Figure 6.2 The correlation between age (days) versus the green value Longkong rind.

Figure 6.3 shows that the correlation between the Longkong age (days) versus the blue value reflected from the skin rind could not be determined because the blue value showed an irregular pattern.. The experiment covered days 70 – 120 of the Longkong fruits while the blue value was in the range of 18 - 165 units. However, due to the high uncertainty, this correlation cannot be used for further prediction.

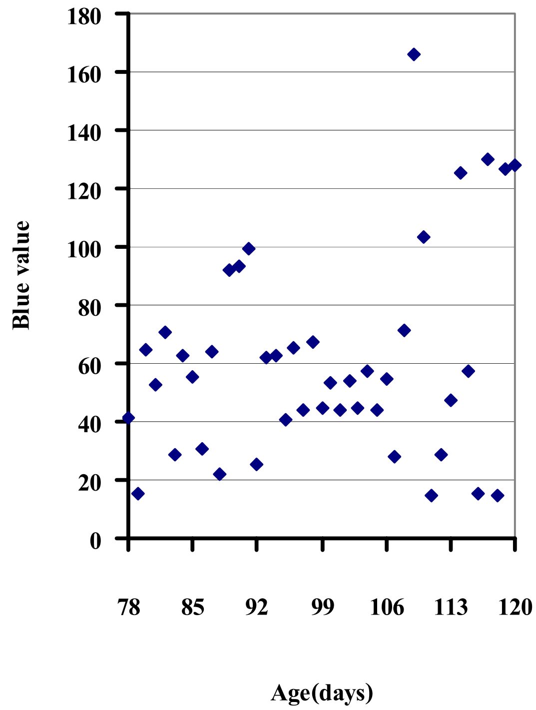


Figure 6.3 The correlation between age (days) versus the blue value Longkong rind

Figure 6.4 shows the correlation between the Longkong age (days) versus the TSS:TA. This experiment was conducted while the Longkong age was 70 - 120 days after the blossom of the first flower bud.

The graph shows that while Longkong fruits were 70 - 89 days old, their TSS:TA was 1.5. During the age interval of 89 – 91 days the TSS:TA continually increased to the value of 2 - 3.6. During this period, the Longkong fruits were ready for sale because the TSS:TA indicated that the fruits were ready for consumption and long distant shipment.

It is notable that the TSS:TA of the experimented Longkong seemed to be low. This might be due to the fact that the experiment was carried out in December – January period, which was during the raining season for the Southernmost area of Thailand. The Longkong fruits might have absorbed more water than usual and thus diluted their sweetness.

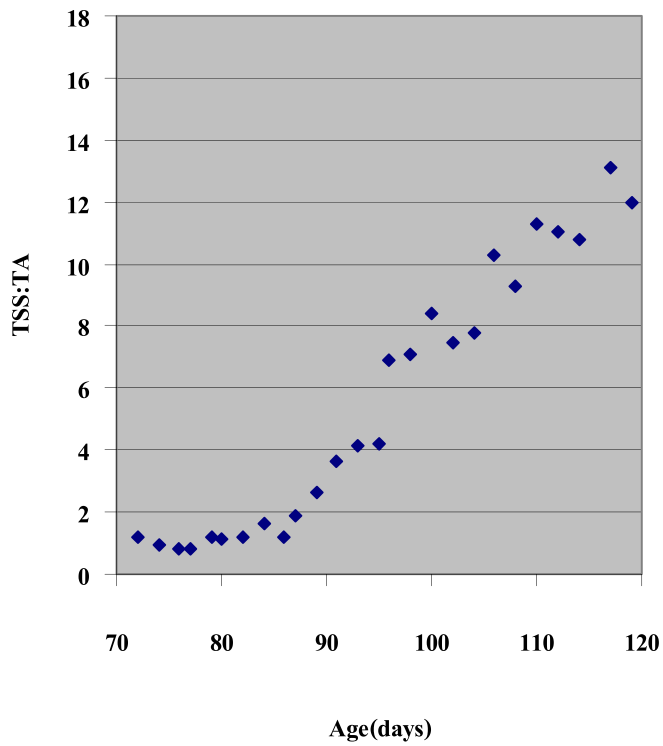


Figure 6.4 The correlation between the Longkong age (days) versus TSS:TA

The correlation between the Longkonga age (days) and the spectral reflectance in red, green and blue values is shown in Figure 6.1, 6.2, and 6.3, respectively. Figure 6.1 shows that the red value of the Longkong skin rind seems to be the most reliable indicator for further prediction.

