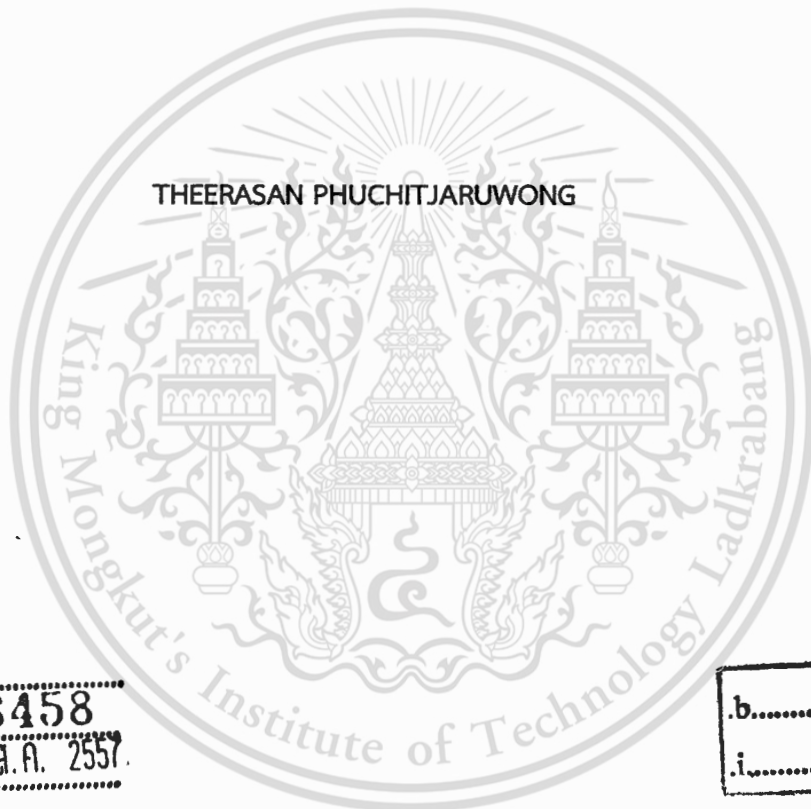
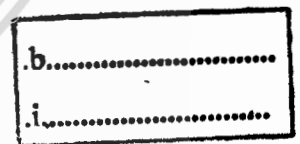


AUTOMATIC VISUAL INSPECTION SYSTEM FOR HDD PRODUCT LABEL
DEFECT DETECTION



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หัวข้อวิทยานิพนธ์	ระบบทัศนจักรอัตโนมัติตรวจสอบความบกพร่องของฉลาก ผลิตภัณฑ์ฮาร์ดดิสก์ไดรฟ์
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บทคัดย่อ

กระบวนการผลิตฮาร์ดดิสก์ไดรฟ์(Hard Disk Drive : HDD) ประกอบไปด้วยขั้นตอนหลัก คือ การประกอบชิ้นส่วนต่างๆ เป็นอุปกรณ์ฮาร์ดดิสก์ไดรฟ์และ การทดสอบใช้งานตามข้อกำหนด จากนั้นก่อนบรรจุฮาร์ดดิสก์ไดรฟ์ที่ผ่านการทดสอบแล้วจะต้องทำการปิดผนึกฉลากผลิตภัณฑ์ (Product label) และ ตรวจสอบข้อบกพร่องหรือ ความไม่สมบูรณ์ในการพิมพ์ฉลากที่อาจมีผลต่อ ความพึงพอใจของลูกค้า เช่น รอยแห้วบนโลโก้ (Logo) หรือ ตัวอักษรพิมพ์ไม่ครบ เป็นต้น สำหรับ ขั้นตอนการตรวจสอบนั้น ปัจจุบันกระบวนการนี้จะอาศัยพนักงานหรือบุคลากรที่ได้รับมอบหมายให้ ทำการตรวจสอบและตัดสินใจยอมรับหรือส่งแก้ไข เนื่องจากหลายๆปัจจัยจากกระบวนการหรือตัว พนักงานเองอาจมีผลกระทบกับประสิทธิภาพของกระบวนการทำงาน

ในงานวิจัยนี้ได้นำเสนอวิธีการใช้การตรวจสอบด้วยภาพถ่าย เพื่อปรับปรุงกระบวนการ ดังกล่าวโดยนำเสนอการตรวจสอบข้อบกพร่องจากภาพถ่าย และใช้เทคนิคเปรียบเทียบภาพถ่ายที่ได้ กับต้นฉบับภาพถ่ายแบบแยกส่วน(Template matching technique) การตรวจสอบด้วยภาพถ่าย สามารถที่จะช่วยให้กระบวนการตรวจสอบมีความถูกต้องแม่นยำและมีประสิทธิภาพมากขึ้น

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ABSTRACT

HDD (Hard Disk Drive) manufacturing contains two main processes which are assembling and testing. Product label will be printed and pasted to HDD then continue to VMI (visual mechanical inspection) process. The VMI process is to detect incomplete printing or defect on logo information of the label. Current VMI process utilize operator who assigned to do this process. And defect criteria judgment is depend on the operator performance. Fatigue or boring of the operator may effect to process efficiency.

This thesis provides inspection method by automatic visual inspection. Template matching and many image vision techniques are used on this thesis. The inspection system can detect defect of the label with satisfy result. The inspection system can improve process efficiency and more accuracy than human.

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Theerasan Phuchitjaruwong



CONTENTS

	Page
บทคัดย่อภาษาไทย	i
Abstract	ii
Acknowledgement	iii
Contents	iv
List of Tables	vi
List of Figures	vii
Chapter 1 Introduction	2
1.1 Motivation	2
1.2 Objective	3
1.3 Scope of research	3
1.4 Research Methodology	3
1.5 Contribution	4
1.6 Literature Review	5
1.7 Thesis Organization	7
Chapter 2 HDD and manufacturing process	9
2.1 Basic on Hard disk drives	9
2.2 Manufacturing process	12
Chapter 3 Relate theory of research	14
3.1 Structure of the Human Eye	14
3.2 Image Acquisition Using Sensor Arrays	16
3.3 Lighting System and Light Source	17
3.4 Digital Image Processing	19
3.4.1 Color image	20
3.4.2 Gray scale image	20
3.4.3 Black and white image	21
3.5 The RGB Color Model	21
3.6 HSI Color Model	23
3.7 Converting colors from RGB to HSI	24
3.8 Lowpass Filters	26
3.9 Thresholding	27
3.9.1 The Role of Illumination	28
3.9.2 Basic Global Thresholding	31
3.9.3 Basic Adaptive Thresholding	33

CONTENTS (Cont.)

	Page
3.10 Template Matching	35
3.11 Automated Visual Inspection	38
3.12 Artificial Intelligence in AVI	42
Chapter 4 Research Methodology	44
4.1 System development	44
4.1.1 Image acquisition	44
4.1.2 Inspection system	47
4.1.2.1 Image segmentation	48
4.1.2.2 Rough Classification	49
4.1.2.3 ROI and Template Matching	50
4.1.2.4 Classification	51
4.2 Optimize inspection limit	52
Chapter 5 Conclusion and Future work	56
5.1 Result and Conclusion	56
5.2 Research advantage	57
5.3 Future work	57
Bibliography	58
Appendix	61
Appendix 1	61
Author Biography	69

List of Tables

Table	Page
3.1 AVI stages and AI techniques	42
4.1 Inspection benchmark rough classification	49
4.2 The inspection limit setting on each inspect items	53
5.1 Result of inspection time	56



List of Figures

Figure	Page
1.1 HDD manufacturing inspection process	2
1.2 The inspection developed system	4
1.3 Samples of target printed labels	4
1.4 Image registration by template matching on gray scale brain image of size 512 x 512 by Template of size 50 x 50 with result registered image And NCC plot	5
1.5 Current process of hook up visual inspection system.....	6
1.6 Acceptable parts solder coverage more than 80%	7
1.7 Acceptable parts distance within specification	7
2.1 Hard disk drives component	9
2.2 Head Stack Assembly (HSA) and VCM Magnet in HDA	10
2.3 Area density per square inch	11
2.4 Brief HDD manufacturing process	12
3.1 Simplified diagram of a cross section of the human eye	14
3.2 An example of the digital image acquisition process	17
3.3 Cost and intensity of lighting sources	19
3.4 Digital image pixel	20
3.5 RGB picture and it value each pixel	20
3.6 Gray scale level	20
3.7 Black and white or Binary image	21
3.8 Schematic showing how pixel color image are formed from the corresponding pixels of the three component images	22
3.9 RGB Color Cube	22
3.10 Conceptual relationships between the RGB and HSI color models	24
3.11 Hue and saturation in the HSI color model	25
3.12 (a) Perspective plot of an ideal lowpass filter transfer function, (b) Filter displayed as an image, (c) Filter radial cross section	26
3.13 Histogram for the example image	27
3.14 Threshold $f(x,y) > T$	27
3.15 (a) Computer generated reflectance function. (b) Histogram of reflectance function. (c) Computer generated illumination function. (d) Product of (a) and (c). (e) Histogram of product image.....	29
3.16 (a) Original image, (b) Image histogram, (c) Result of global thresholding with T midway between.....	31

List of Figures (cont.)

Figure	Page
3.17 (a) Original image, (b) Image histogram, (c) Result of segmentation with the threshold estimated by iteration.....	33
3.18 (a) Original image, (b) Result of global thresholding. (c) Image subdivided into individual sub-images. (d) Result of adaptive thresholding.....	34
3.19 The source image and the template	39
3.20 (a) Image. (b) Subimage. (c) Correlation coefficient of (a) and (b).....	37
3.21 Typical AVI system structure	38
3.22 General AVI process structure	39
4.1 Inspection system structure	44
4.2 Camera and lenses	45
4.3 Light source setting of research study	45
4.4 Output image acquisition from inspection system	46
4.5 Software process of label inspection	47
4.6 Threshold setting and image result	48
4.7 Original product label paper base liner and implement new background	49
4.8 Line defect of product label cause by printer head	50
4.9 Geometric template on bar line	50
4.10 Sub-image template matching	51
4.11 Classification criteria	52
4.12 Inspection result display	52
4.13 Optimization benchmark inspection result	54
4.14 Optimization inspection time by state chart	54



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Chapter 1

Introduction

Hard disk drive is a storage device to store information in it recording disk or media. And read back information form the disk to host. Current hard disk drive (HDD) manufacturing processes are acquiring highly technology. Many technologies are supported for HDD process such as wafer fabrication to design and produce HDD head and media, Very high contamination control in assembly process that need to control particle inside head disk assembled (HDA). Image processing is preferred to design for HDD process, which benefit of accuracy and precision.

1.1 Motivation

The final process of HDD manufacturing is a packing process which includes VMI (visual mechanical inspection) process. The inspection process purposes to inspect physical damage such as scratch, dent and incomplete product label printing. Currently HDD industrial utilize operator who response this process to inspect and judgment result. Figure 1.1 shows the current inspection process.



Figure 1.1 : HDD manufacturing inspection process

Many humans are engaged in inspection task but due to factors such as tiredness and boredom, their performance is often less than satisfactory [1]. HDD Product label contains varies importance information such as serial number, safety

standard certificated logo, bar code and etc. Thus the label defect detection is an important criterion at the VMI process. Image processing on this thesis is designed to inspect HDD product label to improve process efficiency.

1.2 Objective

To develop a new process automatic visual inspection system that can improve efficiency of VMI process, which current depend on human and environment. And gain more customer satisfaction on quality of product on visual inspection defect. This thesis will design image-processing feature to detect defect on HDD product label. Because of the defect is a majority contribution to the VMI process.

1.3 Scope of research

In this research applies various method of image processing to be a detection feature of automatic visual inspection system [2]. The system will detect defect on HDD product label from picture that is captured by CCD camera. The system will result pass or fail after processing detection feature. This system will improve inspection time and process efficiency from existing VMI process. Also defect escape from humane error can fix with the system.

1.4 Research Methodology

- 1.4.1 Capture picture by CCD camera and set up lighting environment to get adequate picture quality suitable to classify defect criteria.
- 1.4.2 Process image in gray scale picture.
- 1.4.3 Count pixel of image to brief classify failure label.
- 1.4.4 Matching master template with sample picture to detect failure on logo area
- 1.4.5 Geometric matching template with sample picture to detect line failure.
- 1.4.6 Judgment sample picture to pass or fail inspection.

1.5 Contribution

1.5.1 The system can detect defect on HDD product label with result pass or fail and detection more accurate than existing VMI process.

1.5.2 Reduce process time to detect the defect and improve process efficiency.

1.5.3 Prevent escape product label failure to ship to customer cause by human error.

1.6 Literature Review

In 2008, Yuhki Shiraishi and Fumiaki Takeda had developed a portable automatic inspection system form printed label using web camera. The printed labels are inspected using the captured images in the capturing part. This is processed in the laptop PC shown in Figure 1.2 [3].



Figure 1.2 : The inspection developed system [3]

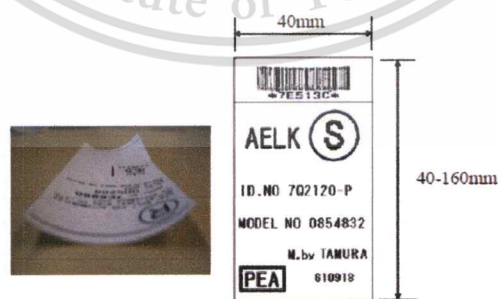


Figure 1.3 : Samples of target printed labels [3]

The printed label sample in this study is shown in figure 1.3. Background and printed part are separated by binarization. After that count pixel is perform to execute detection failure. The experimental results show that the system detects the stain whose size is larger than or equal to 0.1 by 0.1 mm and the patchiness whose width is larger than or equal to 0.3 mm unless conveyance errors occur [3].

In 2009, Jignesh N. Sarvaiya and team study to establish the correspondence between the reference image and sensed image. It gives the measure of the degree of similarity between an image and template. The study describes medical image registration by template matching based on Normalized Cross-Correlation (NCC) using Cauchy-Schwartz inequality [4]. Implementation of NCC algorithm of the study presents the results for medical image registration by template matching. The experiments are conducted on gray scale brain image of size 512 x 512. The different size of template is extracted from the original image. Figure 1.4 shows the result of study perfect registered image using NCC algorithm.

It is clear that Normalized Cross-Correlation (NCC) is the ideal approach to image registration by template matching. It gives perfect template matching in the given reference image. The Maximum Cross-correlation coefficient values indicate the perfect template matching with noise and without noise condition [4].

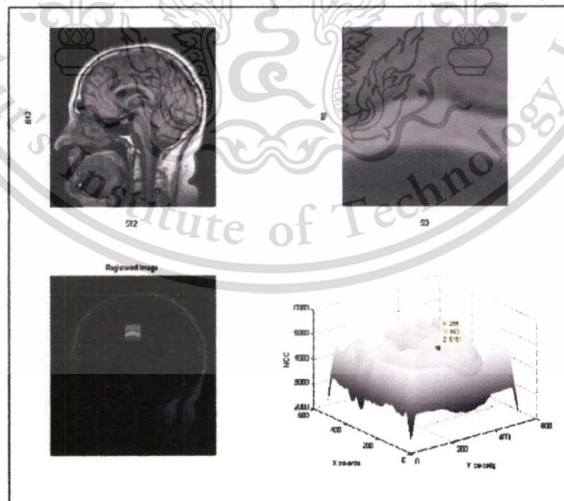


Figure 1.4 : Image registration by template matching on gray scale brain image of size 512 x 512 by Template of size 50 x 50 with result registered image and NCC plot [4]

In 2010, Somboon Thamuntree had studies development of hook up solder head pad location measurement system based on computer vision. The quality assurance and process control are depending on only human decision making. Thus the human inspection error may affect the product quality by allowing poor specification solder head pad to pass through the inspection system. On the other hand, it should be collect rejected part as shown in figure 1.5. The study aims to develop a prototype for automatic solder head pad inspection system by applied the several image processing algorithms such as edge detection, template matching, distance measuring and etc. In this automatic visual inspection system, the operators are only need to insert an inspection assembly part into the system, and monitoring through a result show on the monitor screen.

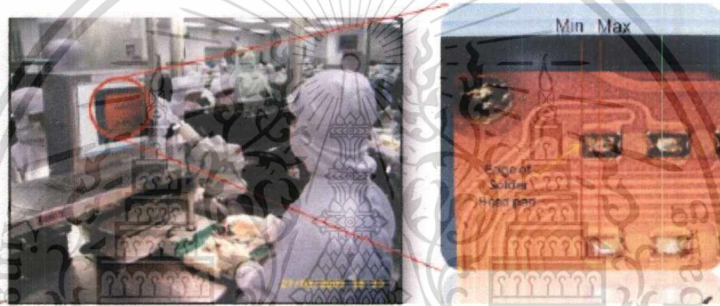


Figure 1.5 : Current process of hook up visual inspection system [5]

Classification criteria of the developed system consist of two feature parameters; a minimum score of pattern matching and a distance of solder head (first pad) as show in figure 1.6 and 1.7.

