**Faculty of Electrical Engineering**

# A THREE DIMENSIONAL (3D) VISION BASED DEFECT INSPECTION SYSTEM FOR GLUING APPLICATION

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**A THREE DIMENSIONAL (3D) VISION BASED DEFECT INSPECTION**

**SYSTEM FOR GLUING APPLICATION**

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# ABSTRACT

A Robot Vision System (RVS) is an adaptive and dynamic system that caters to a wide range of jobs where each involves a set of operations required to be done at a predetermined workstation. This research is focused on the development of a vision system to be integrated with KUKA arm robot. Pyramid object is used as a complimentary of the windscreen car as a model. It developed using plain cardboard with dimension of 15cm x 15cm. 2D matching application introduced to identify the characteristic of the object used in the system using CCD camera. Object used must be trained in training phase to create object template and used again in recognition phase for object classification. Then, two CCD cameras are used; placed at the top and front of the object to extract object's edge location using Harris Point. Data extracted from it are used to find 3D coordination of each edge. Equation of straight line mostly used in this method to identify x, y and z coordinates. Data obtained from the system then used to give instruction to KUKA arm robot for gluing purposes. Pixel coordinates must be converted to robot coordinates for easier understanding by the robot. Three types of defect are trained as model templates and save to the memory known as bumper, gap and bubble defect. Each defect has special characteristic. Inspection system developed to identify problems occurs in gluing process. Template matching method used to call model trained in training phase to identify the uncertainties. Each defect occurs comes with its coordinate's information for correction. Correction of defect consists of two phase; $1^{st}$ CoD where correction is completed in first time and $2^{nd}$ CoD where correction still need to be completed after the first correction. Data for all the process are recorded to prove that this algorithm made improvement with the previous research.

# ABSTRAK

Sistem Robot Penglihatan (RVs) adalah sistem adaptif dan dinamik yang memenuhi pelbagai pekerjaan di mana masing-masing melibatkan satu set operasi yang dikehendaki supaya dilakukan pada stesen kerja yang telah ditetapkan. Penyelidikan ini memberi tumpuan kepada pembangunan sistem penglihatan yang disepadukan dengan robot lengan KUKA. Pyramid objek digunakan sebagai prototaip cermin depan kereta. Ia dibangunkan dengan menggunakan kadbod biasa dengan dimensi 15cm x 15cm. Permohonan 2D sepadan diperkenalkan untuk mengenal pasti ciri-ciri objek yang digunakan dalam sistem menggunakan kamera CCD. Objek yang digunakan mesti dilatih dalam fasa latihan untuk mewujudkan templat objek dan digunakan lagi dalam fasa pengecaman bagi klasifikasi objek. Kemudian, dua kamera CCD digunakan; diletakkan di bahagian atas dan hadapan objek untuk mengekstrak lokasi pinggir objek menggunakan Harris Point. Data yang diekstrak daripada ia digunakan untuk mencari penyelarasan 3D setiap pinggir. Persamaan garis lurus digunakan dalam kaedah ini untuk mengenal pasti koordinat x, y dan z . Data yang diperolehi dari sistem kemudiannya digunakan untuk memberi arahan untuk robot lengan KUKA untuk tujuan penampalan. Koordinat piksel mesti ditukar kepada koordinat robot untuk pemahaman yang lebih mudah oleh robot. Tiga jenis kecacatan dilatih sebagai templat model dikenali sebagai kecacatan jurang, kecacatan bonggol, dan kecacatan gelembung. Kecacatan masing-masing mempunyai ciri-ciri khas. Sistem pemeriksaan yang dibangunkan untuk mengenalpasti masalah yang berlaku dalam proses penampalan. Templat kaedah pemadanan digunakan untuk memanggil model yang dilatih dalam fasa latihan untuk mengenal pasti ketidaktentuan terdapat pada objek. Setiap kecacatan berlaku datang dengan maklumat koordinat untuk pembetulan. Pembetulan kecacatan terdiri daripada dua fasa; 1 CoD di mana pembetulan disiapkan dalam masa pertama dan CoD 2 di mana pembetulan masih perlu diselesaikan selepas pembetulan pertama. Data untuk semua proses direkodkan untuk membuktikan bahawa algoritma ini dibuat penambahbaikan daripada penyelidikan sebelumnya.

# DECLARATION

**"**I hereby declare that the content in this thesis is the result of my own work expect

references and citations which I have clearly stated the source of origin**"**

**Signature** : ...................................

**Name** : **MOHAMAD HANIFF BIN HARUN**

**Date** : **1ˢᵗ MARCH 2013**

# DEDICATION

Specially dedicated to my family

# ACKNOWLEDGEMENTS

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# LIST OF SYMBOLS AND ABBREVIATIONS

SBM      =      Shape-Based Matching

ROI      =      Region of Interest

GDP      =      Gross Domestic Product

IMP3      =      Third Industrial Master Plan

HALCON      =      Machine Vision Software

3D      =      Three Dimensional

GUI      =      Graphical User Interface

RGB      =      Red Green Blue

HCD      =      Harris Corner Detector

RVS      =      Robot Vision Sensor

DOF      =      Degree of Freedom

D-H      =      Denavit-Hartenberg

CCD      =      Charge-coupled Device

VB      =      Visual Basic

DSM      =      Defect Shape Matching

DSP      =      Defect Shape Pointing

DIM      =      Defect Inspection Monitoring

CoD      =      Correction of Defect

MF      =      Multiplication Factor

# CHAPTER 1

# INTRODUCTION

## 1.0    Introduction

Automotive industry is a symbol of technical marvel by human kind. Being one of the fastest growing sectors in the world its dynamic growth phases are defined by nature of competition, product life circle and consumer demand. Today, the global automotive industry is concerned with consumer demands for styling, safety, and comfort. The industry is at the crossroads with global mergers and relocation of production centers to emerging developing economies. Due to its deep forward and backward linkages with several key segments of the economy, the automobile industry is having a strong multiplier effect on the growth of a country and hence is capable of being a driver of economic growth (Nag et al., 2007).

In order to follow the economic growth with the quality of car production, the system in developing the car itself need to improve to keep up with the customer demand. This is important to ensure the productions are based on modern quality in terms of styling, safety and comfort for customer satisfaction. According to the needs of improvement, installation of windscreen car known as gluing or sealing process is one of the important aspects needs to be improved to provide a solution for the problem of leaking. Mostly on automotive industry, gluing process still completed using human labor to monitor and identify the error during the process. This will cost largely on quality and also cost in hiring workers in monitoring the process.

By introducing new automation system for the gluing process, it will helps in rebuilding new technology in the production to increase quality and performance of the car. It also reduces cost in hiring a person to assist the robot if there is an error occurred during the process. Automated inspection is desirable because human inspectors are not always consistent in their product assessments and automated vision inspection systems achieve superior performance in terms of processing speed and detection accuracy.

## 1.1    Background

Machine vision is a highly technology machine used in industrial application nowadays especially in automation industry. The automation industry has long been a leader in the application of the manufacturing and in recent years it is has become more flexible forms of automation to which the industry has turned to meet a growing demand (Rooks, 1997). Researchers on industrial robot application include control system especially when high accuracy and precision is required. The development of industrial robot application with integrated of machine vision such as pick and place (Zhang et al., 2010), spot welding (Hagspiel, 2010), material handling (Yong et al., 2005), maintenance and repair (Parker and Draper, 1998) are used to assist human in monitoring and supervising. As shown in Figure 1.1, industrial robot is classified as robot manipulators which mostly used in industrial or medical task and known as assistive robots (Garcia et al., 2007).
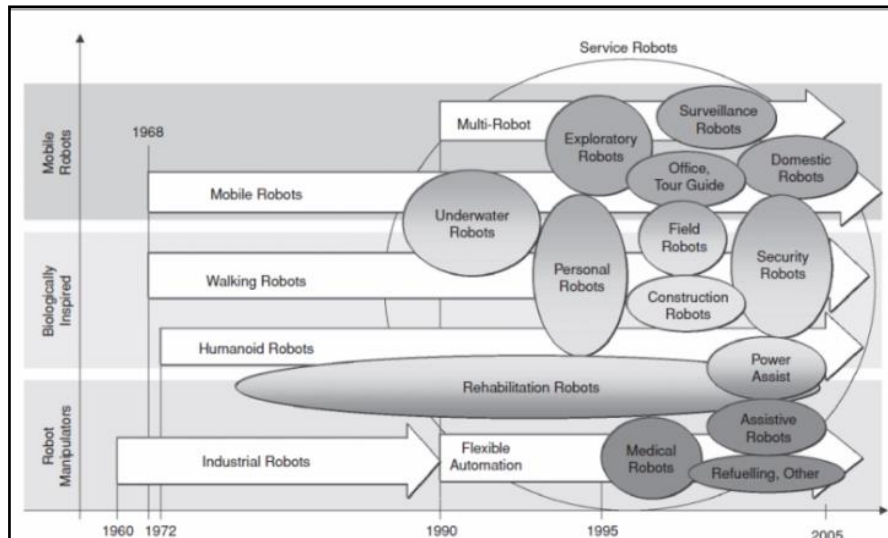
Figure 1.1: Time Evolution of the Robotics Research towards Service Robots
(Garcia et al., 2007)

Industrial robots, a combination of arm and hand, can advantageously be deployed in the manufacturing industry to automate many processes. Obviously, automation using robot shifts the use of human labour from direct interaction with a process to various indirect interactions. These indirect interactions include process monitoring, process diagnostic, equipment setting, equipment programming, the development of automation solutions and etc.

### 1.1.1 Industrial Robot

The wide use of robots in the automation industry will certainly have positive impact in five important aspects (Edler and Ribakova, 1994); productivity, flexibility, quality of products, quality of human life and scientific discipline. By implementing machine vision will provide more reliable robot vision application in automation industry. Machine vision system plays a vital role in manufacturing application, quality inspection and process monitoring as well. Inspection system is one of the famous processes that installed in industrial automation function to classify that the product is in better shape and

quality. There are many researchers invest in inspection system such as 'Car-body Inspection System Using Industrial Robot' by (Kang et al., 1992), 'Semi-Automatic Pipeline Inspection Robot Systems' proposed by (Jae Yeon et al., 2006), 'A New Inspection Robot System for Storage Tank' introduced by (Hua et al., 2008) and 'A Novel Robot System for Surface Inspection' developed by (Xu et al., 2008b) that highly improves in maintaining the quality of products produce batch by batch. The integration of vision sensor (CCD camera) in industrial robot mostly improves the system to be compatible with changes in system environment. It's also simple to modify the system according to the needs of system requirements.

### 1.1.2 Motivation of Research

Since the Industrial Revolution, many production technologies had been introduced and evolved to improve the production efficiency and reducing the production cost. Industrial automation is one of the widely used strategies by the manufacturers to improve their competitiveness, in terms of quality and operating cost. The concept of industrial automation is widely used by manufacturers in automobile, electronic and electrical, chemical and steel industries, for a better plan efficiency or a lower unit cost of production. For better performance of the system, integrating industrial robot with machine vision will helps in increasing production in terms of quality and quantity.

The motivation is to implement robot vision in developing inspection and correction system for gluing process of windscreen car. This is important to increase the quality of the product produce in the system. The use of industrial robot in industrial application was increasing every year in line with the MITI's objectives in developing high technology for industrial sector in Malaysia. With the rapid of proliferation of industry

sector in Malaysia, industrial robot known as a backbone of Malaysian industries. Figure 1.2 shows the statistical of robotic used until 2008.
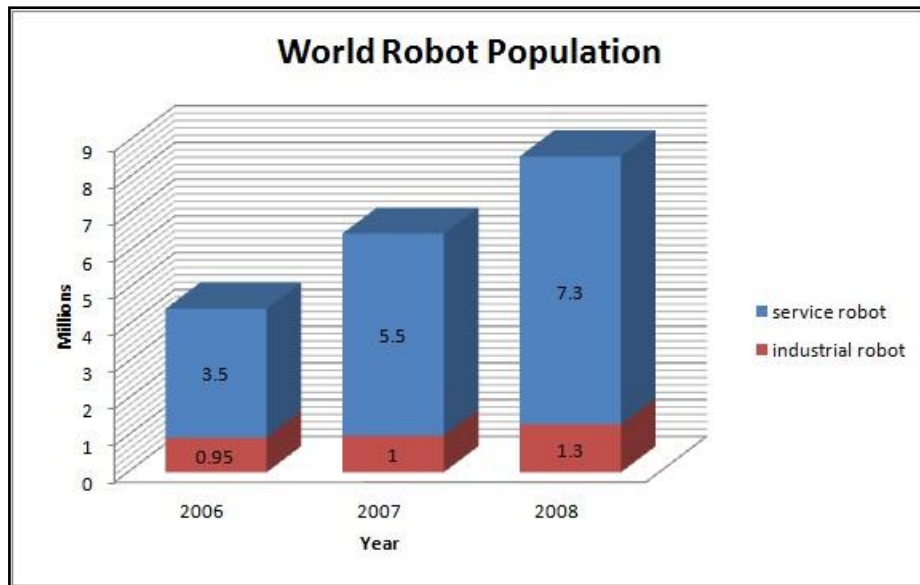


Figure 1.2: World Robot Population (MITI, 2006)

Industrial robot is not has greater influential as service robot in world robot population because its limitation to do the specific task. But in industrial application, it gives high impacts to industrial sector in improving the quality of product along with the increasing of production produces because of the system flexibility. This shows that future of industrial robot was unpredicted and surely gives benefits to the world.

## 1.2 Problem Statement

Automation is the use of control system and information technologies to reduce the needs for human work in the production of goods and services. In the scope of industrialization, automation is the step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the muscular requirement of work, automation greatly decreases the need for human sensory and mental requirements

as well. In automobile industry, mostly every parts of the car are assembled directly using industrial robot as human need to be the second eye for the robot. However, the inspection of windscreen car gluing process still using human eye to classified the gluing quality. Not only that, the correction for defects done manually by human labor in ensuring the product can be reproduced as a quality product. This will effect to the quality of product as well as time consuming in achieving target of each product. Human also has a limitation on focusing a specific task for a long time, so the better solution is applying automation in replacing human to provide more productive and effective system concurrent to the objective of the third Industrial Master Plan (IMP3). By implementing proper system for gluing process, helps in improving quality of the car in terms of aerodynamic. This is because there is no gap between car and windscreen car in preventing drag, wind noise, noise emission and undesired lift forces that causes of aerodynamic instability.

## 1.3    Literature Review

In this section, the literatures are differentiated from two points of view. One is on the vision system and another is on the industrial applications, which focus mainly on installing car windscreen in automation industry.

### 1.3.1    Machine Vision

First and foremost, the first literature review was entitled as "Intelligent Shape Recognition for Complex Industrial Task" (Yang and Sengupta, 1988) states that applications of current machine vision system in industry demand highly constrained environment and also limit the number of objects involved. This paper proposes an intelligent shape representation and recognition system that can handle a large class of

objects under less constraint situations. They investigated on intelligent integration of different shape representation schemes and generation of the best shape recognition strategy using global shape properties. The proposed scheme effectively incorporates model-driven top-down and bottom-up approaches of shape analysis. By analyzing global shape properties, the essential features and their degrees of importance are determined quickly. In the representation phase, objects are described by using these essential features, in recognition phase, searching for the best candidate is restricted to the models represented by these features and the observed shape is matched to the candidate's model in the order of importance of the essential features. Systems are being developed for two and three dimensional shape separately since they are exploiting different visual data photometric and range, respectively.

This two literature reviews gives a lot of idea in implementation Region of Interest in this research. They entitled as "Flexible approach for Region of Interest Creation for Shape-Based Matching in Vision System" by (Teck et al., 2009) and "Implementation of Shape-Based Matching Vision System in Flexible Manufacturing System" by (Teck et al., 2010) that helps a lot in this research. The creation of Flexible Region of Interest (ROI) provides better application that extracts the main features of the image that using as Model Template. Most important thing, the data extraction through this creates a unique data for each model defects that easily to identify defects in matching application. The better creation of ROI gives better processing time in this system.

Besides that, the other literature review that being revised in this project was entitled as "HALCON Application for Shape-Based Matching" (Xu et al., 2008a) that discussed mostly on how to develop an algorithm in determining the 3D object recognition. Shape-based matching provides an application to fulfil its main task in finding the object based on single model image and locate them with sub pixel accuracy. In this algorithm,

template matching act as a tool to provide a powerful solution in recognizing object from its model. First, before matching process takes place, the object must be specified and created object as a model in training phase. Then, the model being used in order to find and localized an object including optimizing the outcome of the matching by minimizing the search space of the object. This unique algorithm helps in handling the changes in illumination, clutter, various in size of object, and also affect in position and rotation of the object. Not only that, this algorithm may affect the relative movement of parts of the template.

HALCON, machine vision software consists of a huge data collection of library that can be used for developing many different tasks. This software can easily construct the tasks that are required by using its image library operators. HALCON can be used to construct most reliable application known as shape based matching application. This application provides superior sub pixels-accurate matching technology finds objects robustly and accurately in real-time. It's also able to find objects even if they are rotated, scaled, perspectively distorted, locally deformed and partially occluded. It can process images with 8 bits or 16 bits and also handles colour or multichannel images. Figure 1 shows the process of the shape based matching used in HALCON system.
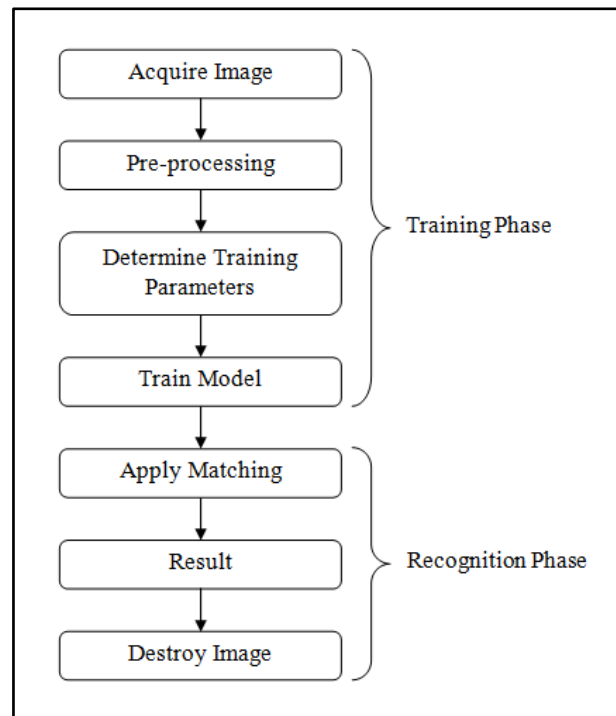
Figure 1.3: Basic Process of Shape-Based Matching using HALCON
(Xu et al., 2008a)

1. Acquire Image – Base images that will be used as the reference image is obtain.

2. Pre-processing – Pre-processing is needed to modify the image so that the further process can be simplified for acquiring a better solution in time consuming. Common pre-processing includes image filter and also image enhancement.

3. Determine Training Parameters – The essential parameters required are identified and created as a unique parameter for identifying certain image.

4. Train Model – The model are created based on the parameter develop in step 3, the speed of the process can be improved by creating Region of Interest (ROI) and also using image pyramid level. ROI create a region where as only focus on the main of interest needs to create an image as a model.

5. Apply Matching – The Test image is the applied for shape matching process.

6. Results – The results can be shown in sentences or images according to requirement.

7. Destroy Model – The test image is deleted or is overwritten after the results have been obtained. This is important in reducing memory usage.

Region is one of the basic frameworks in determining object recognition. As proposed by (Gu et al., 2009) in "Recognition using Regions" stated that each region created, it represents by a rich set of image cues (shape, colour and texture) that accounts as a major target in image processing for recognition object. In this paper, the objective is to provide a region database of image by introducing Generalized Hough transform in detection and segmentation to generate hypothesis of object locations, scales and support, followed by verification classifier. This approach building on a novel region segmentation algorithm which produces robust overlaid regions. By proposed this approach shown that by creating a specific region able to recognize object robustly but proper region creation must be applied. As a result, there are two conclusions obtained 1) cue combination significantly boosts recognition performance; 2) region-based voting scheme reduces the number of candidate bounding boxes by orders of magnitude over standard sliding window scheme due to robust estimation of object scales from region matching.

### 1.3.2 Defect Inspection System

In industry application, there is not much research on recognizing defects in gluing application mostly on applying it automation industry for sealing the car windscreen. But there are a lot of applications that have same features of inspection system such welding. A research entitled 'A Method for Recognition of Defects in Welding Line' (Peng, 2009) uses the feature extraction method in auto-recognize the defects in welding line. First, the digital images of the welding line must be binarized and extracted all the necessary features of all defects for training and modelling in the training phase to figure out each

kind of defects. The algorithm is tested with 500 welding defect consists of all six type of defect to evaluate the defect detection capabilities. The results of this experiments represents defect detection of each defect's type but overall this system able to generate 94.3% success rate in classifying defect's type. 6 Types of defects are identified through this research:

1. Air Hole – Usually are black, round and smooth in boundary and their locations and sizes are uncertain.

2. Crack – Cracks are black, in slightness and needle shape at least at one end, and usually parallel or vertical with welding lines.

3. Strip Inclusion – Strip inclusion are black, in strip and complex in boundary.

4. Round Inclusion – Round inclusion are black, round and complex in boundary.

5. Lack of Penetration – They are black, linear, and straight in both sides.

6. Metal Inclusion – They are bright in defects in the welding line images and their locations, forms and directions are uncertain.

Welding defect technologies is one of the most famous applications. The paper entitled 'Weld Defect Detection Based on Gaussian Curve' (Li and Liao, 1996) developed based on the assumption that a line profile of defect less weld image can be approximated by a Gaussian distribution curve. The line profile variations of weld image caused by defects are classified into three defect patterns, defect-peaks, defect-troughs and defect-slant-concaves. Weld defects are characterized by a local variation in material density, which manifests itself as a local intensity variation in the resulting radiographic images. According to the results, the proposed method capable in achieved successful defect detection rate is 95 percent where 24 images tested consists of 61 defects.

Nowadays, there is too many techniques involved in applying inspection system in surface. According to research entitled as 'A Review of Recent Advances in Surface Detection using Texture analysis Techniques' (Xie, 2008) described all the techniques used and its defect application in surface. The surface defects are loosely separated into two types; first is local irregularities which are the main concern for most visual surface inspection and the other is global deviation of colour and texture. The techniques being discussed in this paper used to inspect textured abnormalities are break to four categories, structural approaches, model based approaches, statistical approaches and filter based method. Every method has its own benefits and disadvantages. The most important thing in providing better services is to understand the formation and nature of the defects. It is important to be able to accurately localise the defective regions rather than classifying the surface as a whole. This can provide possibilities of classifying the defects and further studies of the characteristics of the defects.

In developing an automatic detection, there are a lot of filtering techniques available to that. One of that is Texture Features. Title research of 'Automatic Detection of Welding Defect using Texture Features' are proposed (Mery and Berti, 2003) based on two types texture features: 1) features based on co-occurrence matrix, which gives a measurement of how often one gray value will appear in a specified spatial relationship to another gray value on the other image; 2) feature based on 2D Gabor functions. The proposed method follows the pattern recognition schema: image segmentation, feature extraction and classification. Image segmentation process is oriented towards the detection of edges by employing the LoG filter. Feature extraction main contribution on the measurement of properties of the region and image classification divides segmented region into special region according to the extracted features. According to the results obtained, it can be concluded that best texture features based on the co-occurrence matrix are the mean

of the difference entropy and the mean of the difference variance, for a distance o $d = 3$. On the other hand, the best Gabor features are at $p = 6$ (scale).

Other researchers are using optimised filter in classified texture defect. As shown in paper of 'Optimised Filters for Texture Defect Detection' founded by (Sobral, 2005) present a new approach to texture defect detection based on a set of optimised filter. The main purposed in introducing this method because it is applied to one wavelet sub-band and its size and shape are tuned for a defect type. The wavelet transform provide an excellent framework to deal with multi-scale defects. The first level of the wavelet packet decomposition divides the power spectrum into four square parts and the second level divides the same spectrum into sixteen parts and the third level in sixty four parts. Therefore the filter applied in higher wavelet those results in easier to detect defect by analysing only a small part of the spectrum. The result showed that this masks capable to detect most of the defect and achieved an acceptable detection rate.

Inspection system are not just specific to welding and surface, texture of materials also one of the important subject in using defect inspection system. Textured material can be classified as textile, web, paper and wood. One of the researchers done 'Defect Detection in Textured Materials Using Gabor Filters' by (Kumar and Pang, 2002) proposed Gabor Filter that provides features of decompose image into components corresponding to different scales and orientations. Besides that, it also achieves optimal joint localization in spatial and spatial frequency domain. In the spatial domain, Gabor function is a complex exponential modulated by Gaussian function. It forms a complete but nonorthogonal basis set and its impulse response in the two-dimensional plane. As a result, the proposed of multichannel filtering scheme successfully segmented the defects of varying size, orientation and resolution that proved to be robust.

In textile industry, there are so many problems involving defect inspection. Many fabric defects are very small and undistinguishable, which make the very difficult to detect. According to (Chan and Pang, 2000) entitled as 'Fabric Defect Detection by Fourier Series Analysis' by implementing Fourier series analysis to monitor the spatial frequency spectrum of a fabric. If defect occurs in fabric, the regular structure of fabric changed so that the corresponding intensity at some specific positions of the frequency structure would change. In this paper, the researchers classify defect as four classes: 1) double yarn; 2) missing yarn; 3) webs or broken fabric; and 4) yarn densities variation. Central spatial frequency spectrum approach is proposed that would reduce computational time for defect detection and provide more parameters for defect classification. According to the results, the method proposed is able to extract seven significant parameters that capable for classifying defects in fabric.

In the area of Machine Vision inspection system, there are a lot of different approach has been studied intensively and plenty of machine vision software is available as was stated. In all the above research, the machine vision system and software used has two common similarities, first is the three basic framework of the process involved; image acquisition, preprocessing (image enhancement) and image analysis; second is the two phases required for shape matching, the training phase and the recognition phase. In the above research, it seems that most model based vision programs are developed for a specific task and the environment is implicitly coded into the system. It is difficult to modify the knowledge or extend the scope of such system, and it also requires long development time.

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### 1.3.3    3D Recognition (Camera Placement)

3D recognition system is one of the famous applications that being develops that able to reconstruct the object structure architecturally through the images from several cameras with different orientation and position. According to (Takahashi et al., 2006), the two main point should be considered as important that may cause performance degradation in determining the 3D recognition of object; 1) quality degradation of input images depending on capturing device and conditions; 2) capturing viewpoint not suitable for distinguishing the object. By using two cameras that placed according to the suitable orientation and position calculate using the evaluation function based on universal eigenspace that captured main architecturally of the object. The effectiveness of this method shows a great increment in recognition rate almost 50% from the previous method in low resolution of image tested in the research.

Not only that, in industrial application, there is a lot of machine vision used in industrial application in providing a better supervision features that helps in monitoring process in a system. The introduction of machine vision helps a lot in finding the replacement of human vision in industry. (Karabegovic et al., 2006) proposed a various type of machine vision with single and multiple cameras according to the needs of the process requirements. This research mostly on application of 3D vision in industrial robot working process that describes the position and orientation of the camera used in industrial such as depalletizing crankshafts that using 2D robot vision, depalletizing motor blocks using $2^1/_2$D robot vision and 3D stereo vision using one, two and eight cameras. The implementation of this robot vision system used in various applications present the better solution in replacing human vision.

3D recognition system acts as the backbone of the inspection system where it provides various data in x, y and z coordinates. The position and rotation depends to the requirement of the system that fits to their task but the mathematical approach need to be specified equally to the camera placement. This will help to generate new equation in findings x, y and z coordinates. Several of 3D inspection system applied in industry as described by using multiple cameras with different position and angle according to the task requirement. It seems as a great vision sensor where the entire object can be analyzed throughout the system.

## 1.4    Objectives of Research

The objective of this research is mainly focus to develop a vision based system that can be used in manufacturing such as control and inspection, especially the installation of car windscreen by using gluing application and identify the defects in the process using vision as its feedback and control method. Additionally, the algorithm of the system must also be able to accommodate changes quickly.

1. To analyze, develop and implement the robot vision system for automation glue processes by using Shape-Based Matching application.

2. To design suitable application of two camera application for 3D inspection in order to locate position (x, y and z coordinate) of each defect occurred.

3. To develop system inspection and correction that able to locate and alter defects occur in order to ensure rejected object can be reproducing as quality product.

## 1.5 Contributions of Research

The contributions in this research are mainly to increase flexibility and adaptability of the vision system in order to accommodate changes. A different point of view was exploited especially in automobile industry for windscreen car gluing process.

1. Capabilities of user define ROI creations replacing standard dedicated feature extraction methods that is unique as every solutions is different based on the problems and requirements that are needed specifically.

2. Capabilities of 3D vision inspection using 2D inspection method by just manipulating camera placement, inspection of multiple dimensions are also possible by adding more cameras at different viewing angle.

3. The implementation of inspection system that consume to detect whether the object gluing perfectly or error occurred in gluing line with providing additional data including x, y and z coordinates for gluing process.

4. Correction of defect application (consists of two application $1^{st}$ CoD and $2^{nd}$ CoD) provides a service to alter the uncertainties occurred during inspection system to ensure reject products still can be produced as a quality product.

5. The implementation of this vision system using Graphical User Interface allows everyone to be able to use it even without immense knowledge of the vision background.

## 1.6 Scope of Research

The scope of this research is limited to the following items so that the research could be focused to achieve the stated objectives.

1. The vision system will focusing on recognizing 3D objects by using multi-camera application.

2. The vision system is applied to a control environment, the lighting conditions are assumed constant during the recognizing and identifying defects phase.

3. The GUI will be designed using Visual Basic 6.0 as medium to supervise all process in this research.

4. The vision system is constructed for defect shape matching and inspection of defects application with the assistive from Katana 6M robot arm and KUKA KR5 sixx R650 Robot Arm.

# CHAPTER 2

# THEORETICAL BACKGROUND

## 2.0    Introduction

This chapter will discuss mainly on the theory and current development in Vision System and Industrial Robot Application. This chapter is divided into two parts, one for Vision System and the other is for Industrial Robot Application.

## 2.1    Vision Based Algorithm

To achieve fully flexible automated system, one of the supporting systems is machine vision, which will be discussed in detail in this chapter; the other two is Process Automation and Transportation System. Machine Vision is the application of computer vision to industry and manufacturing sectors, mainly focused on machine based image processing. It is also the study of methods and techniques whereby artificial vision system can be constructed and usefully employed in practical applications (Davies, 2005).

When comparing traditional inspection or measurement gauge techniques to a vision based system, several advantages stand out (Rebner, 1985).

1. Non contact operation. The sensor is not in physical contact with inspected part, therefore, the probe or sensor has no wear and deformable objects such as rubber parts can be easily gauged.

2.  Standoff. The image sensor can be located several inches from the inspecting part, therefore reducing any interference between the part and the sensor, making the online inspection possible.

3.  Speed. With the majority of vision based inspection systems employing solid state circuitry in both the camera sensor and supporting hardware, images can be quickly captured and measurements calculated within seconds or less. Also, image of objects in motion can be easily acquired and analyzed.

4.  Multiple Features. Many features can be inspected almost simultaneously.

There is a wide range of different vision algorithm concept that each has its strengths and weaknesses. From all of these algorithms, shape-based matching using edge detection algorithm was chosen to be used in this research. This is because the requirement of this research is mainly on the inspection and recognition of constant and repetitive type of image. Additionally, because of the wide range of applications that might occurs, shape-based matching which takes only the outline edges of an object into considerations are the best fit for this research since everything has a shape.

### 2.1.1   Theory of Shape Based Matching Application

Image processing has been intensively studied and there are a lot of different ways and methods available to be choose from, each with their own pros and cons. There is no one way to determine the best methods because different object has different characteristic and also each case has different objective, such as image enhancement, pattern recognition, image restoration and many more. In this paper, the concentration will be on pattern recognition (Shape-based Matching).

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. A gray scale digital image is an image in which the value of each pixel is a single sample, that is, it carries only intensity information. Images of this sort, also known as black-and-white, are composed exclusively of shades of gray, varying from black at the weakest intensity to white at the strongest.