Figure 6.5 shows a comparison of two variables: the red value from Longkong skin rind and the TSS:TA versus their age (days) after the first flower bud blossomed. It is remarkable that the two graphs are quite similar.

These results indicated that when the Longkong age was about 89-91 days after the first flower bud blossomed, the TSS :TA changed from 2 to 3.6 units while the red value reflected from the same fruits showed their variation from 52 to 60. We can use number of 60 from the red spectral reflectance from Longkong skin rind as a criterion for Longkong farmers to make a wise decision concerning fruit harvest, especially when the long distance shipment is needed. If the harvest is postponed for a few days the fruits would be proper for local markets.

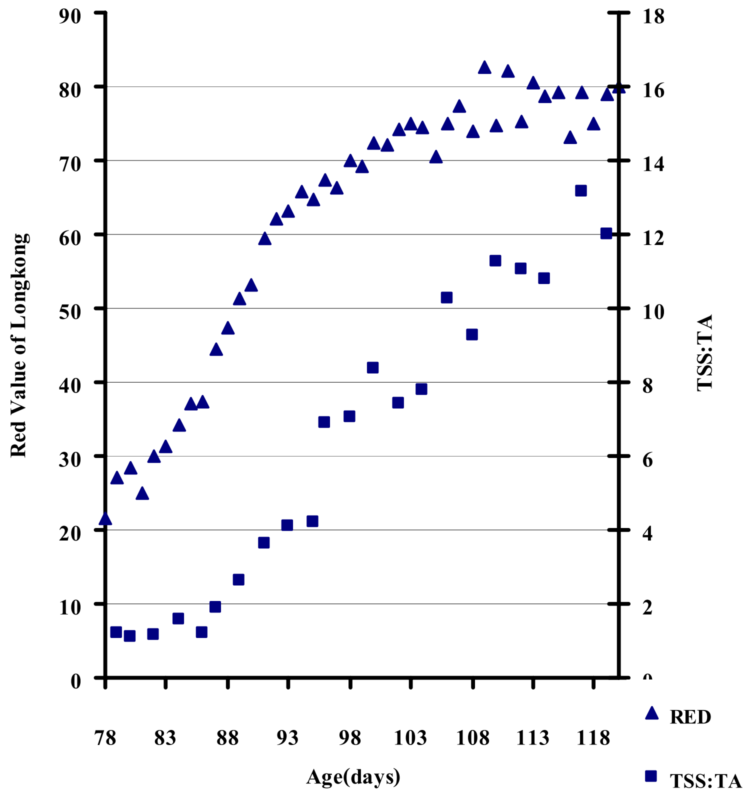


Figure 6.5 The correlation between the Longkong age (days) versus the red value and TSS :TA.

The validating experiment of the designed device for determining Longkong optimum harvest time shows that this new invention is quite accurate. Besides, it is small and simple to use. It can be said that this is the first handy device of its kind.

CHAPTER 7

CONCLUSIONS AND SUGGESTIONS

7.1 Determination of the appropriate harvest time of Longkong fruit-clusters by the spectral reflectance method

To determine the appropriate harvest time of Longkong fruit-clusters, the spectral reflectance of ripening fruit-clusters was investigated from images taken with a digital camera and red LED and green LED light sources. The result showed that the Blue light reflectance from Red LED source (Br) was the best indicator for harvesting Longkong fruit-clusters. This was because the blue value changed linearly against their age and show the highest correlation reliability. The Br was inversely proportional to ripeness of Longkong. The Br decreases linearly while age and TSS:TA increases gradually.

The experiments with CPCAL suggested that the best time to harvest Longkong was when the Br and TSS:TA are in the ranges of 8.67 - 2.39 and 9.85 - 22.72, respectively. With this method the harvest time of Longkong was in the same ranges as indicated by Sapii and coworkers [9], which were days 96 ± 7 after the first flower blossomed. The experimented method has advantages over the day-counting method, which is complicated and time-consuming. It is also better than the use of TSS :TA, which is a reliable technique but has multi-stepped and complicated procedure. However, although the spectral reflectance method for ripening fruit-clusters seems faster and more reliable, its procedure in photographing methods with LED light sources is not convenient, especially when photographs have to be taken in a dark case to prevent sunlight.