The study presented an automated inspection system for solder head pads on a hook-up. The process can increase production efficiency, reduce inspection processing time and improve human error. Classification criteria of the system consist of two main feature parameters are minimum score of pattern matching and distance of solder head (first pad). Experiments also revealed that the processing speed of this automated inspection system can reach up to 2.5 sec.

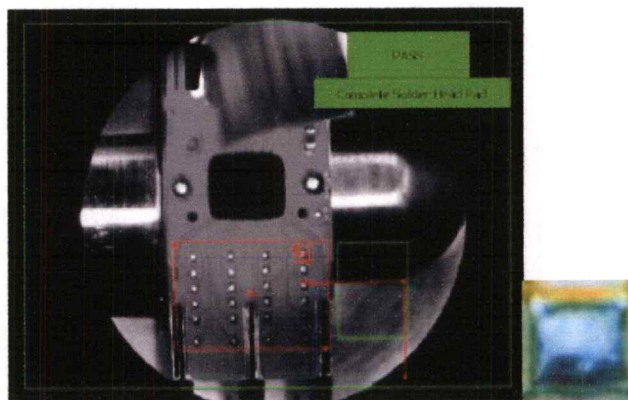


Figure 1.6 : Acceptable parts solder coverage more than 80% [5]



Figure 1.7 : Acceptable parts distance within specification [5]

1.7 Thesis Organization

This thesis is organized in the following manner. Chapter 2 provides an overview of HDD and manufacturing process in currently. Chapter 3 present relates theory of image processing, which reference in this thesis. Chapter 4 shows research methodology and Optimization inspection limit setting. And chapter 5 concludes this research work by providing the conclusion and some importance issue for future work.



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Chapter 2

HDD and manufacturing process

2.1 Basic on Hard disk drives

Hard disk drives (HDD) provide an important data-storage medium for computers and other data-processing systems. In most commercial HDD, rotating disks coated with a thin magnetic layer or recording media are written with data that are arranged in concentric circles or tracks [6]. Data are read or written with a read/write (R/W) head, which consists of a small horseshoe-shaped electromagnet. Components of a typical HDD are shown in Figure 2.1. Other storage devices include floppy disks, CD-ROMs, tape drives, and removable mass storage. HDD differs from others primarily in three aspects: capacity, cost, and performance.

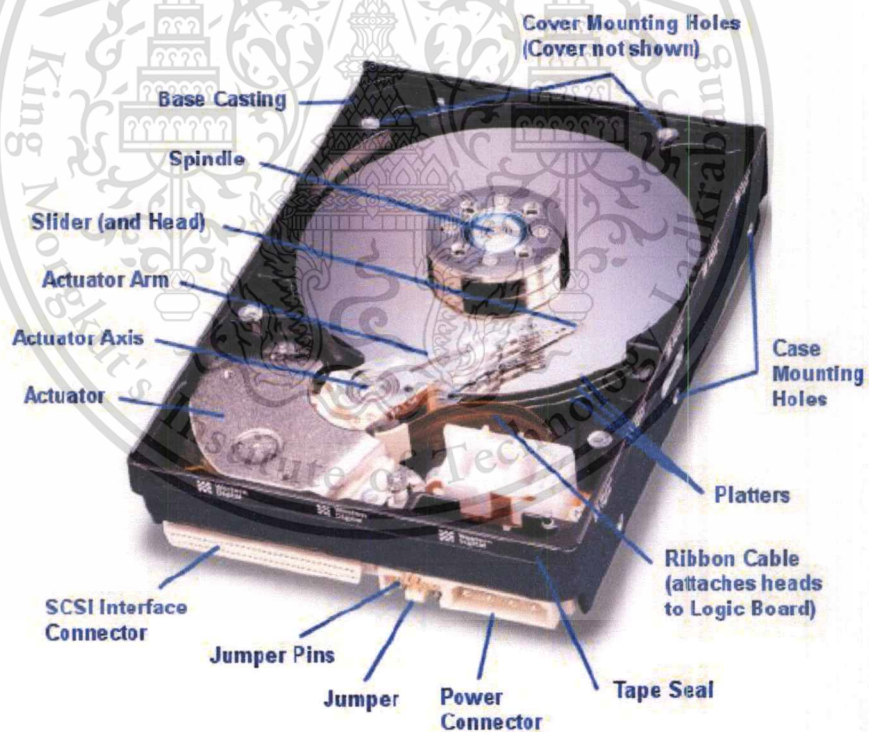


Figure 2.1 : Hard disk drives component [7]

As shown the hard disk component in figure 2.1. HDD contains round, flat disks called platters. Platter is stored on the magnetic coating of the disk surface. The disks have a hole in their center, and are stacked along a spindle. The stacked disks are rotated by an electric motor inside the spindle, called the spindle motor. Electromagnetic read/write (R/W) heads are used to either record information onto the disks or read information from them. The heads are mounted on suspensions through gimbals. Suspensions are mounted on a carriage, or E-block, whose side view has an E shape. The heads, the suspensions, and the E-block together form the Head Stack Assembly (HSA) as showed on figure 2.2. The flexible structure of the gimbals and the suspensions help the heads maintain constant flying height on an air bearing over the rotating disks. During the operation, the heads should never touch the rotating disks. Otherwise, the heads and the disk surface will be severely damaged. The R/W heads over the disk surface are positioned by an actuator, which controls the movement of HSA. Voice coil motor (VCM) is widely used as the actuator in hard disk drives. VCM controls HSA and a selected head to follow a track or to switch from one track to another [8].

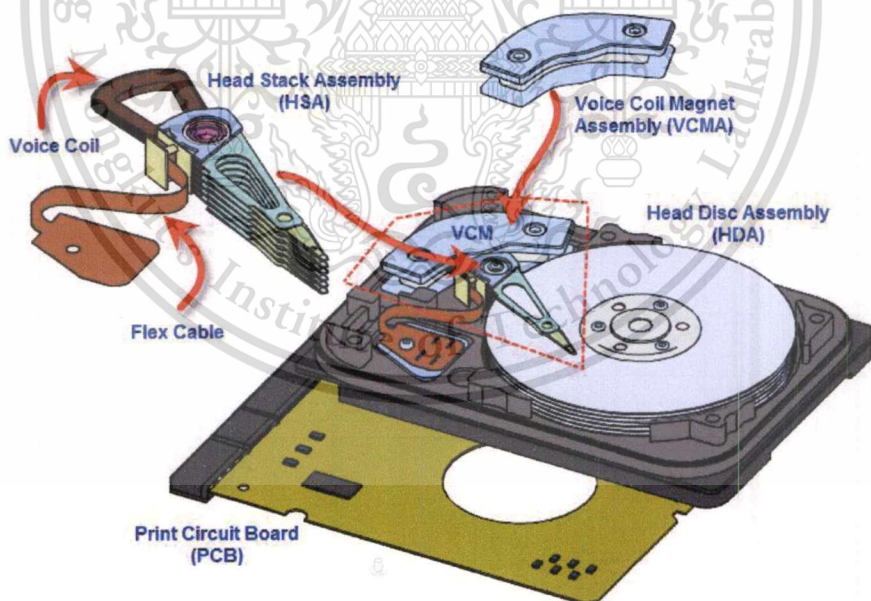


Figure 2.2 : Head Stack Assembly (HSA) and VCM Magnet in HDA [9]

Electronic part of HDD is control read/write and processing data is form at Print Circuit Board (PCB). PCB of HDD can be categorized according to the following functions:

1. Electronics for reading/writing also known as the channel electronics
2. Electronics for spinning the disks and positioning of the read/write head also known as the servo channel
3. Electronics for controlling various operations (such as read data, write data, transfer data between HDD and host etc.) of the disk or the disk controller
4. Electronics for interface with the host system, and
5. RAM, ROM etc.

Several of these functional components are often combined in a single chip. As a result, we do not see many ICs on the PCB (printed circuit board) of an HDD. One IC that is not placed on the PCB but is kept inside HDA is the pre-amplifier. It is put as close to the read/write heads as possible to avoid amplification of noise, and is mounted on the flex-cable that carries signal between heads and PCB. The output of the preamplifier is sufficiently large ensuring good signal-to-noise ratio at the input of the PCB [10].

The former measured HDD capacity by bits per inch (BPI), and the latter by tracks per inch (TPI). Area density, in bits per square inch (BPSI), is the multiplication of BPI and TPI ($AD=BPI \times TPI$). The area density per one square inch is show in figure 2.3.

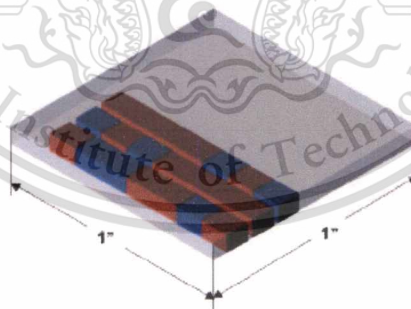


Figure 2.3 : Area density per square inch [9]

Area density is one of the most important factors for HDD performance. To increasing the TPI is a relatively easier approach to increase the area density, but still a challenging task itself. Historically, it involves cross-discipline technological

advances in the magnetic media, actuators design, disk platter material and thickness, servo algorithms, and microprocessors.

2.2 Manufacturing process

A process considers two main parts are assembly HDA and test. The HDA assembly is process under control environment called clean room (C/R). A clean room is a controlled environment where products are manufactured. It is a room in which the concentration of airborne particles is controlled to specific limits. And continue process outside clean room when enclose with cover. Outside clean room process sometime call backend (B/E) process. B/E process is beginning from install PCB to HDA to be complete part of HDD. HDD continue process to test where all HDD function and media scan are performing during the test. Finally packing process that includes final visual inspection before ship the drive to customer. Figure 2.4 shows brief process flow of HDD manufacturing

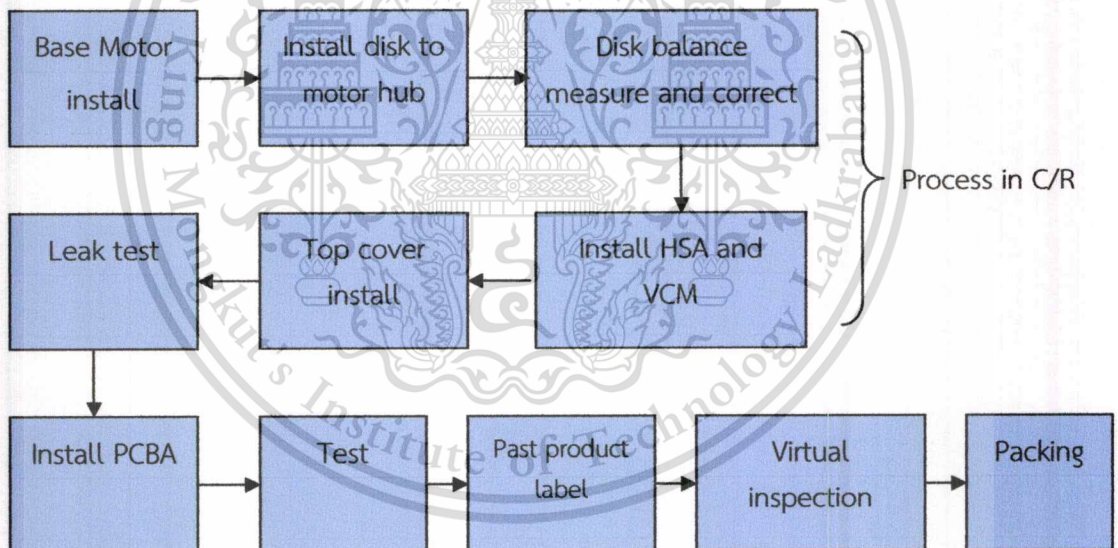


Figure 2.4 : Brief HDD manufacturing process



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Chapter 3

Relate theory of research

3.1 Structure of the Human Eye

Figure 3.1 shows a simplified horizontal cross section of the human eye. The eye is nearly a sphere, with an average diameter of approximately 20 mm. Three membranes enclose the eye: the cornea and sclera outer cover; the choroid; and the retina. The cornea is a tough, transparent tissue that covers the anterior surface of the eye. Continuous with the cornea, the sclera is an opaque membrane that encloses the remainder of the optic globe.

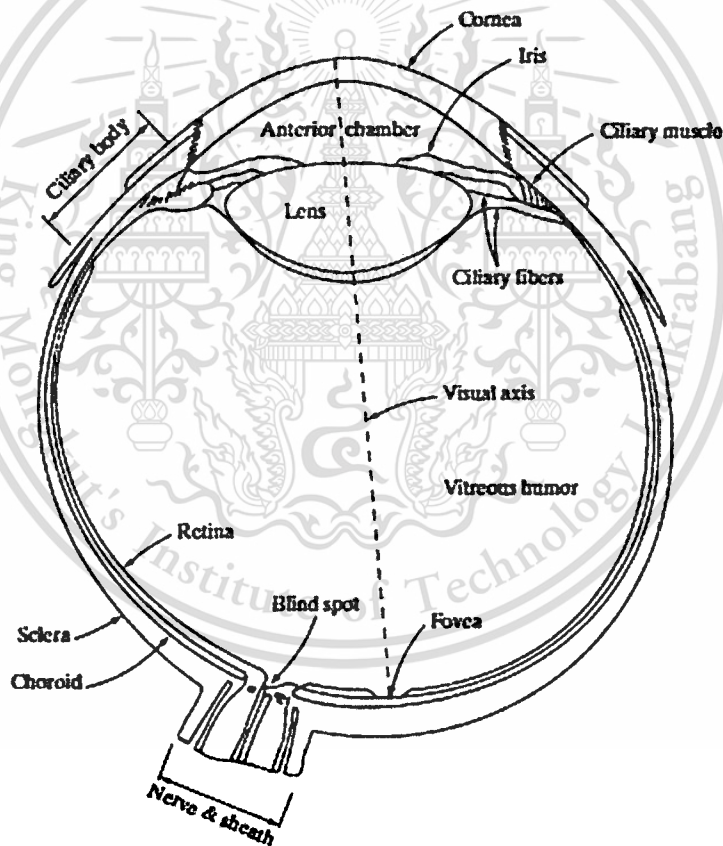


Figure 3.1 : Simplified diagram of a cross section of the human eye [2]

The choroid lies directly below the sclera. This membrane contains a network of blood vessels that serve as the major source of nutrition to the eye. Even superficial injury to the choroid, often not deemed serious, can lead to severe eye damage as a result of inflammation that restricts blood flow. The choroid coat is heavily pigmented and hence helps to reduce the amount of extraneous light entering the eye and the backscatter within the optical globe. At its anterior extreme, the choroid is divided into the ciliary body and the iris diaphragm. The latter contracts or expands to control the amount of light that enters the eye. The central opening of the iris (the pupil) varies in diameter from approximately 2 to 8 mm. The front of the iris contains the visible pigment of the eye, whereas the back contains a black pigment.

The lens is made up of concentric layers of fibrous cells and is suspended by fibers that attach to the ciliary body. It contains 60 to 70% water, about 6% fat, and more protein than any other tissue in the eye. The lens is colored by a slightly yellow pigmentation that increases with age. In extreme cases, excessive clouding of the lens, caused by the affliction commonly referred to as cataracts, can lead to poor color discrimination and loss of clear vision. The lens absorbs approximately 8% of the visible light spectrum, with relatively higher absorption at shorter wavelengths. Both infrared and ultraviolet light are absorbed appreciably by proteins within the lens structure and, in excessive amounts, can damage the eye.

The innermost membrane of the eye is the retina, which lines the inside of the wall's entire posterior portion. When the eye is properly focused, light from an object outside the eye is imaged on the retina. Pattern vision is afforded by the distribution of discrete light receptors over the surface of the retina. There are two classes of receptors: cones and rods. The cones in each eye number between 6 and 7 million. They are located primarily in the central portion of the retina, called the fovea, and are highly sensitive to color. Humans can resolve fine details with these cones largely because each one is connected to its own nerve end. Muscles controlling the eye rotate the eyeball until the image of an object of interest falls on the fovea. Cone vision is called photopic or bright-light vision.