When x, y and the amplitude values of $f$ are all finite, discrete quantities, we call the image 'digital image'. The field of digital image processing refers to processing digital images by means of digital computer. Each of these elements $f(x, y)$ is referred to as pixels. Figure 2.1 shows an image and it's enlarging pixels. The enlarge image on the left hand side shows the pixel that are the basic cells that actually forms the entire images.
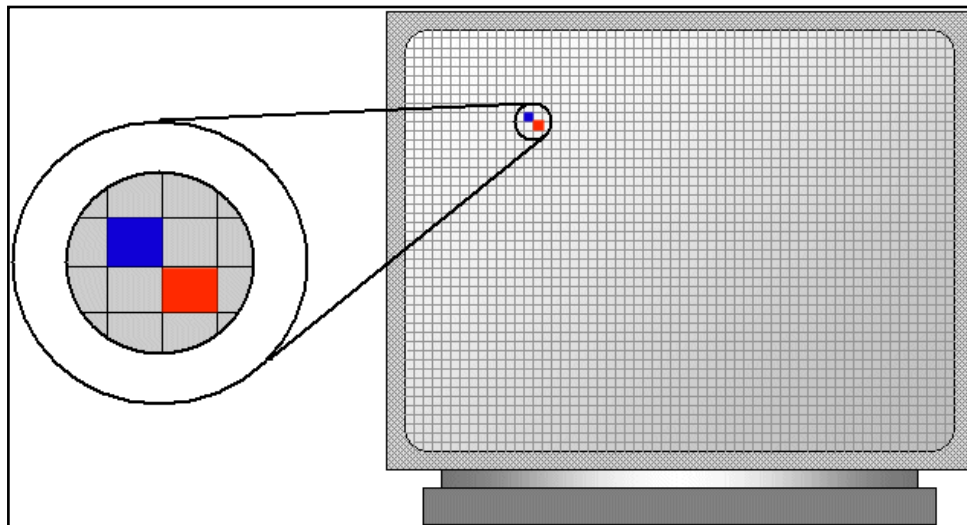


Figure 2.1: Enlarge Pixel from Resolution of LCD Monitor

In order to simplify understanding of image pixel, a simple example is used to explain in detail how image pixel is created. Figure 2.2 shows the example image of three simple shapes in it, while Figure 2.3 shows the image segmented into a 12x8 pixels

division. The image is then rearranged into a digital image as shown in Figure 2.4 and converts into a 255 gray value representation as shown in Figure 2.5.
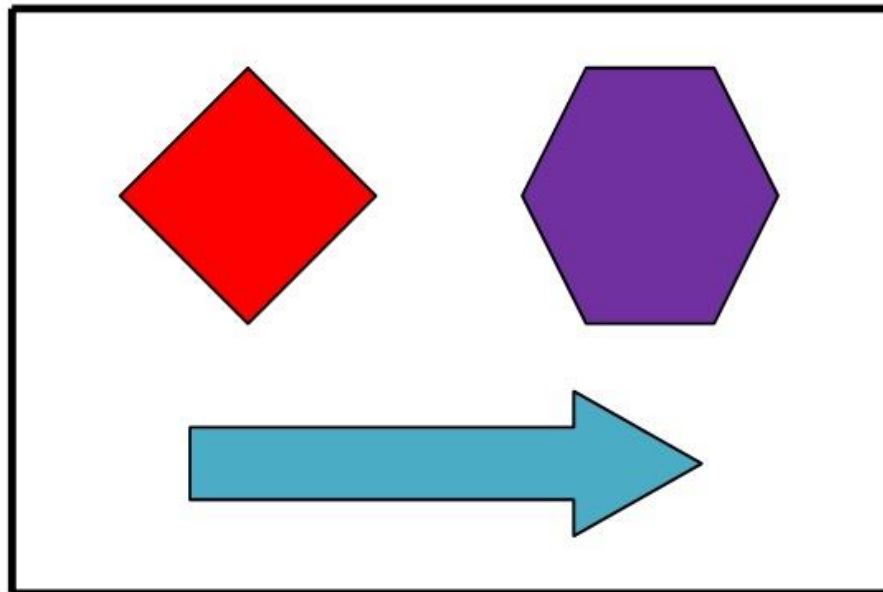


Figure 2.2: Example Image of Three Simple Shapes
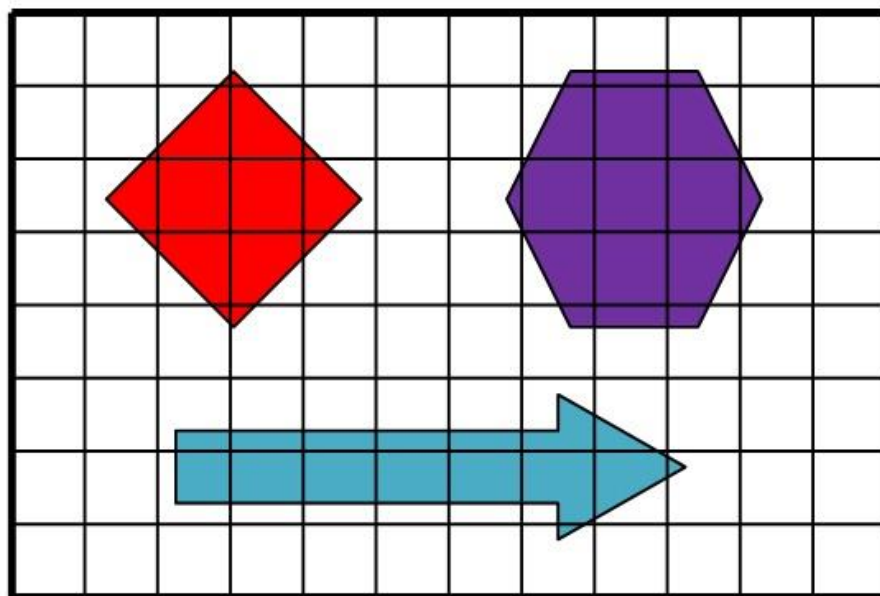


Figure 2.3: Image being divided by 10x8 Pixels Division
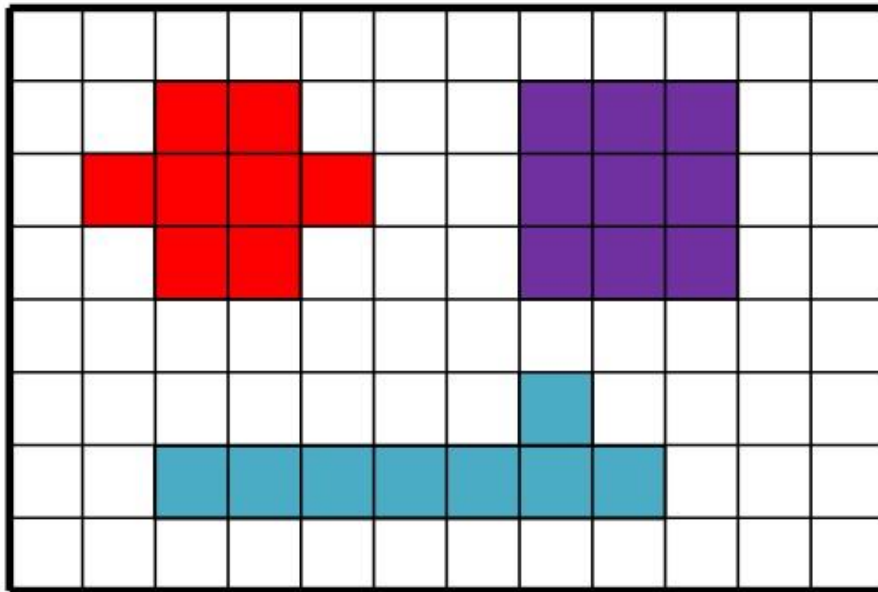
Figure 2.4: Image Rearranged into Digital Pixels

| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 210 | 210 | 0 | 0 | 0 | 150 | 150 | 150 | 0 | 0 |
| 0 | 210 | 210 | 210 | 210 | 0 | 0 | 150 | 150 | 150 | 0 | 0 |
| 0 | 0 | 210 | 210 | 0 | 0 | 0 | 150 | 150 | 150 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 0 | 0 | 0 | 0 |
| 0 | 0 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 2.5: Gray Value Representation of Image

As can be seen the higher the pixels quantity (e.g. 800x600 or 5 Mega Pixels) the better the image quality and also the more accurate the digital image representations of the actual images.

### 2.1.1.1 Gray-scale Transformation

Gray scale images store values for levels of brightness as opposed to colour information. A typical gray scale image is 256 shades of gray ranging from 0 (black) at the weakest intensity to 255 (white) at the strongest intensity. This method are given to transform the image from colour (RGB transformation) to gray scale (black and white) for simplifies the amount of information in the image. Although gray scale image contains less information than a colour image, the majority of important, feature related information is maintained, such as edges, blobs, regions, noise and so on. As shown in Figure 2.6, shows the process of gray scaling from original image to distinguish the RGB channel into gray scale.



(a) Original Image          (b) Grayscale Image
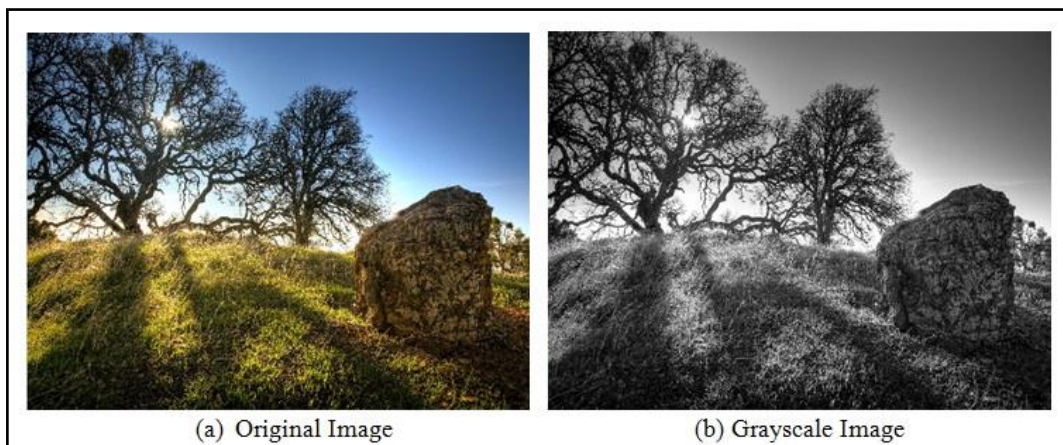
Figure 2.6: Process of Gray Scale Transformation

The importance of gray-scale transformation is to reduce image information and characteristic to be extracted in the system. Colour image have plenty of information regarding on RGB transformation leads to the complex process in the system. In gray-scale, colour information being ignored and the system will focus on the object characteristic for easier processes.

### 2.1.1.2 Thresholding

Thresholding is an indispensable step in extracting pertinent information in image source. A gray-scale image often contains only two level of significant information: the foreground level constituting objects of interest and the background level against which the foreground is discriminated. A complete segmentation of an image, $R$ is a finite set of regions $R_1, R_2,..., R_m$,

$$R = \bigcup_{i=1}^{m} R_i, \quad R_i \cap R_j = \varnothing \quad i \neq j \tag{2.1}$$

If $R_b$ is a background in the image, then $\bigcup_{i=1,i\neq b}^{m} R_i$ is considered the object and $R_b^C = \bigcup_{i=1,i\neq b}^{m} R_i$ where $R_b^C$ is the set complement. While there are two principal peaks of the foreground and the background intensities in the image histogram, there are many others gray intensities present. Binarization can be accomplished by the choice of intensity, between the two histogram peaks, that is the threshold between all background intensities below and all foreground intensities above. The input image $I_1$ is being transformed to an input binary segmented image $I_2$, in the following way:

$$I_2(i,j) = \begin{cases} 1; & I_1(i,j) \geq T \\ 0; & I_1(i,j) < T \end{cases} \tag{2.2}$$

Where $T$ is the threshold, $I_2(i,j) = 1$ for the object elements and $I_2(i,j) = 0$ stated for the background elements (Gonzalez, 2002). Successful threshold segmentation depends on the threshold selection.

By referring to Figure 2.2, its histogram is calculated in Table 2.1 and drawn as shown in Figure 2.7. From Figure 2.7, the x-axis represents the gray values range from 0 to 255 and the y-axis represents the numbers of pixels of the same gray value.

Table 2.1: Histogram Table of Example Images

| Gray Value | Pixels Quantity |
|:----------:|:---------------:|
| 0          | 71              |
| 60         | 8               |
| 150        | 9               |
| 210        | 8               |
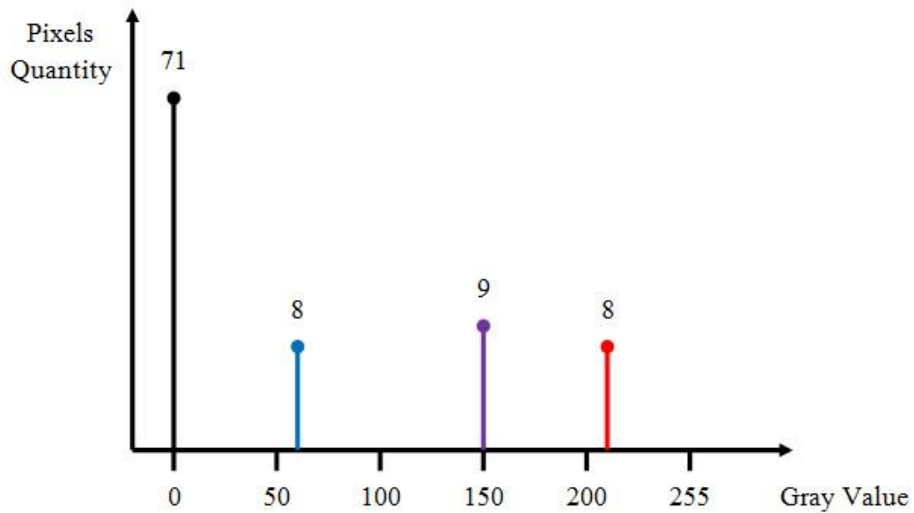


Figure 2.7: Histogram of Example Images

From the histogram, the information can be used to extract the object from the background by selecting a threshold value, T that is suitable to separate the two different modes by using Equation (2.2). For instance, assuming that all three shapes were to be extracted from Figure 2.2, therefore the threshold value of 50 is selected. All pixels with gray value greater than 50 will then be converted into 1 and others will be converted into 0, the resultant result can be seen in Figure 2.8.

| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 2.8: Threshold Results for Example Images using Threshold Value of 50

Similarly if threshold value were to be changed to 200, only pixels with gray value greater than 200 will be converted into 1 while all other pixels converted into 0. The result is shown in Figure 2.9.

| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 2.9: Threshold Results for Example Images using Threshold Value of 200

A number of conditions like poor image contrast or spatial nonuniformities in background intensity can make difficult to resolve foreground and background. These cases require user interaction for specifying the desired object and its distinguishing intensity features.

### 2.1.1.3 Region of Interest (ROI)

The most critical step in applying machine learning is the identification of appropriate features known as Region of Interest (ROI). The raw data in each image basically consists of two attributes for each pixel: intensity and location (Wong and Bishop, 2006). This approach helps to make the data more amenable to machine learning how to draw the ROI based on human perception. Then the creation of ROI is to pick out the approximate region needed in the system by identifying the types of glue defects of the image. Once the approximate region is identified, the information needed must be separated with the model image and its background to ensure there is no other disturbances that might occur in the system.
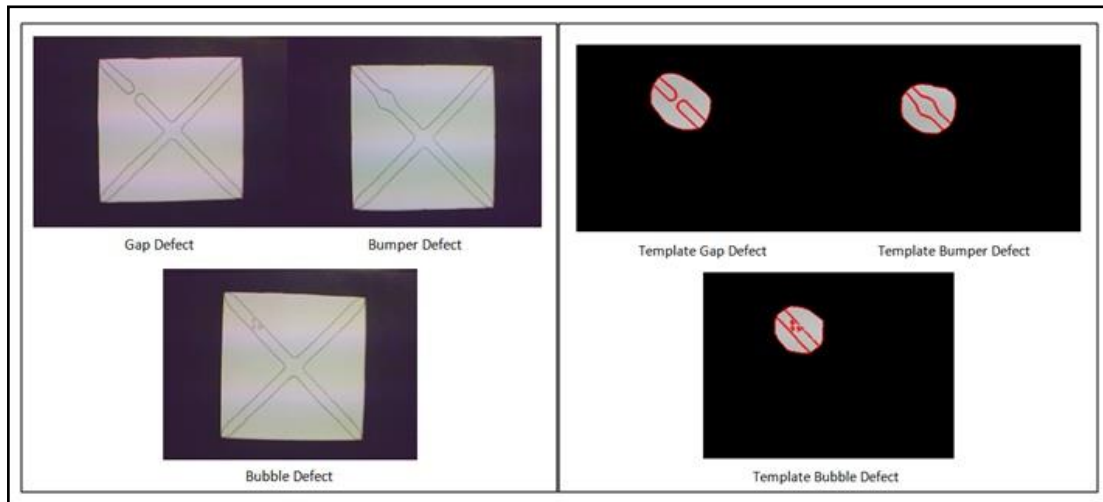
Figure 2.10: Region of Interest Before and After Process

According to Figure 2.10 shows that the left figure is source images used as template model defect in training phase describe in Chapter 3. In order to ensure the system is fully optimized, the approximate location of the desired image needs to be extracted, and then used for correction. This helps the system to differentiate between model and its background in contrast for limiting the space and required time consuming. Right figure of Figure 2.10 shows the resulting image of ROI where the system ignored the background of image and extract only space created through ROI. This algorithm creates a system to be more reliable for extracting using high quality images.

### 2.1.1.4 Median Filter

Median filter is one of the commonly used non-linear filters that replace the value of pixel by the median of the gray-level values of the neighbours of that original value of the pixel. The median is calculated by first sorting all the pixel values from the surrounding neighbourhood into numerical order and then replacing the pixel being considered with middle pixel value. This is given by (Zhang, 2009)

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$$g_{median}(x, y) = median_{(s,t) \in N(x,y)} \{f(s, t)\} \qquad (2.3)$$

Where $N$ (x, y) is the neighbourhood area (the filter mask) centered at (x, y). Figure 2.11 illustrates an example calculation.

| 128 | 123 | 125 | 140 | 130 |
| 122 | **124** | **126** | **129** | 125 |
| 118 | **121** | **150** | **125** | 134 |
| 119 | **117** | **119** | **123** | 127 |
| 123 | 136 | 140 | 120 | 130 |

Neighbourhood values:

117, 119, 121, 123, 124,
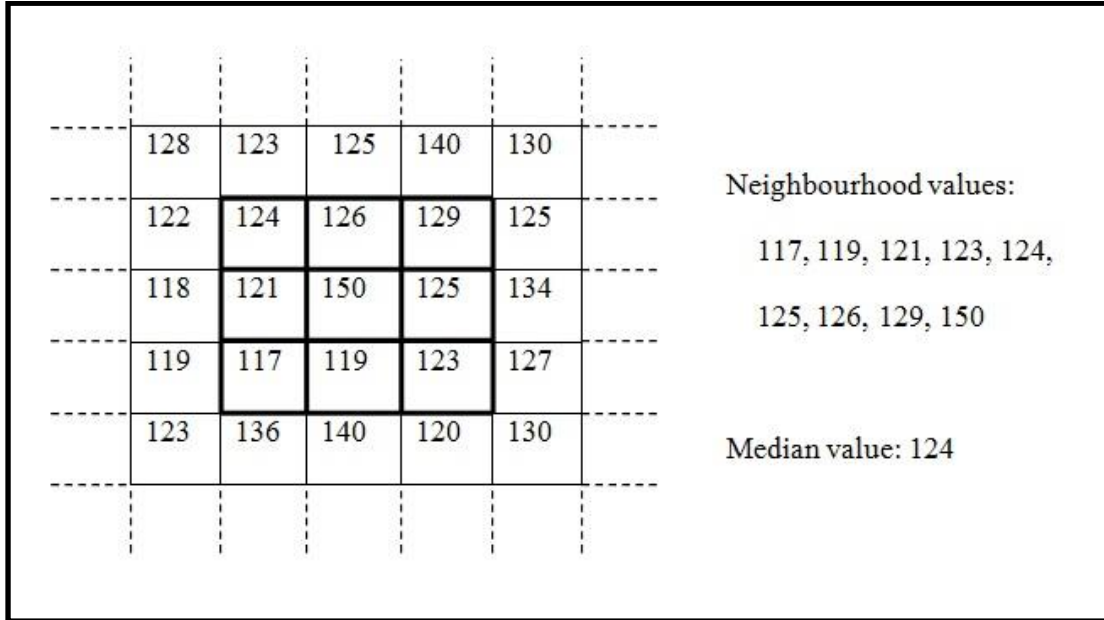
125, 126, 129, 150

Median value: 124

Figure 2.11: Median Filter Application

The median, *m*, of a set of values satisfies such that half of the values in the set are less than or equal to *m*, while the rest are greater than or equal to *m* in order to perform median filtering at a point in an image, the values of the pixel and its neighbors should be sorted. Their median is the determined and assigned to that pixel. Median filter are particularly effective in the presence of impulse noise. It has the advantage of removing noise while keeping the original edges in the image. It can provide excellent noise-reduction capabilities, with considerably less blurriness than the linear smoothing filters of similar size. By removing noise, the image looks sharper in terms of edges and corners that will help mostly on this research. The following example shows the application of a median filter to a simple one dimensional signal. A window size of three is used, with one entry immediately preceding and following each entry.
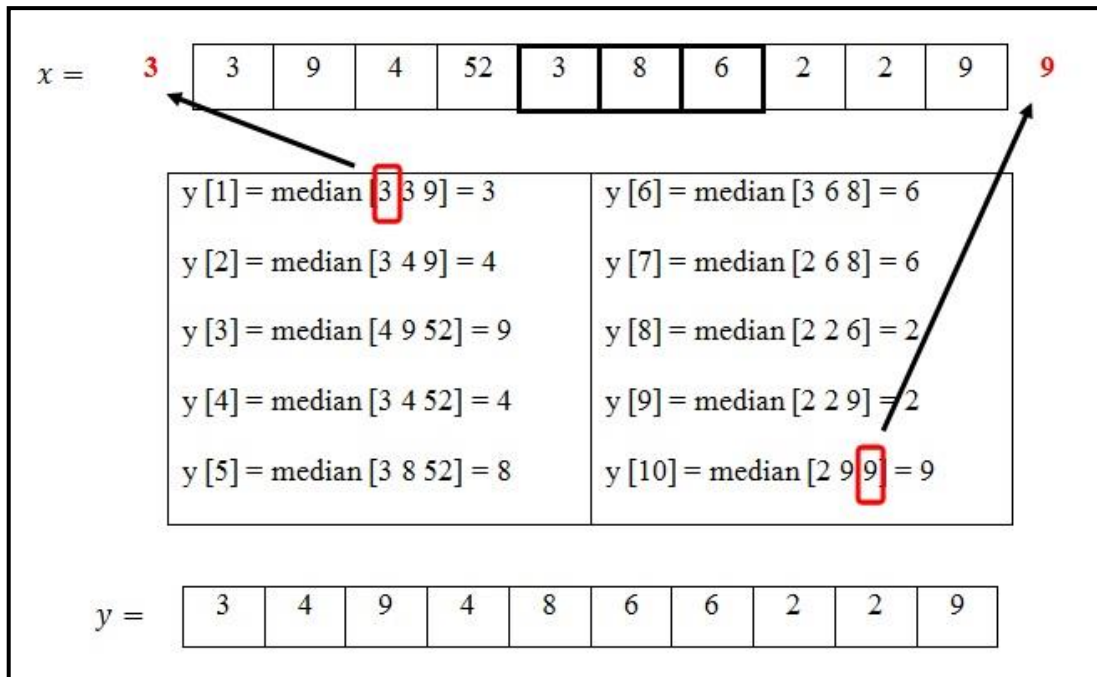
Figure 2.12: Median Filter Example Calculation for 1-Dimensional Data

For y [1] and y [10], extend the left most or right most value outside the boundaries of the image same as leaving left most or right most value unchanged after 1-D median. In Median filtering, the neighboring pixels are ranked according to the brightness (intensity) and the median value becomes the new value for the central pixels. It offers services in rejecting certain types of noise, in particular, "shot" or impulse noise in which some individuals pixels have extreme value. Median filters have its own specialties in terms of removing noise:

1. No reduction in contrast across steps, since output values available consists only of those present in the neighbourhood (no averages).

2. It does not shift boundaries, as can happen with conventional smoothing filters (a contrast dependent problem).

3. Since the median filter is less sensitive than the mean to extreme values (outliers), those extreme values are more effectively removed.

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### 2.1.1.5 Harris Corner Detection

A corner can be defined as the intersection of two edges or point for which there are two dominant and different edge directions in a local neighborhood of the point. The Harris Corner Detector (HCD) also known as Harris Point is a popular interest point detector due to its strong invariance to (Schmid et al., 2000): rotation, scale, illumination variation and image noise. The Harris corner detector is based on the local auto-correlation function of a signal; where the local auto-correlation function measures the local changes of the signal considering the differential of the corner score with respect to the direction directly.

In this research, a fundamental of the corner point detection will be introduced. The Harris corner detection (Harris and Stephens, 1988) method avoids the explicit computation of the eigenvalues of the sum of squared differences matrix by solving the corner metric.

A corner is characterized by a large variation of $M$ in all direction of the vector (x, y). By analyzing the eigenvalues of $M$, this characterization can be expressed in the following way:

1. If both $\Lambda_1$, $\Lambda_2$ are small, so that the local auto-correlation function is flat (little changes in $R$ any direction), the windowed image region is of approximately constant intensity.

2. If one eigenvalue is high and the other low, so the local auto-correlation function is ridge shaped, then only local shifts in one direction (along the ridge) cause little change in $R$ and significant change in the orthogonal direction; this indicates an edge.

3. If both eigenvalues are high, so the local auto-correlation function is sharply peaked, then shifts in any direction will results in a significant increase; this indicates a corner.
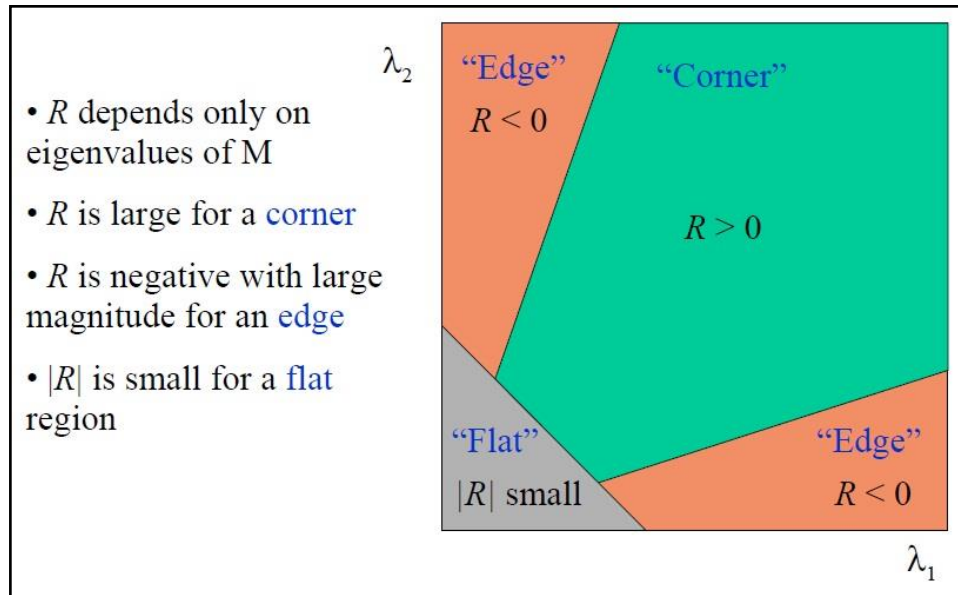


Figure 2.13: Harris Point Application (Schmid et al., 2000)

In this research, each localization point occurs need to be classified by using the 3 conditions as state before. This is important for applying only a corner characteristic that will be used for indicating a critical point of object. Figure 2.14 shows the relation between the object with corner response map in determining the characteristic of each points occurred. Edge, flat and corner is represent using a simple example of square object (red square) combined with their corresponding region and range of determinant value as shown in corner response graph in Figure 2.14.
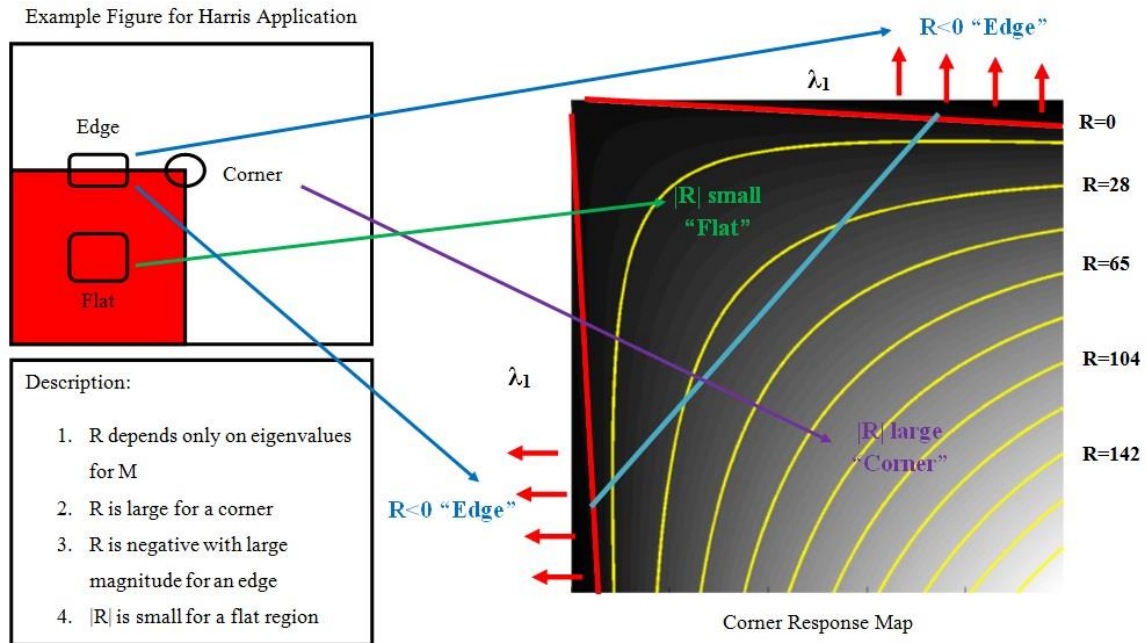
Figure 2.14: Example of Harris Application

### 2.1.1.6 Template Matching

Template matching can be classified into two phases known as classification and recognition. Classification is concerned with establishing criteria that can be used to identify or distinguish different populations of objects that appear in images. Recognition is the process by which these tools are subsequently used to find a particular feature within and image. It functions at many different levels, including such different processes as finding a pyramid object in an image or matching the object to a specific type of object (Russ, 2007). Template matching is an algorithm that compares portions of images against one another. Before hand, the template of an object must be classified first before used it in recognize similar objects in source image (Jurie and Dhome, 2002).
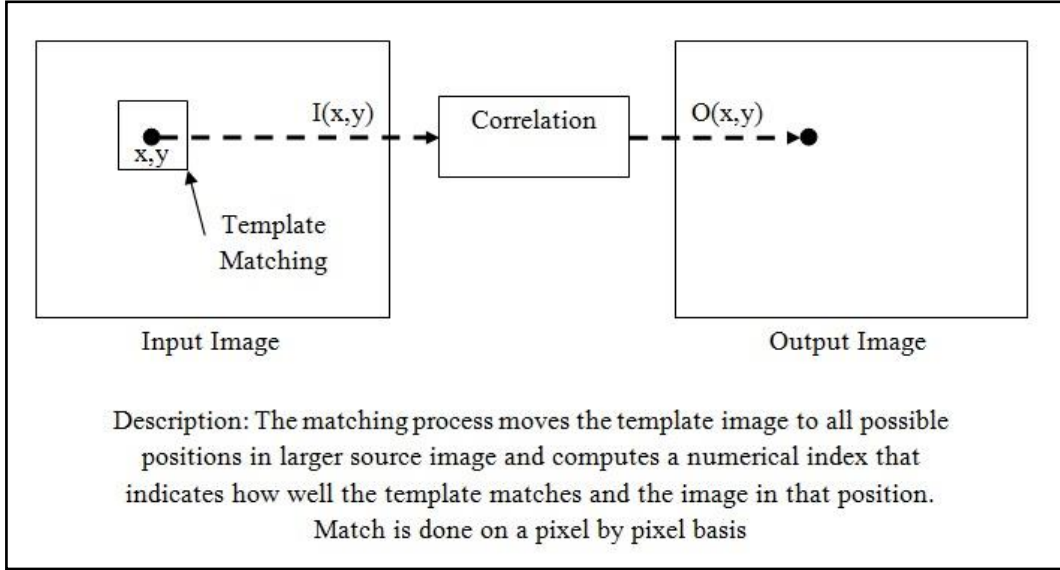
Figure 2.15: Template Matching Process Evaluation

Figure 2.15 shows the process evaluation of the template matching by using correlation method in representing relationship between template and source images. Correlation is a measure of the degree to which two variables (pixel values in template and source images) agree, not necessary in actual value but in general behaviour. In correlation method, results of combination of differences between template gray level image, $x_i$ with average gray level in the template image, $\dot{x}$ and difference between source image sections, $y_i$ with the average gray level of source image, $\dot{y}$ are compared to the square root summation of the pixel differences between two images. Correlation value is between -1 and +1, with larger values representing a stronger relationship between the two images. Equation (2.4) shows the correlation relationship.

$$cor = \frac{\sum_{i=0}^{N-1}(x_i - \dot{x}) \bullet (y_i - \dot{y})}{\sqrt{\sum_{i=0}^{N-1}(x_i - \dot{x})^2 \bullet \sum_{i=0}^{N-1}(y_i - \dot{y})^2}}$$

(2.4)

$$where, N = template\ image\ size = column * row$$

Correlation value totally depends on template creation throughout the system. Without proper contribution on it, may result to poor recognition rate. The important of ROI extraction method that delivers the precise region helps in findings the same object from various types of images.