The best time to harvest Longkong for a long distant shipment should be within 89 - 96 days after the first bud flower blossoms; that is while the Blue values are in the range of 8.67-5.53 and the TSS:TA is in the range of 9.85 - 16.29. At this stage, the fruits taste sweet and sour and are firm enough to stick to inflorescences. For local area markets, the Longkong growers should harvest the fruits when their age is 97-103 days while the blue color value is lower than 5.52 or the TSS:TA is higher than 16.30 units.

The researcher also found that the Br value usually decreases at the rate of 0.45 degree per day and that TSS:TA increases at the rate of 0.91 degree per day. This makes it possible to plan the harvest day. Nevertheless, since Longkong fruit-clusters do not mature at the same time, the growers are recommended to randomly taste Longkong fruits from at least six different areas-- the top, middle and bottom-- of a cluster in order to make sure about their decision. The average Br value for all selected six areas is a good indicator for optimum harvest

In the future this developed device can be modified for modern and convenient application. For example, filters of different colors may be attached to the digital camera instead of using LED bulbs.

7.2 Developing LCM as a device to determine the appropriate harvest time of Longkong fruit-clusters

The LCM receives the spectrum reflectance of red, green and blue color from the Longkong skin rind, but the red reflecting spectrum seems to be the best indicator because it shows a very good correlation with the TSS:TA and their age.

During the period of 89 - 91 days, the red value of the fruits as reflected from their skin rind changes rapidly from 52 to 60 units. Likewise, their TSS :TA change rapidly from 2 to 3.6 units. When the red value reaches 60, the growers are recommended to harvest their Longkong fruit-clusters for a long distant shipment.

At this point the disadvantage of LCM is that it has to be used under the cover of black cloth in order to avoid sunlight that may interfere with the spectral reflectance in determining the harvest time of Longkong fruits.

However, this invention can be easily applied to determination of the harvest time of other economic fruits such as mangosteens and pomelos.

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APPENDIX

APPENDIX A

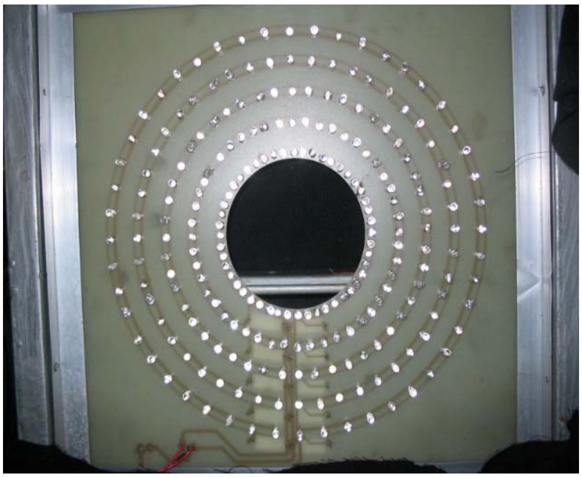
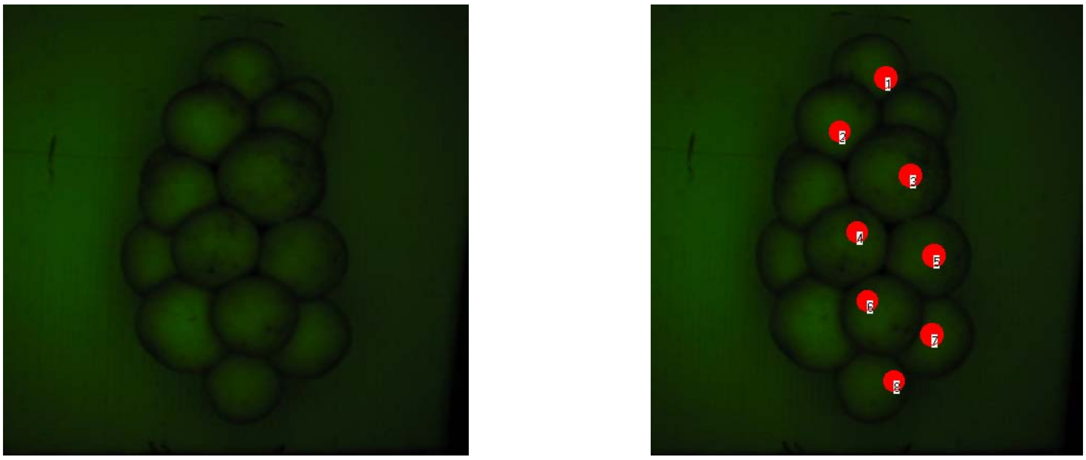