The number of rods is much larger: Some 75 to 150 million are distributed over the retinal surface. The larger area of distribution and the fact that several rods are connected to a single nerve end reduce the amount of detail discernible by

these receptors. Rods serve to give a general, overall picture of the field of view. They are not involved in color vision and are sensitive to low levels of illumination. For example, objects that appear brightly colored in daylight when seen by moonlight appear as colorless forms because only the rods are stimulated. This phenomenon is known as scotopic or dim-light vision [2].

3.2 Image Acquisition Using Sensor Arrays

Figure 3.2 (c) shows individual sensors arranged in the form of a 2-D array. Numerous electromagnetic and some ultrasonic sensing devices frequently are arranged in an array format. This is also the predominant arrangement found in digital cameras. A typical sensor for these cameras is a CCD array, which can be manufactured with a broad range of sensing properties and can be packaged in rugged arrays of elements or more. CCD sensors are used widely in digital cameras and other light sensing instruments. The response of each sensor is proportional to the integral of the light energy projected onto the surface of the sensor, a property that is used in astronomical and other applications requiring low noise images. Noise reduction is achieved by letting the sensor integrate the input light signal over minutes or even hours. Since the sensor array shown in figure 3.2(c) is two dimensional, its key advantage is that a complete image can be obtained by focusing the energy pattern onto the surface of the array. Motion obviously is not necessary, as is the case with the sensor arrangements discussed in the preceding two sections.

The principal manner in which array sensors are used is shown in figure 3.2. This figure shows the energy from an illumination source being reflected from a scene element, but, as mentioned at the beginning of this section, the energy also could be transmitted through the scene elements. The first function performed by the imaging system shown in figure 3.2(c) is to collect the incoming energy and focus it onto an image plane. If the illumination is light, the front end of the imaging system is a lens, which projects the viewed scene onto the lens focal plane, as figure 3.2(d) shows. The sensor array, which is coincident with the focal plane, produces outputs proportional to the integral of the light received at each sensor. Digital and analog circuitry sweep these outputs and convert them to a video signal, which is then digitized by another section of the imaging system. The output is a digital image, as shown diagrammatically in figure 13.2(e) [2].

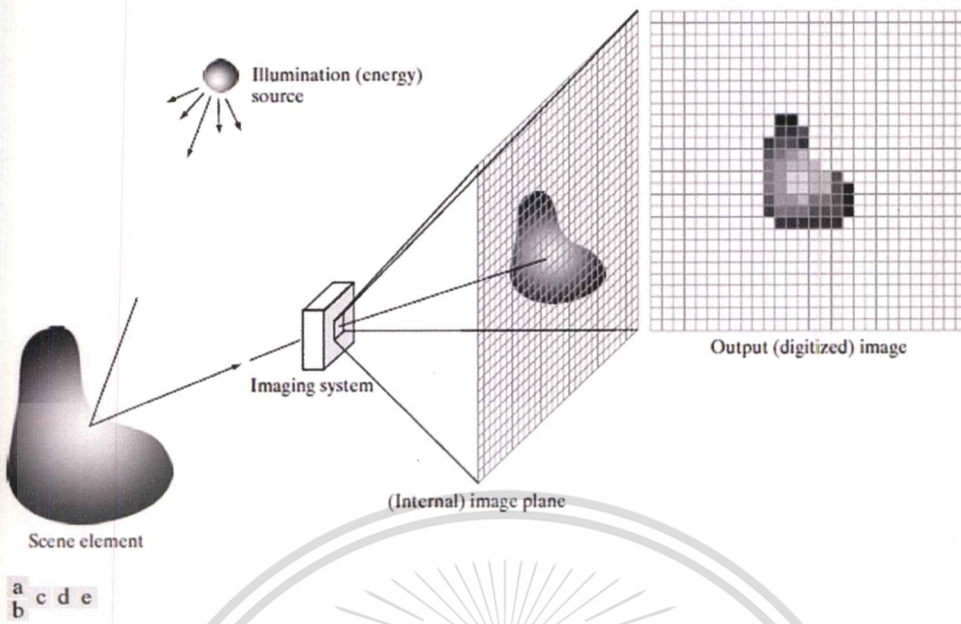


Figure 3.2 : An example of the digital image acquisition process
 (a):Energy (“illumination”) source (b):An element of a scene (c):Imaging system.
 (d):Projection of the scene onto the image plane (e):Digitized image [2]

3.3 Lighting System and Light Source

Lighting is one of the most important factors in obtaining high quality images. Ambient lighting is subject to large variations and so it is not a recommended lighting method. Typically, the inspection area is surrounded by a black box and controlled light sources are used. The current importance of lighting in inspection system design is highlighted by Braggins, who states that machine vision illumination is itself becoming an industry. In the beginning of AVI, the inspection system designer would purchase lights from an electrical shop but now there are companies available to offer specialized advice on machine vision lighting systems [1].

Front lighting is lighting from above the object, which is utilized when the surface finish of an object is important. It can be further divided into directional and diffuse front lighting. An example of a directional front lighting device is a spotlight.

There are many types of light source available for AVI applications. These include

- Ambient light.
- Incandescent tungsten lamps.
- Quartz-halogen lamps.
- Arc and gas discharge lamps.
- Lasers.
- LEDs.
- Spectral light sources.

Ambient light includes natural sunlight and light from the surroundings. In a manufacturing environment, surrounding light consists mainly of fluorescent ceiling lights. Advantages of ambient light are that it is readily available and cheap. However, the major disadvantage is that it is uncontrollable by the vision system engineer. The intensity of daylight varies considerably over the course of a day and from day to day. This has a very significant effect on the image acquisition process. Therefore, it is recommended that the inspection area be shielded from ambient light using a black box. A more expensive alternative in the long run is to include light sources that are so strong that the effect of ambient light is negligible.

LEDs (light emitting diodes) are very small sources of light that produce nearly monochromatic intense light. Several LEDs mounted in an array can provide sufficient light for inspection. Titus highlighted the increased use of LEDs for industrial inspection for three reasons. First, they are low cost compared to other lighting methods. Second, they have a relatively long lifetime. Third, LEDs can be turned on and off very quickly. This means that they can be employed in applications where strobe lighting is needed or where different patterns of lighting are required at different times during the inspection cycle. LED lights can be arranged to create spotlights, ring lights, diffuse lighting and back lighting. They have now become the preferred source of illumination in the machine.

Depending on the object being inspected, different parts of the light spectrum may be suitable. Thus, infrared or ultraviolet illumination may be beneficial. Most objects emit infrared radiation naturally, so infrared illumination is seldom required. Infrared techniques are suitable to inspect items that have internal defects. It has been utilized to inspect objects such as pipes, soya beans, almonds, and apples. Outside the area of AVI, infrared sensing is used widely by the police and military, vision industry. Ultraviolet light is useful in cases when the object being

inspected fluoresces. It was not expected that fluorescent light would be useful in this application but it was tried when other types of illumination did not give images of sufficient quality [1]. A comparison of the various lighting methods, both in terms of intensity levels and costs shows in figure 3.3.

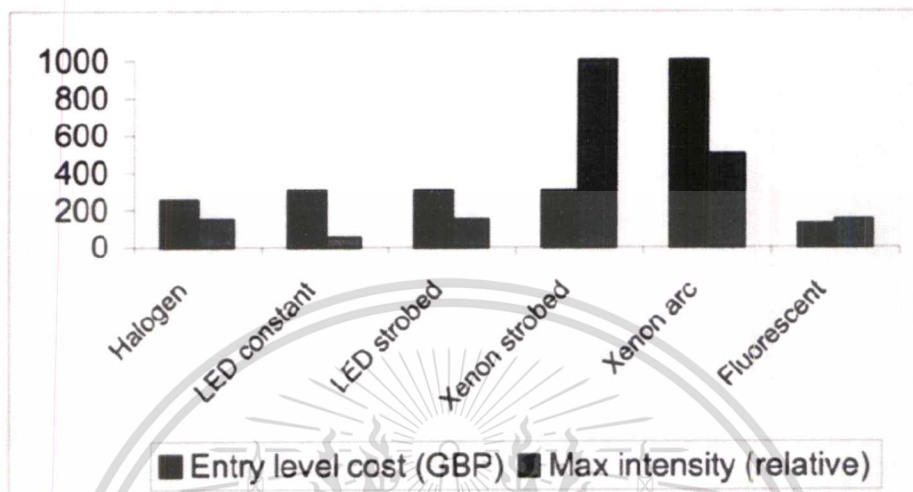


Figure 3.3: Cost and intensity of lighting sources [1]

3.4 Digital Image Processing

The digital images are definite by color such as black and white, gray scale or color image. An image may be defined as a two-dimensional function, $f(x, y)$, where x and y are spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called the *intensity* or *gray level* of the image at that point. When x, y , and the amplitude values of f are all finite, discrete quantities, we call the image a digital image. Processing of image is call image digitization with 3 process step. There are image acquisitions, image sampling and image quantization.

3.4.1 Color image

On each pixel of color image considers 8 bit vector of color i.e. red (R), green (G) and blue (B). RGB image 1 pixel contains 24 bits and 1 picture can identify difference 224 colors as figure 3.5.

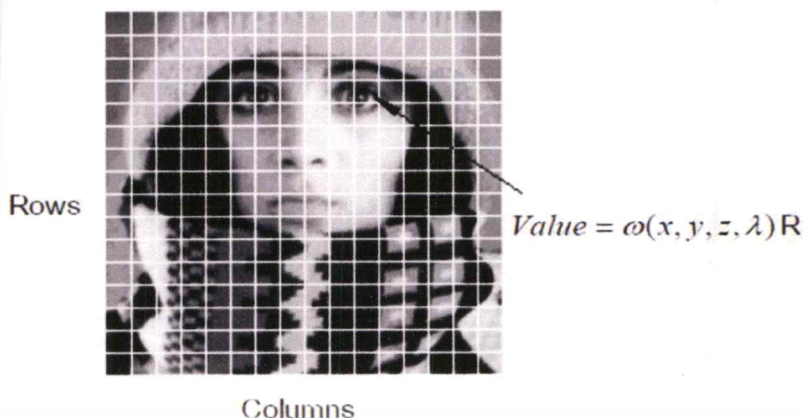


Figure 3.4 : Digital image pixel [11]

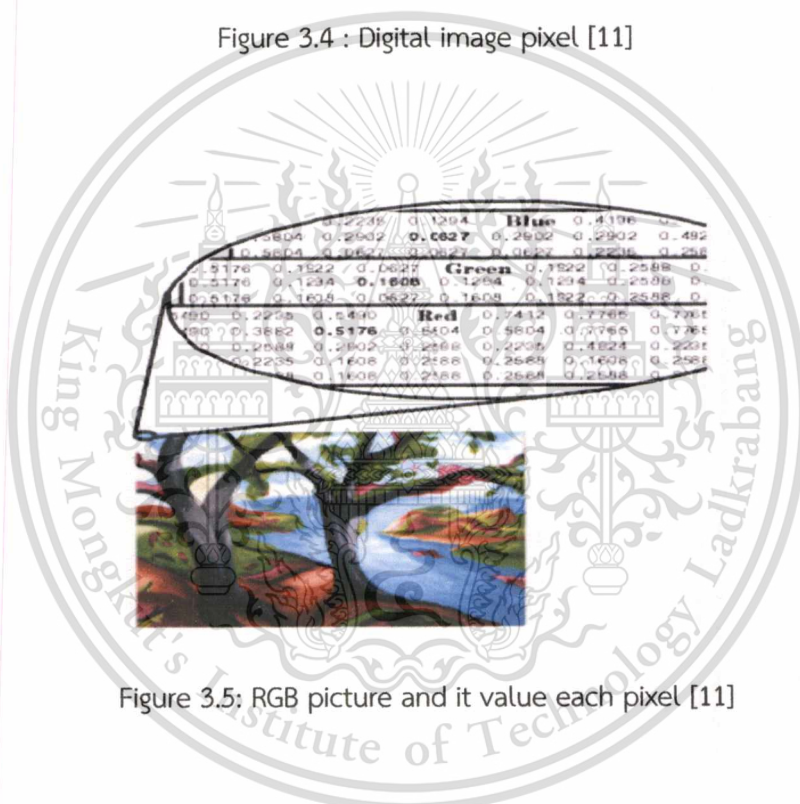


Figure 3.5: RGB picture and it value each pixel [11]

3.4.2 Gray scale image

Light that is void of color is called achromatic or monochromatic light. The only attribute of such light is its intensity, or amount. The term gray level generally is used to describe monochromatic intensity because it ranges from black, to grays, and finally to white. Gray scale (Gray level) of each pixel considers by bit e.g 8-bit monochrome will level 256 gray scales as figure 3.6.



Figure 3.6: Gray scale level [11]

3.4.3 Black and white image

Black&white or a binary image is a digital image that has only two possible values for each pixel. Typically the two colors used for a binary image are black and white though any two colors can be used as show in figure 3.7.



Figure 3.7 : Black and white or Binary image [12]

3.5 The RGB Color Model

An RGB color image is an $M \times N \times 3$ array of color pixel, where each color pixel is triplet corresponding to the red, green, and blue components of an RGB image at specific spatial location as figure 3.8.

Images represented in the RGB color model consist of three component images, one for each primary color. When fed into an RGB monitor, these three images combine on the phosphor screen to produce a composite color image. The number of bits used to represent each pixel in RGB space is called the pixel depth. Consider an RGB image in which each of the red, green, and blue images is an 8-bit image. Under these conditions each RGB color pixel [that is, a triplet of values (R, G, B)] is said to have a depth of 24 bits (3 image planes times the number of bits per plane). The term full-color image is used often to denote a 24-bit RGB color image. The total number of colors in a 24-bit RGB image is $2^{24} = 16,777,216$.

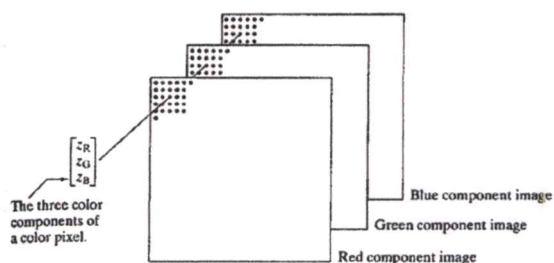


Figure 3.8 : Schematic showing how pixel color image are formed from the corresponding pixels of the three component images

The RGB image is referred to as the red, green, and blue component images. The data class of the component images determine their range of values. If RGB image is of class double, the range of values is $[0,1]$. Similarly, the range of value is $[0,255]$ or $[0, 65535]$ for RGB image of class 8 or 16 bit. The RGB color space usually is shown graphically as an RGB color cube, as show in figure 3.9.

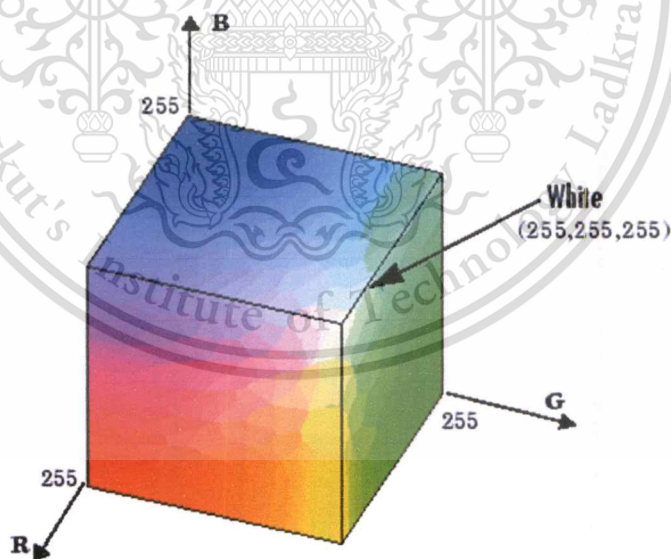


Figure 3.9 : RGB Color Cube [13]

3.6 HSI Color Model

In addition, the RGB system matches nicely with the fact that the human eye is strongly perceptive to red, green, and blue primaries. Unfortunately, the RGB, CMY, and other similar color models are not well suited for describing colors in terms that are practical for human interpretation. For example, one does not refer to the color of an automobile by giving the percentage of each of the primaries composing its color. Furthermore, we do not think of color images as being composed of three primary images that combine to form that single image.