### 2.1.2 3D Recognition Object based on 2D Images

Gluing process involves x, y and z-axis in determining the position according to the working space of the KUKA arm robot. Matching process involves one camera placed at the top of the object as a purpose in identifying the object that need to go for gluing process. Improvement of this system is created by applying another camera in front of the object for purpose in reviving the z-coordinate in the image. According to (Takahashi et al., 2006) the method used are to find the 3D object recognition defining as x, y and z-axis by using evaluation function in order to determine better position and orientation for camera placement. Figure 2.16 shows the proposed method by using two cameras from the researcher.
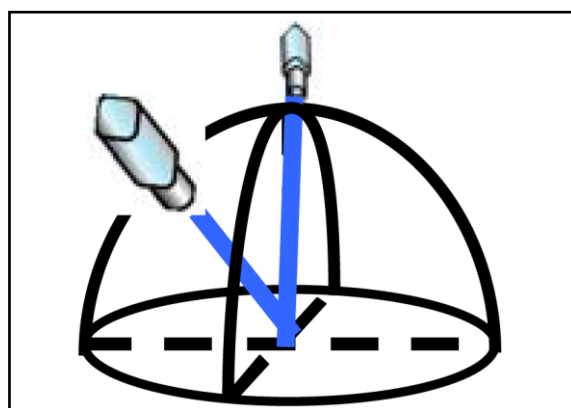
Figure 2.16: Placement of two Camera of 3D Recognition (Takahashi et al., 2006)

Referring to the Figure 2.16, this configuration has the ability to reproduce the 3D transformation according to the model template that being created in the system. The measurements of the camera takes account all the side of the object which will be process in determining the exact value of transformation with the original. From this application, the development of new proposed method by using two cameras with different positions and orientations in purpose of determining x, y and z-coordinate for further process in this research. The renovation of this new method being proposed is used in creating a z-coordinate according to the x and y-axis from images captured. Figure 2.17 shows the new proposed method developed in this research.
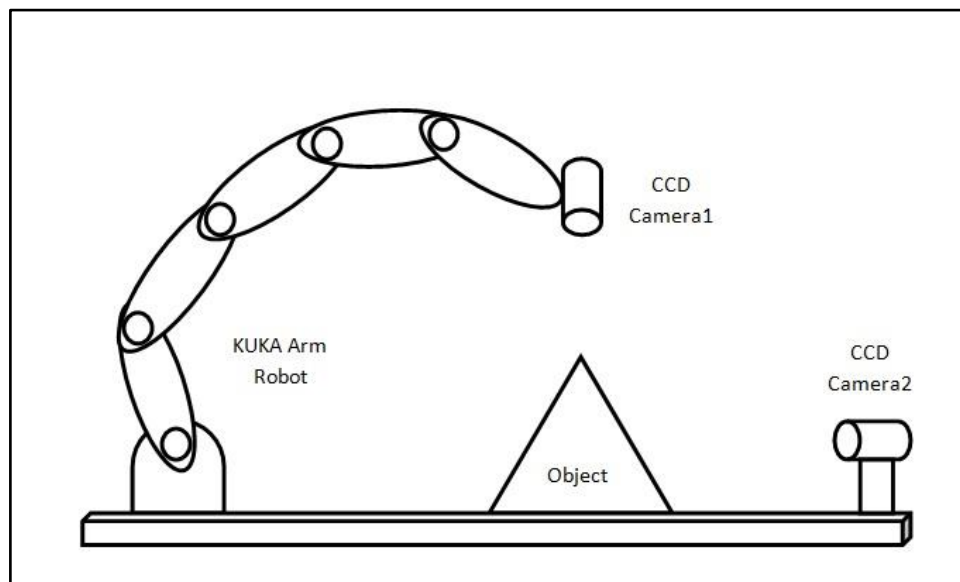


Figure 2.17: Proposed of two Camera Placement in 3D Recognition

Requirement of the proposed method are to define coordinate x, y and z in order to get the clear view and information of the object for further process. First camera placed at the end of the KUKA arm robot to get clear view at the top of the image (more specific x and y-coordinate) and second camera at the front of the object for obtaining information about side of object (more correctly x and z-coordinate). Each image from both cameras is

differentiating through the x-coordinate by referring to the edge of the object. Both edges coordinate should exactly the same in order to define the z-coordinate through the front camera. The proposed methods describe on next chapter.

## 2.2 Robot Vision System

Flexibility is an increasingly high priority for many manufacturers, and the vision-guided robot has become an important asset to meet this demand. Robot Vision System (RVS) systems can enhance assembly, packaging, test and inspection processes, and they can perform in environments that are hazardous to human. Robots have been the forefront of flexible automation system for many years, but until recently robot vision still limited. Vision systems required a PC with a custom frame grabber to capture or "grab" images from cameras, and custom software was needed to analyze the images. RVS for robot guidance provides the robot or handling system with information of where the component to be processed or moved is located spatially. This way, it is possible to automate handling, assembly and processing without having to precisely position and fix the components. This saves precious cycle time in production and reduces costs significantly

In ascending to the Robot Vision System (RVS) era, KUKA KR5 sixx R650 arm robot and Katana 6M arm robot have been used to meet requirement in automation industry. Forward kinematics architecture for these robots should be identified before continuing studies. In this analysis KUKA arm robot's based coordinate will be considered unchanged. Tip of the robot arm will be considered and treated as an end point of the arm, so that the robot will considered as 6 degree of freedom (DOF) arm robot during the analysis. This robot has its own limitation on its workspace as shown in Figure 2.18.
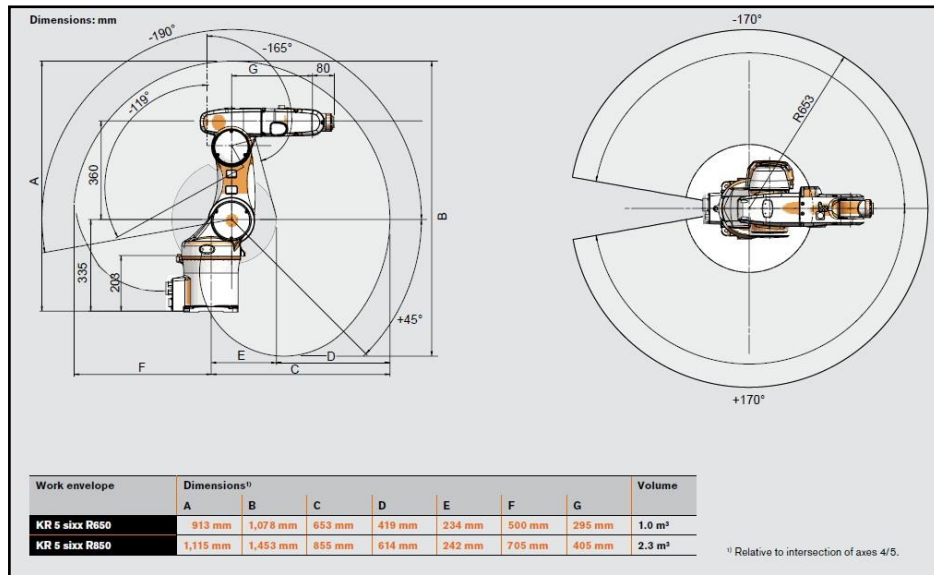
Figure 2.18: Workspace of KUKA Robot Arm

The D-H parameter for the KUKA is given in the Table 2.2 as the frame assignment is as shown in Figure 2.19. The associated interlink homogeneous transformation matrices are easily found from the D-H parameter values listed in Table 2.2. As the sixth link of this robot is also an end effecter, it is more efficient to numerically compute the forward kinematics function $T_5^0$ via a link-by-link iteration of the form.
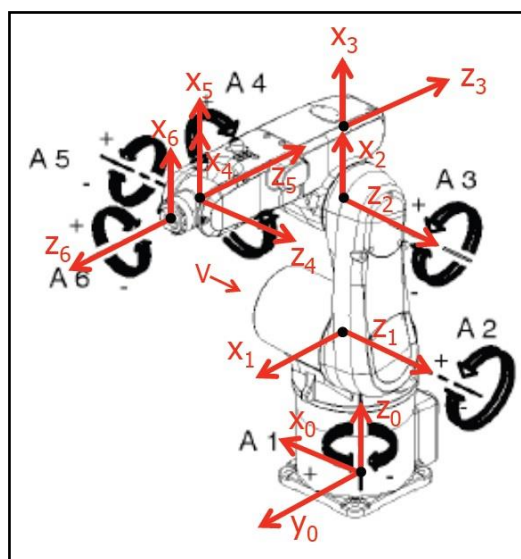


Figure 2.19: Framework for KUKA KR5 sixx R650

Table 2.2: Link parameter for 6-DOF KUKA Arm Robot

| DOF | $a_i$ | $\alpha_i(°)$ | $d_i$ | $\theta_i(°)$ |
|---|---|---|---|---|
| 1 | 75 | -90 | 335 | $\theta_1$ |
| 2 | 270 | 0 | 0 | $\theta_2$ |
| 3 | 90 | 90 | 0 | $\theta_3$ |
| 4 | 0 | -90 | -295 | $\theta_4$ |
| 5 | 0 | 90 | 206.1 | $\theta_5$ |
| 6 | 0 | 180 | -80 | $\theta_6$ |

Besides using KUKA arm robot in this research, Katana 6M arm robot also been used for testing this system. The purpose is to acquire which robot is capable in developing a complete system. Before going through the system integrate with Katana arm robot, the Denavit-Hartenberg (D-H) parameter must be evaluated to predict the behaviour and also the restriction area especially singularity case of each robot. In this analysis Katana 6M arm robot's based coordinate will be considered unchanged. Tip of the robot arm will be considered and treated as an end point of the arm, so that the robot will considered as 5 degree of freedom (DOF) arm robot during the analysis. This robot has its own limitation on its workspace as shown in Figure 2.20.
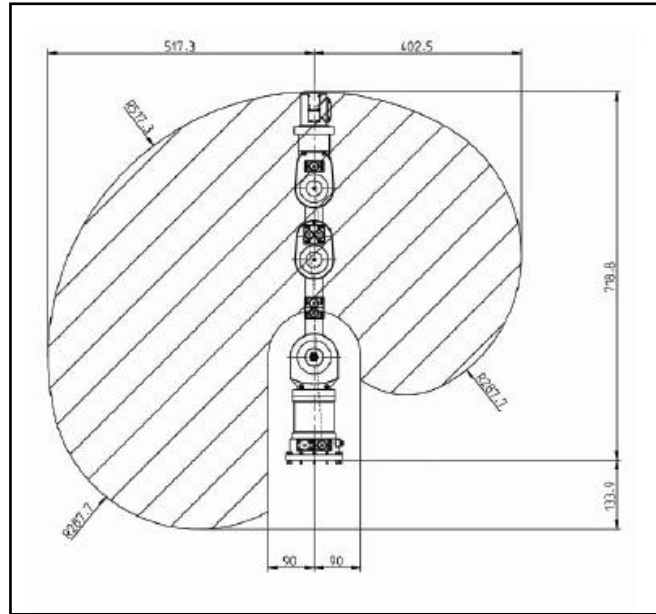
Figure 2.20: Workspace of Katana 6M Robot Arm

The D-H parameter for the Katana 6M are given in the Table 2.3 as the frame assignment is as shown in Figure 2.21. The associated interlink homogeneous transformation matrices are easily found from the D-H parameter values listed in Table 2.3. As the sixth link of this robot is also an end effecter, it is more efficient to numerically compute the forward kinematics function $T_5^0$ via a link-by-link iteration of the form.
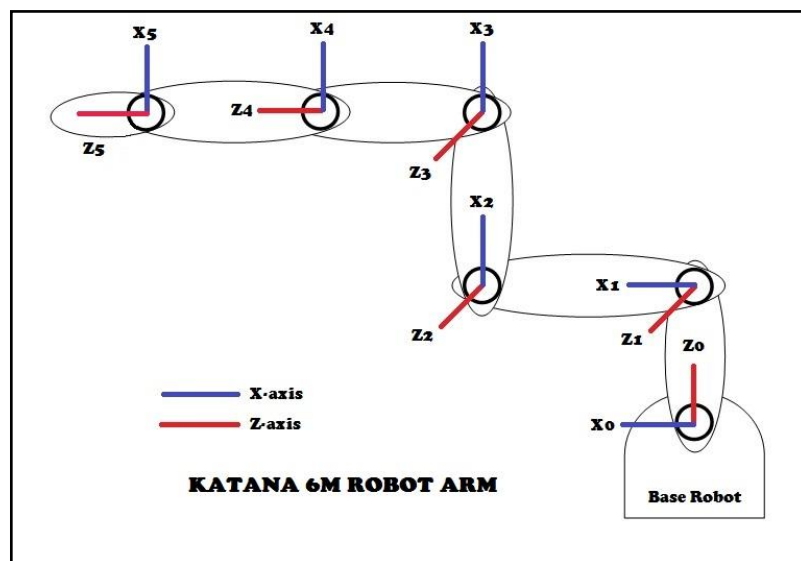


Figure 2.21: Framework for Katana 6M

Table 2.3: Link parameter for 5-DOF Katana Arm Robot

| DOF | $a_i$ | $\alpha_i(°)$ | $d_i$ | $\theta_i(°)$ |
|-----|-------|---------------|-------|---------------|
| 1 | 0 | -90 | 171 | $\theta_1$ |
| 2 | 190 | 0 | 0 | $\theta_2$ |
| 3 | 138 | 0 | 0 | $\theta_3$ |
| 4 | 0 | -90 | 0 | $\theta_4$ |
| 5 | 0 | 0 | 206.1 | $\theta_5$ |

# CHAPTER 3

## SYSTEM DESIGN AND DEVELOPMENT

### 3.0 Introduction

In this chapter, details of the complete development of the proposed system are discussed including machine vision, all the essential software, interface communication and also industrial robot application and the corresponding hardware. After that, the system is tested through a series of experiments to determine its efficiency; capabilities in providing complete system for gluing process

### 3.1 Computer Vision Development

Computer Vision Development consists of software development in building a system to assists human being in industrial application. HALCON and Visual Basic 6 software is used in this research as a compiler in building a better solution in solving inspection and correction system for gluing process by providing data and characteristics of each defect detected.

#### 3.1.1 CCD Camera (Samsung SDC-410N)

The Samsung camera (SDC-410N) is a series of high speed mainstream CCD cameras with superior image quality, even at high image capture rates. Samsung cameras are equipped with Kodak's CCD sensor with four tap readout technology. This sensor is up

four times faster than standard CCD sensor of the same resolution. This camera offers optimal resolutions of 1, 2 (4:3 and HDTV), and 4 megapixels, each in mono and colour. It provides more than 25 camera features, such as auto-gain and auto-exposure or the signal input debouncer, allow simple integration into many different application and system environments. The camera housing has a 58 mm x 52 mm footprint and provides screw holes for all five mounting positions. The industrial-proven aluminium body also includes screw holes for the safe locking of all cable connections. Samsung SDC-410N camera specifications are stated in Appendix D.

### 3.1.2   Software Description

In this research, both HALCON and Visual Basic 6 software had been used in developing this system as HALCON focused on image processing and Visual Basic 6 more on real-time monitoring for the system. The main objective for HALCON is to define the matching shape of an object by extracting data required with the model template that already being train in training phase. The extraction data goes through pixels by pixels in order to find the better shape with the model template. Visual Basic 6, which is Object Oriented Programming (OOP) software (Perry, 1998), had been used as real time monitoring for the system according to the specification needed. This real-time monitoring helps in developing online operation between the HALCON and Visual Basic 6 for easier in operating the system.

### 3.1.2.1 HALCON Software

HALCON (GmbH, 2012), one of the image processing software provides an Integrated Development Environment (IDE) for machine vision which provides a comprehensive vision library based on the latest and most advanced technology with more than 1100 image processing operators, the software development is supported by the interactive tool HDevelop, which are used mainly for vision process manipulation. HDevelop is a highly interactive environment that enables to build image processing solutions fast and efficiently – even while acquiring images from a capture device. HDevelop consists of 4 main windows that required fulfilling the job in image processing:

1. Graphic Window – shows all the process required by displayed results of each process.

2. Variable Watch – provided the complete variable used in the system.

3. Program Window – shown the entire algorithm developed from this system.

4. Operator Window – to add, edit and display operator with all its parameter.

### 3.1.2.2 Visual Basic 6 Software

Visual basic (VB) is a fairly easy programming language to learn and it is purely design for graphical user interface (GUI) for monitoring in a different ways. VB is event-driven that provides the user to click randomly, so each object has to be programmed independently to be able to response to those actions (events). Examples of events are clicking a command button, entering text into a text box, selecting an item in a list box etc. Therefore, a VB program is made up of many subprograms; each with its own program code which can be executed independently and at the same time can be linked together in one way or another. In this project, the GUI consists of 3 main parts: 1) Defect Shape

Matching (DSM) Application, 2) Defect Shape Pointing (DSP) Application and 3) Defect Inspection Monitoring (DIM) Application. This application is developed to show the respectful result to more convincing ways.

## 3.2 Development of Vision System

In this research, suggested vision system are developed into 4 phases which each of them have their own application and algorithm. This system developed according to the requirements and needs of the research according to the problem statement stated before.

### 3.2.1 Defect Shape Matching Application

Application of Defect Shape Matching (DSM) is introduced to identify the correct object used in the beginning of the process. In this research, pyramid (developed using plain cardboard) is used as the specimen for gluing process. This system is based on camera placed at the top of the object in order to monitor object placed at the working space. It's also to identify whether the object is in correct batch to process. Defect Shape Matching (DSM) application is introduced because it offers a better solution in 2D matching application compares to the other method as discussed in Chapter 2. It helps in reducing the size image in creating model template which will reduce processing time for the system known as Region of Interest (ROI). The created template then stored in memory and being called every time recognition processes takes place of each object. Every object comes across the system must be through DSM for enabling the system identifying type of object being process and to changed directory of module to cope with the task. Figure 3.1 shows the suggested 2D matching application algorithm by introduced DSM.
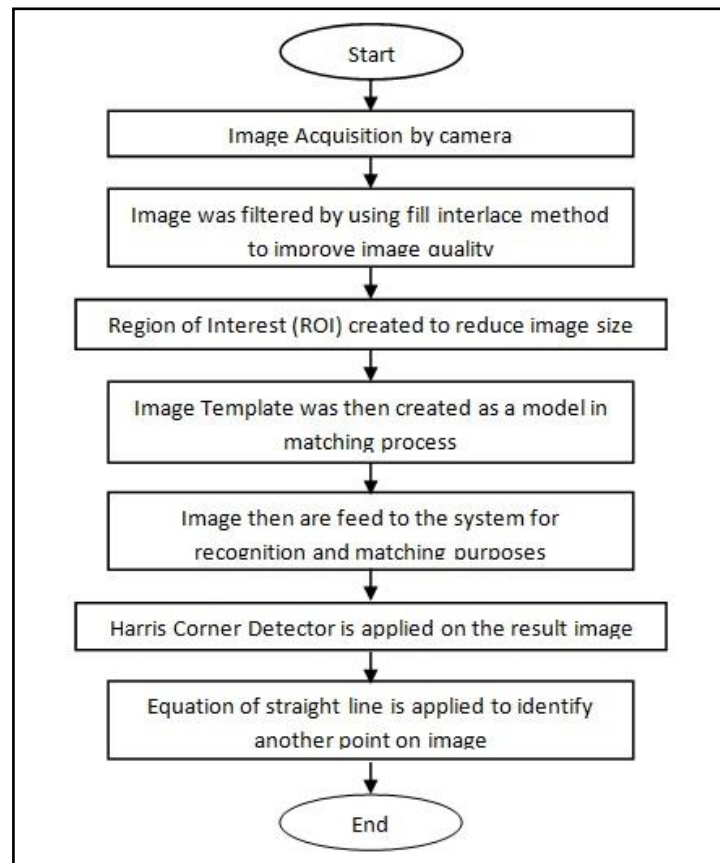
Figure 3.1: Suggested Algorithm for Matching Object

As shown in Figure 1.3, DSM is divided into two phases; 1) training phase and 2) recognition phase. The crucial part is in determining the best model template in training phase. From the original image, model template need to be extracted from its background by using Region of Interest (ROI) technique. This technique helps in reducing a large number of unused sizes occur by considering only the extracted region to meet the task requirement. Then, filtering method such as fill interlace technique is applied to improve the quality image of the template and remove noise which can greatly influence obtained recognition rate. Next process is to implement the median filter as effective method to remove noise occurs from the image in order to give a new life for the image look as more productive than before. The template created are then stored in the memory. As long as the template is in high quality, recognition rate for matching purposes definitely in high

percents. Figure 3.2 shows the transition step from original image until model template being created.



<div align="center">(a)          (b)</div>
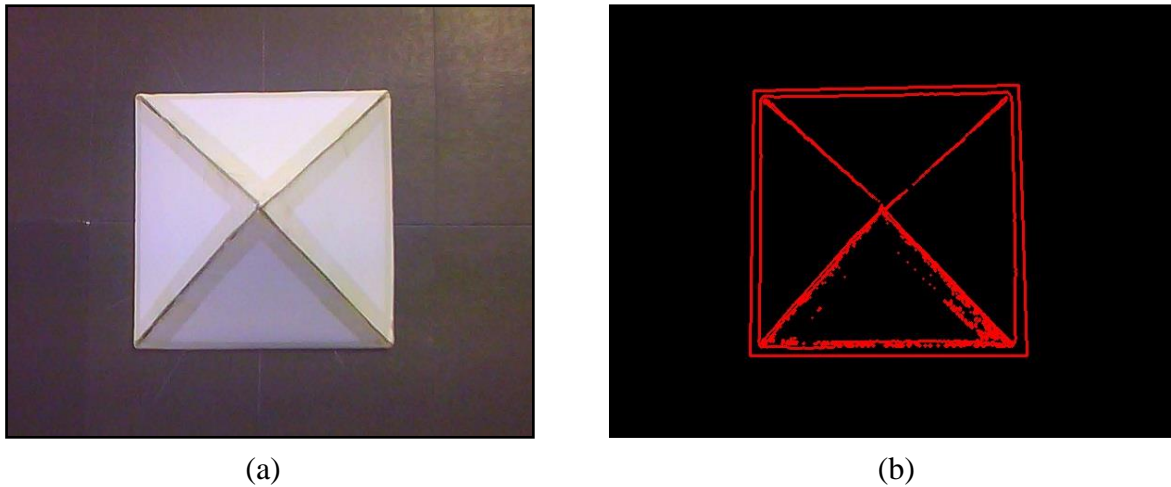
Figure 3.2: (a) Original Image; (b) Image Model Template

According to Figure 3.2, from original image turned into template image by applying all the method stated before to improve desired image for recognition purposes. The template is stored into the system memory for able to calling it each time of matching step is takes place. In recognition phase, template matching is used by comparing the template image with the process image pixels by pixels by referring to template image saved in the memory. The matching process moves the template image to all possible position in larger source image and computes a numerical index that indicates how well the template matches and the image in that position. The result of the template matching known as recognition rate which it depends on how much region its cover according to the template creation. DSM is robust to noise, clutter, occlusion, and arbitrary non-linear illumination changes. Objects are localized with sub-pixel accuracy in 2D.

After results are obtained, the system decides whether to go further process or went back to previous process (recognition phase) are depends on the recognition rate of the process to ensure the correct batch are running at that time. According to Figure 3.5, matching fail means the system looping back to recognition phase and continue with another image object which means if there is other type of object included in the process, system can identified and continue again with the correct one. Matching success allow the system continue to Harris Corner Detector (HCD) process. HCD is a critical interest point detector due to its strong invariance to rotation, scale, illumination variation and image noise. This feature enables the system to locate the corner position of the image in order to gain data for generate other points based on mathematical equation of straight line (Sastry). Figure 3.3 shows the result for HCD process with additional data from x, y and z coordinates.
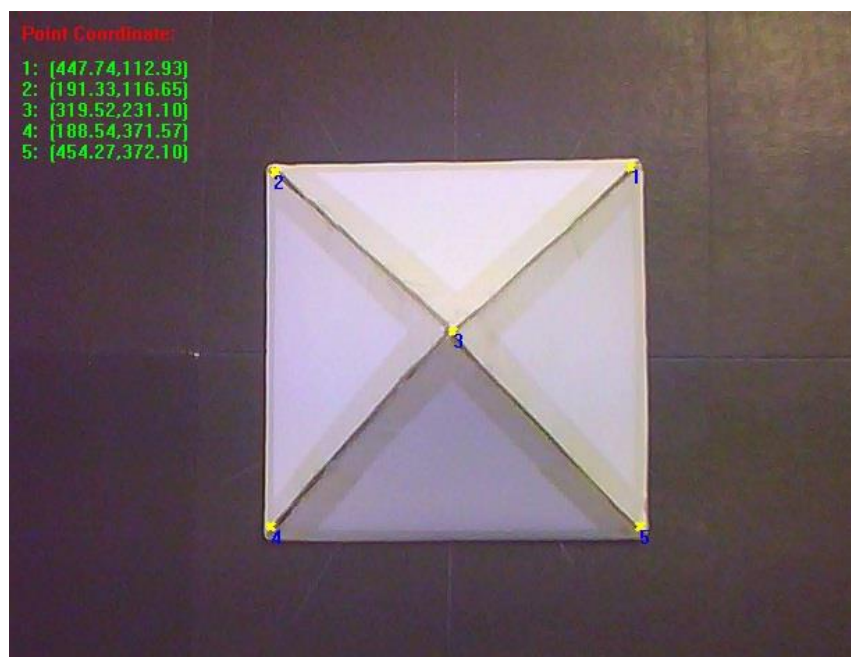


Figure 3.3: Result from HCD Process

Result from Figure 3.3, shows that HCD process occurred in point 1, 2, 3, 4 and 5 where the system detects the entire possible corner appear on the image. In order to define the other points as shown in Figure 3.4, the additional of mathematics application is introduced in this system. Equation of straight line is applied to find the other point location between two points in the image. This application is introduced to provide additional data in defining the gluing line for further process in the system as shown in Figure 3.4.
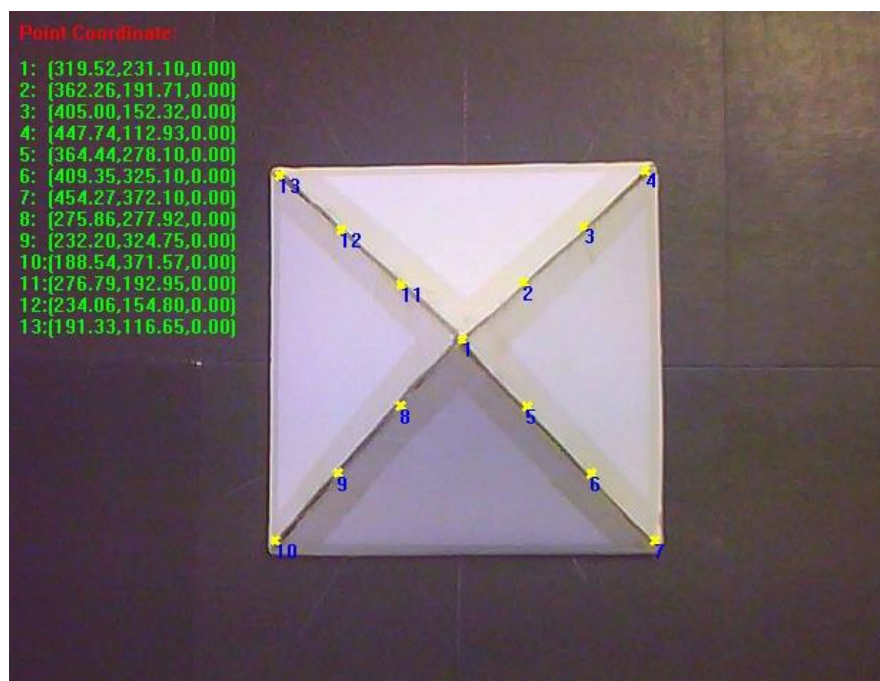


Figure 3.4: Results of Combination HCD Process with Equation of Straight Line

According to the results obtained, the corner point and generated point stated in x and y-axis with no coordinates for z axis. In order to integrate system with arm robot, the generated coordinates information must consist x, y and z axis. Hence, the next process known as Defect Shape Pointing (DSP) provide with another installed camera that will be placed in front of the object to meet the requirement of robot vision system in acquiring the 3D information. In giving more illustration about DSM process, Figure 3.5 shows the step

by step process that will include from training phase until recognition phase and the next process occur after DSM process had been done.
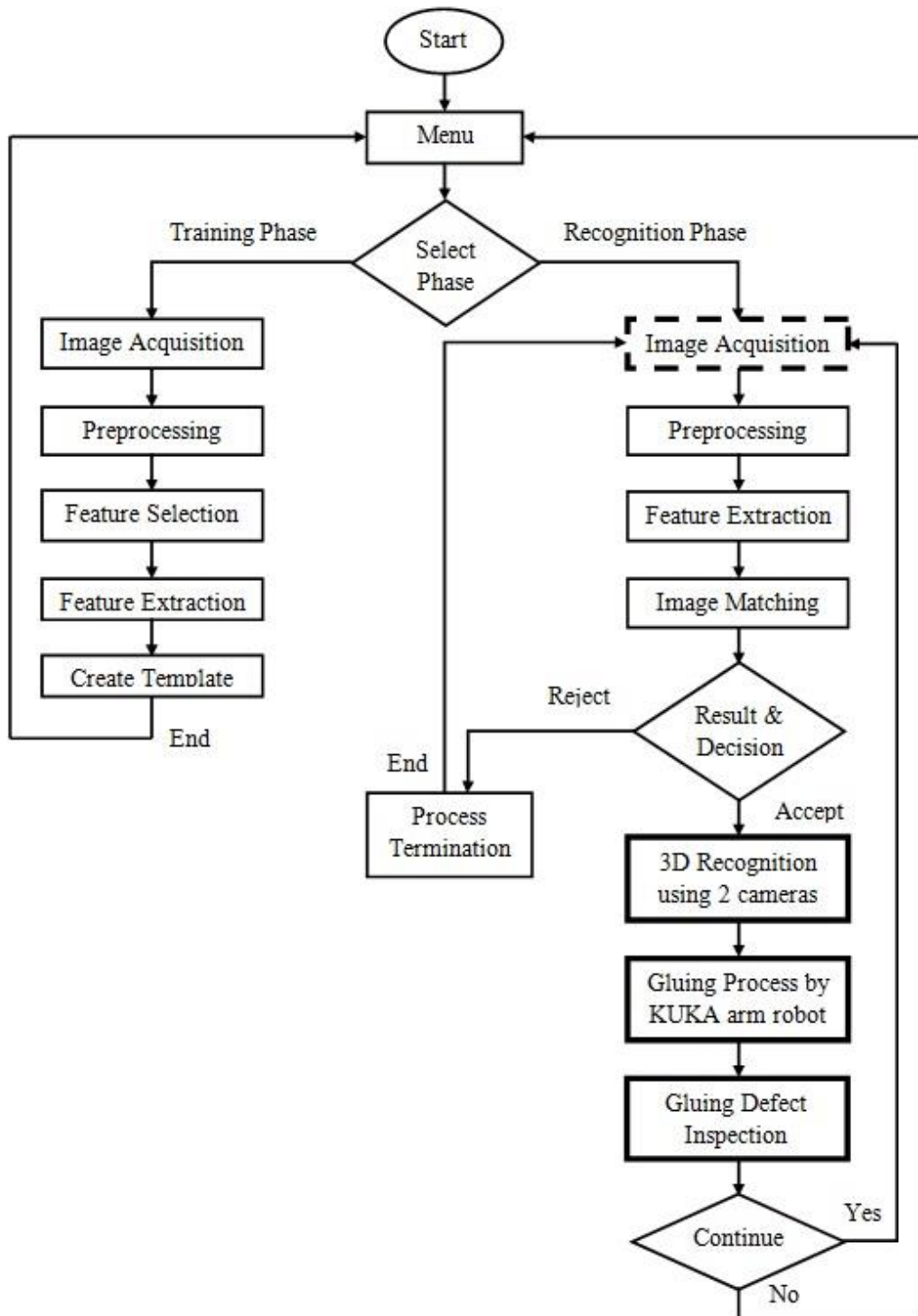


Figure 3.5: Flow Chart of Defect Shape Matching (DSM)

### 3.2.2 Defect Shape Pointing Application

Defect Shape Pointing (DSP) application develop based on the information of 3D transformation (x, y and z coordinates) used in this research. In order to create application with all these information, development of application by using two cameras each of them placed at different angle and rotation (Takahashi et al., 2006). The proposed method as shown in Figure 3.6, introduced two cameras application where one of them placed at the top of object and the other placed in front of it. Based on this, the x, y and z coordinates can be generated by combining images capture from both cameras act as medium in determine z coordinate.
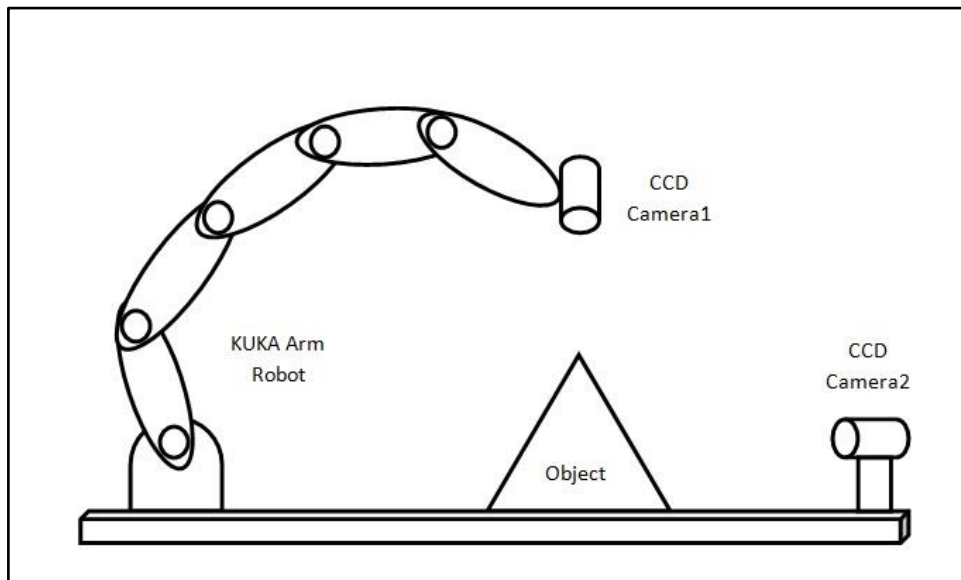


Figure 3.6: Proposed of two Camera Placement in 3D Recognition

Camera placement has been developed according to the needs of the system requirement as described before. The arrangement helps in determining z-coordinate by applying two-dimensional image. The z-coordinate are based on combination of two pixel coordinate of 5.0 megapixels CCD camera placed as shown in Figure 3.6. In order to develop system that involve with 3D transformation all the x, y and z-coordinate must be

appointed which means the image should have length, width and height. In providing system with such information, Harris Corner Detector (HCD) process is introduced once again in determining the perfect location of object's corner for both situations as shown in Figure 3.7. The transformation of z-coordinate in 3D involves of two images which are taken from both camera, top and front. The information of each corner is recorded to ensure the positioning of each corner is located perfectly. The information gathered will be used to generate additional point throughout the gluing line for better solution in gluing the object.