Figure A-1 Image Acquisition setting box control sunshine

Figure A-2 Image Acquisition setting box control sunshine with Longkong fruit-clusters and PowerShot A20

Figure A-3 Image Acquisition setting piece of future board behind a Longkong fruit-clusters



(a) **(b)**

Figure A- 4 Image of Longkong fruit-clusters (a) Before analysis (b) After analysis

Table 1A Camera specification

Image sensor :	Approx. 2.11 million-pixel (total). ½.7 in. CCD (effective pixel: approx. 2.02 million)
Lens :	5.4 (W) – 16.2 (T) mm (35 mm film equivalent : 35-105 mm) F 2.8 (W) – 4.8 (T)
Digital Zoom :	Maximum 2.5x (Maximum 7.5x with optical Zoom)
Optical Viewfinder :	Real – image optical zoom viewfinder
LCD monitor :	1.5 inch low temperature polycrystalline silicon TFT color LCD, approx. 120,000 pixels
Autofocus :	TTL 3 point AiAF
Focusing Rang : (from tip of the lens barrel)	Normal : 76 cm (2.5 ft.) – infinity 16 – 76 cm (6.3 in. – 2.5 ft.)(W) Macro : 26 – 76 cm (10.2 in. – 2.5 ft.)(T)
Shutter :	Mechanical + electronic
Shutter Speed :	1-1/1500 sec.
Sensitivity :	ISO 100 equivalent (automatically raised to ISO 150 in low light)
Light Metering Method :	Evaluative metering (linked to focusing point)
Exposure Control :	Program AE
Exposure Compensation	+2 EV (1/3 steps)
White Balance :	TTL auto/ preset (daylight, cloudy, tungsten, fluorescent)
Flash :	Red-eye reduction auto/ auto/ on/ off/ slow-synchro
Flash Range :	Normal Mode : 76 cm – 4.2 m (2.5 – 13.8 ft.) (W), 76 cm – 2.3 m (2.5 – 7.5 ft.) (T) Macro Mode : 26 – 76 cm (10.2 in. – 2.5 ft.) (W/T)
Shooting Modes :	Auto/ manual/ stitch assist
Self-Timer :	Shoots after approx. 10 sec.

Table 1A Continued

Continuous Shooting :	Approx. 2.5 images/sec (Large/ Fine mode, LCD monitor off)
Recording Media :	CompactFlash™ card (Type I)
File Format :	Design rule for Camera File system, DPOF compliant
Image Recording Format :	JPEG
Compression :	Superfine/ fine/ normal
Resolutions :	Large : 1600x1200 pixels Medium : 1024x768 pixels Small : 640x480 pixels
Replay Modes :	Single image replay/ index replay (9 thumbnails)/ zoomed view (LCD monitor zooms images up to 2.5x)/ auto play/ printing with Card Photo Printing CP-10 (print image directly)
Interface :	USB (mini-B) Video output terminal (NTSC or PAL, selectable)
Power Source :	Four AA alkaline batteries or fur AA rechargeable NiMH batteries (Canon NB-1AH is recommended.) Compact Power Adapter CA-PS500
Dimensions (WxHxD) :	110.3 x 71.0 x 37.6 mm (4.3x2.8x1.5 in.) (excluding protrusions)
Weight :	Approx. 250 g (8.8 oz.) (excluding batteries and CF card)