When humans view a color object, we describe it by its hue, saturation, and brightness. Hue is a color attribute that describes a pure color (pure yellow, orange, or red), whereas saturation gives a measure of the degree to which a pure color is diluted by white light. Brightness is a subjective descriptor that is practically impossible to measure. It embodies the achromatic notion of intensity and is one of the key factors in describing color sensation. We do know that intensity (gray level) is a most useful descriptor of monochromatic images. This quantity definitely is measurable and easily interpretable. The model we are about to present, called the HSI (hue, saturation, intensity) color model, decouples the intensity component from the color carrying information (hue and saturation) in a color image. As a result, the HSI model is an ideal tool for developing image processing algorithms based on color descriptions that are natural and intuitive to humans, who, after all, are the developers and users of these algorithms. We can summarize by saying that RGB is ideal for image color generation (as in image capture by a color camera or image display in a monitor screen), but its use for color description is much more limited. The material that follows provides a very effective way to do this.

RGB color image can be viewed as three monochrome intensity images (representing red, green, and blue), so it should come as no surprise that we should be able to extract intensity from an RGB image. This becomes rather clear if we take the color cube from figure 3.10 and stand it on the black (0, 0, 0) vertex, with the white vertex (1, 1, 1) directly

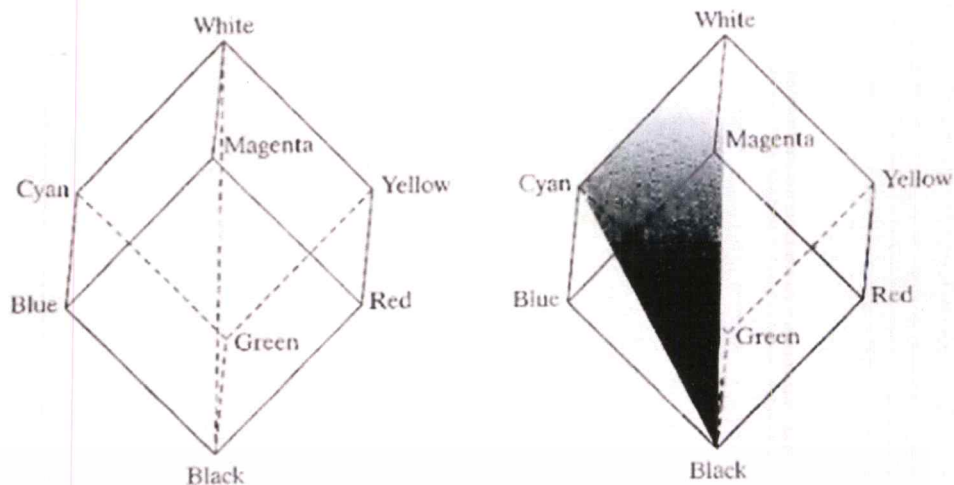


Figure 3.10 : Conceptual relationships between the RGB and HSI color models [2]

3.7 Converting colors from RGB to HSI

Given an image in RGB color format, the H component of each RGB pixel is obtained using the equation.

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases} \quad (3.1)$$

With

$$\theta = \cos^{-1} \left\{ \frac{1/2[(R-G)+(R-B)]}{\sqrt{[(R-G)^2 + (R-B)(G-B)]^2}} \right\} \quad (3.2)$$

The saturation component is given by

$$S = 1 - \frac{3}{(R+G+B)} [\min(R, G, B)] \quad (3.3)$$

Finally, the intensity component is given by

$$I = \frac{1}{3}(R + G + B) \quad (3.4)$$

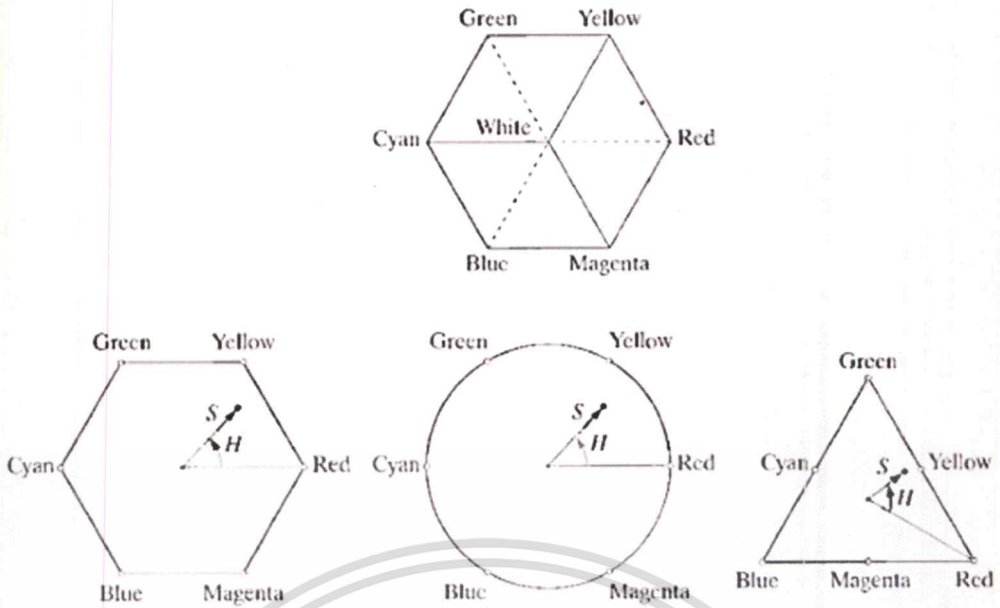


Figure 3.11 : Hue and saturation in the HSI color model [2]

It is assumed that the RGB values have been normalized to the range [0,1] and that angle θ is measured with respect to the red axis of the HSI space, as indicated in figure 3.11. Hue can be normalized to the range [0,1] by dividing by 360° all values resulting from equation (3.2). The other two HSI components already are in this range if the given RGB values are in the interval [0,1]. The results in equation (3.2) through (3.4) can be derived from the geometry shown in figure 3.10 and 3.11.

3.8 Lowpass Filters

The simplest lowpass filter we can envision is a filter that "cuts off" all high-frequency components of the Fourier transform that are at a distance greater than a specified distance D_0 from the origin of the (centered) transform. Such a filter is called a two-dimensional (2-D) ideal lowpass filter (ILPF) and has the transfer function

$$H(u, v) = \begin{cases} 1 & \text{if } D(u, v) \leq D_0 \\ 0 & \text{if } D(u, v) > D_0 \end{cases} \quad (3.5)$$

where D_0 is a specified nonnegative quantity, and $D(u, v)$ is the distance from point (u, v) to the center of the frequency rectangle. If the image in question is of size

$M \times N$, we know that its transform also is of this size, so the center of the frequency rectangle is at $(u, v) = (M/2, N/2)$ due to the fact that the transform has been centered. In this case, the distance from any point (u, v) to the center (origin) of the Fourier transform is given by

$$D(u, v) = \left[\left(u - \frac{M}{2} \right)^2 + \left(v - \frac{N}{2} \right)^2 \right]^{1/2} \quad (3.6)$$

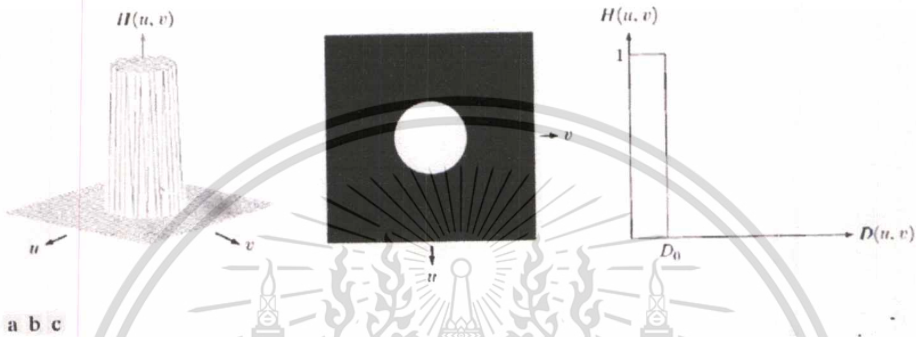


Figure 3.12 : (a) Perspective plot of an ideal lowpass filter transfer function, (b) Filter displayed as an image, (c) Filter radial cross section [2]

Figure 3.12(a) shows a 3-D perspective plot of $H(u, v)$ as a function of u and v , and figure 3.12(b) shows $H(u, v)$ displayed as an image. The name ideal filter indicates that all frequencies inside a circle of radius D_0 are passed with no attenuation, whereas all frequencies outside this circle are completely attenuated. The lowpass filters considered in this chapter are radially symmetric about the origin. This means that a cross section extending as a function of distance from the origin along a radial line is sufficient to specify the filter, as figure 3.12(c) shows. The complete filter transfer function can be visualized by rotating the cross section 360° about the origin.

For an ideal lowpass filter cross section, the point of transition between $H(u, v) = 1$ and $H(u, v) = 0$ is called the cutoff frequency. In the case of figure 3.12, for example, the cutoff frequency is D_0 . The sharp cutoff frequencies of an ideal lowpass filter cannot be realized with electronic components, although they can certainly be implemented in a computer.

3.9 Thresholding

The simplest and fastest of segmentation methods is thresholding and this has been used widely. Thresholding is based on the idea that different objects or regions in the image have significantly different grey levels. Thresholds are usually determined from the grey-level histogram of an image. Figure 3.13 shows the histogram for the example image. The image consists of grey levels from 0 to 255. It can be seen that the histogram contains two large peaks. The leftmost peak takes values of grey levels roughly between 10 and 80. This corresponds to most of the pixels that represent the seal. The rightmost peak takes values roughly between 180 and 220, representing most of the background pixels. Segmentation of this image can be performed by thresholding at grey level values somewhere between the two main peaks [1]. One obvious way to extract the objects from the background is to select a threshold T that separates these modes. Then any point (x,y) for which $f(x,y) > T$ is called an object point otherwise, the point is called a background point as show in figure 3.14.



Figure 3.13 : Histogram for the example image [1]

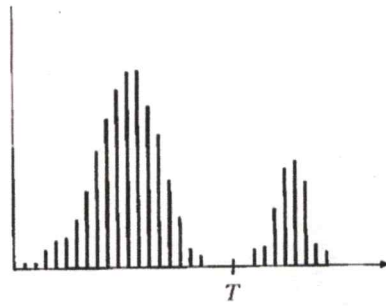


Figure 3.14 : Threshold $f(x,y) > T$ [2]

3.9.1 The Role of Illumination

The purpose of this section is to use this model to discuss briefly the effect of illumination on thresholding, especially on global thresholding. Consider the computer generated reflectance function shown in figure 3.15(a). The histogram of this function, shown in figure 3.15(b), is clearly bimodal and could be partitioned easily by placing a single global threshold, T , in the histogram valley. Multiplying the reflectance function in figure 3.15(a) by the illumination function shown in figure 3.15(c) yields the image shown in figure 3.15(d). Figure 3.15(e) shows the histogram of this image. Note that the original valley was virtually eliminated, making segmentation by a single threshold an impossible task. Although we seldom have the reflectance function by itself to work with, this simple illustration shows that the reflective nature of objects and background could be such that they are easily separable. However, the image resulting from poor (in this case nonuniform) illumination could be quite difficult to segment.

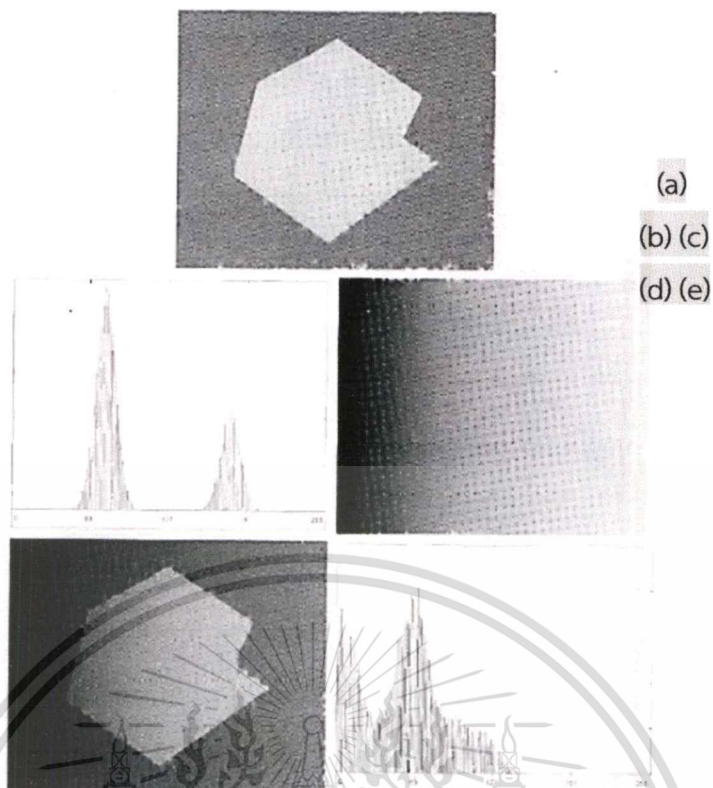


Figure 3.15 : (a) Computer generated reflectance function.
 (b) Histogram of reflectance function. (c) Computer generated illumination function.
 (d) Product of (a) and (c). (e) Histogram of product image.

The reason why the histogram in figure 3.15(e) is so distorted can be explained from equation (3.7).

$$f(x, y) = i(x, y)r(x, y) \quad (3.7)$$

Taking the natural logarithm of this equation yields a sum:

$$\begin{aligned} z(x, y) &= \ln(i(x, y)r(x, y)) \\ &= \ln i(x, y) + \ln r(x, y) \\ &= i'(x, y) + r'(x, y) \end{aligned} \quad (3.8)$$

From probability theory, if $i'(x, y)$ and $r'(x, y)$ are independent random variables, the histogram of $z(x, y)$ is given by the convolution of the histograms of $i'(x, y)$ and $r'(x, y)$. If $i'(x, y)$ were constant, $i'(x, y)$ would be constant also, and its histogram would be a simple spike (like an impulse). The convolution of this impulselike function with the histogram of $r'(x, y)$ would leave the basic shape of this histogram unchanged. But if $i'(x, y)$ had a broader histogram (resulting from nonuniform illumination), the convolution process would smear the histogram of $r'(x, y)$, yielding a histogram for $z(x, y)$ whose shape could be quite different from that of the histogram of $r'(x, y)$. The degree of distortion depends on the broadness of the histogram of $i'(x, y)$ which in turn depends on the nonuniformity of the illumination function.

We have dealt with the logarithm of $f(x, y)$, instead of dealing with the image function directly, but the essence of the problem is clearly explained by using the logarithm to separate the illumination and reflectance components. This approach allows histogram formation to be viewed as a convolution process, thus explaining why a distinct valley in the histogram of the reflectance function could be smeared by improper illumination.

When access to the illumination source is available, a solution frequently used in practice to compensate for nonuniformity is to project the illumination pattern onto a constant, white reflective surface. This yields an image $g(x, y) = ki(x, y)$, where k is a constant that depends on the surface and $i'(x, y)$ is the illumination pattern. Then, for any image $f(x, y) = i(x, y)r(x, y)$ obtained with the same illumination function, simply dividing $f(x, y)$ by $g(x, y)$ yields a normalized function $h(x, y) = f(x, y)/g(x, y) = r(x, y)/k$. Thus, if $r(x, y)$ can be segmented by using a single threshold T , then $h(x, y)$ can be segmented by using a single threshold of value T/k .

3.9.2 Basic Global Thresholding

The simplest of all thresholding techniques is to partition the image histogram by using a single global threshold, T , as illustrated in figure 3.14. Segmentation is then accomplished by scanning the image pixel by pixel and labeling each pixel as object or background, depending on whether the gray level of that

pixel is greater or less than the value of T . As indicated earlier, the success of this method depends entirely on how well the histogram can be partitioned.

Example figure 3.16(a) shows a simple image, and figure 3.16(b) shows its histogram. Figure 3.16(c) shows the result of segmenting figure 3.16(a) by using a threshold T midway between the maximum and minimum gray levels. This threshold achieved a "clean" segmentation by eliminating the shadows and leaving only the objects themselves.

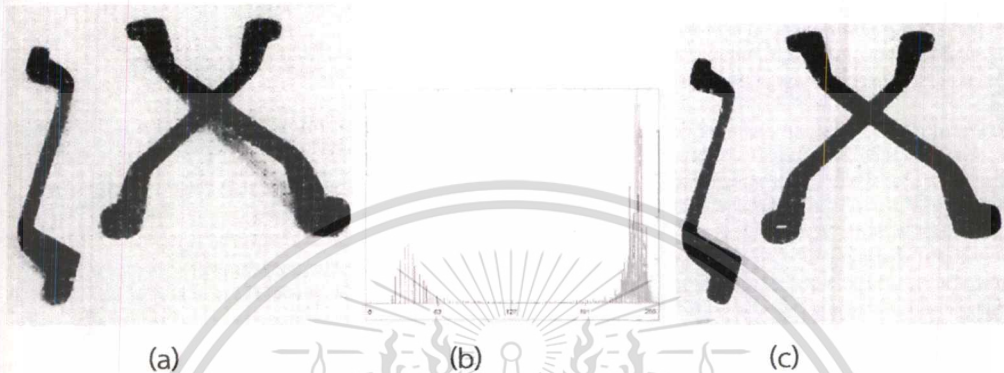


Figure 3.16 : (a) Original image, (b) Image histogram, (c) Result of global thresholding with T midway between the maximum and minimum gray levels

The objects of interest in this case are darker than the background, so any pixel with a gray level $\leq T$ was labeled black (0), and any pixel with a gray level $> T$ was labeled white (255). The key objective is merely to generate a binary image, so the black-white relationship could be reversed. The type of global thresholding just described can be expected to be successful in highly controlled environments. One of the areas in which this often is possible is in industrial inspection applications, where control of the illumination usually is feasible.