(a)      (b)
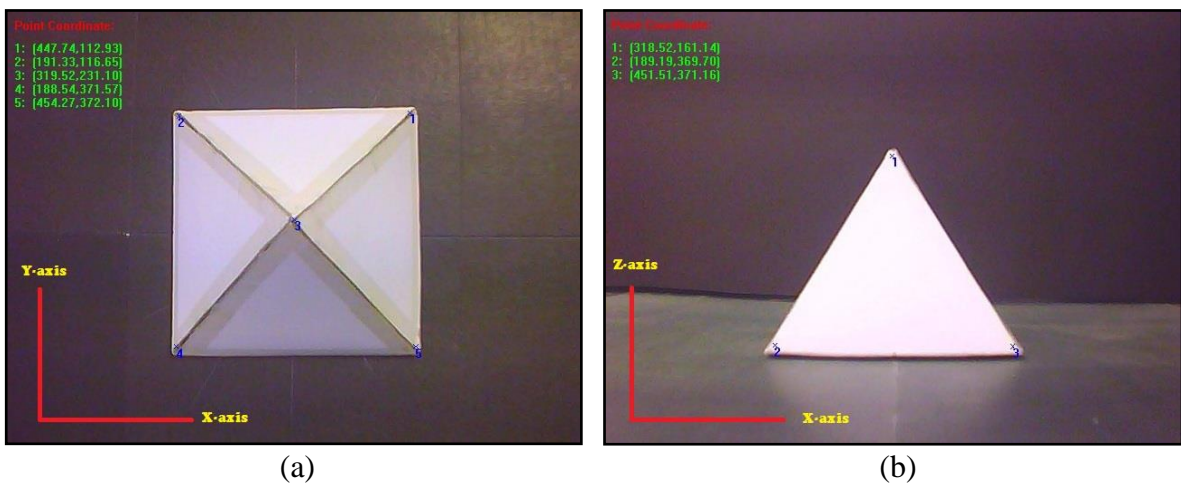
Figure 3.7: (a) Captured Image from Top Camera and (b) Captured Image from Front

Camera

Both images are used as a reference images for further process. The first reference image (top camera) will generate the x and y-coordinate. Then the second reference image (front camera) will generate the x and z-coordinate. Both coordinates are generate by using mathematical approach of straight line (Sastry) according to the object specimen that has a shape of rectangle. The calculation between one points to another retrieve all the information needed to be used in pointing another point between the previous two points. Firstly, the system should identify all the edge point within both images. Then, identified

the two points needed to be calculated and labelled as $(x_{n-1}, y_{n-1})$ and $(x_n, y_n)$. Then, the

points are applied it into the equation to define the slope of the line in pixels coordinate.

$$m_n = (y_n - y_{n-1})/(x_n - x_{n-1}) \tag{3.1}$$

After that, value of the slope and point is used in the slope-intercept equation to define the

intersection of the line. $m_n = ( y_n - y_{n-1} ) / ( x_n - x_{n-1} )$

$$y_n = m_n x_n + c_n \tag{3.2}$$

Then, the distance in x-axis and y-axis between two points is calculated and defines

it as *k* and *l*. The point will then be integrated into Equation (3.1) and Equation (3.2) to find

new location of the point based on the information obtained. Lastly, new point being

declared and classified as one of the point needed in the system. The pointing results of

both images are shown in Figure 3.8.



(a)                                      (b)
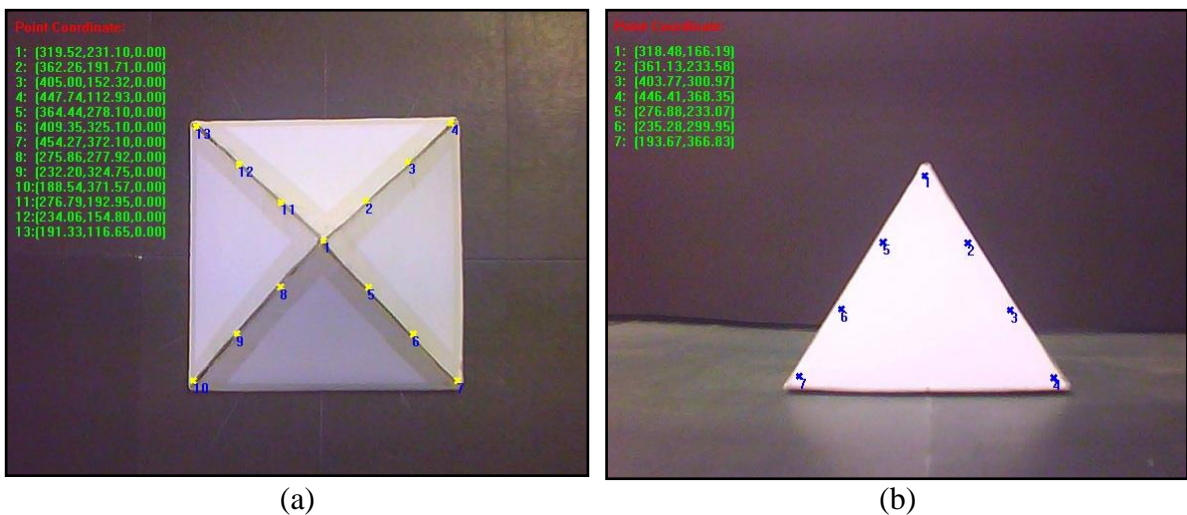
Figure 3.8: A New Point Appointed from Top and Front Camera

In applying glue application, the point of each coordinate must be accurate for precise operation. Therefore, the findings of this z- coordinate provide an additional data in order to minimize error of the system. In real operation, the shape of object is not exactly the same as the image taken. So, by providing a mathematical approach of straight line helps in rebuilding the z-coordinate based on their own image taken through the systems. In order to reconstruct 3D image from both 2D images, there are 3 steps to follow respectively with addition of sample calculation at the end of this sub chapter.

1. Determine position of camera.

In order to get the exact value from both images, the object captured must be adjusted for obtaining better position from both cameras. Every centimetre different will result to inaccurate size of image. For beginning, set the top and front camera as 50 cm from base. Let the top be constant at 50 cm and front as adjustable in acquiring exact value of x-coordinate for both as shown in Figure 3.9.
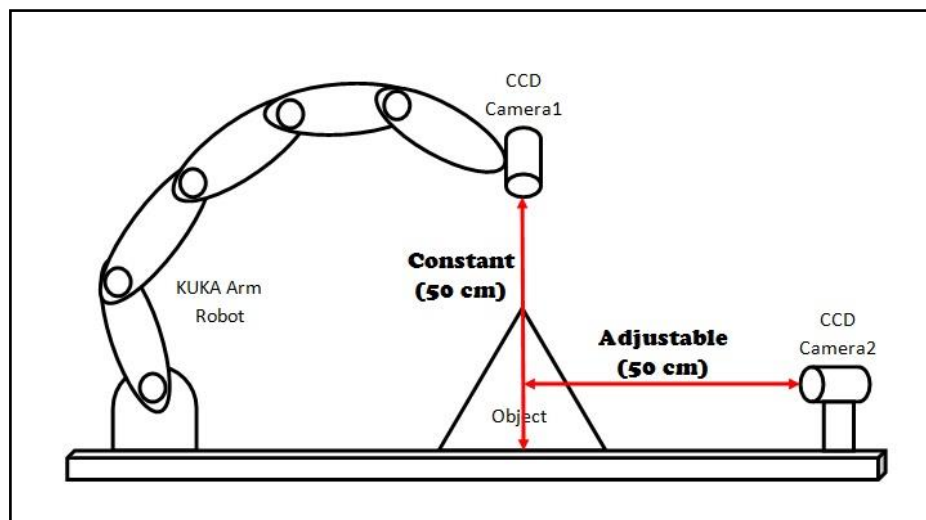


Figure 3.9: The Proposed of two Camera Placements in 3D Recognition

By adjusting the position of second camera step by step, then compare the coordinate determine through the system in order to identify a better position for

acquiring exact size of object from both images. The results determine should be able to synchronize with the x-coordinate where it's as a backbone for completing the 3D image construction.

2.  Comparing both images by using x-coordinate.

After step 1 completed, which means the exact position of front camera is determined. Then the next step is to ensure that both images being line in one axis in order to compare each edge point from both images. In Figure 3.10, each point is numbered according to the sequences. Point 1, 5, 6, 7, 8, 9 and 10 from top camera are compared with the same point from the front camera. The x-coordinate should be exactly the same by both images in claiming that the images have the same size and height can be measured through image from front camera.
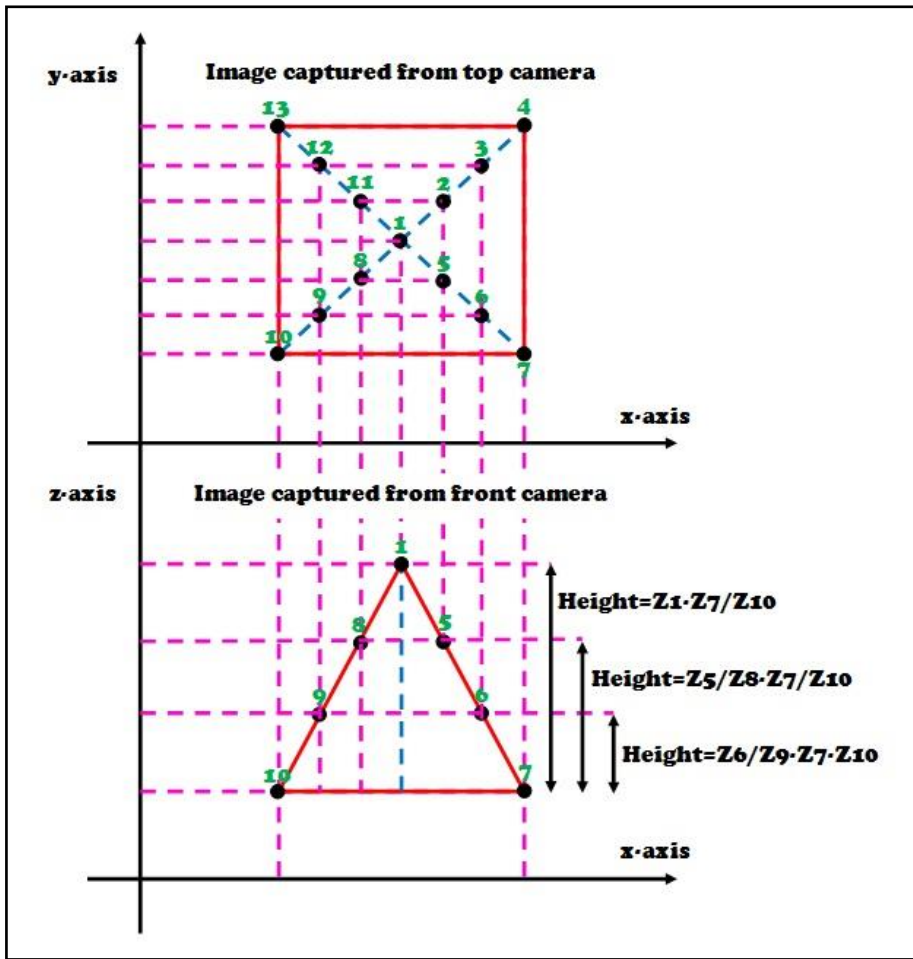
Figure 3.10: Integration of two Image Source in Finding New z-coordinate

Measurement of the height (z-coordinate) of each point should be done by using mathematical approach which point 7 and 10 appointed as a reference point. All the data generated will be used as an additional data in doing glue process to ensure the systems work smoothly and efficient.

$$Height, H_n = Z_n - Z_{7,10} \tag{3.3}$$

3. Combine features from both images.

The next step is to combine all data gathered from step 1 and 2 for constructing 3D image from 2D image. The height of each point appointed are being illustrated as shown in Figure 3.11 where the transformation of 3D image are developed. The transformation is based on the 2 reference image that used in determining the height of each point.
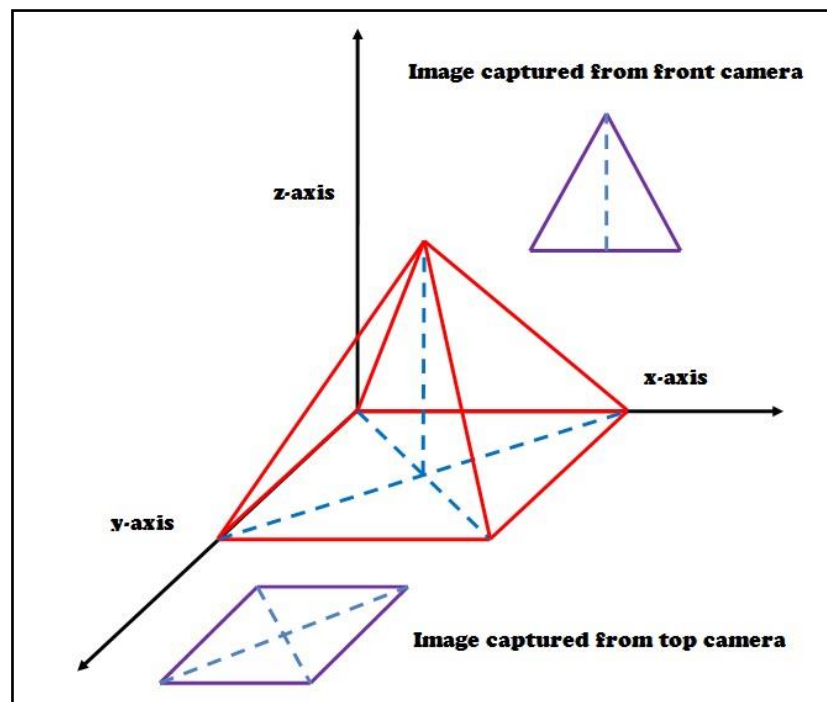


Figure 3.11: Information Gathered from two Source Images in Generate 3D Image from 2D Image

According to the Figure 3.11, the development of 3D image are based on x, y and z-plane where it's consists of length, width and height. This application helps in rebuilding data of 3D image by using two cameras which have their own position and rotation that are important in classifying the 3D transformation. For top camera, image extracted gives information in x and y coordinates. As for front camera, image extracted must be synchronized in x coordinate from top camera to gain information of x and z coordinates. As a result, image constructed from both

2D images able to 3D transformation. Hence, this method is proposed according to the needs of the system in this research. Figure 3.12 shows the flow chart of Defect Shape Pointing (DSP) process from image acquisition of both cameras until the 3D transformation data are obtained through it.
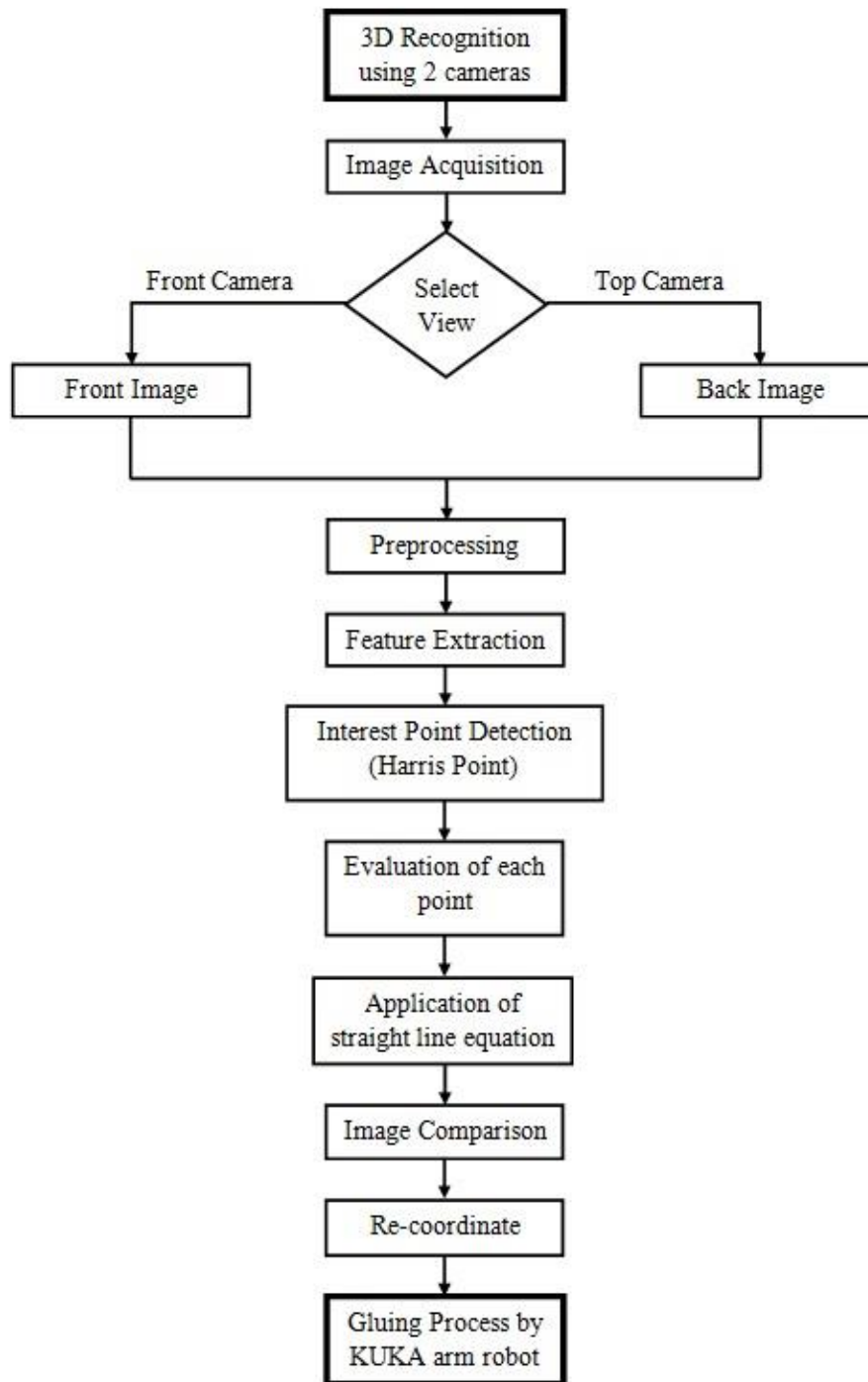
Figure 3.12: Flow Chart of Defect Shape Pointing (DSP)

In this section, sample calculation will be added to give more details on determining the new point between the object gluing line. Also sample calculation in generate z coordinate of the object as useful information in gluing process.

1. Sample Calculation for New Point between Object Gluing Line
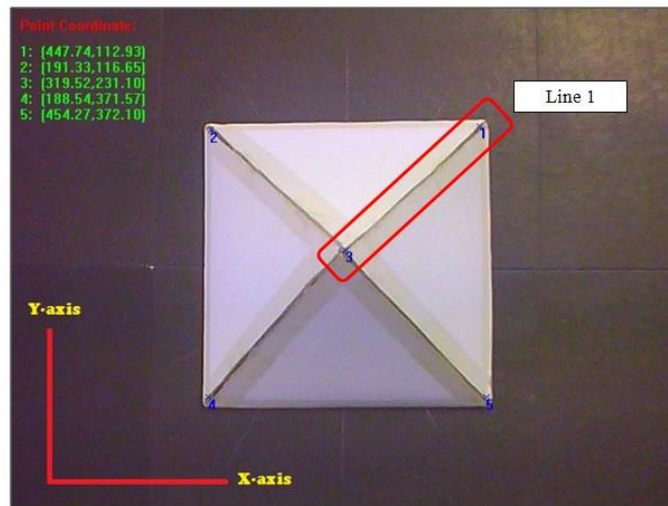


Figure 3.13: Sample Calculation in Solving New Point in Line 1 (top camera)

According to Figure 3.13, the generated point comes from Harris Corner Detector (HCD) process. This information is used to find new generated point in Line 1 as shown in figure. The information is recorded in Table 3.1.

Table 3.1: Information Gathers from HCD Process

| Point | X coordinate | Y coordinate |
|-------|--------------|--------------|
| 1 | 447.74 | 112.93 |
| 2 | 191.33 | 116.65 |
| 3 | 319.52 | 231.10 |
| 4 | 188.54 | 371.57 |
| 5 | 454.27 | 372.10 |

60

Firstly, use data available at point 1 and 3 as information to generate new point between them in first object gluing line.

$$Point\ 1 = (447.74, 112.93) \quad \& \quad Point\ 3 = (319.52, 231.10)$$

Then, find slope of the line by using Equation (3.1) and its y interception by using Equation (3.2).

$$m_1 = \frac{y_3 - y_1}{x_3 - x_1}$$

$$m_1 = \frac{231.10 - 112.93}{319.52 - 447.74}$$

$$\boldsymbol{m_1 = -0.9216}$$

$$c_1 = y_1 - m_1 x_1$$

$$c_1 = 112.93 - (-0.9216 \times 447.74)$$

$$\boldsymbol{c_1 = 525.567}$$

After data of m1 and c1 are obtained, by using data of Point 1 integrate the entire information gather to find new point between first gluing lines (Line 1). Number of points along gluing line needs to be specified to define the range between each point generated. For this research, each gluing line consists of 4 points along it.

$$p_{1x} = abs\left[\frac{(x_3 - x_1)}{n - 1}\right]$$

$$p_{1x} = abs\left[\frac{(319.52 - 447.74)}{3}\right]$$

$$\boldsymbol{p_{1x} = 42.74}$$

$$p_{1y} = abs\left[\frac{(y_3 - y_1)}{n - 1}\right]$$

$$p_{1y} = abs\left[\frac{(231.10 - 112.93)}{3}\right]$$

$$\boldsymbol{p_{1y} = 39.39}$$

Data obtained are range between each point in x and y coordinates. This point will be used in determine second and third point in gluing line.

$$x_{1a} = \frac{[y_1 + (p_{1y} \times 2) - c_1]}{m_1}$$

$$x_{1a} = \frac{[112.93 + (39.39 \times 2) - 525.567]}{-0.9216}$$

$$\boldsymbol{x_{1a} = 362.26}$$

$$y_{1a} = m_1 \times [x_1 - (p_{1x} \times 2)] + c_1$$

$$y_{1a} = -0.9216 \times [447.74 - (42.74 \times 2)] + 525.567$$

$$\boldsymbol{y_{1a} = 191.71}$$

$$x_{1b} = \frac{(y_1 + p_{1y} - c_1)}{m_1}$$

$$x_{1b} = \frac{(112.93 + 39.39 - 525.567)}{-0.9216}$$

$$\boldsymbol{x_{1b} = 405.00}$$

$$y_{1b} = m_1 \times (x_1 - p_{1x}) + c_1$$

$$y_{1b} = -0.9216 \times (447.74 - 42.74) + 525.567$$

$$\boldsymbol{y_{1b} = 152.32}$$

Data of $(x_{1a}, y_{1a})$ and $(x_{1b}, y_{1b})$ are located as point 2 and 3 in Figure 3.14. This result still not included with z coordinate because this system is assume as 2D information to fine the location in x and y coordinates. After this process done, next must be determining 3D information of z coordinate by combining two 2D images information. The sample calculation is shown in next sub chapter.
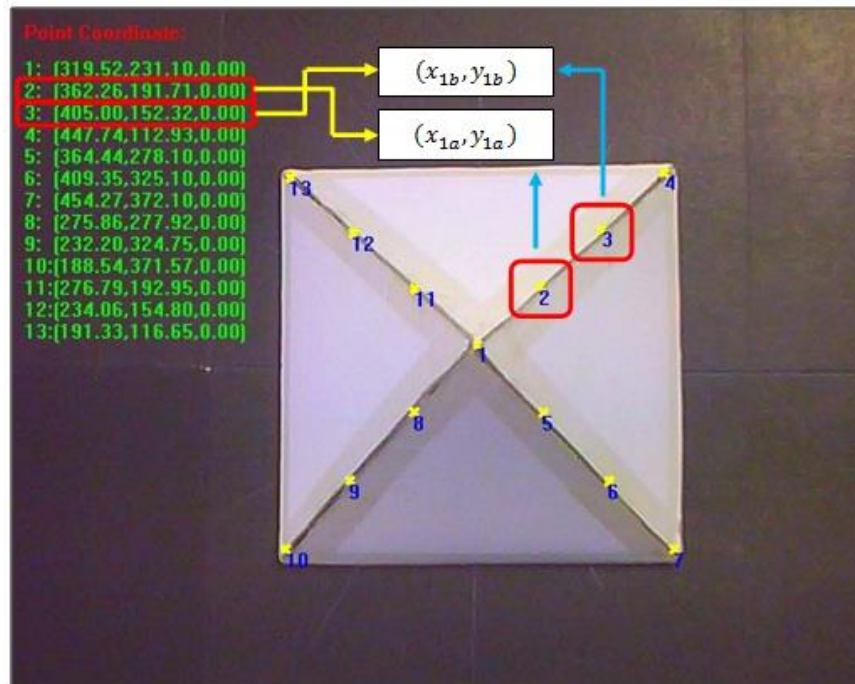


Figure 3.14: Result for New Generated Point (top camera)

2.  Sample Calculation in Determine z coordinate

In this section will shows the step in determining third data information of z coordinate. For this example, image obtained is from front camera which is conclude as x and z axis. Figure 3.15 shows the image captured from front camera that need to configure the x and z coordinates.
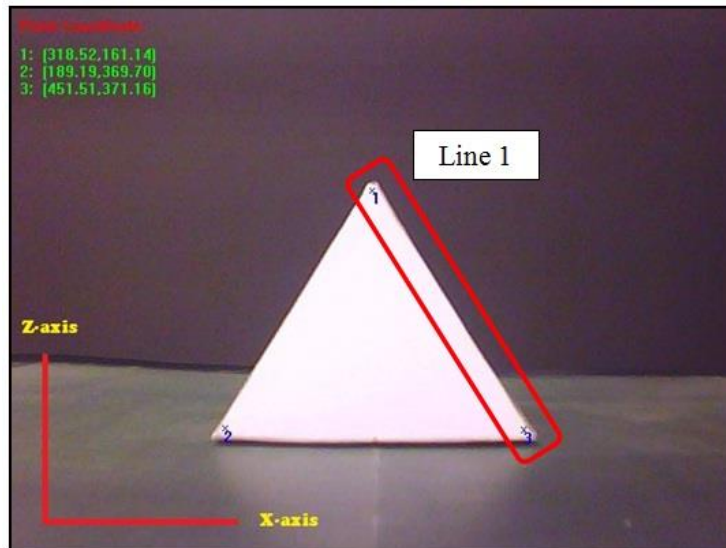
Figure 3.15: Sample Calculation in Solving New Point in Line 1 (front camera)

According to figure, the red square shows the line that need to analyze the x and z coordinates through this sample calculation. The steps in configuring the points are basically the same as previous sample, but the arrangement of object in x-axis must be equal for both of images as described in this sub chapter. So, Figure 3.16 shows the result of new generated point in x and z coordinates.
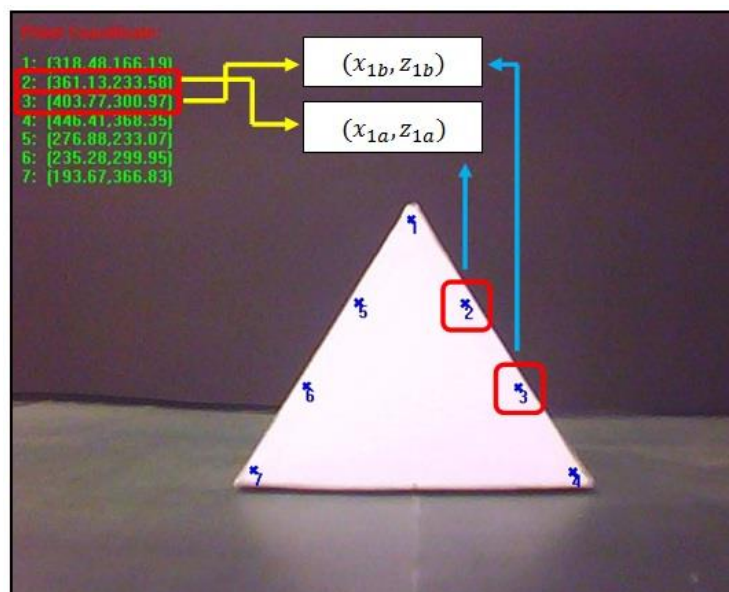


Figure 3.16: Result for New Generated Point (front camera)

According to Figure 3.16, the generated point comes from combination of Harris Corner Detector (HCD) process and mathematical equation of straight line. This information is used to find new generated point in Line 1 as shown in figure. The information is recorded in Table 3.2.