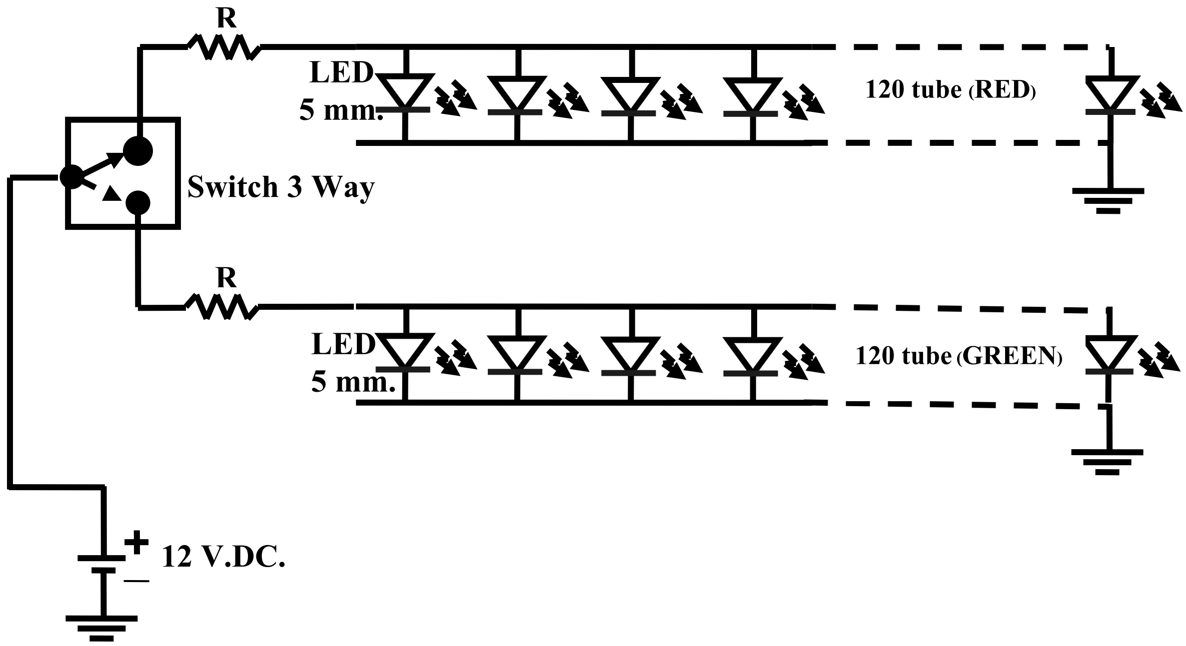


Figure A-5 Circuit of LED in the box control sunshine

APPENDIX B

Figure B-1 The Longkong Color Meter (LCM)