The threshold in the preceding example was specified by using a heuristic approach, based on visual inspection of the histogram. The following algorithm can be used to obtain T automatically:

1. Select an initial estimate for T .
2. Segment the image using T . This will produce two groups of pixels: G_1 consisting of all pixels with gray level values $> T$ and G_2 consisting of pixels with values $< T$.

3. Compute the average gray level values μ_1 and μ_2 for the pixels in regions G_1 and G_2 .

4. Compute a new threshold value:

$$T = \frac{1}{2}(\mu_1 + \mu_2) \quad (3.9)$$

5. Repeat steps 2 through 4 until the difference in T in successive iterations is smaller than a predefined parameter T_0 .

When there is reason to believe that the background and object occupy comparable areas in the image, a good initial value for T is the average gray level of the image. When objects are small compared to the area occupied by the background (or vice versa), then one group of pixels will dominate the histogram and the average gray level is not as good an initial choice. A more appropriate initial value for T in cases such as this is a value midway between the maximum and minimum gray levels. The parameter T_0 is used to stop the algorithm after changes become small in terms of this parameter. This is used when speed of iteration is an important issue.

Figure 3.17 shows an example of segmentation based on a threshold estimated using the preceding algorithm. Figure 3.17(a) is the original image, and figure 3.17(b) is the image histogram. Note the clear valley of the histogram. Application of the iterative algorithm resulted in a value of 125.4 after three iterations starting with the average gray level and $T_0 = 0$. The result obtained using $T = 125$ to segment the original image is shown in figure 3.17(c). As expected from the clear separation of modes in the histogram, the segmentation between object and background was very effective.

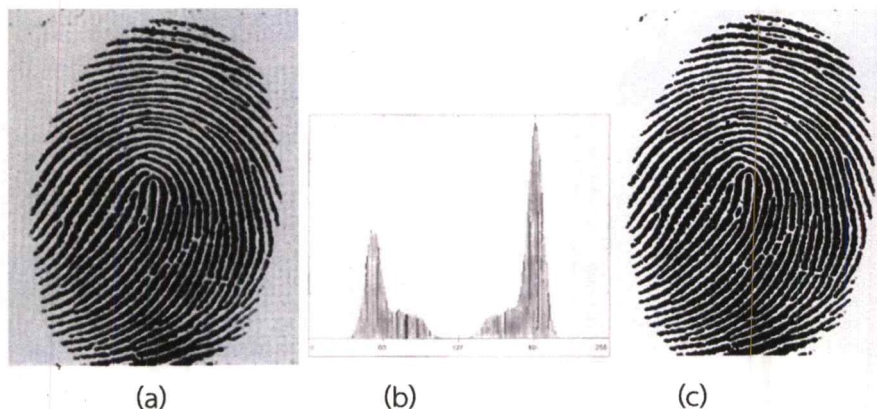
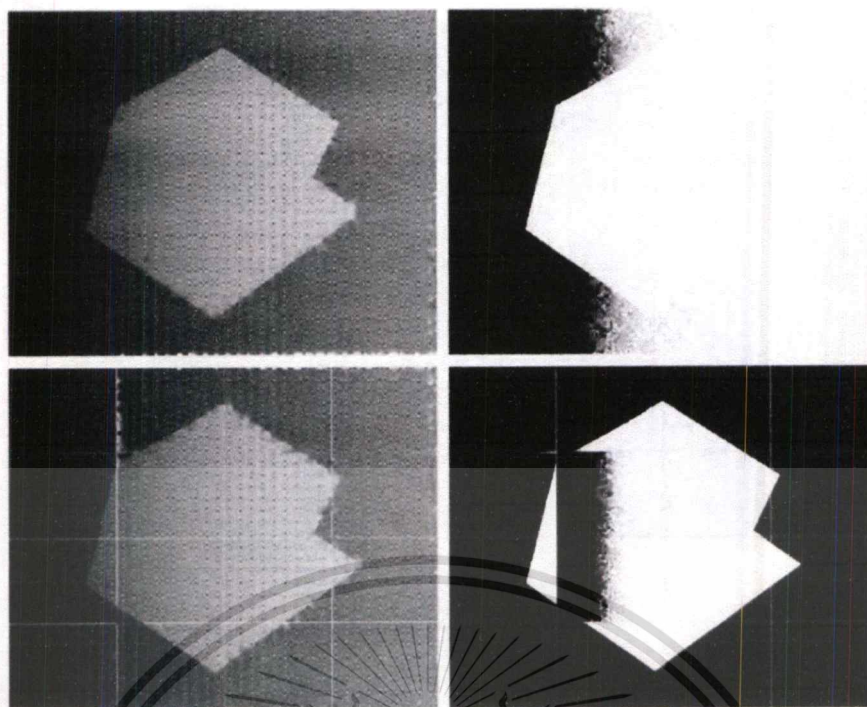


Figure 3.17 : (a) Original image, (b) Image histogram,
(c) Result of segmentation with the threshold estimated by iteration

3.9.3 Basic Adaptive Thresholding

Imaging factors such as uneven illumination can transform a perfectly segmentable histogram into a histogram that cannot be partitioned effectively by a single global threshold. An approach for handling such a situation is to divide the original image into sub-images and then utilize a different threshold to segment each sub-image. The key issues in this approach are how to subdivide the image and how to estimate the threshold for each resulting sub-image. Since the threshold used for each pixel depends on the location of the pixel in terms of the sub-images, this type of thresholding is adaptive. We illustrate adaptive thresholding with a simple example.

Figure 3.18(a) shows the image which we concluded could not be thresholded effectively with a single global threshold. In fact, figure 3.18(b) shows the result of thresholding the image with a global threshold manually placed in the valley of its histogram. One approach to reduce the effect of nonuniform illumination is to subdivide the image into smaller sub-images, such that the illumination of each sub-image is approximately uniform. Figure 3.18(c) shows such a partition, obtained by subdividing the image into four equal parts, and then subdividing each part by four again.



(a) (b)

(c) (d)

Figure 3.18 : (a) Original image, (b) Result of global thresholding.
 (c) Image subdivided into individual sub-images.
 (d) Result of adaptive thresholding.

All the sub-images that did not contain a boundary between object and background had variances of less than 75. All sub-images containing boundaries had variances in excess of 100. Each sub-image with variance greater than 100 was segmented with a threshold computed for that sub-image using the algorithm. The initial value for T in each case was selected as the point midway between the minimum and maximum gray levels in the sub-image. All sub-images with variance less than 100 were treated as one composite image, which was segmented using a single threshold estimated using the same algorithm.

The result of segmentation using this procedure is shown in figure 3.18(d). With the exception of two sub-images, the improvement over figure 3.18(b) is evident. The boundary between object and background in each of the improperly segmented sub-images was small and dark, and the resulting histogram was almost unimodal.

3.10 Template Matching

Template matching is comparing the identified template with a region of the same size in the original image. The objective is to find out the optional matching position. At first, the up-left corner point of the template covers the counterpart of the original image, and the template and the region of the same size in the original image are compared. Then the template is moved to the next pixel, and again the comparison is made. After all the pixels are tried, the area with the least difference is the optional region. As figure 3.19 shows, template $T(X, Y$ pixels) is to be moved horizontally on the original image S . The area that the template covers on S is called sub image. (i, j) is the coordinate of the up-left corner of sub image on S .

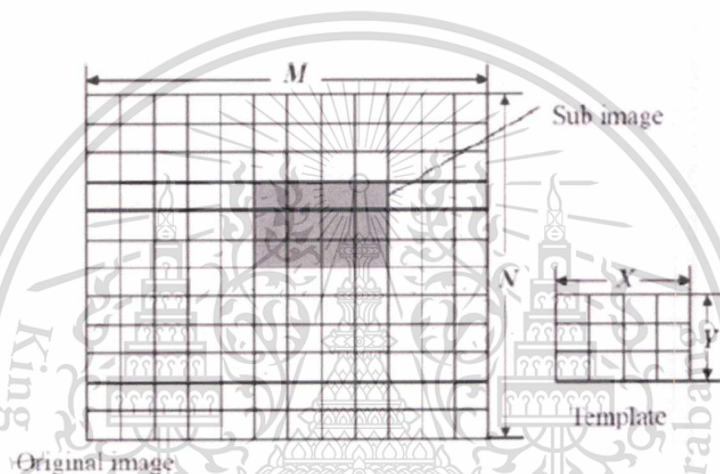


Figure 3.19 : The source image and the template [14]

The difference between the sub image and the template is measured by the sum of square errors. The size of the template is supposed to be $X \times Y$ (width times height), and the size of the original image is $M \times N$. The coordinate of a point in the template is (x, y) . The grey value of this point is $T(x, y)$. The coordinate of the point that matches (x, y) is $(i - x, j - y)$ and its grey value is $S(i - x, j - y)$. Here it is denoted by $S^{ij}(x, y)$. Then the sum of square errors of one matching is

$$D(i, j) = \sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} [S^{ij}(x, y) - T(x, y)]^2 \quad (3.21)$$

And it is expanded as follows:

$$D(i,j) = \sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} [S^{ij}(x,y)]^2 - 2 \sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} [S^{ij}(x,y) \times T(x,y)] + \sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} [T(x,y)]^2 \quad (3.22)$$

In the equality above, the first item on the right is called the energy of the template. It relates to the location of sub image, and changes slightly as the sub image moves. The second item is called the correlation between the template and the sub image. It changes with the location of the sub image (i,j) , and reaches its maximum when $T(x,y)$ matches the corresponding region. The third item is the energy of the template. It is irrelevant to (i,j) , and only needs to be calculated once.

When T and S^{ij} match, the second item achieves its maximum. So this one item can decide image matching. The following correlation function can be set to measure the similarity.

Given the item DS is a constant, which may give rise to inaccuracy and even worse may greatly affect the matching, it is considered in the normalization processing. Then a normalized cross correlation function is obtained below :

$$R(i,j) = \frac{\sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} [S^{ij}(x,y) - T(x,y)]}{\sqrt{\sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} [(S^{ij}(x,y))]^2} \sqrt{\sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} [(T(x,y))]^2}} \quad (3.23)$$

According to this equality, every $R(i,j)$ has a value. As (i,j) changes, the maximum of $R(i,j)$ indicates the best position for T, and thus the matching image is got. As can be seen, image matching involves a large amount of computation. One matching requires $X \times Y$ times of subtractions, $X \times Y$ times of squares, $X \times Y - 1$ times of addition, and the whole image needs to be matched $(M - X + 1) \times (N - Y + 1)$ times.

In normalized cross correlation algorithm, relative calculation shall be done on $(M - X + 1) \times (N - Y + 1)$ points. Besides on the best matching point, the rest computation is worthless.

Figure 3.20 illustrates the concepts just discussed. Figure 3.20(a) is original image and figure 3.20(b) is sub image. The correlation coefficient $R(i, j)$ is shown as an image in figure 3.20(c). The higher (brighter) value of $R(i, j)$ is in the position where the best match between original and sub image was found.

Although the correlation function can be normalized for amplitude changes via the correlation coefficient, obtaining normalization for changes in size and rotation can be difficult. Normalizing for size involves spatial scaling, a process that in itself adds a significant amount of computation. Normalizing for rotation is even more difficult. If a clue regarding rotation can be extracted from original image, then we simply rotate sub image so that it aligns itself with the degree of rotation in original image. However, if the nature of rotation is unknown, looking for the best match requires exhaustive rotations of sub image. This procedure is impractical and, as a consequence, correlation seldom is used in cases when arbitrary or unconstrained rotation is present.

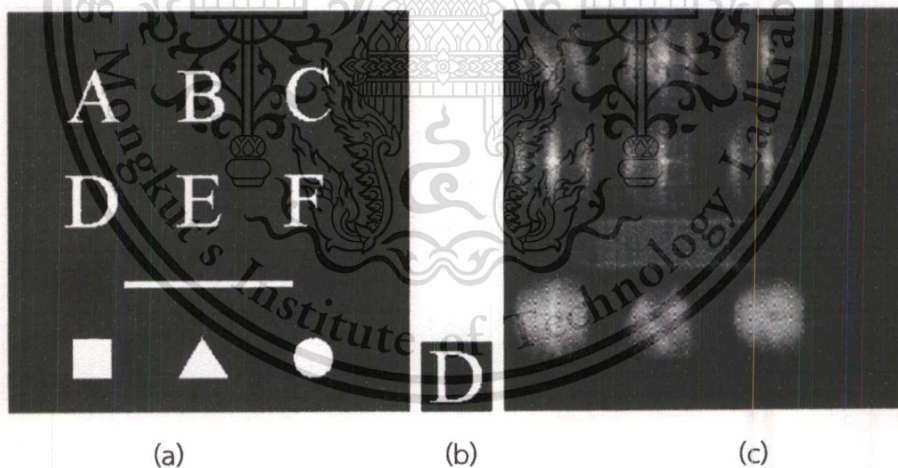


Figure 3.20 : (a) Image. (b) Subimage. (c) Correlation coefficient of (a) and (b). [2]

3.11 Automated Visual Inspection

AVI operates by employing a camera to acquire an image of the object being inspected and then utilizing appropriate image processing hardware and software routines to find and classify areas of interest in the image. Figure 3.21 shows the setup of an AVI system based around a central computer. In this system, the computer controls the camera, lighting and handling system. It also takes images acquired by the camera, analyses them using image processing routines and then issues an appropriate action to be performed by the handling system. Images from the inspected objects and the number of parts accepted and rejected may be displayed on a monitor or Visual Display Unit (VDU).

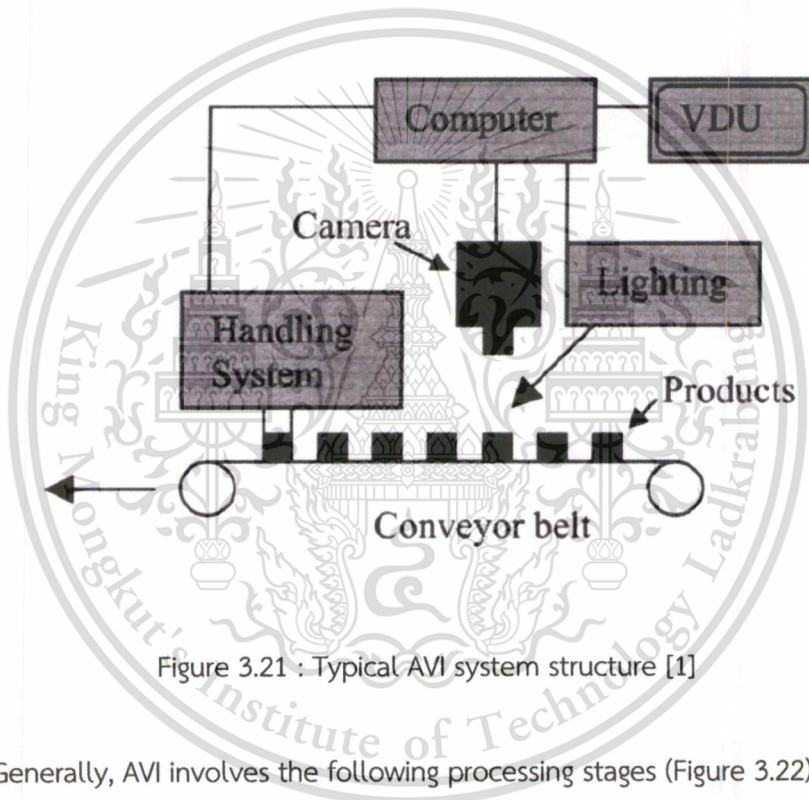


Figure 3.21 : Typical AVI system structure [1]

Generally, AVI involves the following processing stages (Figure 3.22):

- Image acquisition to obtain an image of the object to be inspected.
- Image enhancement to improve the quality of the acquired image, which facilitates later processing.
- Segmentation to divide the image into areas of interest and background. The result of this stage is called the segmented image, where objects represent the areas of interest.