Table 3.2: Information Gathers from both Processes

| Point | X coordinate | Z coordinate |
|-------|--------------|--------------|
| 1 | 318.48 | 166.19 |
| 2 | 361.13 | 233.58 |
| 3 | 403.77 | 300.97 |
| 4 | 446.41 | 368.35 |
| 5 | 276.88 | 233.07 |
| 6 | 235.28 | 299.95 |
| 7 | 193.67 | 366.83 |

In order to find the height of the image from top camera, by using coordinate from Table 3.2 it can be done by minus the top point with below point as shown in calculation below.

$$z_1 = Point\ 4@7 - Point\ 1 \approx 202$$

$$z_{2,5,8\&11} = Point\ 4@7 - Point\ 2@5 \approx 134$$

$$z_{3,6,9\&12} = Point\ 4@7 - Point\ 3@6 \approx 66.5$$

$$z_{4,7,10\&13} = Point\ 4@7 - Point\ 4@7 \approx 0$$

After the height of object obtained, combination of entire point are integrate in one 2D image captured from top camera as shown in
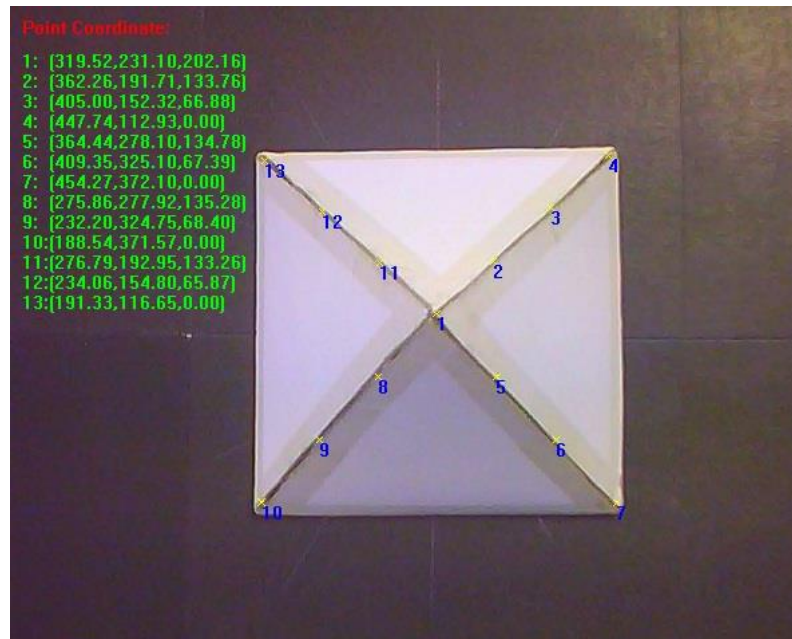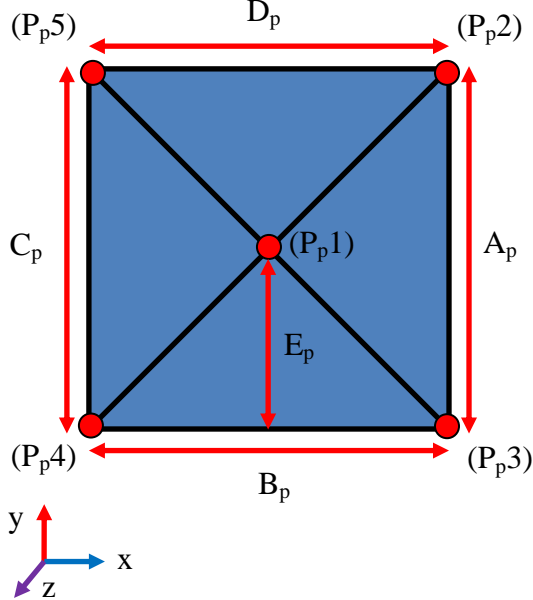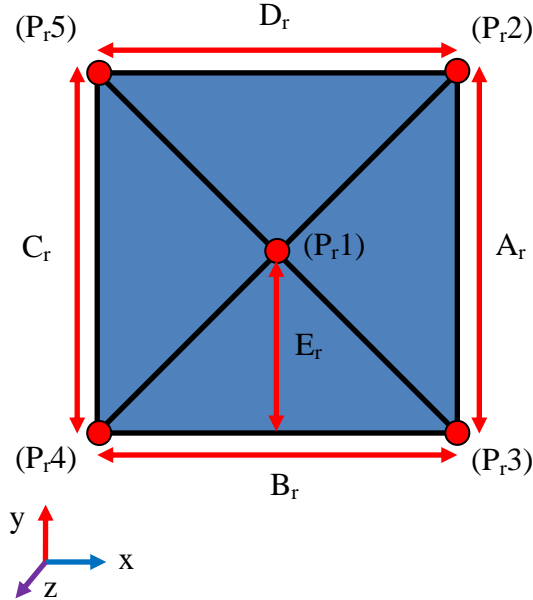
Figure 3.17: Result of Image in x, y and z Data

So, the provided data can be used in gluing process with assisting of KUKA arm robot. As in robotic automation system, the robot must be filled with 3D data configuration for robot to do the task.

### 3.2.3   Converting Robot Coordinate to Robot Coordinate

The information of robot coordinate is really important in providing the robot with coordinate that the robot understands. In order to achieve that, the comparing between pixels coordinate and robot coordinate needs to be done in acquiring the new equation in converting pixels coordinate to robots coordinate. Table 3.3 shows data recorded used in generate equation for converting pixels to robot coordinate.

Table 3.3: Data Recorded from Pixel and Robot Coordinate

| Pixel Coordinate | Robot Coordinate |
|---|---|
|  |  |
| $P_p1 = (319.52, 231.10, 202.16)$ | $P_r1 = (365.87, 0.01, 383.76)$ |
| $P_p2 = (447.74, 112.93, 0)$ | $P_r2 = (458.05, 78.52, 263.54)$ |
| $P_p3 = (454.27, 372.10, 0)$ | $P_r3 = (456.74, -78.09, 264.66)$ |
| $P_p4 = (188.54, 371.57, 0)$ | $P_r4 = (287.42, -76.53, 263.08)$ |
| $P_p5 = (191.33, 116.65, 0)$ | $P_r5 = (288.19, 77.51, 263.96)$ |
| $A_p = 259.17$ | $A_r = 156.61$ |
| $B_p = 265.73$ | $B_r = 169.32$ |
| $C_p = 254.92$ | $C_r = 154.04$ |
| $D_p = 256.41$ | $D_r = 169.86$ |
| $E_p = 202.16$ | $E_r = 119.95$ |

By using the data available, ratio between pixels and robots coordinate can be calculated and used that data in generating new equation as shown below.

$$X_{ratio} = \frac{pixels\ diff\ (Xp_{avg})}{robots\ diff\ (Xr_{avg})}$$

$$X_{ratio} = \frac{261.07}{169.59}$$

$$\boldsymbol{X_{ratio} = 1.5394}$$

$$Y_{ratio} = \frac{pixels\ diff\ (Yp_{avg})}{robots\ diff\ (Yr_{avg})}$$

$$Y_{ratio} = \frac{257.05}{156.61}$$

$$\boldsymbol{Y_{ratio} = 1.6413}$$

$$Z_{ratio} = \frac{pixels\ diff\ (Zp_{avg})}{robots\ diff\ (Zr_{avg})}$$

$$Z_{ratio} = \frac{202.16}{119.95}$$

$$\boldsymbol{Z_{ratio} = 1.6854}$$

From the information above, data ratio for each coordinate are determined in findings the differences between pixels and robots coordinate. By applying that, the new generated equation in converting pixels to robot coordinate can be achieved. The equation developed based on the same data used in pixels and robots coordinate as shown in Equation (3.4). The equation is shown as:

$Robot\ Coordinate, (x, y, z)$

$$= \left[ \left( \frac{X(pixels)}{X_{ratio}} \right) + X_{avg}(robots) \right] (X) \tag{3.4}$$

$$+ \left[ \frac{240 - Y(pixels)}{Y_{ratio}} \right] (Y)$$

$$+ \left[ \frac{Z_{avg}(pixels)}{Z_{ratio}} + Z_{ravg} \right] (Z)$$

### 3.2.4 Defect Inspection Monitoring Application

Inspection system is one of the important aspects that will be required in industrial application. Every product produced must be through inspection system first to ensure the quality of the product before it can be claimed as a quality product. In this research, defect inspection system known as Defect Inspection Monitoring (DIM) is introduced in order to ensure that the gluing process done perfectly with quality is on hands. Defect can be occurring when the system is not well calibrated and the information send to the system cannot be extracted efficiently according to the system required. This is one of the important aspects that need to be focus during the production of any product. Thus, DIM is proposed to meet requirement of the task in developing complete system. According to the Figure 3.18, the suggested vision algorithm is applied based on the needs of the system that required detecting two types of defect; 1) Gap defect and 2) Bumper defect in gluing line.
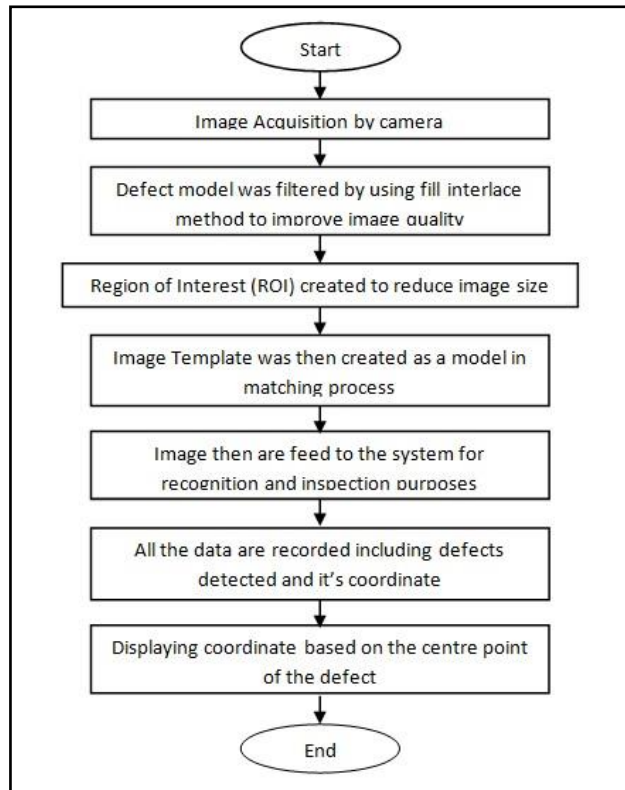
Figure 3.18: Suggested Algorithm for Defect Inspection System

According to Figure 3.18, the proposed algorithm introduced two phase in Defect Inspection Monitoring (DIM) are defect training phase and defect recognition phase. Defect training phase required the system to identify the usual error to be trained as the defect template. In acquiring a better template, the source image needs to be emphasized in order to return the quality value of the image. The crucial part is involving the noise reduction from source image that reflects mostly on recognition rate in defect recognition phase. Better quality for template creation, recognition rate results is higher. Less quality image template provided, it turns the result low in recognition rate.

In this research, two types of defect are trained according to the need of the system. Each defect has its own special characteristic which is extracted that information and used as a medium of defect detection. Technique of ROI once again introduced to limit the process region that used as a template defect image. Fill interlace and median filter as

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important features in removing noise in the image defect. All information is saved into the system and being group into two categories; gap defect and bumper defect. In gluing application, there are three major defects that are usually occur in gluing line, gap, bumper and bubble defect. Gap and bumper are one of the major problem occur during gluing process because of the robot system is not well-calibrated. For gap defect, the problem occurs when the gripper speed a little bit fast from usual that makes the empty region along the gluing line. As well as bumper defect, the gripper is far too slow that might cause at certain region too much glue that looks like a bumper along gluing line. Bubble defect might occur when the gluing tool has inconsistent to distribute the glue along gluing line but the defect is too small to determine that the product is rejected. So, bubble defect is assumed as a minor defect and the product is accepted. Figure 3.19 show the templates that are used in this research for classification defects in gluing line.
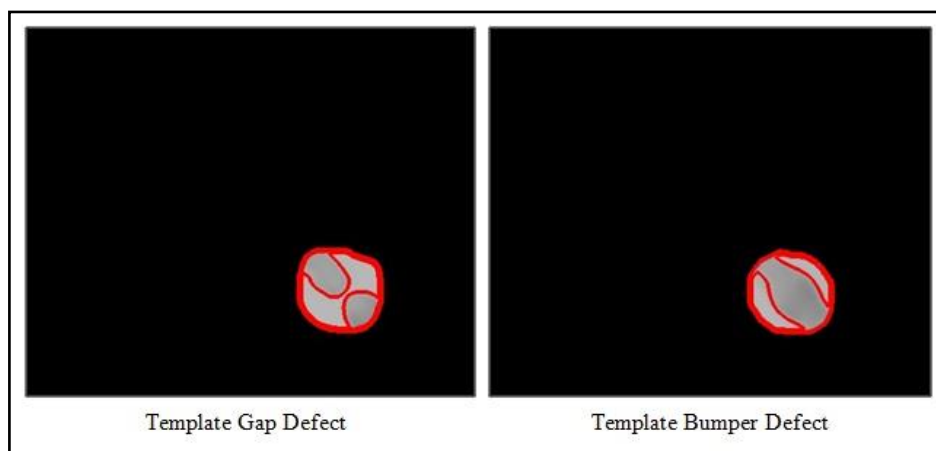


Figure 3.19: Template Using in Defect Inspection

By referring to Figure 3.19, both templates are created with less noise and better quality of the image. After the template had been created and stored in memory, the recognition phase is takes placed. In order to accommodate the testing image with the template image, several techniques are introduced to free image testing from noise and its

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background those usually affecting results of recognition rate. Auto threshold is used demanding of the system requirement that need to separate between image object and background automatically without user specified threshold value. Fill interlace also introduced in order to make the testing image smooth by removing odd or even line number occur in the image. With this, the image is more soft compare to the original image.

15 types of image testing had been used in this software development to configure whether this system is capable in determining the defects in all possible direction. Each of tested images has different number of defects and various type of defect with each in different location and direction. These tested images are developed to cope with the system development in order to meet objective of the research. Plain cardboard is used as object specimen in order to do the classification of defects. According to Figure 3.19, by applying those templates each defects can be detected as long as the source image characteristic is exactly the same with template image. In this software version, there is 4 types of classification to identify problem occur in the object after gluing process done that will discussed thoroughly in next sub chapter of simulation results. Each classification needs to be repaired in Correction of Defect (CoD) application to ensure every rejected product can be process again to produce a quality product.
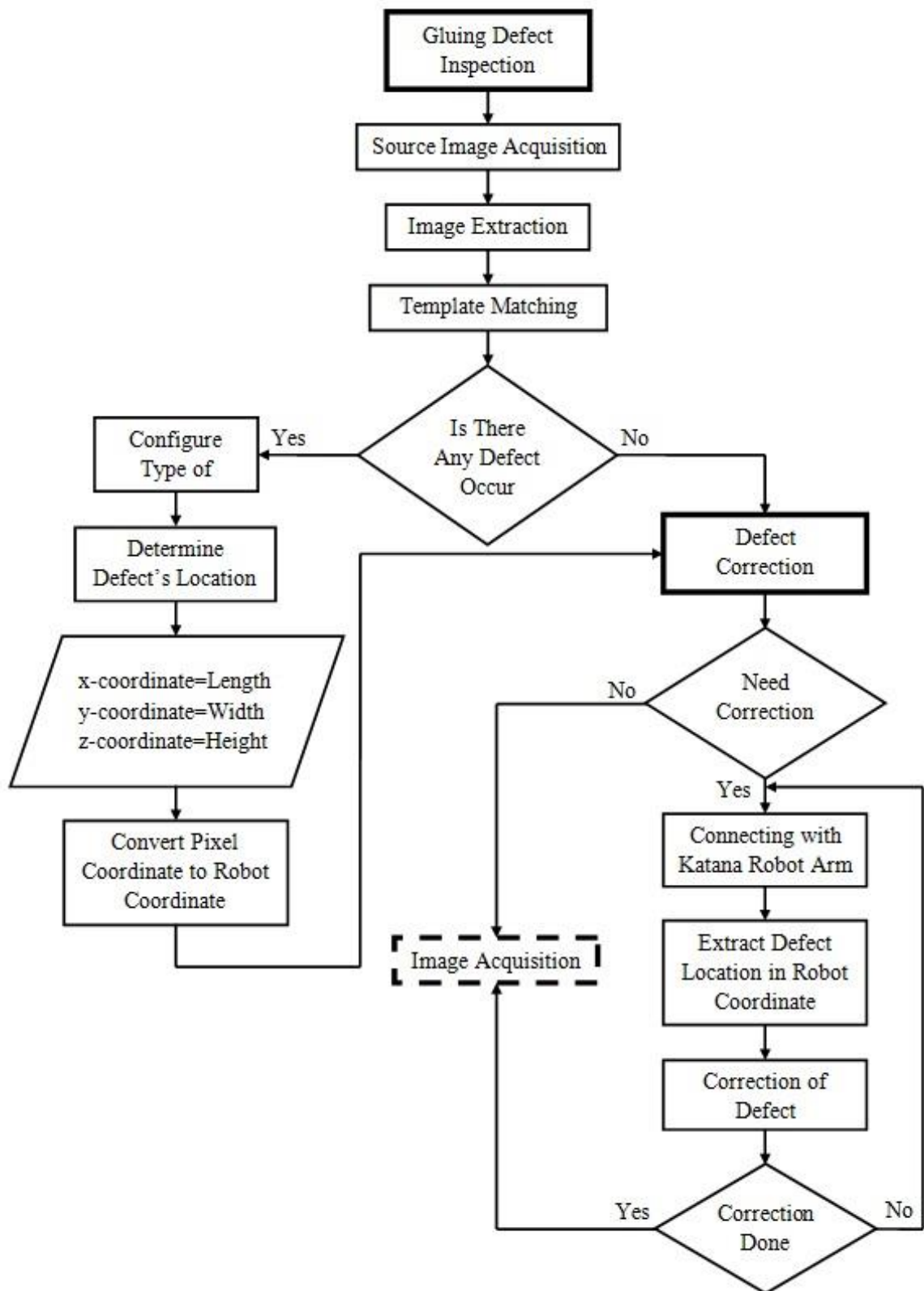
Figure 3.20: Flow Chart of Defect Inspection Monitoring (DIM) and Correction of Defect (CoD)

## 3.3     Simulation Results

Each of simulation development is tested using sample object to configure whether the system capable in achieving the objectives of the research. Flexibility of the system is stressed in this research in order to produce a system that able to complete its task with high efficiency. The testing is conducted using webcam 12.1 megapixels instead of CCD camera. The purpose is to clarify the algorithm efficiency and accuracy using low quality image before testing using real application.

### 3.3.1     Defect Shape Matching

In this system, object pyramid is created using plain cardboard with base dimension 15cm x 15cm and height nearly about 11.82cm from base. 15 tested pyramids used in testing the availability of the algorithm in classifying pyramid object. Three factors that play a major role in determining the success of the best available is the object scale, rotation of objects and lights from environment. These three factors are tested for their efficacy to carry out three experiments respectively using the three most important factors in determining the level of matching object model used. The first experiments carried out at a height of 60cm from the webcam to the base where it is regarded as a position scale. The second and third experiments were conducted at the height of 40cm and 80cm respectively.

Experiment is conducted in the dim light lab to prevent the emission of light is so bright that could affect the results. The processed images will undergo 6 matching process from 0 degrees to 360 degrees (0 / 360 degrees, 60 degrees, 120 degrees, 180 degrees, 240 degrees and 300 degrees). All images are gone through the matching process to determine if the system is able to get good results even if the image is rotated from the original

position. In addition, each image will also be tested with the light-controlled webcam with no lighting, half lighting and full lighting. All the data are recorded in Table 3.4, Table 3.5 and Table 3.6, as shown.

Table 3.4: Experiment 1; Webcam Position = 60 cm (from base)

| Figure | No Lighting (Webcam) | Half Lighting (Webcam) | Full Lighting (Webcam) | Pointing Result |
|---|---|---|---|---|
| 1 → 0°/360° | Score=0.976433 | Score=0.980151 | Score=0.982591 | Success |
| 2 → 60° | Score=0.911244 | Score=0.914525 | Score=0.891157 | Success |
| 3 → 120° | Score=0.865419 | Score=0.868720 | Score=0.892017 | Success |
| 4 → 180° | Score=0.919319 | Score=0.928821 | Score=0.957525 | Success |
| 5 → 240° | Score=0.914869 | Score=0.891402 | Score=0.911028 | Success |
| 6 → 300° | Score=0.878182 | Score=0.869127 | Score=0.902388 | Success |
| Total | Score=91.09% Scale=1.002931 | Score=90.88% Scale=1.004977 | Score=92.28% Scale=1.007235 | |

Table 3.5: Experiment 2; Webcam Position = 40 cm (from base)

| Figure | No Lighting (Webcam) | Half Lighting (Webcam) | Full Lighting (Webcam) | Pointing Result |
|---|---|---|---|---|
| 1 → 0°/360° | Score=0.897040 | Score=0.883717 | Score=0.873799 | Success |
| 2 → 60° | Score=0.828437 | Score=0.87104 | Score=0.874709 | Success |
| 3 → 120° | Score=0.806566 | Score=0.845248 | Score=0.836497 | Success |
| 4 → 180° | Score=0.921424 | Score=0.937709 | Score=0.873799 | Success |
| 5 →240° | Score=0.886828 | Score=0.856704 | Score=0.832641 | Success |
| 6 → 300° | Score=0.825031 | Score=0.864090 | Score=0.848658 | Success |
| Total | Score=86.09% Scale=1.475830 | Score=87.64% Scale=1.479893 | Score=85.67% Scale=1.484594 | |

Table 3.6: Experiment 3; Webcam Position = 80 cm (from base)

| Figure | No Lighting (Webcam) | Half Lighting (Webcam) | Full Lighting (Webcam) | Pointing Result |
|---|---|---|---|---|
| 1 → 0°/360° | Score=0.810524 | Score=0.810285 | Score=0.873630 | Success |
| 2 → 60° | Score=0.802063 | Score=0.771798 | Score=0.848408 | Success |
| 3 → 120° | Score=0.851231 | Score=0.793409 | Score=0.864623 | Success |
| 4 → 180° | Score=0.852781 | Score=0.835162 | Score=0.858725 | Success |
| 5 →240° | Score=0.800803 | Score=0.808714 | Score=0.852678 | Success |
| 6 → 300° | Score=0.790774 | Score=0.806396 | Score=0.900508 | Success |
| Total | Score=81.80% Scale=0.754380 | Score=80.43% Scale=0.762243 | Score=86.64% Scale=0.758876 | |

### 3.3.2 Defect Shape Pointing

After the matching results are obtained from Defect Shape Matching (DSM) application, the pointing application will takes place to identify the edges of process object. These edges are important in determining the position for gluing process. The information gathers consists of x and y coordinates in camera pixel. In order to determine the edges point from object, it consist 2 types of function being used to accomplish the hypothesis of this research: 1) Harris Corner Detector and 2) applying equation of straight line. This two function integrate together to produce new algorithm in industrial application used as a vision sensor optimization. Harris Corner Detector (HCD) is used in finding the edges point while equation of straight line used in integrate data obtained in HCD to generate new point for gluing process.

Equation of straight line (Sastry) is applied in this research according to the object specimen used that has a shape of rectangle. The calculation between one points to another retrieve all the information needed to be used in pointing another point between the previous two points. Firstly, identified the two points needed to be calculated and labelled as $(x_0, y_0)$ and $(x_1, y_1)$. Then, the points are applied it into the equation to define the slope of the line in pixels coordinate.

$$m = \frac{y_1 - y_0}{x_1 - x_0} \tag{3.5}$$

After that, value of the slope and point is used in the slope-intercept equation to define the intersection of the line.

$$y = mx + c \tag{3.6}$$

Then, the distance in x-axis and y-axis between two points is calculated and defines it as $d_x$ and $d_y$. The distance value for x and y-axis will be divided according to the numbers of point need to be generated in each gluing line. After that, $d_x$ and $d_y$ along with a point

available in process gluing line will then be integrated into Equation (3.6) to find new

location of the point based on the information obtained. Lastly, generated point obtained

being declared and classified as one of the point needed in the system that will be further

used in gluing process with assisting oh KUKA arm robot. Figure 3.21 shown all the new

point being subjected into the object and displayed using Graphical User Interface (GUI)

generate from software Visual Basic 6.
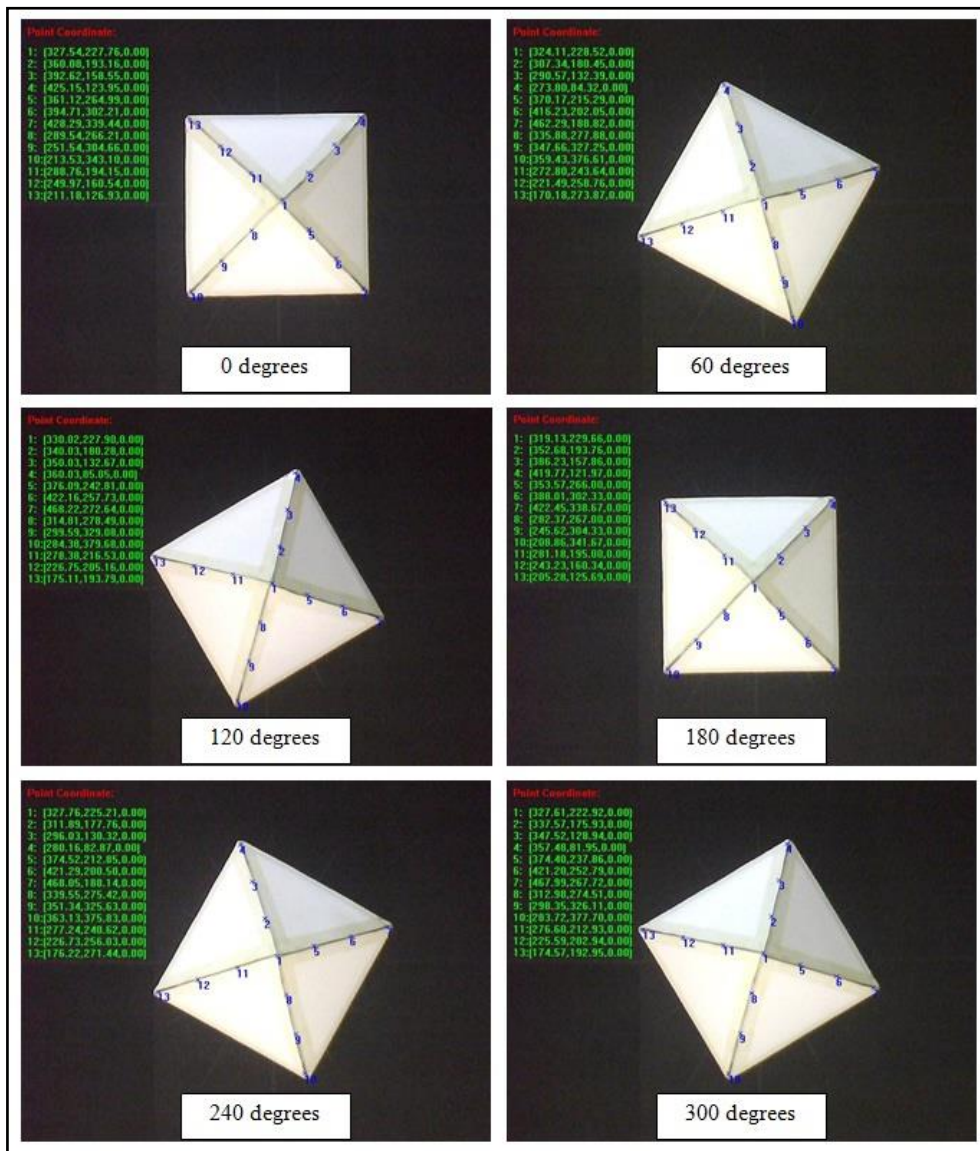


Figure 3.21: Pointing Result from Table 3.2 (No Lighting)

According to Figure 3.21, the data generated only in x and y coordinates in all possible angle rotation. This Defect Shape Pointing (DSP) offer a service that able to recognize data in 3 dimension (3D) as describe in previous sub chapter. The data captured consists of x, y and z coordinates that will be very useful in gluing process using KUKA arm robot. This is because robot automation needs data in length, width and height or more accurate 3D location for moving it to specific location. The calculation in determining z coordinate as described in previous sub chapter of Defect Shape Pointing (DSP) application. The combination of two 2D images can possibly generate data of x, y and z coordinates with corresponding of camera placement in top and front camera. Figure 3.22 shows the pointing result in x, y and z coordinates.
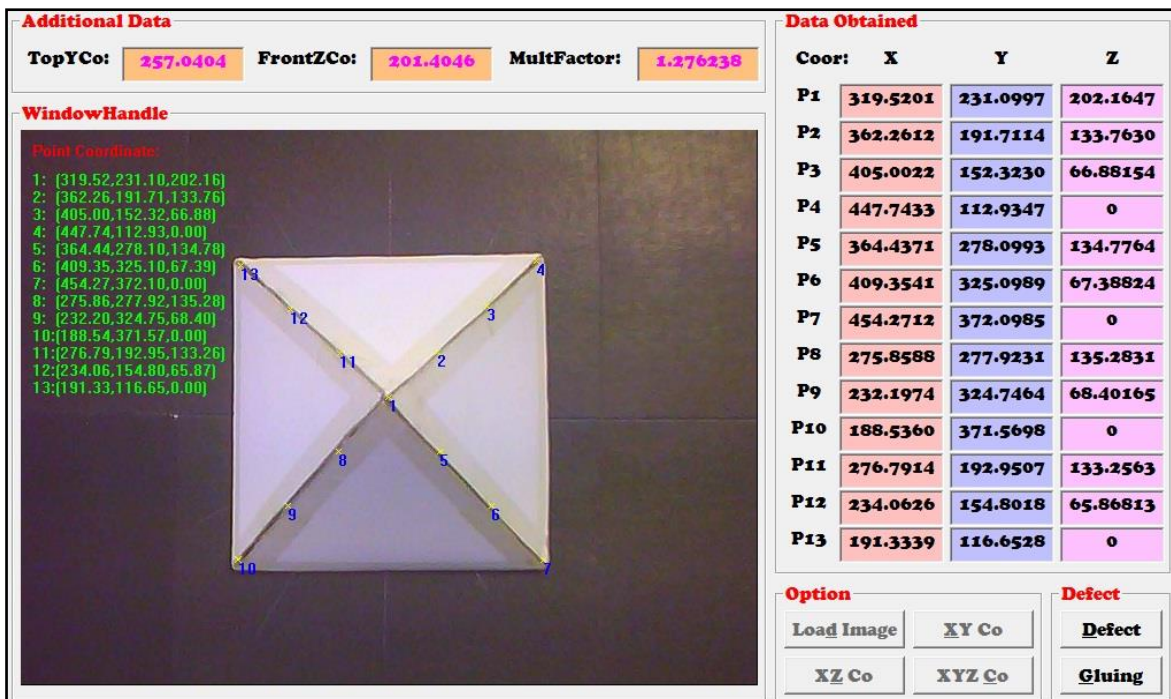


Figure 3.22: Results of Image with Pointing Result in x, y and z Coordinates

The results obtained can be used in programming KUKA arm robot to glue the object according to the data given in the robot system. According to Figure 3.22, the result obtained with additional data at the top of object window. The additional data obtained is

very important in conjunction to determine defect location in Defect Inspection Monitoring (DIM). By doing that, defect detected can be corrected according to the system requirement. Additional data consists of y coordinate difference from lower to upper point (TopYCo), z coordinate difference from lower to upper point (FrontZCo) and the offset of image between two 2D images (MultFactor).

1. Sample Calculation



Figure 3.23: Combination Data from Top and Front Camera

According to Figure 3.23, it shows two 2D images that used to find the differences (offset ratio) in both images known as MultFactor in this research. In order to find it, the differences between lower and upper value (y and z coordinate) must be obtained. The calculation step is shown below.

$$AverageTopYCo = \frac{(P_{7y} - P_{4y}) + (P_{10y} - P_{12y})}{2}$$

$$AverageTopYCo = \frac{(372.10 - 112.93) + (371.57 - 116.65)}{2}$$

$$AverageTopYCo = 257.045$$

$$AverageFrontZCo = \frac{(P_{4z} - P_{1z}) + (P_{7z} - P_{1z})}{2}$$

$$AverageFrontZCo = \frac{(368.35 - 166.19) + (366.83 - 166.19)}{2}$$

$$AverageFrontZCo = 201.40$$

$$MultFactor = \frac{AverageTopYCo}{AverageFrontZCo}$$

$$MultFactor = \frac{257.045}{201.40}$$

$$MultFactor = 1.2763$$

This multiplication factor is important in order to recognize 3D information in detecting defect just only with one camera. The result of defect detection with x, y and z coordinates' data information will be shown in the next sub chapter.