APPENDIX C

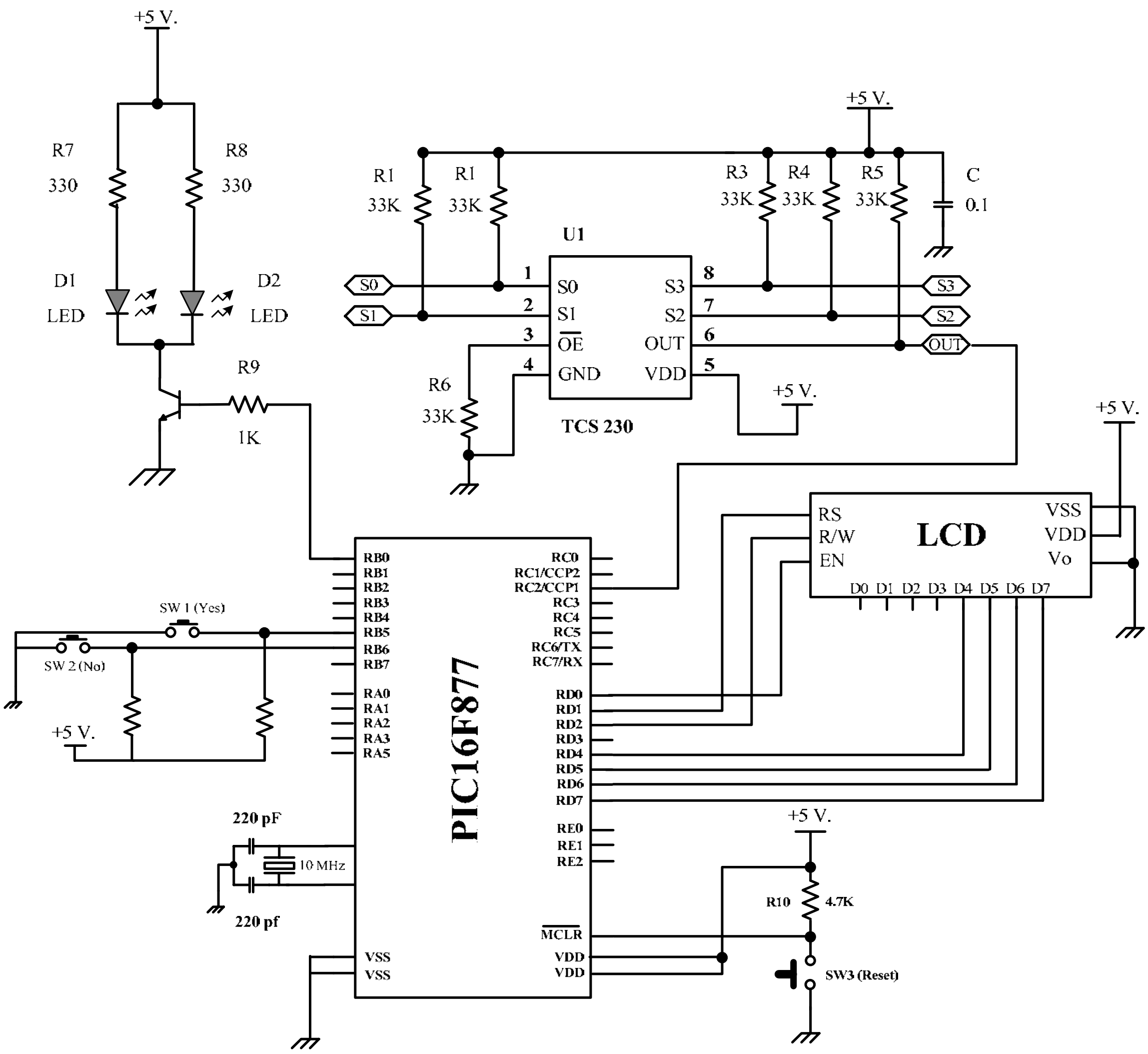


Figure C-1 The electronic circuit of the LCM

APPENDIX D

The computer program used to control the LCM

```
/******************************************************************
* Release  :  PCWH Compiler 3.242
******************************************************************/

#define _PIC16f877_              // Use PIC16F877 device

#ifdef _PIC18f458_
#include <18F458.h>              // Header file for the PIC18F458 device
#define  TxD        PIN_C6       // Define Transmitted Data
#define  RxD        PIN_C7       // Define Received Data
#define  CLOCK_SP   40000000     // Clock Speed (Hz)
#fuses   H4                  // Oscillator mode H4

#elif _PIC16f877_
#include <16F877.h>              // Header file for the PIC16F877 device
#define  TxD        PIN_C6       // Define Transmitted Data
#define  RxD        PIN_C7       // Define Received Data
#define  CLOCK_SP   20000000     // Clock Speed (Hz)
#fuses   HS                  // Oscillator mode HS

#endif

// Device Specification
#fuses NOLVP, NOWDT              // No Low Voltage program, No watchdog timer
#fuses NOPROTECT                // Code no protection
#use delay (clock=CLOCK_SP)
#use rs232 (baud=9600, xmit=TxD, rcv=RxD)

// I/O Ports for TCS230
#define  LEDs         PIN_B0
#define  S2          PIN_B2
#define  S3          PIN_B3
#define  YES          PIN_B6
#define  NO          PIN_B7

// LCD Driver
#include <LCD.C>                 // Use LCD Driver

/******************************************************************
 * Global variables
*******************************************************************
/
```

```
float time1, time2;
BOOLEAN Hook_ccp1 = TRUE, HookRise = TRUE;
float Red_Factor, Green_Factor, Blue_Factor;

/*****************************************************************
 * Function    :  Capture Interrupt
 * Description :  CCP1 capture mode
 * Parameters  :  Nothing
 * Returned    :  Nothing
*****************************************************************/
#int_ccp1
void capture_isr(void)
{
  if (HookRise)
  {
    time1 = get_timer1();        // Get time1 from low to high
    HookRise = FALSE;
  }
  else
  {
    time2 = get_timer1();        // Get time2 from low to high
    HookRise = TRUE;
    Hook_ccp1 = FALSE;
  }
}

/*****************************************************************
 * Function Declaration
*****************************************************************/
float Read_Color(char);
void White_Balance(void);

/*****************************************************************
 * Function    :  Main
 * Description :  This is the main entry point for the program
 * Parameters  :  Nothing
 * Returned    :  Nothing
*****************************************************************/
void main(void)
{
  char R, G, B;
  float Red_RawColor, Green_RawColor, Blue_RawColor;
  float Red_Result, Green_Result, Blue_Result;
  BOOLEAN Ans_Yes = TRUE, Ans_No = TRUE;

  output_b(0x00);                  // B0 - B7 are low
```

```
SET_TRIS_B(0xc0);                        // B6 and B7 are inputs

lcd_init();                              // Initial LCD
output_low(PIN_D3);                      // Ground of LCD

setup_ccp1(CCP_CAPTURE_RE);              // Configure CCP1 to cature rise
setup_timer_1(T1_INTERNAL|T1_DIV_BY_8);  // Setup timer 1

White_Balance();

do
{
  printf(lcd_putc,"\f.READ THE COLOR.\n");
  printf(lcd_putc,"...PLEASE WAIT..");

  output_high(LEDs);                     // Turn on white LEDs
  enable_interrupts(INT_CCP1);           // Enable CCP1 Interrupts
  enable_interrupts(GLOBAL);             // Enable Global Interrupts