- Feature extraction to calculate the values of parameters that describe each object.
- Classification to determine what is represented by each object.

Based on the classification, the parts are passed or failed. Accepted parts may then be graded. Another possible use of the classification information is as feedback for the production process. For example, it may be noticed that a particular type of defect is occurring frequently. This indicates that one of the machines or processes may not be operating optimally.

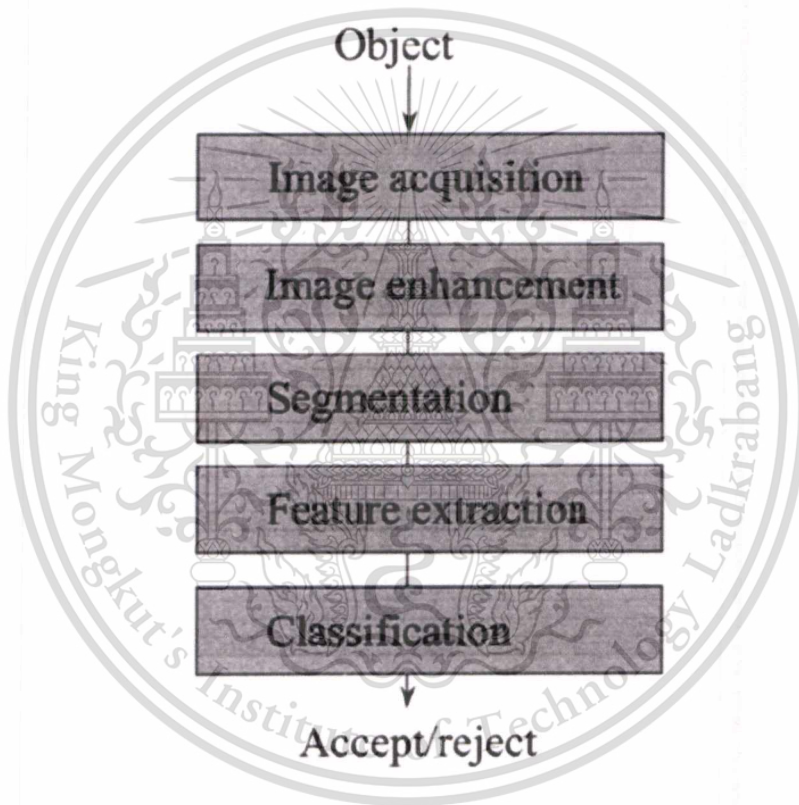


Figure 3.22 : General AVI process structure [1]

Before implementing an AVI system, it is useful to consider some of the practical.

- System concept : AVI systems should not be developed just for the sake of doing so. If a cheaper or easier alternative solution to the problem is available, then this is preferable. Also, neither

humans nor vision systems will achieve 100% accuracy consistently. Thus, considering the importance of quality, the best solution may be to use humans and machines together.

- Requirements : It is important to start AVI system development with a clear system specification, detailing the customer requirements.
- Design : The system should be designed to be as simple as possible. This is called the principle of Occam's razor. If two systems are developed with the same performance, the one with the simplest implementation should be chosen. The justification for this is that a simple system has fewer components that can fail.
- Implementation : A larger part of the cost of the system development is spent on making the system work in a factory environment than on developing the image processing routines.
- Visualization : It is beneficial to attach a VDU to the inspection system to inform personnel of its operation. Users and managers feel more confident with a system when they can visualize what it is doing.

The general requirements of an AVI system are that it should be:

- Accurate : It should improve upon human capabilities. The performance of human inspectors is usually well under 100%.
- Fast : The system should be able to work in real time. This is very important because objects in production lines arrive for inspection in rapid succession.
- Robust : The system should be insensitive to industrial environments. Such factors as variable light, vibrations and dust must be taken into consideration.
- Complete : The system should be able to identify, as well as locate, defects. The grade of an object can depend not only on the number and size of defects but also their type and location. In addition, the system should accumulate and make available statistical information about its operation for performance analysis

purposes. If a defect, which is caused during production, occurs frequently then the system should notify the workers in the factory to correct the problem.

- Flexible : Ideally, the system should have some user-configurable modules so that it can be easily transferred from one product or production line to another. However, access to user-configurable parts of the system should be rigorously controlled and monitored.
- Reliable : If failure of the system is detected, a backup system or alarm will be required.
- Maintainable : The inspection equipment should be arranged so that all parts may easily be accessed. Also, computer programs should be written so that they are readable and easy to understand. Program code should contain a large number of comments and be logically structured.
- Cost effective : The cost of developing and running the system should be more than compensated for by its economic benefits. Often, the major cost in the development of an inspection system is not the hardware but the cost of employing developers to write dedicated software. However, considering the importance of quality in today's marketplace for acquiring and maintaining customers, the payback time for AVI systems can be short.

3.12 Artificial Intelligence in AVI

It can be argued that machine vision is by its nature intelligent because the interpretation of images requires intelligence. Humans find vision tasks trivial as the brain processes images subconsciously, without any need for deliberate thought. Conversely, interpretation of images is complex for computers but tasks depending on a large amount of known calculations, such as playing chess, are relatively simple. No computer system has so far been developed which can interpret all images. Rather, many machine vision systems have been built that deal with one specific object in a restricted environment.

A growing amount of research has been aimed at incorporating artificial intelligence techniques into AVI systems to increase their capability. Table 3.1 shows the techniques for each stage of the AVI process that are described.

Tabel 3.1 : AVI stages and AI techniques

	Conventional methods	Expert systems	Fuzzy logic	Inductive learning	Neural networks	Generic algorithms, simulated annealing and Tabu search
Image acquisition	X	X				
Image enhancement	X		X		X	X
Segmentation	X		X		X	X
Feature selection	X		X	X	X	X
Classification	X	X	X	X	X	

Automated visual inspection is becoming increasingly important for the inspection of many industrial products. It can be decomposed into the stages of image acquisition, image enhancement, segmentation, feature extraction and classification. Artificial intelligence techniques are being increasingly utilized. Common artificial intelligence techniques include expert systems, fuzzy logic, inductive learning, neural networks, genetic algorithms, simulated annealing and Tabu search. One or more of these methods has been used at each stage of the inspection process [1].



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Chapter 4

Research Methodology

4.1 System development

Designed system considers off line process to acquisition sample product label image picture for input to automatic visual inspection system. The system constitution based on machine vision, which divides two parts: image acquisition of product label and inspection system. The part of image acquisition includes illumination.

4.1.1 Image acquisition

The system is processing base on laptop computer CPU Intel® Core™ i5 2.53GHz RAM 3.42GB. CCD camera is setting up with figure to acquire image picture of failure product label sample. The CCD camera are mounted with polarize filter to reduce LED light source reflection. LED ring light source is preferred to be source of illumination in the system. The system structure is shown as figure 4.1.

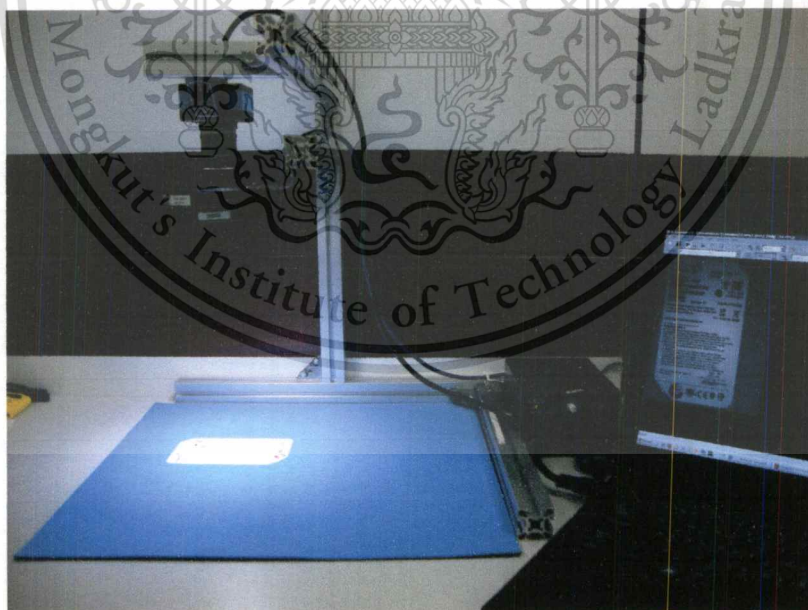


Figure 4.1 : Inspection system structure

USB CMOS Color Camera model DFK 61AUC02 of The Imaging Source, LLC [15] is selected camera equipment of this research study. The camera is mounted with TV lenses 16 mm. F1.4 field of view $23.0^{\circ} \times 30.4^{\circ}$ (VxH). Closest distance spec is 0.4 m.



Figure 4.2 : Camera and lenses

LED ring light source is applied to spot the target object of image acquisition. Direct Ring Illumination from MORITEX SCHOTT is selected to be a light source for this research study. The model and specification is MDRL-CW50 with white emitting color, internal ring diameter 50 mm., external diameter 90 mm. light angle 70° [16]. Figure 4.3 shows the actual setting on the study.

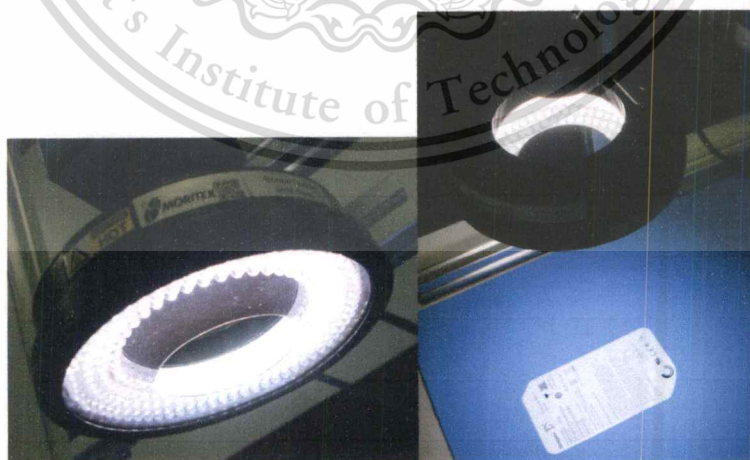


Figure 4.3 : Light source setting of research study

The image is acquired in format 1024x768 pixels with 35.5 frame per second and sensitivity 1.0 V/lux-sec by IC Capture 2.2 software [17]. Figure 4.4 shows image output from acquisition.

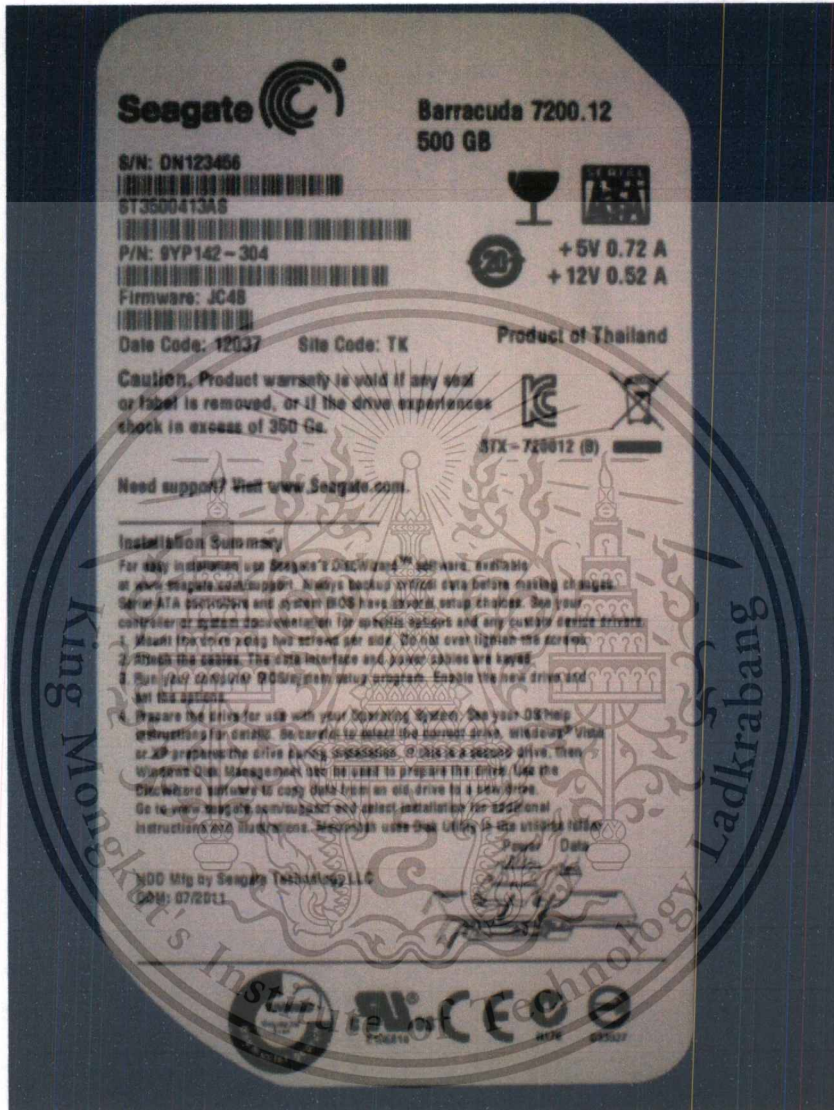


Figure 4.4 : Output image acquisition from inspection system

4.1.2 Inspection system

The inspection system configuration is preferred vision builder software version 3.6. The software process of label inspection flowchart is shown in figure 4.5.

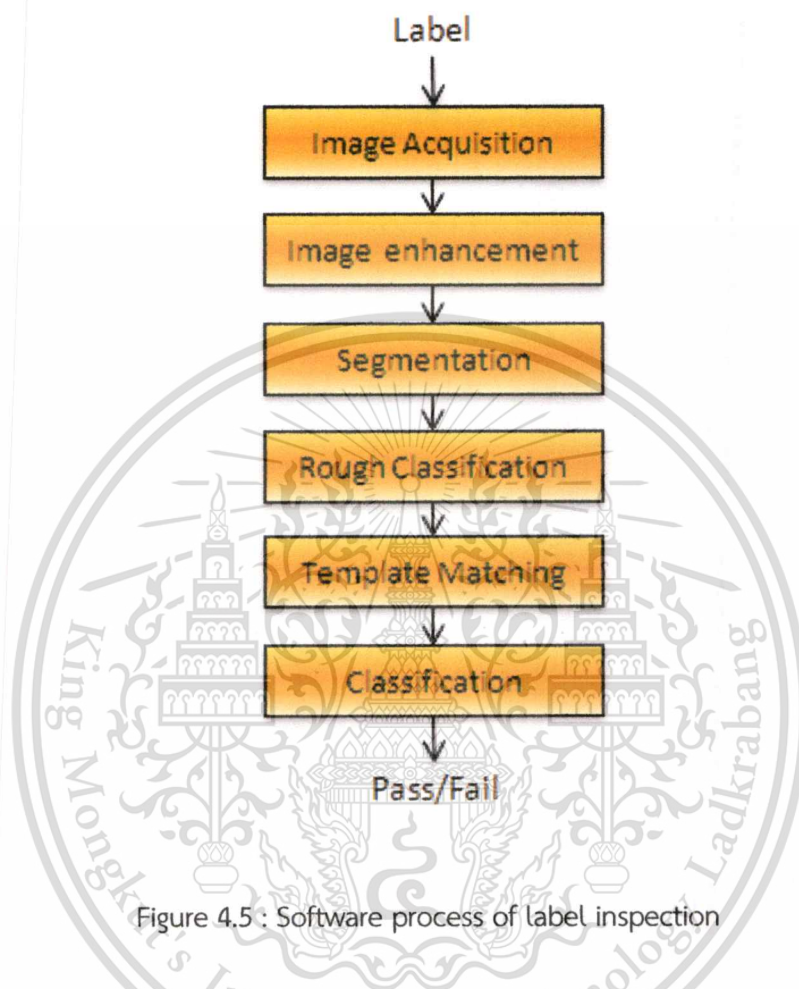


Figure 4.5 : Software process of label inspection

Since pre-processed image is a better contrast and brightness, it is convenient to implement image segmentation in the candidate area. The proposed method extracts target image section in Hue, Saturation, Intensity (HSI) color space. Compared to the RGB model, color description based on the HSI model is closer to the feeling of human eyes. Moreover, the hue and saturation parameter in the HSI model is mainly determined by the absorption and reflection nature of the material and immune to the disturbance generated by the variation of illumination and viewing angle. Consequently, the HSI model can be applied to getting rid of the luminance component from the image [18]. Since the label is a polished material. Image are frequently accompanied with noise light generated by diffuse and

reflection on the label surface, the image segmentation and color extraction in the HSI space would efficiently and effectively eliminate the noise and disturbance from the background and attain a better extraction image.