### 3.3.3  Defect Inspection Monitoring

The potential of the proposed visual algorithm system was the flexibility of the program to accommodate changes. 15 tested images are being used to test the flexibility of the system in determining all defects occur in the tested images. The tested images are filled with all the two model defects that are already being trained and fed into the system. Each defect that are match through the system will provide with its own position in the tested images act as row and column coordinate according to the pixel coordinate in the system. This information is important as the task continuing in correcting all the defects after the matching process done its part. Correction phase consists of KUKA arm robot to alter the defects to ensure that glue is in fine shape. Sample result of Defect Inspection Monitoring (DIM) is shown in Figure 3.24.
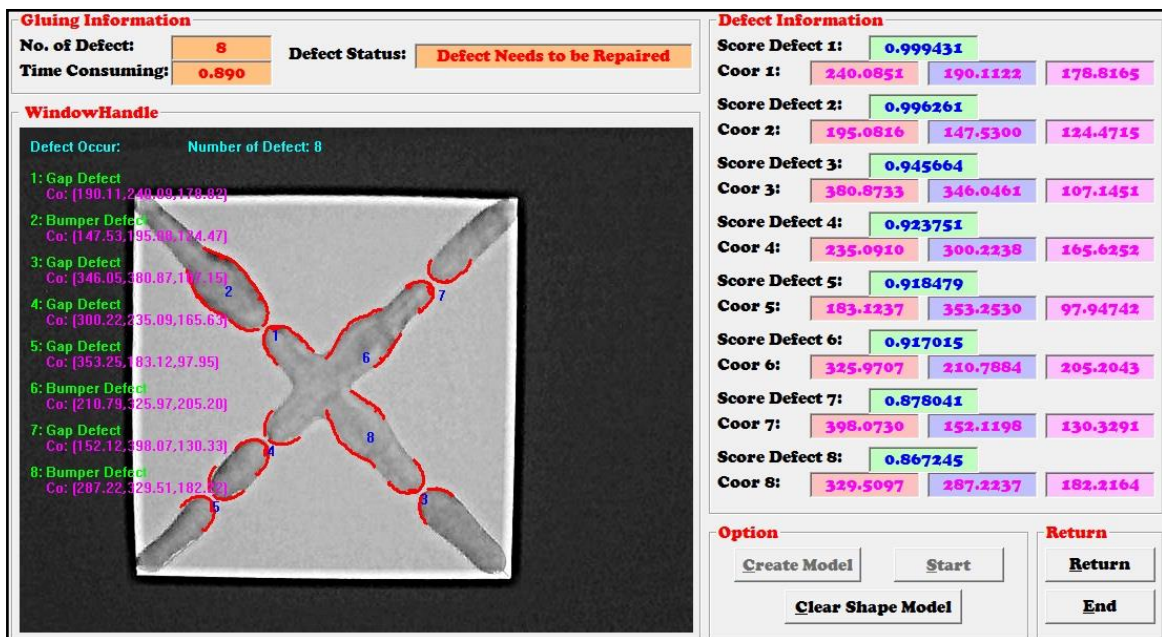


Figure 3.24: Results of Defect Inspection Monitoring (DIM)

This automatic defect detection is design according to the matching score for each defect. Parameter *score* in this software is set to 0.85 or 85 percent of similarity with the defect models. Which means the originality of the models is presented each time the

defects occur. This is important because with minimal score are set will results to the inaccuracy. The numbering of each defect is referring to which defect that have higher score in the system. The sequential of defects are depends on the defects occur in the system

Table 3.7 shows the result of defect matching by using 15 tested images. According to the results, the recognition rate of the experiment about 94.55% based on 2 model defects created through the system. This recognition rate shows that the higher accuracy can be achieved through this method. But, with the increasement of the training samples, the recognition rate would be much better. This achievement are depend on how the creation of region of interest being picked all at once gives the almost perfection of the inspection system. Every image character is kept play role in ascertaining process that makes the system capable of working in a short period of time with great accuracy in determining defects occur in the image.

Table 3.7: Results for 15 Tested Images in DIM

| Figure | Total Defect | Defect Detected | Defect Detected (%) |
|--------|--------------|-----------------|---------------------|
| 1 | 8 | 8 | 100 |
| 2 | 9 | 9 | 100 |
| 3 | 7 | 7 | 100 |
| 4 | 7 | 6 | 85.71 |
| 5 | 8 | 8 | 100 |
| 6 | 6 | 6 | 100 |
| 7 | 7 | 7 | 100 |
| 8 | 8 | 7 | 87.5 |
| 9 | 5 | 4 | 80 |
| 10 | 7 | 7 | 100 |

| Figure | Total Defect | Defect Detected | Defect Detected (%) |
|--------|--------------|-----------------|---------------------|
| 11 | 6 | 5 | 83.33 |
| 12 | 9 | 8 | 88.89 |
| 13 | 8 | 8 | 100 |
| 14 | 8 | 8 | 100 |
| 15 | 7 | 6 | 85.71 |
| Total | 110 | 104 | 94.55 |

In DIM, the defect occur are depends on how regularly the system is calibrate. Without proper monitoring, the system might occur in various forms of irregularities. In this research, the errors occur are classified in 4 cases; 1) Minor Case (Defect in single line); 2) Half Major Case (Defect in two lines); 3) Major Case (Defect in three lines) and 4) Worst Case (Defect detected in all gluing lines). Each case has their own characteristic and error occurred that might take account in determining better solution for Correction of Defect (CoD).

## 3.4     Example for Curve Pyramid

According to the flow of this system, the object tested using pyramid where the KUKA arm robot able to gluing from one point to another point specified in the system. The contour of the pyramid is straight line but it has a height to count with. So, the linear movement is used in order to move robot from one point to another but the rotation of the gripper maintain as in previous point. The other example that KUKA arm robot capable in complete its task is curve pyramid as shown in Figure 3.25 where at the center of each gluing line there is a curve fitting developed with $30^0$ of circular angle.
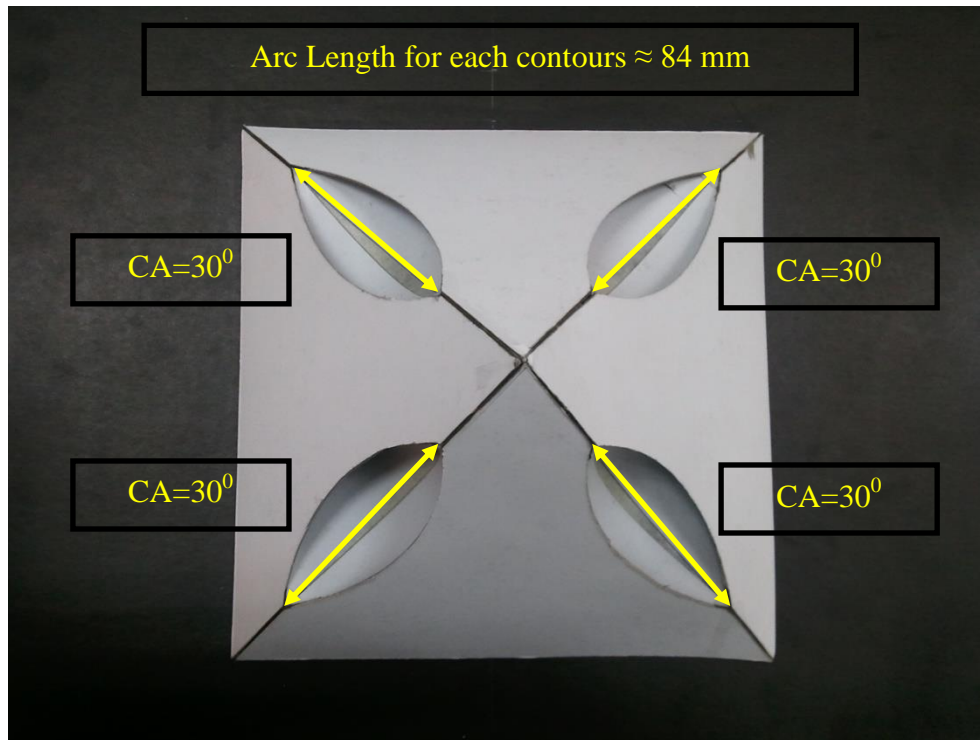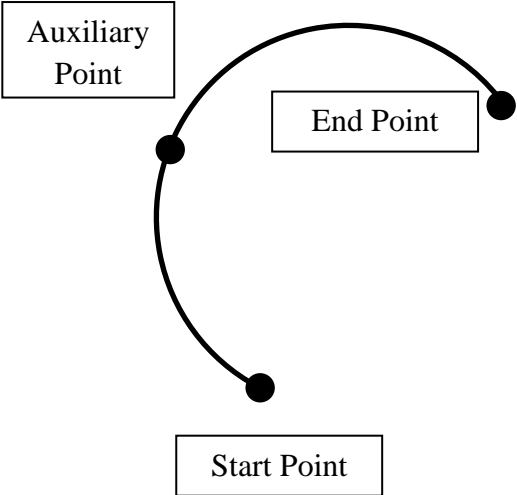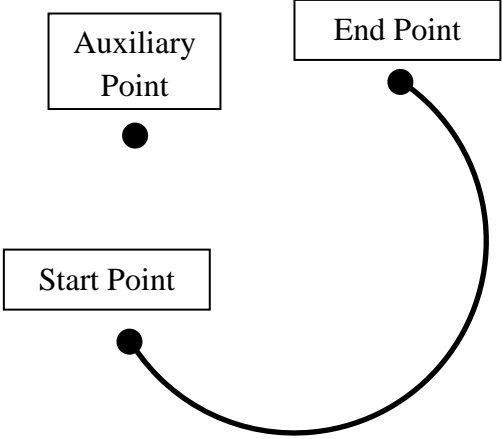
Figure 3.25: Curve Pyramid with $30^0$ Circular Angle

According to Figure 3.25, each gluing line has developed curve contours to show another example of KUKA arm robot in gluing curve pyramid with circular angle is stated as $30^0$ and arc length recorded value is approximately 84 mm. For this example, KUKA used circular movement with maintaining the gripper position from start to auxiliary and finally end point. Auxiliary point is another point added to create other geometry elements by providing optional route for the arm robot. The Circular Angle (CA) depends on position gripper from start point to auxiliary point. The description on circular motion movement as describe in Table 3.8 complete with the movement of arm robot from stat to end point.

Table 3.8: Description on Circular Motion of KUKA Arm Robot

| Description | |
|---|---|
| Circular Angle, CA $> 0^0$ | Circular Angle, CA $< 0^0$ |
| Circle is executed in the direction programmed: start point → auxiliary point → end point | Circle is executed in the direction programmed: start point → end point → auxiliary point |
|  |  |

The result according this circular motion is KUKA arm robot is capable in doing such a contours movement with precise location but its takes time to program it because all point need to be pointed perfectly with desired circular angle regarding contours characteristic. In achieving the real value is equal to calculated value, the circular path assumed as quarter of a circle for this contour pyramid. The mathematical equation of arc length of the circle is used (Sastry).

$$arc\ lenght, s = 2\pi r \tag{3.7}$$

$$arc\ lenght\ for\ \frac{1}{4}\ circle, s_{1/4} = \frac{1}{4}(2\pi r)$$

$$So, s_{1/4} = \frac{\pi r}{2}$$

In order to prove the real and calculated value is almost the same, one of the contours is investigated to relate the equation with the result obtained. Figure below shows the calculation related to the contours.



By assuming the contours are a quarter of circle, the approximate radius is:

$$r \approx \frac{45.77 + 47.18}{2} \approx 46.475\ mm$$

So, the arc length of the quarter circle is:

$$s_{1/4} = \frac{\pi r}{2} + (total\ width\ difference\ between\ glue\ gun\ and\ pyramid)$$

$$s_{1/4} = \frac{46.475\pi}{2} + 10\ mm$$

$$s_{1/4} = 83\ mm$$
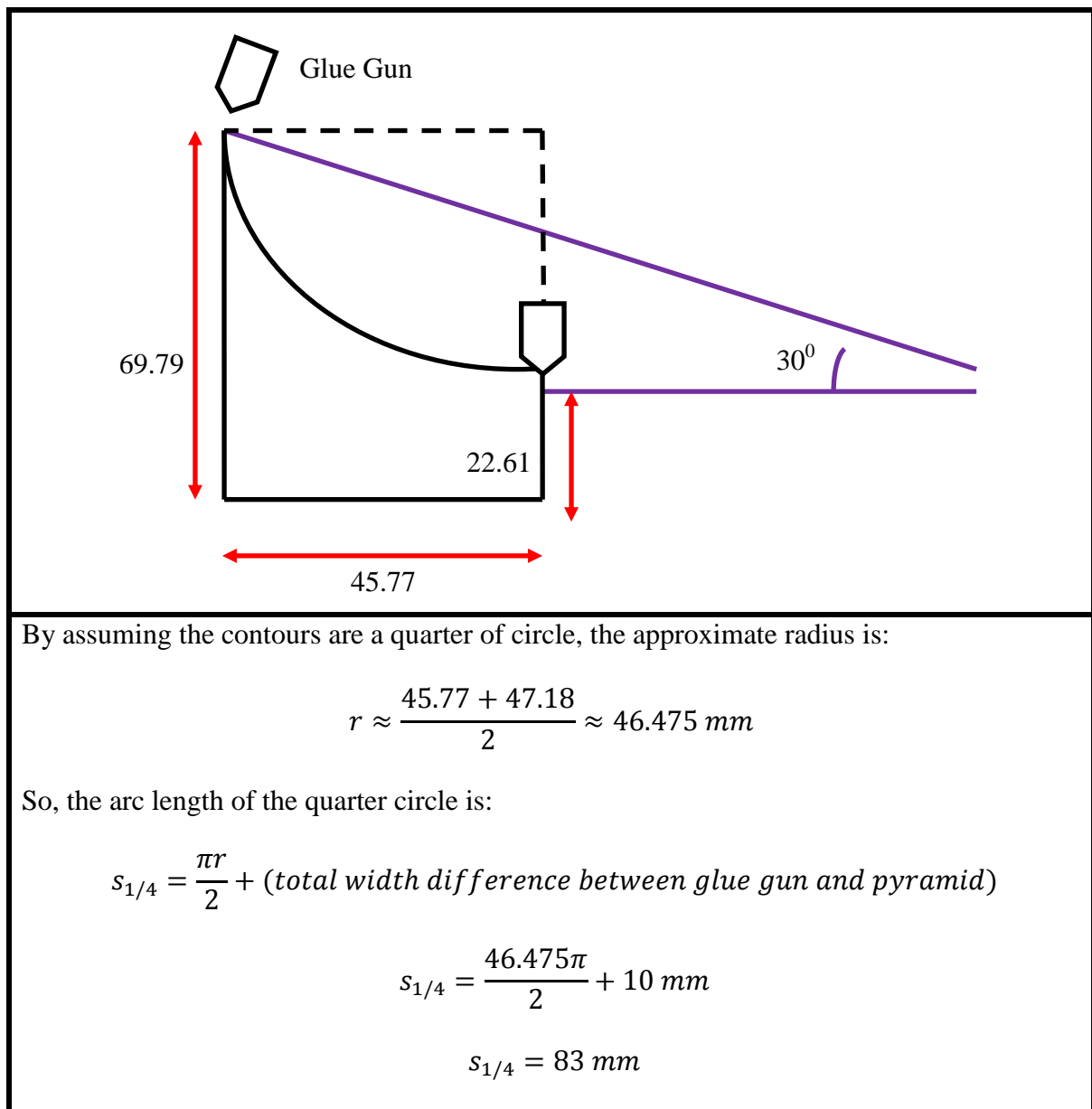
Figure 3.26: Calculation for Arc Length of Contours

According to Figure 3.26, the result shows in calculation of arc length of the contours is 83 mm differs only 1 mm from the real value. Total width difference between glue gun and pyramid means in teaching the points using robot, the robot location is program slightly offset from the exact location about 5 mm from start to end point to prevent gripper and object from collides. As a result, the calculated value must be adding with the total difference value to find the real arc length is exactly the same with the real one.

# CHAPTER 4

## DEVELOPMENT OF ROBOT VISION

### 4.0    Introduction

This chapter discuss about the effectiveness of the system depending on the experiments done at the previous chapter. The effectiveness of the system will focus on three features that are flexibility, adaptability and reliability. Discussion of the experimental results will also be included in this chapter.

### 4.1    Development of Robot Vision

From previous chapter, the development of software design being developed based on the application needed in hardware development. So, in this chapter the integration between software and hardware are focused in bringing the effective, adaptability and reliability in nowadays. The experimental is testing based on real-time monitoring to get the result and apply it in industrial automation. Katana and KUKA arm robot is used in this research in determining which are suitable arm based robots fit in the system. The overall system operation is also being described briefly to give the idea about this research.

#### 4.1.1    Katana 6M Arm Robot

Katana 6M Arm Robot is six degree of freedom, the repeatability of this robot is ±0.1mm, the weight that could be grasped is 0.4kg and weight of this robot is 4.8kg that are shown in Figure 4.1. With its six motors, it provides up to 6 degree of freedom. The joint that connects to the gripper is available in a straight (6M180) or perpendicular

(6M90) configuration, which allow to tailor the positioning exactly to the requirements of the application. All six axes are equipped with "Harmonic Drive" gears. These allow precise movements without slackness and a high repeatability of up to 0.1mm.



Figure 4.1: Katana 6M Robot Arm

### 4.1.2 KUKA KR5 sixx R650 Robot Arm

KUKA KR5 sixx R650 Robot is six degree of freedom, the repeatability of this robot is ±0.02mm, the weight that could be grasped is 5.0kg and weight of this robot is 28kg that are shown in Figure 4.2. It has low weight and fist-shaped work envelope, that helps the robot work quickly and flexibly even in confine space with a reach up to 850mm. With its six motors, it provides up to 6 degree of freedom. This robot provides with integrated routing of the energy supply system for air and I/O signals significantly reduce the wear. This robot has plentiful applications in various industries consist of arc welding, material handling, machine loading or unloading, sealing, cutting and polishing.

Figure 4.2: KUKA KR5 sixx R650 Robot Arm

### 4.1.3 Overall System

Introduction to this research is to improve gluing windscreen car in automation industry. The system is developed to cope with the environment such as lighting condition, scaling and rotating of the object. Pyramid object developed from plain cardboard is created based on the shape object that has a contour that involves height, length and width. Plain cardboard is design exactly like pyramid to get the data from the Defect Shape Matching (DSM) whether the system able to recognize the object. Two cameras are used to locate x, y and z location for each corner detected through the system. Equation of straight line will be used in determining additional point between two corners. Data gathered must be converted to robot coordinate for easier process by Katana and KUKA arm robot. This information then used to instruct robot for gluing purposes. Three types of defect are trained through Defect Inspection Monitoring (DIM) known as gap defect, bumper defect and bubble defect. Result obtained from DIM will decide whether the object is successful

gluing or needs to be corrected through Correction of Defect (CoD). Figure 4.3 below show the overall system of this research.



Figure 4.3: Overall System Design

According to the Figure 4.3, KUKA arm robot act as assistive robot vision and its movement control based on the information send using serial communication between system servers with robot system. Glue gun is attached at the gripper and the workspace in front of the robot. The vision sensor is placed at the top of object also at the front of the object. The teach pendant used to program the robot according to the needs of the system.

The computer will be used as a whole control system integrate with the GUI developed in implementing and displaying results through Visual Basic 6 software (VB6). The overall system of all the components is connected as shown in Figure 4.4.
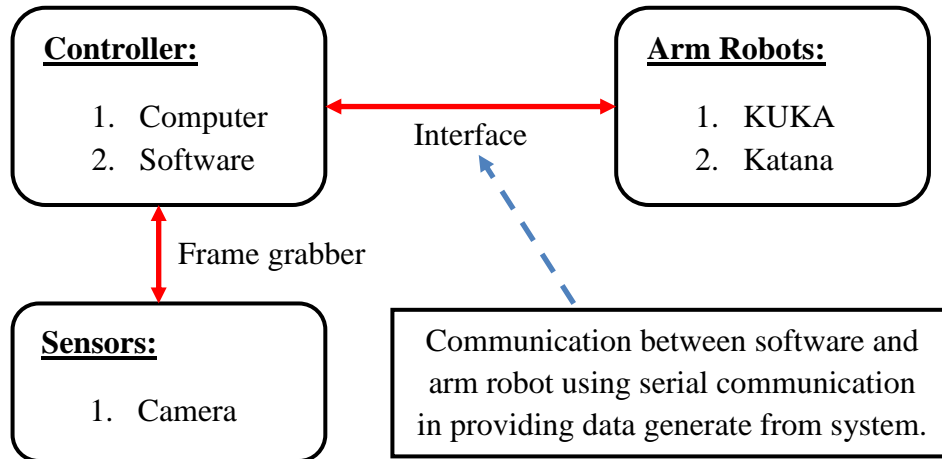


Figure 4.4: System Overview

From figure, the cameras are connected to the computer via Framegrabber; the KUKA arm robot is also connected to the computer via serial communication; Computer will act as both medium and controller in the system. The following steps describe the process cycle of the suggested system:

1. Object (pyramid) being tested using Defect Shape Matching (DSM) in recognizing a correct process model.

2. The correct model will go through next phase, while the rejected one will be replaced with another object and start from step 1.

3. Next phase known as Defect Shape Pointing (DSP) where the process image will be tested with 3D transformation. First the image will be taken from top camera for generate data x (horizontal) and y coordinate (vertical) coordinates.

4. Then, second camera (front camera) will capture image in order to get data generate from the image. Data generate gives information for x (horizontal) and z (vertical) coordinates.

5. Then, evaluate both pictures to get the multiplication factor (MultFactor) for generate z coordinate based on 2D image capture from top camera.

6. After that, gluing process will takes placed using the information generate from DSP.

7. Then, Defect Inspection Monitoring (DIM) inspects the gluing object whether to decide the object is perfectly gluing or need to be corrected.

8. If there are defects occur, first Correction of Defect (1$^{st}$ CoD) will done the correction in order to reuse the reject product to be perfectly glue.

9. Then, the object once again inspect to classify whether the object perfectly glue or not.

10. If yes, the system will go back to the first step and if not the object will go 2$^{nd}$ CoD for correction.


## 4.2    Hardware Development and Experimental Works

Based on the simulation results occur in Chapter 3, the experimental for real-time application is designed in supporting the simulation results with experimental results. Developing real-time application consists with integration software and hardware application involving two cameras, system PC and KUKA arm robot as assistive robot for gluing process. Four experimental processes are developed in findings the algorithm capabilities integrate with software and hardware. The position of complete hardware is shown in Figure 4.5.
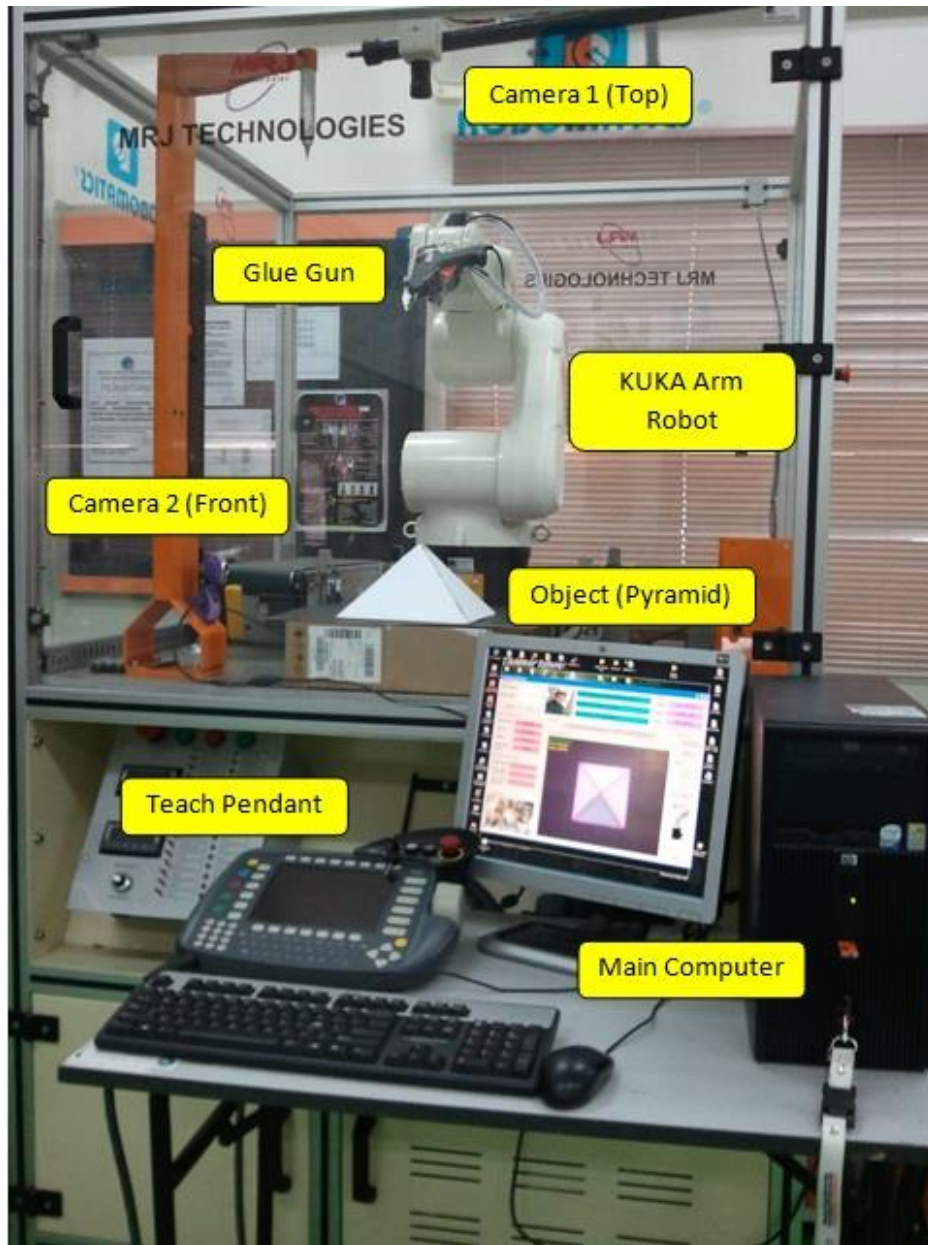
Figure 4.5: Experimental Setup

As shown in Figure 4.5, experimental setup consists of several types of hardware that will be used in testing the effectiveness of the system. Each of the hardware is listed and describes their tasks based on all experiments. Table 4.1 shows all the hardware used complete with their tasks based on the experiments.

Table 4.1: Hardware Description and their Tasks

| No. | Hardware Description |
|---|---|
| 1. | **<u>Camera 1 (Top)</u>**<br><br>1. To capture image object from top position in defining object x and y coordinates.<br><br>2. Camera used almost on all operation in this system.<br><br>3. Used CCD camera for sharp image acquisition. |
| 2. | **<u>Camera 2 (Front)</u>**<br><br>1. To capture image object from front position in defining object x and z coordinates.<br><br>2. Camera used in Defect Shape Pointing (DSP) application in defining Multiplication Factor (MultFactor) for generating new z coordinate for defect occurs.<br><br>3. Used webcam just in collecting data from front of the object. |
| 3. | **<u>KUKA arm robot</u>**<br><br>1. To assist this system in operating glue process using information data from DSP application.<br><br>2. Also used in providing application Correction of Defect (CoD) purpose to correct the defects occurs. |

| No. | Hardware Description |
|---|---|
| 4. | **<u>Katana arm robot</u>**<br><br>1. To assist this system in operating glue process using information data from DSP application.<br><br>2. Cannot being further processed because of the limitation of the robot itself. |
| 5. | **<u>Glue gun</u>**<br><br>1. Act as a tool of gluing and attached at the end effector of the robot. |
| 6. | **<u>Object (Pyramid)</u>**<br><br>1. Object being used in testing the effectiveness of this system based on contours and heights.<br><br>2. Developed using plain cardboard (white) for better recognition process.<br><br>3. The size of pyramid is 15cm (width) x 15cm (length) |
| 7. | **<u>Workspace</u>**<br><br>1. Workplace to execute all the process of this system.<br><br>2. The gluing process and correction also don on this workplace. |
| 8. | **<u>Teach Pendant</u>**<br><br>1. Tools for program KUKA arm robot using their own language. |
| 9. | **<u>Main computer</u>**<br><br>Used for controlling and monitoring all system operated in the same time. |

### 4.2.1  Experiment 1 (2D Matching)

The first experiment is done by recognizing object going to process in the first place. In this research, object pyramid had been stressed to be used because of its contour and shape (consists of width, length and height). The object pyramid is developed using plain cardboard as shown in figure below.
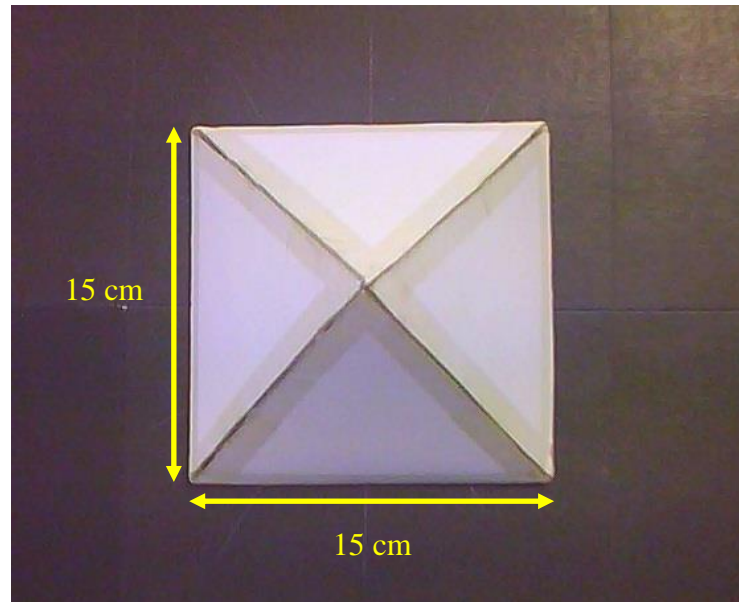


Figure 4.6: Object Pyramid Developed using Plain Cardboard

This experimental is based on the shape characteristic of the object. Better the template creation create in training phase will result to better recognition rate (also known as Score). This experiment will consist of two phases known as training and recognition phase. Training phase will require important step in creating and developing image template while recognition phase will call back image template to be comparing with the process object to identify whether it's the right object to be processed. The experimental setup consists of one camera, object pyramid and KUKA arm robot in home position as shown in Figure 4.7. The objectives for this experimental has divided into two characteristics:

1. To create model template in training phase to be match in recognition phase.

2. To test 50 pyramid images to identify the effectiveness of this system in classifying correct image being process or not in recognition phase.
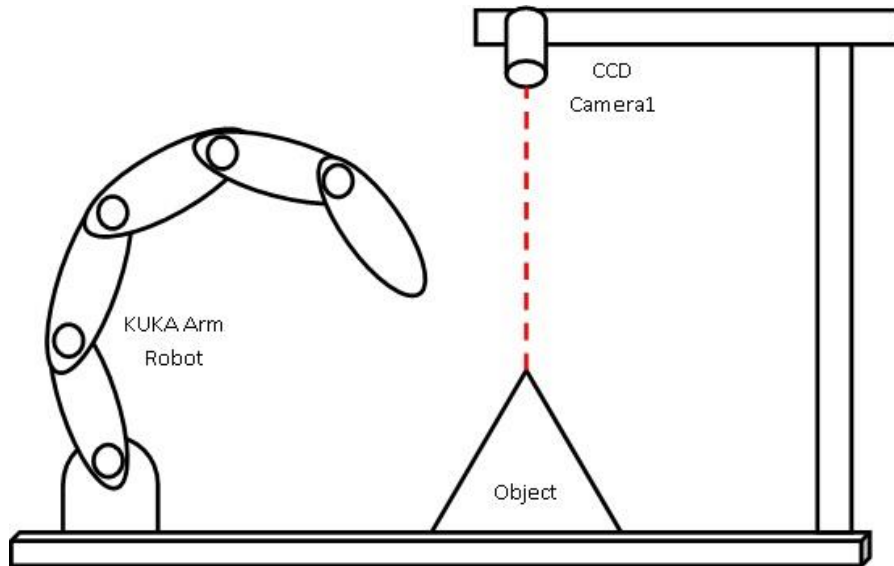


Figure 4.7: 2D Matching Experimental Setup

In this experiment, before the experiment start, template of object pyramid being trained according to the original specification of object used. The template creation then being saves into the system memory before it will call back in recognition phase. After that, object pyramid is put into the workspace for starting the experiment procedure. By clicking the button 'Start', Camera 1 will trigger and capture image instantaneously and show it in display window. The system automatically starts classifying object by comparing image template with the image taken directly from Camera 1. The process will take through in defining whether the object process is the correct object or not. If yes, the system will go through to the next process and data recorded as accepted object in the system. If no, the object is rejected and recorded as rejected object in the system. The process of 2D matching will continue with another object.

### 4.2.2 Experiment 2 (Classification of Types of Defect)

For this second experiment, involves KUKA arm robot as assistive robot for gluing process. KUKA arm robot get the information from the Defect Shape Pointing (DSP) application where it generates 3D transformation that involves x, y and z coordinates. These coordinates supplied by the system after all the required point generates from DSP application. After the gluing process done, the classification of defect's type will takes placed in determining the defect types also its location. As same with first experiment, the shape of the defect needs to be trained first before matching it with the process object. Figure 4.8 shows the model template used in this experiment.