  Red_RawColor = Read_Color('R');        // RawColor from RedFilter
  delay_ms(1000);                        // Delay Time
  disable_interrupts(INT_CCP1);          // Disable CCP1 Interrupts
  disable_interrupts(GLOBAL);            // Disable Global Interrupts

  enable_interrupts(INT_CCP1);           // Enable CCP1 Interrupts
  enable_interrupts(GLOBAL);             // Enable Global Interrupts
  Green_RawColor = Read_Color('G');      // RawColor from GreenFilter
  delay_ms(1000);                        // Delay Time
  disable_interrupts(INT_CCP1);          // Disable CCP1 Interrupts
  disable_interrupts(GLOBAL);            // Disable Global Interrupts

  enable_interrupts(INT_CCP1);           // Enable CCP1 Interrupts
  enable_interrupts(GLOBAL);             // Enable Global Interrupts
  Blue_RawColor = Read_Color('B');       // RawColor from BlueFilter
  delay_ms(1000);                        // Delay Time
  disable_interrupts(INT_CCP1);          // Disable CCP1 Interrupts
  disable_interrupts(GLOBAL);            // Disable Global Interrupts
  output_low(LEDs);                      // Turn off white LEDs

  Red_Result = (Red_RawColor*Red_Factor);         // Calculate the red
  Green_Result = (Green_RawColor*Green_Factor);   // Calculate the green
  Blue_Result = (Blue_RawColor*Blue_Factor);      // Calculate the blue

  if(Red_Result>255)
  {
    Red_Result = 255;
  }
```

```
    if(Green_Result>255)
    {
      Green_Result = 255;
    }

    if(Red_Result>255)
    {
      Blue_Result = 255;
    }

    printf(lcd_putc,"\f.THE RGB RESULT.\n");
    printf(lcd_putc,"R%3.0f G%3.0f B%3.0f", Red_Result, Green_Result,
Blue_Result);
    delay_ms(1000);

    while(input(YES) && input(NO));          // Wait for push the buttons
    delay_ms(1000);

    printf(lcd_putc,"\f.READ OTHER OBJ.\n");
    printf(lcd_putc,"....YES or NO...");

    while(input(YES) && input(NO));          // Wait for push the buttons

    Ans_Yes = input(YES);
    Ans_No = input(NO);

  }while(Ans_Yes != TRUE);

  printf(lcd_putc,"\f.PLEASE TURN OFF\n");
  printf(lcd_putc,"..POWER SWITCH..");

}

/*******************************************************************
 * Function    :  Read_Color
 * Description :  Read the color from the filters
 * Parameters  :  RGB Code
 * Returned    :  RawColor
*******************************************************************/
float Read_Color(char code)
{
  float tms, RawColor;

  switch(code)
  {
    case 'R':                              // RedFilter
    {
```

```
      output_low(S2);
      output_low(S3);
      printf(lcd_putc,"\f...RED FILTER...\n");
      printf(lcd_putc,"...PLEASE WAIT..");
      delay_ms(250);
      break;
    }

    case 'G':                        // GreenFilter
    {
      output_high(S2);
      output_high(S3);
      printf(lcd_putc,"\f..GREEN FILTER..\n");
      printf(lcd_putc,"...PLEASE WAIT..");
      delay_ms(250);
      break;
    }

    case 'B':                        // BlueFilter
    {
      output_low(S2);
      output_high(S3);
      printf(lcd_putc,"\f...BLUE FILTER..\n");
      printf(lcd_putc,"...PLEASE WAIT..");
      delay_ms(250);
      break;
    }
  }

  set_timer1(0);

  while (Hook_ccp1);

  #ifdef _PIC18F458_
    tms = abs((time2-time1))*8*100*0.000000001;    // Get period
    RawColor = 1/tms;                              // Get frequency
  #elif _PIC18F877_
    tms = abs((time2-time1))*8*200*0.000000001;    // Get period
    RawColor = 1/tms;                              // Get frequency
  #endif

  return(RawColor);
}

/*************************************************************