4.1.2.1 Image segmentation

The simplest and fastest method of segmentation is thresholding and this had been used widely. The idea is different object or regions in the image have significant different gray level. Basic global thresholding is to partition the image histogram by using a single global threshold. The thresholding consider gray level histogram of count pixel which looks for bright contents. Setting T level of histogram can manual set by user at gray level on histogram chart. Figure 4.6 show a threshold setting at gray scale level 80 and the result of image segmentation.

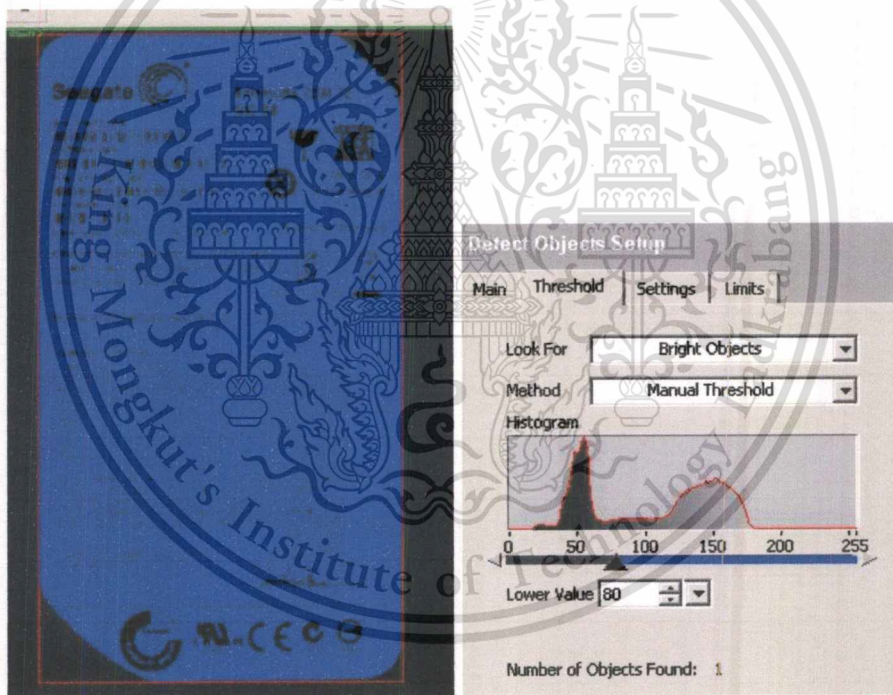


Figure 4.6 : Threshold setting and image result

Current HDD product label raw material is paper base liner as show in figure 4.7. Implement new color background to be light blue will get better result on

thresholding to segment the image. Implementation on mass production may need to change material support this purpose.



Figure 4.7 : Original product label paper base liner and implement new background

4.1.2.2 Rough Classification

Setting count pixels in dark object to rough classify fail/pass label by set count pixels at setting threshold. Limit setting is maximum number count of pixel at 347000 counts. This classify can help system improve processing time before continue to perform matching for whole templates. Comparing between addition rough classify and without this function on this study. The average inspection time can improve faster. Table 4.1 compare inspection benchmark between addition this function and without the function.

Table 4.1 : Inspection benchmark rough classification.

	Inspection time (ms)		
	Average	Shortest	Longest
With count pixel function	132.439	85.872	407.479
Without count pixel function	343.761	258.699	448.082

4.1.2.3 ROI and Template Matching

There are two major category of product label defect failure which is incomplete printed on logo area and line defect cause by printer head as show in figure 4.8. Using both geometric and sub-image template matching to detect defect on printed product label to detect both two failure mode.

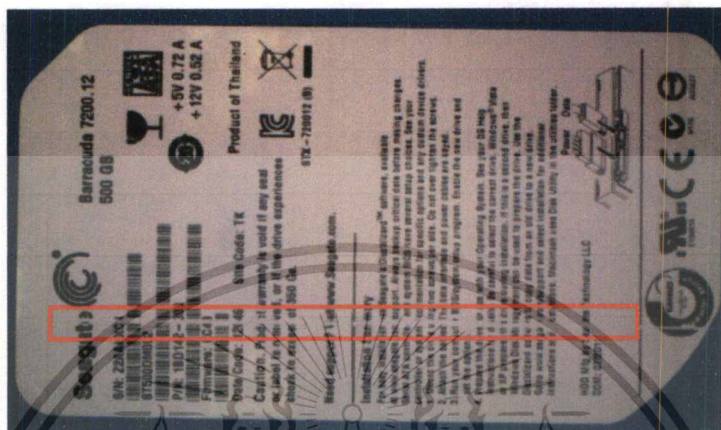


Figure 4.8 : Line defect of product label cause by printer head

There are 2 geometric template of bar line in middle and bottom of printing template information. And 11 sub-images of logo picture information on the label are decided to be template master to inspect the label. Each template is optimized to limit setting specific per its detail quality.

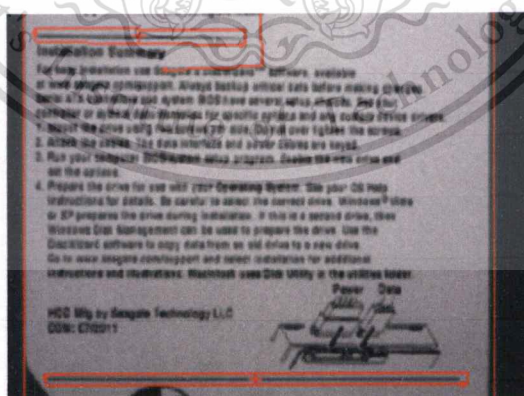


Figure 4.9 : Geometric template on bar line

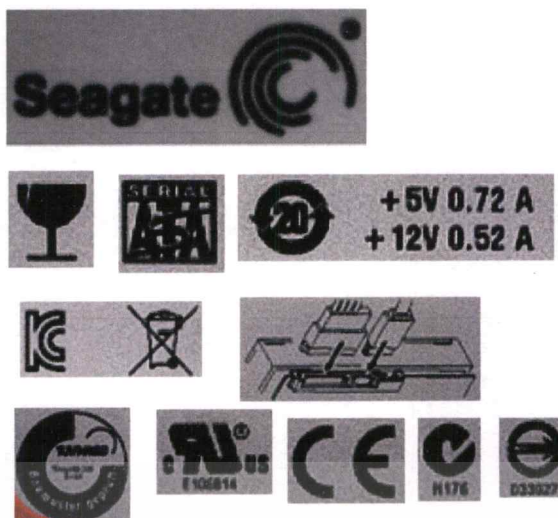


Figure 4.10 : Sub-image template matching

4.1.2.4 Classification

A classification criterion of the developed system considers a minimum score of each pattern matching. These parameters contained characteristic values that are directly related to completely of printed logos quality on the label. The classification process compares this value as a specific feature. Before classification stage, the different pattern will be separated by pattern detection. Using logical AND in classifier scheme that a failed of each template matching will fail. And all passes each template will pass as shown in figure 4.11. The inspection result will display on monitor as show in figure 4.12.

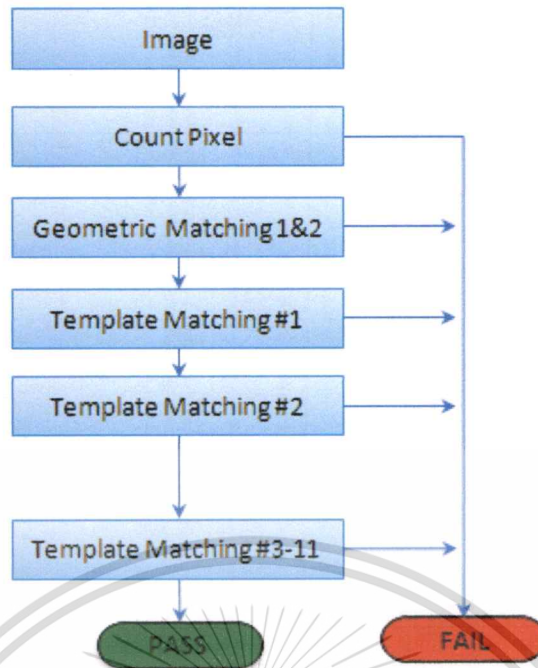


Figure 4.11 : Classification criteria



Figure 4.12 : Inspection result display

4.2 Optimize inspection limit

A difference printer equipment, raw bank label material and printer ribbon will generate vary difference printing quality on printed label. Also information detail on each logo affects to the quality. Selecting 10 good and 40 obviously defective product labels are candidate sample to optimize inspection limit. All 10 known good label will optimized an inspection result to be pass. And all 40 known failed label

will optimize the inspection result to be fail. After optimize the inspection limit benchmark inspection is performed to verify the result of setting. The inspection limit setting and benchmark result are following.

Table 4.2 : The inspection limit setting on each inspect items.

Inspection items	Score	Limit
1. Count pixels	34500	Min number of pixel
2. Geometric Template Matching#1	800	Min 1 matched
2. Geometric Template Matching#2	800	Min 1 matched
3. Template Matching subimage#1	820	Min 1 matched
4. Template Matching subimage#2	750	Min 1 matched
5. Template Matching subimage#3	750	Min 1 matched
6. Template Matching subimage#4	750	Min 1 matched
7. Template Matching subimage#5	700	Min 1 matched
8. Template Matching subimage#6	650	Min 1 matched
9. Template Matching subimage#7	750	Min 1 matched
10. Template Matching subimage#8	700	Min 1 matched
11. Template Matching subimage#9	750	Min 1 matched
12. Template Matching subimage#10	700	Min 1 matched
13 Template Matching subimage#11	700	Min 1 matched

The benchmark result is passes inspection at 10 labels (all known good label) and fails 40 labels (all known fail) as show in figure 4.13. The average inspection time is 248.66 ms. The detail inspection time by state are show in figure 4.14. The chart show highest contribute to total inspection from geometric and subimage#1 matching. The rest are almost nearly inspection time result average about 10 ms.

Name	Value
I- System Variable - Active Time (s.)	0.00000
I- System Variable - Idle Time (s.)	0.00000
I- System Variable - Inspection Rate	0.00000
I- System Variable - Inspection Status	Pass
I- System Variable - # Pass	10.00000
I- System Variable - # Fail	40.00000
I- System Variable - # Parts Inspected	50.00000
I- System Variable - Yield (%)	20.00000
O- Step Result	False

Compute Results

Figure 4.13 : Optimization benchmark inspection result

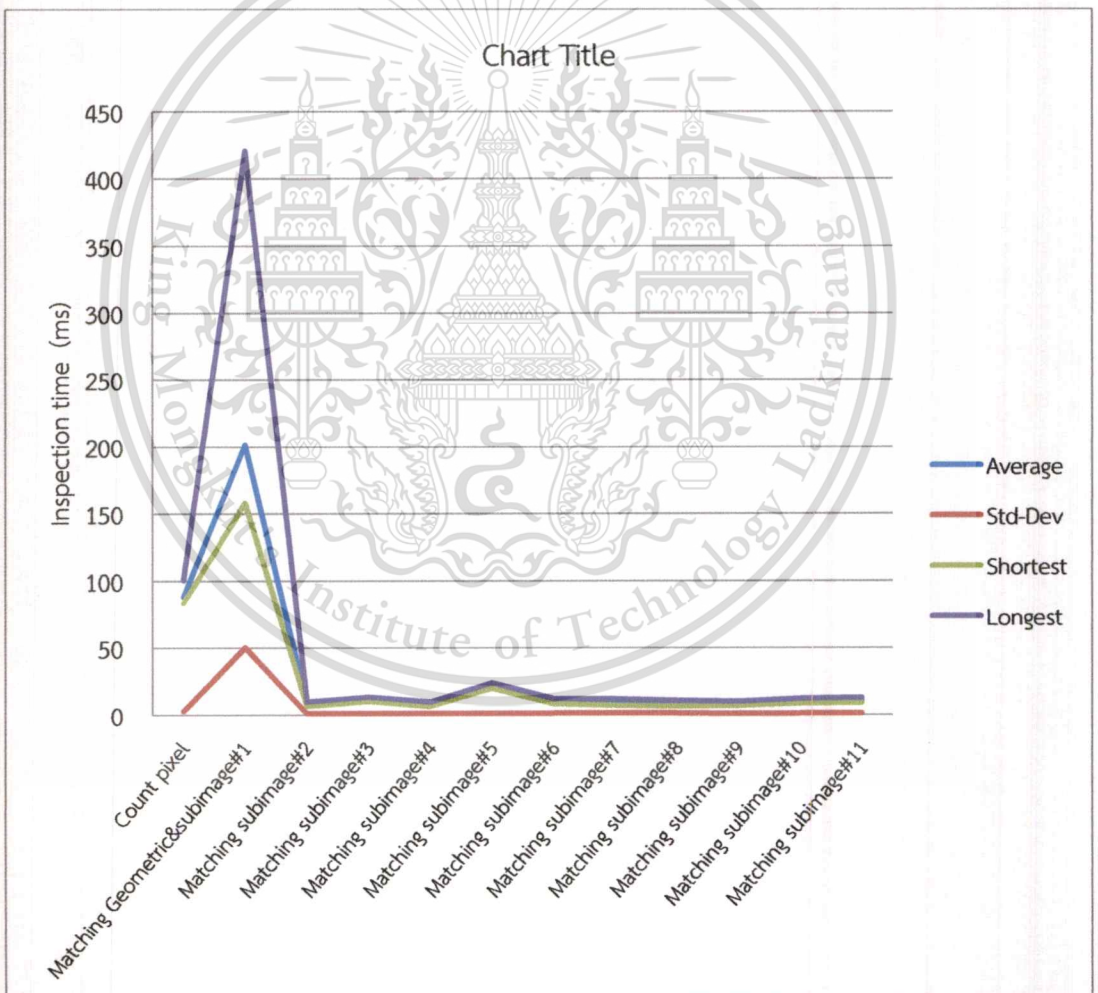


Figure 4.14 : Optimization inspection time by state chart



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Chapter 5

Conclusion and Future work

5.1 Result and conclusion

Evaluation the optimized inspection limit applies the inspection system to 1000 failure labels. The inspection result is fail 82.5% (825 labels) and 17.5% pass (175 labels). Inspection time is show in table 5.1. Passed inspection 17.5% cannot detect the failure. Almost of them are border line and marginally cases.

Also evaluation to 53 good labels show 85% pass (45 labels) and 15% fail (8 labels). The 15% fail from good labels inspection are major fail at rough classification step (count pixel). Almost of them pixel score are nearly to spec but still lower than limit setting. There are intensity of input picture quality or quality of printing (some printer set up or ribbon may cause printing intensity quality). Thus more optimization of feature and process may need to work together to improve productivity.

Table 5.1 : Result of inspection time

Average Inspection Time:	258.853	ms
Standard Deviation:	129.715	ms
Shortest Inspection Time:	83.93	ms
Longest Inspection Time:	590.714	ms

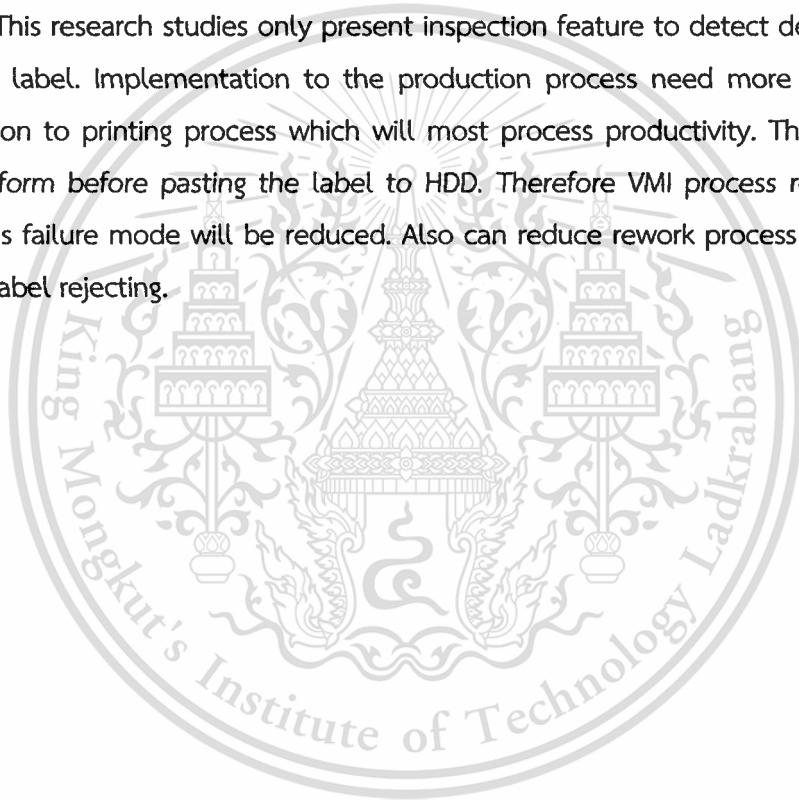
This research studies an automated inspection system for HDD product label. This aimed to increase the production efficiency, reduce the inspection processing time and human error. Event some defect still cannot capture the failure but major defect locate on logo each position can captured by the inspection system. Average inspection time is 259 msec. comparing to inspection by human at 2 sec. which probability use for automatic visual inspection system. Combine with other detection feature and implement together with human process still meet both process time and quality.