Template Gap Defect          Template Bumper Defect
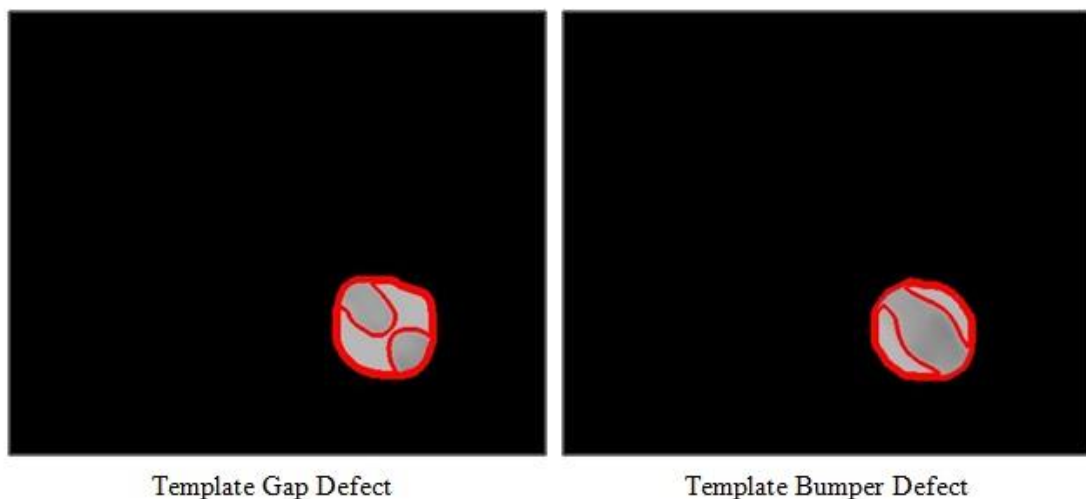
Figure 4.8: Template Creation for Defect Model

This experiment combines step matching and classifying the defects occurs in the system also known as Defect Inspection Monitoring (DIM). DIM consists of 2 cameras, KUKA arm robot as assistive robot, object pyramid after finished gluing process and a glue gun attached at the end effector of the robot. Figure 4.9 shows the experimental setup of this experiment.
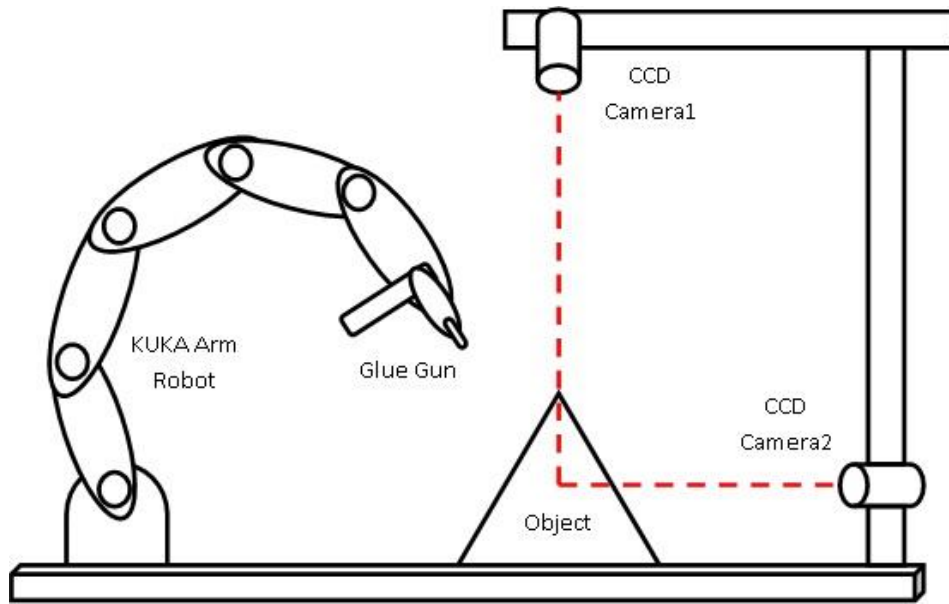
Figure 4.9: Classification of Defect's Types Experimental Setup

In this experiment, KUKA arm robot will complete its task in gluing object pyramid according to the data given from DSP. Data sending includes with defect position in x, y and z coordinates. Then, the complete gluing object will then process by clicking button 'Start' from Defect Inspection Monitoring (DIM) application. Camera 1 will trigger and directly capture image and display it in display window. Then, the image will process automatically by comparing image process with the train image template in determining and classifying defects occur. Number and type of defects occur are recorded with their position. The position data then will be used in next experiment for correcting any defects occur through the system. Results obtained will decide whether the object is perfectly gluing or needs to be corrected in Correction of Defect (CoD) application. If the system detects any defect, it will result to the next experiment while the system will continue with another object when the result is otherwise.

### 4.2.3    Experiment 3 (Correction of Defects)

Correction of Defect (CoD) offers service in correcting defects occurs in Defect Inspection Monitoring (DIM) application. Correction done according to the data available consists of position, types and total number of defect. The characteristic of each defect describes based on the appearance and shape of defects occurs in gluing process. Two defect types are available in this research:

1.  Gap Defect
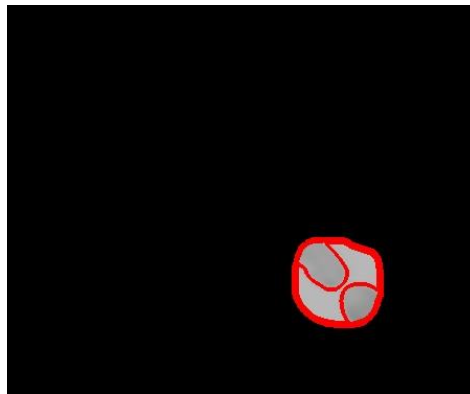


Figure 4.10: Gap Defect Characteristic

Characteristic of gap defect:

a)  Has a gap along gluing line (one straight gluing line) that makes it look like there are two lines in gluing line.

b)  How to solve: glue again where there is a gap by using hot glue gun from upper value to lower value according to the defect's data coordinate.

2.  Bumper defect
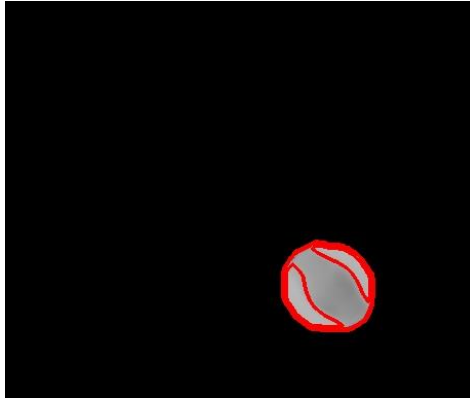


Figure 4.11: Bumper Defect Characteristic

Characteristic of bumper defect:

   a) Has a round shape (hemisphere shape) at both sides that looks like a "tumor" at gluing line.

   b) How to solve: trim the bumper shape by using hot glue gun to remove the "tumor" by separating it until it forms a straight gluing line.

In this experiment, it focused on the system can detect any defect after gluing process. Not only that, it also focused on the correcting the entire defects occur using Correction of Defect (CoD) application. This system correct any of defects including gap and bumper defects by using KUKA arm robot with the guidance of position (x, y and z coordinates) of them. Then, the system once again will be checked after the 1$^{st}$ CoD using DIM application to identify whether the object clear with any defects or not. If yes, the object classified as quality gluing while the system will go to 2$^{nd}$ CoD if the result is otherwise. Figure 4.12 shows the experimental setup for Correction of Defect (CoD) application.
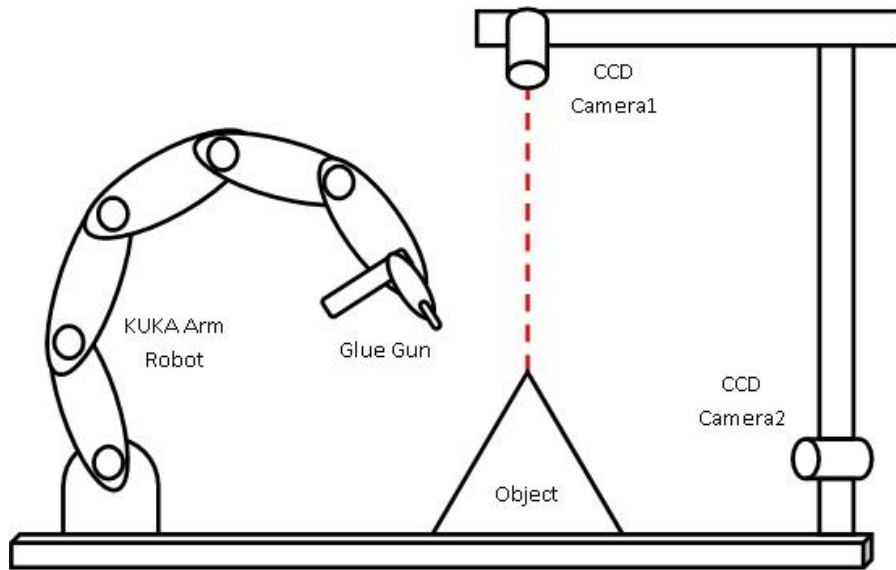
Figure 4.12: Correction of Defect Experimental Setup

## 4.3 Experimental Results

The integration between software and hardware is important aspect in determining the approval and recognition of the method being used. So, this system is designed and developed based on software and hardware capabilities. For this chapter, its consists of three results recorded in determining that the software and hardware results is tally based on the shape matching (DSM application), classification of defect's type (DIM application) and correction of defect (CoD application).

### 4.3.1 2D Matching

The development of this complete system comes with 2D matching application also known as Defect Shape Matching (DSM). For the simulation, algorithm is tested with four parameters that would affect the recognition rate such as scales of image captured, rotation of image and lighting from environment. Those parameters are important aspects in considering the algorithm perfectly fit with environment or not. For this section, the

experimental being done in 10 experiments each of them have 5 pyramids design using plain cardboard with same dimension. The idea based on the real-time experimental by integration between software and hardware (consists camera and KUKA arm robot). Table 4.2 shows the results occur from 50 tested images.

Table 4.2: Defect Shape Matching (DSM) for 50 Tested Images

| No. of Experiment | Total Pyramid | Average Recognition Rate | Total Pyramid Classified |
|---|---|---|---|
| 1 | 5 | 0.974635 | 5 |
| 2 | 5 | 0.984562 | 5 |
| 3 | 5 | 0.975542 | 5 |
| 4 | 5 | 0.966687 | 5 |
| 5 | 5 | 0.958846 | 5 |
| 6 | 5 | 0.977913 | 5 |
| 7 | 5 | 0.979128 | 5 |
| 8 | 5 | 0.934389 | 4 |
| 9 | 5 | 0.983135 | 5 |
| 10 | 5 | 0.961359 | 5 |
| Total | 50 | 0.9696196 | 49 |
| Success Rate (%) | | 96.96196 | 98.00 |

### 4.3.2 Classification of Types of Defect

Based on the experiment 3 in classifying the defect's types, three types of defect used as model template and each of them being trained in training phased of Defect Inspection Monitoring (DIM) algorithm. Three of them are; 1) gap defect; 2) bumper defect; and 3) bubble defect. There are 50 images being tested using this system in findings

the relevant information regarding of successful recognition rate in classified defects occur in every images. The results are recorded as shown in table below.

Table 4.3: Result for Defect Inspection Monitoring (DIM) for 50 Tested Images

| Total Defect in Image | Total Image (Total Defect) | Defect Detected | Defect Undetected |
|---|---|---|---|
| 1 | 2 (2) | 2 | 0 |
| 2 | 7 (14) | 14 | 0 |
| 3 | 6 (18) | 18 | 0 |
| 4 | 10 (40) | 39 | 1 |
| 5 | 7 (35) | 32 | 3 |
| 6 | 5 (30) | 28 | 2 |
| 7 | 7 (49) | 47 | 2 |
| 8 | 6 (48) | 46 | 2 |
| Total | 50 (236) | 226 | 10 |
| Percentage (%) | | 95.76 | 4.24 |

According to data collected, there are about 226 from 236 defect are classified as defect through the system which means the system achieved about 95.76 percent of successful recognition rate. There is still having its error in determining the defects from tested images which compile about 4.24 percentage of failure. Results of each image process with its defect classification shown in Figure 4.13 below.
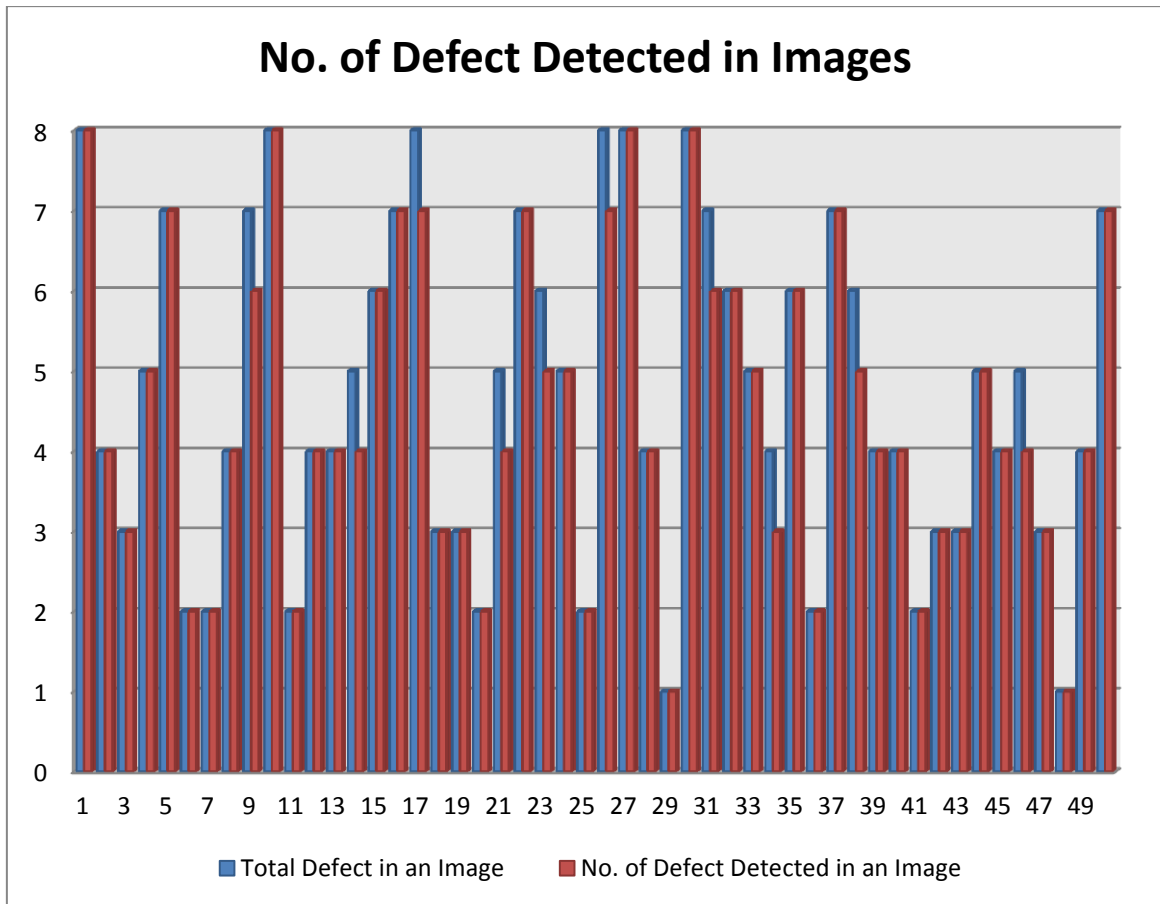
Figure 4.13: Result for Defect Inspection Monitoring (DIM)

### 4.3.3 Correction of Defects

After the classification of defect had been made, the object rejected will go through correction of defect (CoD) to modify the object gluing line. Each of defect has their own location in x, y and z coordinates generate from previous system. The process consists of 2 correction layer known as $1^{st}$ CoD where object corrected for the first time and $2^{nd}$ CoD where object corrected for the second time based on inspection from $1^{st}$ CoD. Instead of using 50 tested images as previous experiment, only 15 images will be selected in testing it with process correction of defect (CoD). The results are recorded based on their performance in CoD process as shown in Table 4.4.

Table 4.4: Result of Correction of Defect (CoD) for 15 Tested Images

| Image No. | No. of Defect Detected | No. of Defect Detected (1st CoD) | No. of Defect Detected (2nd CoD) |
|---|---|---|---|
| 1 | 7 | 2 | 0 |
| 2 | 3 | 1 | 0 |
| 3 | 4 | 1 | 0 |
| 4 | 2 | 0 | 0 |
| 5 | 5 | 1 | 0 |
| 6 | 2 | 0 | 0 |
| 7 | 4 | 0 | 0 |
| 8 | 6 | 2 | 0 |
| 9 | 3 | 0 | 0 |
| 10 | 3 | 0 | 0 |
| 11 | 4 | 1 | 0 |
| 12 | 2 | 0 | 0 |
| 13 | 3 | 0 | 0 |
| 14 | 5 | 0 | 0 |
| 15 | 6 | 1 | 0 |
| Total | 59 | 9 | 0 |
| Successful Rate (%) | | 84.75 | 100 |

By referring to the Table 4.4, only 7 images need to re-correction using $2^{nd}$ CoD where the $1^{st}$ CoD cannot completely conceal the defects occur along gluing line. So, $2^{nd}$ CoD is introduced in backing up $1^{st}$ CoD in terms of correcting and inspecting the object. The purpose is to provide services in modifying rejected product so it still can be used as a

complete product without any scar. Figure 4.14 shows the result in graphical method for more information.



**Correction of Defect (CoD) Process**

Legend:
- ■ No. of Defect Detected
- ■ No. of Defect Detected (1st CoD)
- ■ No. of Defect Detected (2nd CoD)
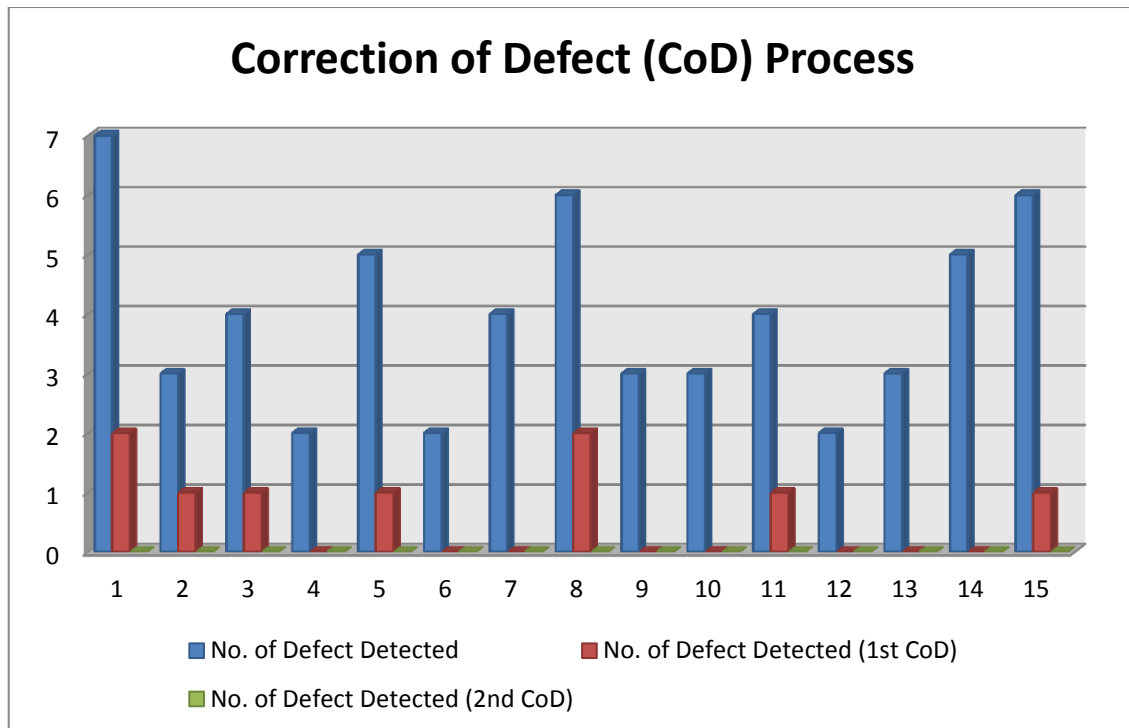
Figure 4.14: Graph Result of Correction of Defect (CoD)

## 4.4    Discussion of Results

From the results, it can be seen that the system's efficiency is very good, even when the percentage of defects occur is not 100% but still improve from other researchers. 95.76% defects occur from 50 tested images where it able to classify 226 defects out of 236 defects (including gap and bumper defect). Not only that, efficiency for Correction of Defect (CoD) for rejected gluing object from DIM quite impressive where it recorded 84.75% for $1^{st}$ CoD and 100% for $2^{nd}$ CoD. CoD application where it corrects the entire defect detected from the DIM application. $1^{st}$ CoD means the gluing object are corrected for first time and if still have defect detected so it will comes to $2^{nd}$ CoD to complete the

CoD process whether the gluing object being accepted as perfect gluing object or recognize it as rejected object.

### 4.4.1　Constraint in Template Creation

In all the experiments extra care must be taken in order to achieve good acceptance rate. During the template creation step, the size of the required features must be considerably large so that the created outline does not overlap as this can causes inaccuracy. Not only that, the extraction between background and its image must be done perfectly in capturing a good template images.

For experiment 1 (2D Matching) and 2 (Classification's of Defect), simple shapes are used for template creation. In order to achieve good template matching results, the pixel value difference between the object and the background must be sufficient for the system to work effectively. During the training step, the resultants template must have an obvious shape. The training template for experiment 1 are shown as example, the pyramid shape is shown in Figure 4.15 and the defects template (gap and bumper defect) are shown in Figure 4.16 and Figure 4.17 where as Figure 4.18 shows when a poor pixel difference that was used during template creation therefore the resultant template is undesirable. All the Figures on the left side show the capture image of the objects and Figures on the right side shows the reduced image showing the trained template in red lines.
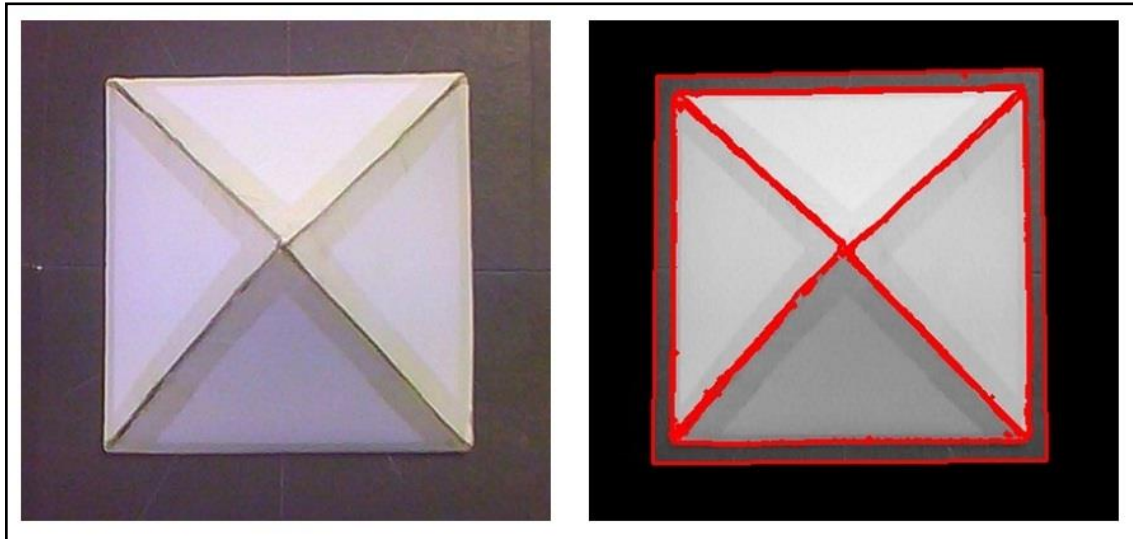
Figure 4.15: Pyramid Shape and its Corresponding Template
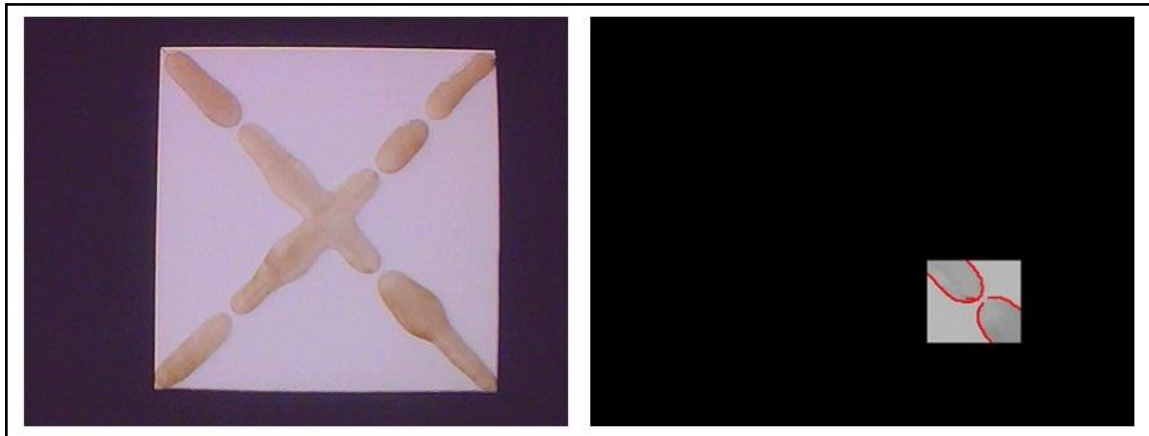


Figure 4.16: Defect Gap and its Corresponding Template
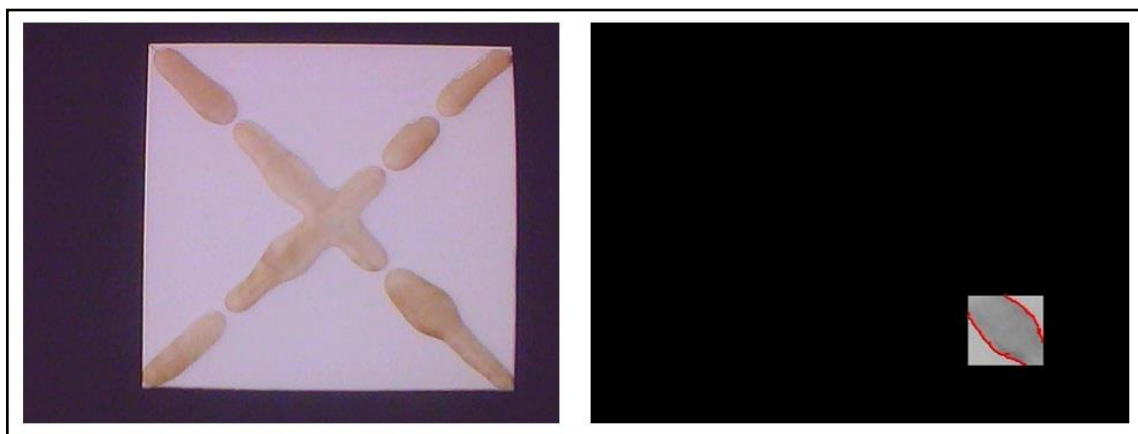


Figure 4.17: Bumper Defect and its Corresponding Template
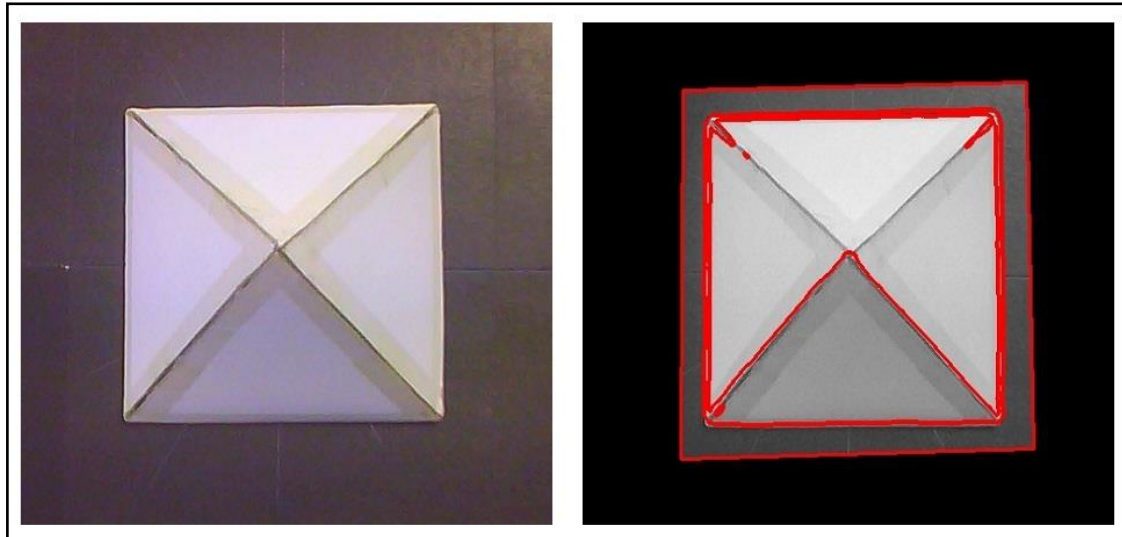
Figure 4.18: Poor Template for Image Pyramid

In developing good template image, each characteristics of the object must be obtained perfectly as shown in Figure 4.15, Figure 4.16 and Figure 4.17. Better template image created will result to better recognition rate. As shown in table below where it shown the difference between good and poor template that cause greatly in recognition result. The results is comparing using 50 tested images same as experiment 1.

Table 4.5: Comparison between Good and Poor Template Image

| Condition Template Image | Recognition Rate | Recognition Rate (%) |
|---|---|---|
| Good Template Image | 0.9696196 | 96.96196 |
| Poor Template Image | 0.824591 | 82.4591 |

$$Percentage\ Error = \frac{0.9696196 - 0.824591}{0.9696196} \times 100$$

$$Percentage\ Error = 14.96\%$$

The percentage error is too large to be implemented in industry where it can reflect to their quality product. Without proper step in defining good or poor template will be crucial to machine vision system where it cause system to be less effective and productive.

### 4.4.2    Constraint in Camera Placement

The important step to vision system is image acquisition, where the captured image of the object is gone through the next process. If the capture image is in poor condition such as blurring and contains noise, then the corresponding process step certainly cannot achieve its effectiveness. In this research, the image acquisition process is done using a static camera placement and a static object. There are two cameras used in this research and each of them placed in static. Two possible position of camera are:

1. Top Camera – placed at the top of the object for capturing image in defining x and y coordinates. Used in Defect Shape Matching (DSM), Defect Shape Pointing (DSP) and Defect Inspection Monitoring (DIM).

2. Front camera – placed at the front of object (perpendicular to top camera) in defining x and z coordinates. Used in Defect Shape Pointing (DSP) in providing data of 3D transformation.

Static camera placement is preferred compared to the moving camera because the noise of capturing a moving object is less than the noise of capturing using a moving camera, however small the movement. The most recommended setup however is to locate the camera directly above or to the side of the object in a static position.

### 4.4.3 Constraint in Workspace Area Size

From the previous discussions, it is known that the image size is important during template creation step, but the workspace size must also be considered carefully during the training phase. Workspace size refers to the area that the camera can observe; in this case it will be equal to the image shown in the window screen at the GUI. In this research, the object placed at the centre of the workspace to get the better view of the object. The perfectly place object will result to the better recognition rate while the object placed slightly out the workspace are will result to poor recognition rate because of the missing characteristic of the object. Therefore care must be taken to ensure that the feature size is big enough while sufficient workspace size is still able to allow a deviation that might occurs. Figure 4.19 shows an illustration of good captured image within the workspace and Figure 4.20 shows an image that is partially absent from the workspace.
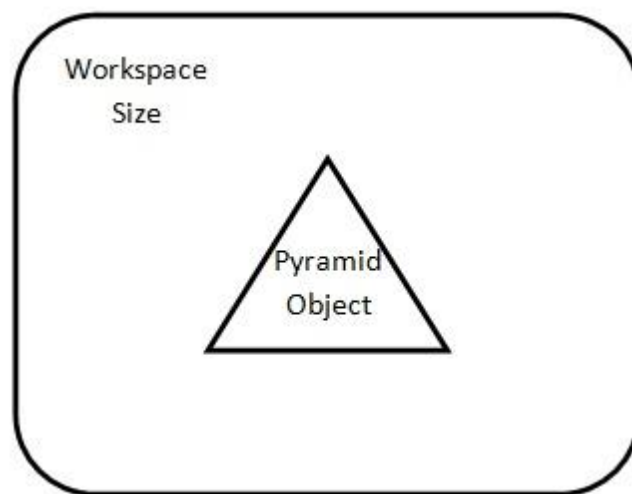


Figure 4.19: Good Placement of Required Features in Workspace
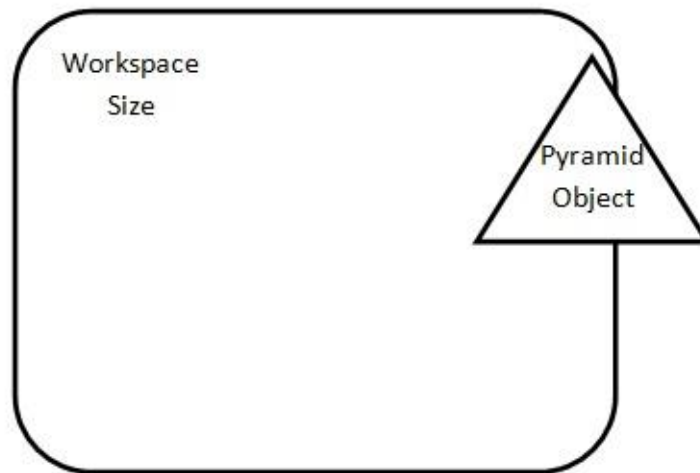
Figure 4.20: Required Features are Out of Workspace Area

### 4.4.4    Constraint in Katana Arm Robot

This research is based on two type arm robot; one of them is Katana arm robot. Katana application is based on pick and place application. The motion of the arm robot can be set only for point to point motion where the movement of the robot according to the easiest path created by robot itself. The constraints are the movement of the arm robot unable to set to linear and circular motion where both of them mostly used in this research. Compare to KUKA arm robot, it can be done all of the motion state previously such as point to point motion, linear motion and also circular motion. Based on that features, KUKA arm robot is most applicable and reliable in assisting this system.