 * Function    :  White_Balance
 * Description :  Color calibration
```

```
 * Parameters  :  Nothing
 * Returned    :  Nothing
*****************************************************************/
void White_Balance (void)
{
  BOOLEAN WB_Ans_Yes = TRUE, WB_Ans_No = TRUE;
  BOOLEAN Cont_Ans_Yes = TRUE, Cont_Ans_No = TRUE;
  float Red_RawWB, Green_RawWB, Blue_RawWB;

  do{
    delay_ms(2000);

    printf(lcd_putc,"\f.WB Calibration.\n");
    printf(lcd_putc,"....YES or NO...");

    while(input(YES) && input(NO));             // Wait for push the buttons

    WB_Ans_Yes = input(YES);
    WB_Ans_No = input(NO);

    switch (WB_Ans_Yes)
    {
      case FALSE:
      {
        printf(lcd_putc,"\f...CALIBRATION..\n");
        printf(lcd_putc,"...PLEASE WAIT..");
        output_high(LEDs);                   // Turn on white LEDs
        enable_interrupts(INT_CCP1);          // Enable CCP1 Interrupts
        enable_interrupts(GLOBAL);            // Enable Global Interrupts
        Red_RawWB = Read_Color('R');           // RawColor from RedFilter
        delay_ms(1000);                      // Delay Time
        disable_interrupts(INT_CCP1);         // Disable CCP1 Interrupts
        disable_interrupts(GLOBAL);           // Disable Global Interrupts

        enable_interrupts(INT_CCP1);          // Enable CCP1 Interrupts
        enable_interrupts(GLOBAL);            // Enable Global Interrupts
        Green_RawWB = Read_Color('G');         // RawColor from GreenFilter
        delay_ms(1000);                      // Delay Time
        disable_interrupts(INT_CCP1);         // Disable CCP1 Interrupts
        disable_interrupts(GLOBAL);           // Disable Global Interrupts

        enable_interrupts(INT_CCP1);          // Enable CCP1 Interrupts
        enable_interrupts(GLOBAL);            // Enable Global Interrupts
        Blue_RawWB = Read_Color('B');          // RawColor from BlueFilter
        delay_ms(1000);                      // Delay Time
        disable_interrupts(INT_CCP1);         // Disable CCP1 Interrupts
        disable_interrupts(GLOBAL);           // Disable Global Interrupts
```

```
          output_low(LEDs);                    // Turn off white LEDs

          Red_Factor = (256/Red_RawWB);
          Green_Factor = (256/Green_RawWB);
          Blue_Factor = (256/Blue_RawWB);

          break;
        }
        default:
        {
          Red_Factor = 0.01207;
          Green_Factor = 0.01488;
          Blue_Factor = 0.01506;
          break;
        }
      }

        printf(lcd_putc,"\f.WB: RED FACTOR.\n");     // Show red factor
        printf(lcd_putc,"%9.3e Hz", Red_Factor);
        delay_ms(1000);

        printf(lcd_putc,"\fWB: GREEN FACTOR\n");     // Show green factor
        printf(lcd_putc,"%9.3e Hz", Green_Factor);
        delay_ms(1000);

        printf(lcd_putc,"\f.WB: BLUE FACTOR\n");     // Show blue factor
        printf(lcd_putc,"%9.3e Hz", Blue_Factor);
        delay_ms(1000);

        printf(lcd_putc,"\f..MAIN PROGRAM..\n");
        printf(lcd_putc,"....YES or NO...");

        while(input(YES) && input(NO));          // Wait for push the buttons

        Cont_Ans_Yes = input(YES);
        Cont_Ans_No = input(NO);


    }while(Cont_Ans_Yes != FALSE);

  }
```

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List of Publication and Proceedings

พวงทิพย์ แก้วทับทิม ธวัช ชิตตระการ ไตรภพ ผ่องสุวรรณ ภัทร อัยรักษ์ และ สมศักดิ์ คงแสง. 2549. การคัดแยกระดับความสุกของผลลองกองโดยใช้ค่าอาร์จีบี. ว.วิทย์.กษ. 37 (6) (พิเศษ) : 651-654.

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