5.2 Research advantage

1. The inspection system can improve process efficiency and productivity.
2. Increase more accuracy of inspection process.
3. Implement the inspection system can help replace process which require high skill worker to process.
4. Prevent escape defect label to customer and gain more customer satisfaction.

5.3 Future work

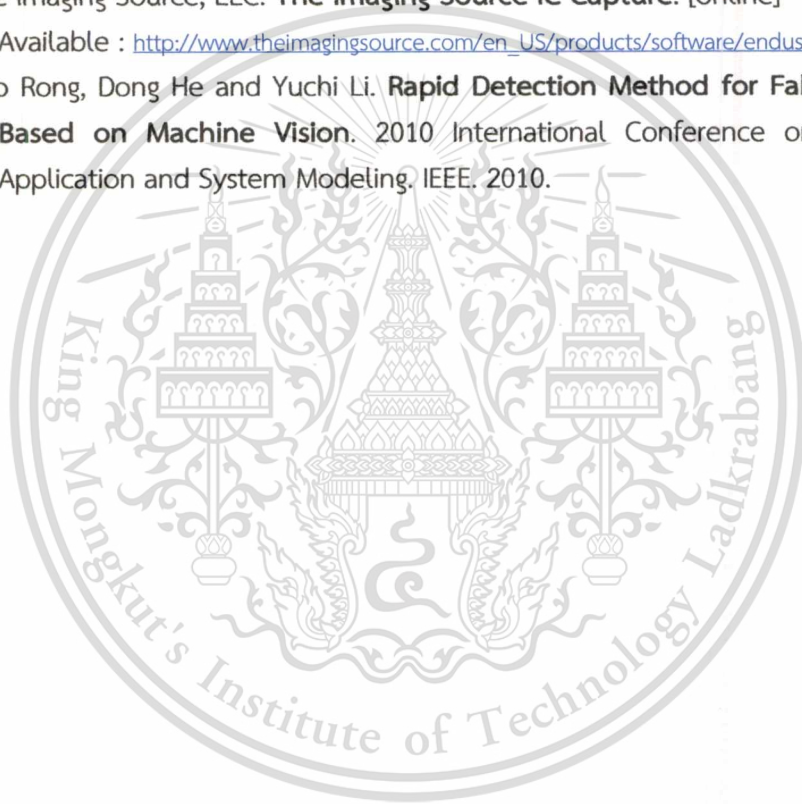
This research studies only present inspection feature to detect defect of HDD product label. Implementation to the production process need more develop on integration to printing process which will most process productivity. The inspection will perform before pasting the label to HDD. Therefore VMI process rejecting rate form this failure mode will be reduced. Also can reduce rework process cost for the defect label rejecting.



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Appendix 1

Publication List

1. Theerasan Phuchitjarowong, Surapan Airphaiboon, “HDD product label defect detection using template matching technique”, In proceeding of DST-CON 2011, Muangthong Thani,Nonthaburi,Thailand 9-10 January,2012.



DST-CON 2011

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ACD8	Morphology-Based Automatic Visual Inspection for 5JB Defect on HGA	1.Jirarat Ieamsaard 2.Paisarn Muneesawang 3.Suchart Yammen 4.Thanapoom Fuangpian	Naresuan University
ACD9	Finite element analysis to assist design of an automated assembly machine	1.Prasertsak Naksakul 2.J. Camai 3.A. Manonukul	King Mongkut's University of Technology North Bangkok
ACD10	HDD product label defect detection using template matching technique	1.Theerasan Phuchitjaruwong 2.Surapan Airphaiboon	King Mongkut's Institute of Technology Ladkrabang
ACD11	Application of Code39 Barcode Recognition on Web-camera	1.Chavalit Chiangpiw 2.Somsak Choomchuay	King Mongkut's Institute of Technology Ladkrabang
ACD12	Simulation Model for Reducing Spring constant (Kv) in HDD Suspension After The Forming Process	1.Sanga Kongkaew 2.Nitin Afzulpurkar 3.Nattawut Thepayasuwan 4.Manukid Parnichkun 5.Khampon Sittipongpanich	Asian Institute of Technology
ACD13	Effects of Rotating Speed on Flow Field around the Arm of Dual R/W Heads	1.Yuwathida Lamkam 2.Daranee Hormdee	Khon Kaen University

ACD10

Title: HDD Product Label Defect Detection Using Template Matching Technique

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Abstract: Hard Disk Drive (HDD) manufacturing process is finally with pasting product label. Then continue next to visual mechanical inspection (VMI) process for ensure no cosmetic failure such as scratch or defect on label is shipped out. Current process almost performs manually by operators who taking care VMI process. The process depends on human performance that fatigue may impact to quality. Automated visual inspection (AVI) is most useful in automatic manufacturing process which improves process quality and reliability. This work proposes a technique of template matching to detect the defect on HDD product label to prevent human error and improve more reliability of detecting label defect. Several image processing techniques are implemented to detect and classify pass or fail label. The system is capable to detect the failure and improve performance with achieved fast processing time.

HDD product label defect detection using template matching technique

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Abstract— Hard Disk Drive (HDD) manufacturing process is finally with pasting product label. Then continue next to visual mechanical inspection (VMI) process for ensure no cosmetic failure such as scratch or defect on label is shipped out. Current process almost perform manually by operators who taking care VMI process. The process depends on human performance that fatigue may impact to quality. Automated visual inspection (AVI) is most useful in automatic manufacturing process which improves process quality and reliability. This work proposes a technique of template matching to detect the defect on HDD product label to prevent human error and improve more reliability of detecting label defect. Several image processing techniques are implemented to detect and classify pass or fail label. The system is capable to detect the failure and improve performance with achieved fast processing time.

Keywords— HDD, label, AVI, image processing, template matching, cross correlation.

I. INTRODUCTION

HDD manufacturing process is consider in two major processes by area specific. There are cleanroom and backend process. Head disk assembly (HDA) is assembled in clean room environment control. It is a room in which the concentration of airborne particles is controlled to specific limits. And continue process outside clean room when enclose with cover. Outside clean room process sometime call backend (B/E) process. B/E process is beginning from install printed circuit board (PCB) to HDA to be complete part of HDD. Then continue process to test where all HDD functional and media scan are performing during the test. Finally packing process starts from attaching product label and continue VMI to inspection the drive before ship to customer. Label defect is major failure can be found at VMI process. Fig. 1 shows brief process flow of HDD manufacturing.

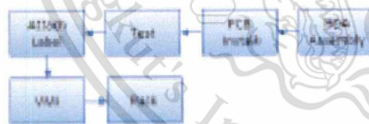


Fig. 1 HDD manufacturing process.

Current VMI process handles by operator to finding any cosmetic defect all area of HDD including product label. As shown in Fig. 2. The label is located many information such as serial number, model number, company logo, product safety standard logo and etc.

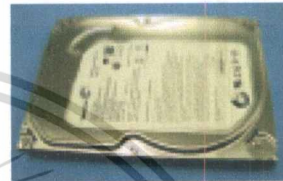


Fig. 2 HDD with pasted product label.

Many humans are engaged in inspection task but due to factors such as tiredness and boredom, their performance is often less than satisfactory [1]. In HDD manufacturing, quality is so important that AVI systems and human inspectors may be used together synergistically to achieve improved quality control. The machine vision system is used to inspect a large number of products rapidly. The human inspector can then perform slower but more detail inspection on objects that the machine vision system considers to be borderline cases.

Defect on logos are often occurred. AVI is selected to help capture the defect due to its performance on large number and less inspect time. This work aims to develop a detection feature by machine vision system with template matching technique. The several image processing algorithm such as image enhancement, filter image, thresholding, template matching and etc. are applied. The system processes can be classify pass or fail sample meet requirement of quality and process time.

II. METHODOLOGY

AVI operates by employing a camera to acquire an image of product label being inspected as show in Fig. 3. And then utilizing computer vision software to find and classify areas of interest in the image till classify and resulting the inspection. The software process of label inspection is shown in Fig. 4.

A. Image Acquisition

The complete of image processing and analysis is highly dependent on the quality of information taken from the image. This means that the information is dependent on the quality of lighting, lens magnification, focus length and image sensor. Image acquisition transforms the physical object's visual image and its intrinsic characteristic into a set of digitized data. This type of data can use by the processing unit of a system. In a controlled lighting condition, CCD camera will capture the label image after the signal through the lens.

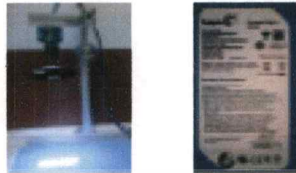


Fig. 3 Image acquiring structure and image output

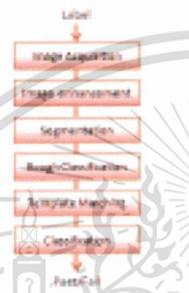


Fig. 4 Software program label inspection

B. Image Enhancement

Since pre-processed image is a better contrast and brightness, it is convenient to implement image segmentation in the candidate area. The proposed method extracts target image section in Hue, Saturation, Intensity (HSI) color space. Compared to the RGB model, color description based on the HSI model is closer to the feeling of human eyes. Moreover, the hue and saturation parameter in the HSI model is mainly determined by the absorption and reflection nature of the material and immune to the disturbance generated by the variation of illumination and viewing angle. Consequently, the HSI model can be applied to getting rid of the dominance component from the image [2]. Since the label is a polished material, image are frequently accompanied with noise light generated by diffuse and reflection on the label surface, the image segmentation and color extraction in the HSI space would efficiently and effectively eliminate the noise and disturbance from the background and attain a better extraction image.

The equation (1) shows the mathematical transform from the RGB space to the HSI space [3].

$$\begin{cases}
 H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases} \\
 \theta = \cos^{-1} \left\{ \frac{1/2[(R-G) + (R-B)]}{\sqrt{[(R-G)^2 + (R-B)(G-B)]^2}} \right\} \\
 S = 1 - \frac{\min(R, G, B)}{(R+G+B)} \\
 I = \frac{1}{3}(R+G+B)
 \end{cases} \quad (1)$$

C. Image Segmentation

The simplest and fastest method of segmentation is thresholding and this had been used widely [1]. Thresholding is based on the idea that different object or regions in the image have significant different gray level.

Fig. 5 shows the histogram on sample label image and its segmentation result at lower value 80.



Fig. 5 Object detection with thresholding

D. Region of Interest (ROI) and Template Image

Logos on the label are importance information to print out which its reason such as company logo, safety standard logo and etc. And it located cover almost area of the label which defect can happen.

This study selects 11 sub-templates from each logo that located on the product label. Selection sub-template by define mask manually scope on logo area. Some logo template that selected for matching process is shown in Fig. 6.

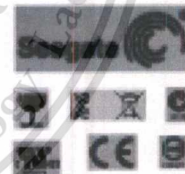


Fig. 6 Selected logos for matching process.

E. Rough Classification

Setting count pixels in dark object to rough classify fail/pass label by set up count pixels at setting threshold. This classify can help system improve processing time before continue to perform matching for whole templates. Comparing between addition rough classify and without this function on this study. The average inspection time can improve faster.

F. Template Matching

Template matching is an approach used in finding similarity between the small part of searched image (target) and template image. It is widely used to locate the position of the small parts in a searched image that matched with the template image. This work is comparing the identified logo on the label with a region of the same size in the original image. The objective is to find out the optimal matching position.

The matching method used in this project is implemented by cross correlation [4], [5] show in equation (2). In matching process, the template image is moved to all possible positions in a searched image and computes the similarity value of pixel brightness between the template and the searched image. The position, where the process retrieves the highest value, is the best match position.

$$CC(k, l) = \frac{\sum_{i,j} I_{i,j} \cdot T_{i-k, j-l} - M_i \cdot N_j}{\sqrt{(\sum_{i,j} I_{i,j}^2 - M_i^2) (\sum_{i,j} T_{i,j}^2 - N_j^2)}} \quad (2)$$

Where $N(i, j)$ and $M(i, j)$ is matrix of the template image and matrix of the image acquire from the camera, respectively.

G. Classification

A classification criterion of the developed system is consideration a minimum score of pattern matching. These parameters contained characteristic values that are directly related to completely of printed logos quality on the label. The classification process compares this value as a specific feature. Before classification stage, the different pattern will be separated by pattern detection. Using logical AND in classifier scheme that a failed of each template matching will fail. And all passes each template will pass as shown in Fig. 7.

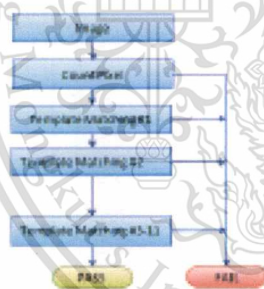


Fig. 7 Classification criteria

III. MEASUREMENT MATCHING TEMPLATE

Design to use image processing software. Match pattern is adjustable by minimum score and search for rotated pattern at maximum ± 20 degrees of each sub-template that depends on detail on each template, e.g. sub-template#1 setting up minimum score at 820 as Fig. 8. This mean 84% expose cover master sub-template image is acceptable on sub-template#1.

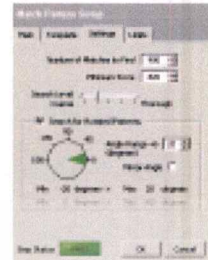


Fig. 8 Minimum score setting of pattern matching

Fig. 9 and Fig. 10 are shown the result of Pass and Fail of sub-template#1. There are scoring 846 on pass and 783 on fail image.



Fig. 9 Pass image sub-template#1 matching



Fig. 10 Fail image sub-template#1 matching

IV. RESULT AND DISCUSSION

This project studies of template matching for various logos on the label by using vision builder software. The software executed on a Windows XP, Intel(R) Core(TM) i5 2.53GHz CPU, 3.42 GB of memory. Selecting 10 known good and 50 known fail labels are an experiment sampled. The image acquired in format 1024x768 pixels by IC Capture 2.2 software. There are 11 sub-templates matching on each label

HDD Proceeding



sample. The summary of test component specification and experiment result are show in Table I and II.

TABLE I
SPECIFICATION OF TEST COMPONENT

Image Information	
Image Source	Database
File Type	JPG
No. of image sample	60
No. of template	11
Image Size (pixel)	768x1024
Template#1 Size (pixel)	230x88
Template#2 Size (pixel)	59x23
Template#3 Size (pixel)	74x26
Template#4 Size (pixel)	107x39
Template#5 Size (pixel)	146x51
Template#6 Size (pixel)	212x90
Template#7 Size (pixel)	105x102
Template#7 Size (pixel)	83x24
Template#9 Size (pixel)	78x39
Template#10 Size (pixel)	42x33
Template#11 Size (pixel)	50x37

TABLE III
EXPERIMENTAL RESULT

Item	Input		Inspection Result	
	Q/ty	%	Q/ty	%
Good label	16	17%	16	27%
Fail label	50	83%	44	73%
Total Sample	60 (100%)			
Average Inspection Time	90.869 ms			
Shortest Inspection Time	36.943 ms			
Longest Inspection Time	168.811 ms			

V. CONCLUSIONS

This paper presented an automated inspection system for HDD product label. This aimed to increase the production

efficiency, reduce the inspection processing time and human error. Classification criteria of the system consider all pass resulting of each sub-template that achieves minimum score of pattern matching. Scoring of each sub-template can be individual setting up to optimizing inspection per logo detail. It can capture defect that appear on the label on each sub-template position.

The result of experiment shows 27% pass inspection. There is 10% fail label cannot capture by the matching. Most of them are borderline cases. Average inspection time is 90.869 ms which is probability use for AVI system. Combine with other detection feature and implement together with human process still meet both process time and quality.

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