### 4.4.5    Advantages of Proposed Vision Algorithm

First main advantage being introduced in this research is the application of Region of Interest (ROI). The differences of the suggested vision algorithm with other literatures are the ROI creation in Image Segmentation Step (DSM and DIM application). This user's define ROI creation capability enable users to extract the wanted features by simply using

the mouse button or fixed the area by using rectangle, where as in other literature the feature extraction steps are done using combinations of filters and methods to extract the wanted features.

Second main advantage of the suggested algorithm is that the system can be easily trained without pre-knowledge of the requirement needed. In all other literature the system was built to solve a specific requirement that was pre-determined, any changes in the requirement will causes the system to be ineffective. The drawback of this algorithm is the reduced accuracy in detecting very fine or very complex images.

Third main advantage is the system able to reproduce rejected object to be accepted by making correction for each defect by introducing $1^{st}$ and $2^{nd}$ Correction of Defect (CoD). The rejected product will undergo $1^{st}$ CoD where it provides altering the uncertainties with inspection system as it cores for classified the product status. While $2^{nd}$ CoD act as the backup plan for rejected product from $1^{st}$ CoD where as in literature review for other researchers only for the inspection in detecting defects.

## 4.5    Comparison of Results

This part presents the comparison of results from other experiments found in the literatures. Although the experiments setup, objective and methods are not entirely similar but basically the goal of each experiment is to develop a vision system in inspection for defect detection in industry. Even though gluing application is still new, but the technique in inspection are still the same with welding and fabric application just difference in how to analyze characteristic of each defects.

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First literature review is on 'A Method for Recognition of Defects in Welding Lines' by (Peng, 2009), the literature considered the problem in detecting welding defects in welding lines where the past researchers put an effort on more complex algorithm or limited in efficiency. The main objectives of this research is to classify 6 types of defect might occur in welding lines such as air hole, crack, strip inclusion, round inclusion, lack of penetration and metal inclusion. The suggested computer auto-recognized welding defect is put forward to define the capable of this algorithm. The algorithm is tested with 500 welding defect consists of all six type of defect to evaluate the defect detection capabilities. The results of this experiments represents defect detection of each defect's type but overall this system able to generate 94.3% success rate in classifying defect's type. Table below shows the result collected from this research.

Table 4.6: The Results of Defect Detection

| Defects | Air Hole | Crack | Strip Inclusion | Round Inclusion | Lack of penetration | Metal Inclusion | Total |
|---|---|---|---|---|---|---|---|
| Recognition rate (%) | 97.2 | 95.3 | 94.5 | 92.6 | 90.7 | 93.2 | 94.3 |

For second literature review on 'Fabric Defect Detection Method Based on Image Distance Difference' by (Zheng and Wang, 2007) represents the problems in detecting fabric defects where it mostly done by manual detecting where is low efficiency, fatigable and easily leaking detecting. The main objectives of this research to identify more than 30 common kinds of defect by using image distance difference arithmetic. Results of this research are able to detect more than 30 common kinds of defect and the rate of identification correctness is high to 92% with error rate under 5%. The defect can be occurring in three ways;

1. If there is crease in the fabric and the fabric is not tight in the process of inputting cloth.

2. As image distance difference arithmetic is based on the gray scale image, the defects, of such as blue and red threads.

3. The system limited in the defects of the pigments fabric.

The comparison of the vision system in all the researches can be summarized in Table 4.7. The comparison might not be reasonable because of different situations and objectives, for the first literature 500 samples of weld defect with 6 different of defects are included and the result of successful defect recognition rate is 94.3 percent and error rate recorded as 5.7 percent. Which means, total of 472 defects are detected out of 500 samples and 28 samples from it cannot be classified in this system because of some reason. For second literature, total of samples not stated in their research but more than 30 types of fabric defects are available. From the results occur, about 92 percent of defect recognition rate recorded from the system and about 5 percent error rate for unable to define defects occur from tested samples. Lastly is the proposed visual system of this research, 50 tested images is used consists of 236 samples defect and 3 types of sample defect which each of them known as gap, bumper and bubble defect. From 236 samples defect, 226 samples can be classified from this system where it equal to 95.76 percent recognition rate and 4.24 error rate recorded. Based on the Table 4.7, shows the proposed result has better defects recognition rate compare to the others.

Table 4.7: Comparison of Results

| | Weld Defect Detection | Fabric Defect Detection | **Glue Defect Detection** |
|---|---|---|---|
| Number of Samples | 500 samples defect | Not stated | 236 samples defect |
| Variation of Samples | 6 types | >30 types | 3 types |
| Correct Recognition Rate (%) | 94.3% | 92% | 95.76% |
| Error Rate (%) | 5.7% | 5% | 4.24% |

Table 4.7 shows the comparison between glue defect detection with both weld and fabric defect detection. The comparison is based on the method being used in introducing training and recognition phase. Each defect detection recognition rate are evaluated using pattern recognition which compares pixels by pixels between model template trains through training phase with the object tested capture from recognition phase. Pixels matching between both models will be calculated known as Score for this research.

In this research, the inspection system is expanded through to another application where it combines with Correction of Defect (CoD). The experimental develop as describes in Experimental 3 where the gluing object need to be corrected if there is at least one defect occur. CoD consist of two phase known as $1^{st}$ CoD (first time alter) and $2^{nd}$ CoD (second time alter). Each CoD process comes along with Defect Inspection Monitoring (DIM) to define whether the object is completely corrected or not. Table 4.8 below shows the recorded data for CoD and DIM application.

Table 4.8: Results for CoD Process

| Total Image Tested | Total Defect Detected | 1st CoD | 2nd CoD |
|---|---|---|---|
| 15 | 59 | 9 | 0 |
| Recognition Rate (%) | | 84.75 | 100 |

According to Table 4.8, 1st CoD recognition rate recorded 84.75 percent where it covers about 50 defects while the remaining is altered completely from 2nd CoD where it recorded to 100 percent recognition rate. So, the Correction of Defect (CoD) combined with Defect Inspection Monitoring (DIM) provide services to alter defects of gluing object from being automatically rejected.

Additionally, Defect Shape Pointing (DSP) developed based on information in getting z coordinate based on two 2D images captured from both top and front camera. Before proving that the best result generate from the algorithm, the dimension of pyramid object developed from white cardboard is calculated. Figure below shows the result in proving the real dimension of the pyramid object.



Finding height of the pyramid,

$$z = \sqrt{x^2 + y^2}$$

$$y = \sqrt{z^2 - x^2}$$

$$y = \sqrt{14^2 - 7.5^2}$$

$$y = 11.82 cm$$

So, the height of the pyramid is 11.82 cm based on original pyramid size developed.
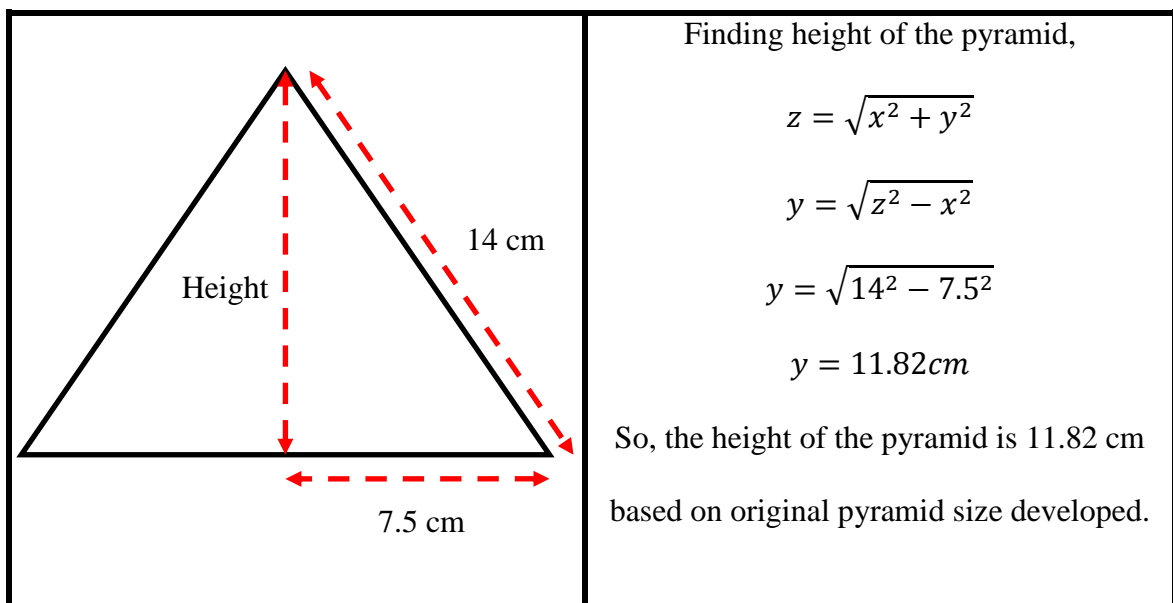
Figure 4.21: Calculation for Real Pyramid Object

Based on the result, the height of the pyramid is approximately 11.82 cm from base

location which means the simulation result should be exactly the same as the real object. In

proving that, the calculation between results in pixels coordinate and real dimension of

pyramid object are determine as shown in calculation below.
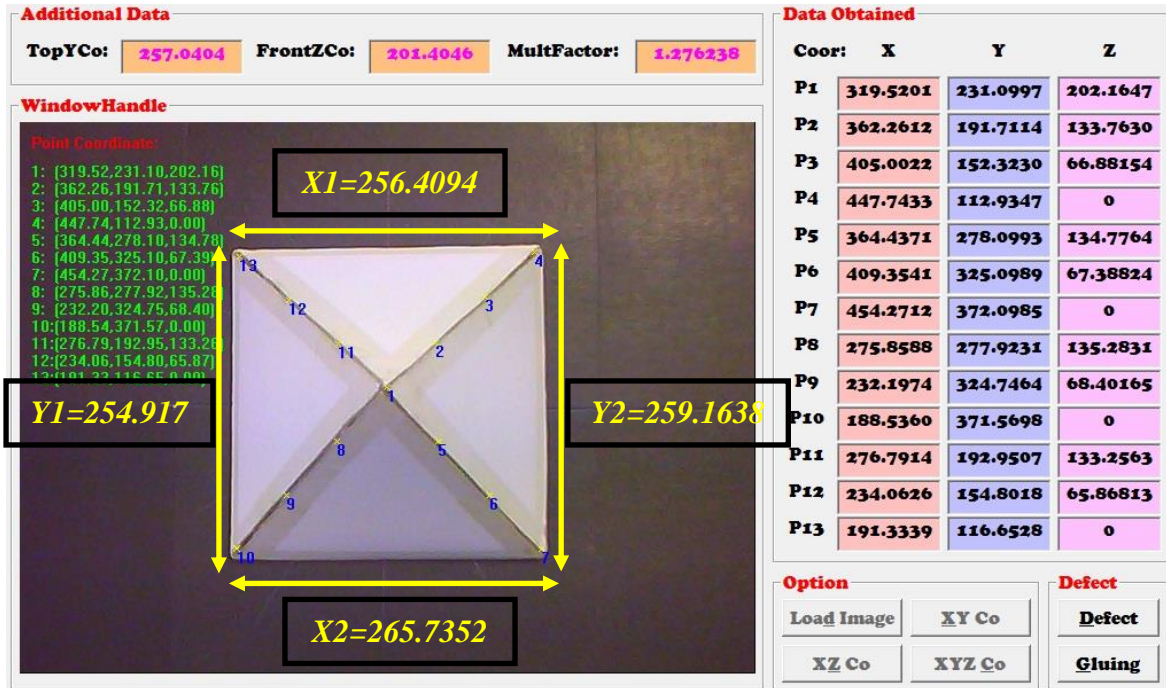


Figure 4.22: Information Data Used of Pyramid Algorithm

According to the figure, the x value are gained from the differences between x

coordinate of point 7 (P7) and point 10 (P10) while the y value generate from y-coordinate

of point 10 (P10) and point 13 (P13). Use all the information gathers from the system to

find $x_{avg}(value)$ and $y_{avg}(value)$ by using Equation (4.1) and (4.2).

$$x_{avg}(value) = \frac{[P4(x) - P13(x)] + [P7(x) - P10(x)]}{2} \tag{4.1}$$

$$x_{avg}(value) = \frac{256.4094 - 265.7352}{2}$$

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$$x_{avg}(value) = 261.0723$$

$$y_{avg}(value) = \frac{[P10(y) - P13(y)] + [P7(y) - P4(y)]}{2} \quad (4.2)$$

$$y_{avg}(value) = \frac{254.917 - 259.1638}{2}$$

$$y_{avg}(value) = 257.0404$$

So, the differences value for x and y coordinates are calculated. Then, the pixels display used in this algorithm are 640x480 pixels. So each coordinates has their own ratio for converting pixels to centimetres based on the pixels value.

$$x(ratio), 1cm = \frac{x_{avg}(value)}{width\ (in\ cm)}$$

$$x(ratio), 1cm = \frac{264.0723}{15}$$

$$x(ratio), 1cm = 17.40482$$

$$y(ratio), 1cm = \frac{y_{avg}(value)}{length\ (in\ cm)}$$

$$y(ratio), 1cm = \frac{257.0404}{15}$$

$$y(ratio), 1cm = 17.13603$$

$$pixels(ratio) = \frac{x(ration) + y(ration)}{2}$$

$$pixels(ratio) = \frac{17.40482 + 17.13603}{2}$$

$$pixels(ratio) = 17.270425$$

The data calculated will be used in generating the real value of the real image based on the DSP algorithm. So, the height of the pyramid object is calculated based on the calculated data of ration.

$$z - coordinate\ for\ P1 = 202.16 = 11.82cm\ (real)$$

$$z(value\ in\ cm) = \frac{P1(z)}{pixels(ratio)}$$

$$z(value\ in\ cm) = \frac{202.16}{17.270425}$$

$$\boldsymbol{z(value\ in\ cm) = 11.71\ cm}$$

The z (value) calculated is slightly differs with the height value determined from real object about 0.11 cm. This is because of the edge point generated from Harris Corner Detected (HCD) is slightly offset with the current edge point that supposedly being detected. Larger difference in pixels coordinate will result to the inaccurate result. So, with the differences makes the system acceptable but need to improve the edge detection to be more accurate based on the real object.

Last but not least, converting pixels coordinate to robots coordinate is really important in order to give information in same format with the arm robot. In previous subchapter described briefly in determining the exact equation for converting to robots coordinates shown as shown in Equation (3.4).

$$Robot\ Coordinate, (x, y, z)$$

$$= \left[\left(\frac{X(pixels)}{X_{ratio}}\right) + X_{avg}(robots)\right](X) + \left[\frac{240 - Y(pixels)}{Y_{ratio}}\right](Y)$$

$$+ \left[\frac{Z(pixels)}{Z_{ratio}} + Z_{ravg}\right](Z)$$

In order to prove that the robot coordinate generate using equation above is related to robot coordinate generate from the robot, three points from the each coordinates is used to determine the relationship is correct. The three coordinates are:

| Pixels Coordinate | Robots Coordinate |
|---|---|
| $P_p1 = (319.52, 231.10, 202.16)$ | $P_r1 = (365.87, 0.01, 383.76)$ |
| $P_p2 = (447.74, 112.93, 0)$ | $P_r2 = (458.05, 78.52, 263.54)$ |
| $P_p4 = (188.54, 371.57, 0)$ | $P_r4 = (287.42, -76.53, 263.08)$ |

For point 1 in robots coordinate, $P_r1 = (365.87, 0.01, 383.76)$

$$P_r1, (x, y, z) = \left[\left(\frac{319.52}{1.5394}\right) + 169.59\right](X) + \left[\frac{240 - 231.10}{1.6413}\right](Y)$$

$$+ \left[\frac{202.16}{1.6854} + 263.81\right](Z)$$

$$P_r1, (x, y, z) = 377.15(X) + 5.422(Y) + 383.76(Z)$$

For point 2 in robots coordinate, $P_r2 = (458.05, 78.52, 263.54)$

$$P_r2, (x, y, z) = \left[\left(\frac{447.74}{1.5394}\right) + 169.59\right](X) + \left[\frac{240 - 112.93}{1.6413}\right](Y)$$

$$+ \left[\frac{0}{1.6854} + 263.81\right](Z)$$

$$P_r2, (x, y, z) = 460.44(X) + 77.42(Y) + 263.81(Z)$$

For point 4 in robots coordinate, $P_r4 = (287.42, -76.53, 263.08)$

$$P_r4, (x, y, z) = \left[\left(\frac{188.54}{1.5394}\right) + 169.59\right](X) + \left[\frac{240 - 371.57}{1.6413}\right](Y)$$

$$+ \left[\frac{0}{1.6854} + 263.81\right](Z)$$

$$P_r2, (x, y, z) = 292.07(X) - 80.16(Y) + 263.81(Z)$$

The calculated robot coordinate achieved from the equation shown the slightly different with real robot coordinates. It proves that the equation can be used in this research in getting information of robots coordinate generate from pixels coordinate. The differences for both coordinates are shown in table below.

Table 4.9: Comparison between Calculated and Real Robot Coordinate

| Point | Calculated Robot Coordinate | Real Robot Coordinate | Error (mm) |
|---|---|---|---|
| $P_r1$ | (377.15, 5.42, 383.76) | (365.87, 0.01, 383.76) | (11.28, 5.41, 0) |
| $P_r2$ | (460.44, 77.42, 263.81) | (458.05, 78.52, 263.54) | (2.39, 1.1, 0.27) |
| $P_r4$ | (292.07, -80.16, 263.81) | (287.42, -76.53, 263.08) | (4.65, 3.63, 0.73) |

The differences recorded from calculated and real coordinate shows that slightly error occur where mostly all the points recorded error below 5mm except point 1 recorded 11.28mm.

# CHAPTER 5

## CONCLUSION

### 5.0    Introduction

This chapter discusses the conclusion and suggests future work to further improve the development of the system. It also stresses the significance and potential application from the research output.

### 5.1    Summary of Research

Based on this research works, this thesis presented the development of machine vision with additional of KUKA arm robot as assistive robot for windscreen gluing application. This system is presented with the Graphical User Interface (GUI) to ease users' utilization. This thesis consists of two main parts, first mostly on vision system and the other is robotic system.

For vision system, techniques of edge detection and template matching are used to create a shape-based matching method. It involves two phase processes of training and recognition phase. Fixed template creation of ROI replacing other feature extraction methods enables the system to be train to recognize various type of unknown objects instead of pre-determined objects. Median filtering technique helps in providing better image display by removing noise for better recognition rate. Template matching is introduced in performing pattern recognition for comparing between source images with

template images saved from training phase. Recognition rate known as the result for template matching where pixels equal recorded from both images.

Two cameras are introduced in determining 3D transformation generate from two 2D images capture from both cameras. Harris Corner Detector (HCD) used to determine edge of the object with its location stated in x and y coordinates. The recognised edges then used to generate additional point by using mathematical equation. The combinations of two 2D images in generate 3D transformations by integrating HCD and mathematical equation of straight line to define Multiplication Factor (MultFactor). MultFactor is the value in pixel location used to locate z coordinate for defects occur in the system by multiplying it with y coordinate generate from top camera.

Robotic system, the automatic robot application is integrating in the system to add services of gluing process of the object. Data generate from vision system then being sent to robot system to do task according to the information given. Data generate must be transform to robot coordinate for ensuring the location recognised by the robot itself. It also able to do correction for each defect occur to ensure that reject gluing object still can be reproduced as perfect gluing object. This system tested by three experiments conducted to evaluate the effectiveness of the system.

1.  2D Matching

Experimental setup based on classifying the types of process object to cope with the further process in the system. For example, this system running using pyramid object developed using white cardboard with dimension of 15cm x 15cm. So, the system will recognise the object as pyramid and pyramid algorithm being used until the system detect other object.

2.  Classification of Types of Defects

Experimental done in testing the effectiveness of the system in detecting glue defects occur in gluing pyramid. 50 tested images being run using this system with 236 defects appeared in the images. The purposed are detecting defects occur in the image and providing location for each defects in x, y and z coordinates.

3.  Correction of Defects

Experimental tested by using 15 tested images occur from inspection system. This application used to provide altering the defects in order to reduced rejected product. Correction done in two steps where 1$^{st}$ CoD introduced first time correction and 2$^{nd}$ CoD provides additional correction from 1$^{st}$ CoD.

## 5.2    Achievement of Research Objectives

The goal of this research can be summarized as a development of a machine vision system that can be used in automation industry such as inspection of installing windscreen car. The system's inspection and control will then determine the results and process of the following steps. The basic requirement of the machine vision system such as object recognition and 3D transformation in generating x, y and z coordinates are also included. Also the additional steps of ROI creations that substitute the normal method in features selection in order to cope with unknown objects that were going to be identify later, this method increases flexibility at the cost of accuracy but as long as the images captured are in fine conditions (constant lighting and with a clear and distinct pixel value difference that differs the object from the background) the accuracy of the system can achieve up to 98% (Experiment 1).

In inspection system known as Defect Inspection Monitoring (DIM), the development is based on the characteristic of defect that might occur in the system and saved in system memory. By applying each defect characteristic, the system able to classify whether the gluing object free from any defects. Once again ROI creation is introduced to train sample defects to be remembered in the system. Each defect recognized will provides with defect's information of x, y and z coordinates where the z coordinate generate by multiplying y coordinates with Multiplication Factor (MultFactor) occur from Defect Shape Pointing (DSP) application. DIM (Experiment 2) able to achieve 95.76% efficiency that is greater from the other two researchers that develop inspection system for weld and fabric defect.

Development of Correction of Defect (CoD) is introduced to alter the uncertainties occur in DIM. The purpose is to reduce number of reject product in order to increase production as well as quality of the product. Information recorded from DIM will sent automatically to the KUKA arm robot and synchronously alters the reject object according to their characteristic. Reject object occur in DIM application will directly through 1st CoD combine with DIM process to check again the gluing object. 2nd CoD will take placed when process on 1st CoD still occur any defects. The efficiency of this system is quite good where 1st CoD recorded 84.75% manage to alter 50 defects out of 59 that tested in this research. 2nd CoD complete the system with 100% efficiency manage to alter all the remaining defects occur from 1st CoD (Experiment 3).

This system's advantages will be mainly on its user define solutions, which the users can decide and manipulate how they want the system to react to the input that were predetermined. Other than that, the use of an interface between the system's vision system (PC) and KUKA arm robot not only enables the system to be compatible with different

brands of arm robot system, it also greatly reduces the set-up time during product changes as the modifications are towards hardware alteration and not software alterations.

## 5.3    Significance of Research

The significance in this research is mainly to increase flexibility and adaptability of the vision system in order to accommodate changes. A different point of view was exploited especially in automobile industry for windscreen car gluing process.

First contribution in this research is by applying shape based matching (SBM) application with additional of segmentation step in providing better image quality. With better image presented, it wills results to higher recognition rate based on the training image template. This algorithm used in both Defect Shape Matching (DSM) and Defect Inspection Monitoring (DIM) for better improvements in detecting objects also in classification of defect's types.

Second contribution is developed based on the system requirement that needs information in 3D coordination. By referring to (Teck et al., 2010), introducing 3D inspection by using two cameras in vision system is all new dimension in vision technologies. By integrating the idea with mathematical equation of straight line will creating new idea in generate 3D transformation of x, y and z coordinates. The idea needs the data on top camera (x and y coordinates) and front camera (x and z coordinates) before combining it to identify the z coordinates of the image. From that, the Multiplication Factor is identified that can directly generate z coordinate based on single 2D image.

Last but not least, the introduction of Correction of Defects (CoD) provides more flexibility in the system. It offers to alter the defects occur in order to ensure that rejected product still can be produces as quality product. This correction can be done twice a time

where the second times will corrected the remaining defects occur after the 1$^{st}$ CoD. Each CoD integrate with inspection system to identify the effectiveness of the system by considering each defects occur after the process.

Potential application can be described based on the results mostly for detecting defects in preventing the system from producing low quality products. One of them is gluing inspection for installing car windscreen in automation industry. Human vision is still being used in detecting defects; human easily get distracted with the surroundings and it will result inaccurate detection. By applying automation inspection will result in high efficiency and accuracy in detecting defects also able to work nonstop.

### 5.4    Problems Faced During Research

Despite the system is being shown great accuracy in all aspects, there are still problems occur in completing this research. One of them is the object used in testing the algorithm. The main application of this research is to improve gluing process in installing windscreen car in automation industry. But, in affording a windscreen car, it will be costly in testing the system with 50 tested objects. As a solution, pyramid object developed using white cardboard is decided in terms of low cost and easy to develop. On top of that, pyramid will consists of height, width and length in order to glue it from center to corner of the pyramid. Pyramid has been used according to its base that has the shape of rectangle similarly to windscreen car. But the difference is that windscreen has a contour exactly like concave shape. Therefore, the pyramid is decide to used because it provide a straight contour with need to analyze its width, length and height for gluing purposes.

Not only that, in achieving a real application of gluing process, the specific tools that works with KUKA arm robot should be used. In order to achieve that, the cost in ordering the gluing tools is too expensive. For the solution, the gluing tool is being

replaced with hot glue gun attached at the center of the gripper act as the gluing tools of the system. By applying that, the gluing process cannot be done using robot because there is no tools available in controlling the trigger of the glue gun. For solving that matter, the gluing process and correction of defect are done manually. The robot application shows the path for both processes.

In order to make this system more compatible and flexible, the online process between software and hardware are created. KUKA arm robot is one of the famous arm robots that capable of accomplished that but the available KUKA arm robot comes only with the teach pendant. The unavailable in doing so, the data are recorded in offline version but the system still can be running in online version if the robot can be applied in online mode.

## 5.5    Suggestion for Future Work

In order to further investigation the effectiveness of this system, a configuration of Flexible Manufacturing System (FMS) can be implemented. FMS is a system that is able to respond to changed conditions. In general, this flexibility is divided into two categories and several subcategories. The first category is the so called machine flexibility which enables to make various products by the given machinery. The second category is routing flexibility enabling to execute the same operation by various machine (Judi et al., 2004). FMS usually consists of three main parts: CNC machine tools, transport system and control system.  So, in this research it is suggested that a FMS system using robotic arm is more efficient rather using conveyor belt to transport object from one station to another because it offer more flexibility and agility to the system.

**APPENDICES**

Appendix A – GUI User Guide

Appendix B – Experimental Guide

Appendix C1 – Software Guide (HALCON)

Appendix C2 – Software Guide (Visual Basic 6.0)

Appendix D – Hardware Specifications

Appendix E – List of Publications

# APPENDIX A


# GUI USER GUIDE

# Appendix A - GUI User Guide

## First Processing GUI - Defect Shape Matching (DSM)

The GUI is created according to the needs of the system to enable the simplest programming flow for 2D matching in identifying the correct shape to process. This features support the camera interaction using frame grabber and the matching process involving training and recognition phase. All the data occurred in the system is recorded for inspection purposes in identifying the system effectiveness. There is a step in using the DSM application in correct order to smoothly run the system.
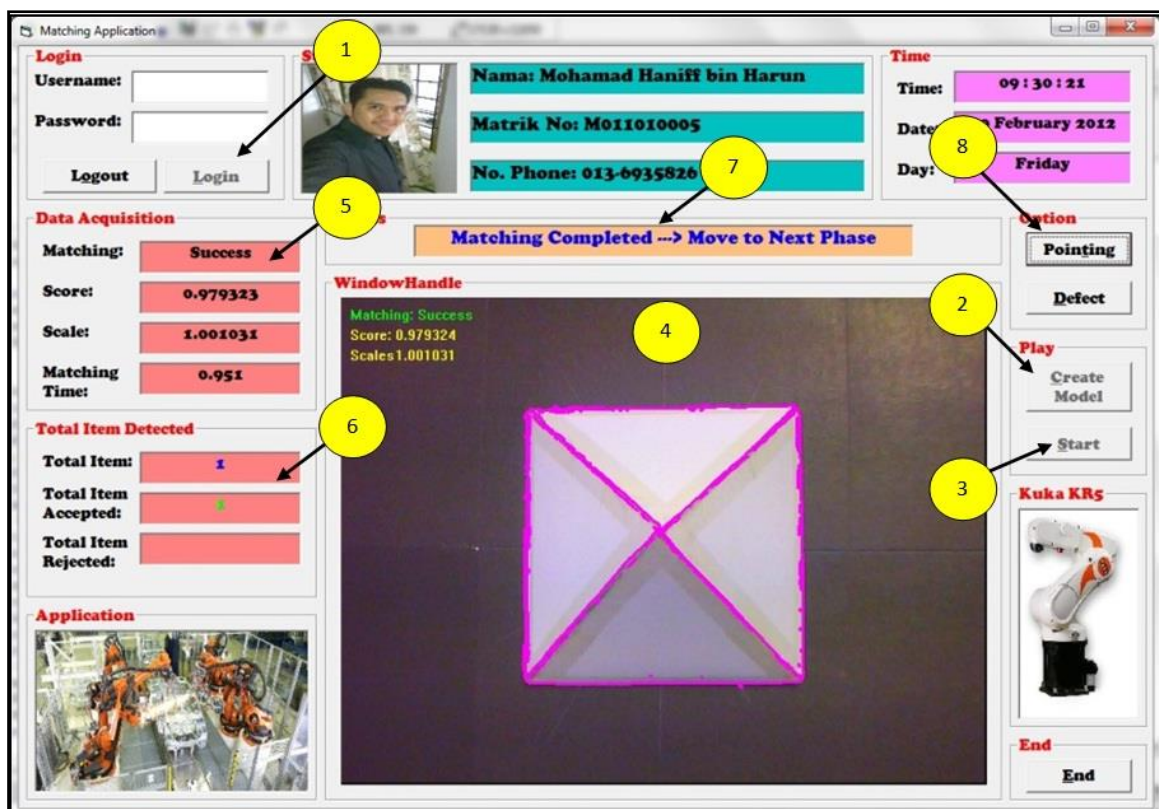
<u>Procedures:</u>

**Info 1**: For security of the system, the authorized username and password must be activated first before able to use the system. Once the system is activated, it turns on the frame grabber in the PC for initialized the camera connected through this system.

**Info 2**: Click on the 'Create Model' button, this activates the system model creation by using Region of Interest features in providing perfect region to process as a template model that will be used in identify the correct shape of object.

**Info 3**: Click on the 'Start Program' button, this activates the camera to capture images continuously. This let users to monitor and calibrate the required setting such as object size (zoom), focus (image clarity), and also brightness (light intensity). Not only that, it also combines with recognition phase to classify whether the object is well matched or not.

**Info 4**: The image display is using the HALCON window display known as WindowHandle to show all the process occur during every process. This application is imported from HALCON software by using Visual Basic 6 library to integrate between them. It's also able to describe status of image being process by applying a simple algorithm in the display window.

**Info 5**: In this section describe status of recognition object whether image is accepted or rejected with including their recognition rate. Not only that, the scaling of image capture and process time also is recorded in this section.

**Info 6**: Number of total item being process is recorded alongside the number of total item accepted and rejected during the process system. Each item success in matching recorded as item accepted while the others recognized as rejected item.

**Info 7**: Shows status for current process whether the system can be proceed to the next phase or not. The system cannot move on to another phase if the recognition is failed because of the system can only be precede when the system is in correct shape.

**Info 8**: Option tab is enabled when the system triggered success matching process to move onto the next process called as Defect Shape Pointing (DSP).

## Second Processing GUI - Defect Shape Pointing (DSP)

This GUI is created based on the data needed to process in determining 3d transformation data using two 2D images. Its combine two cameras (one at the top and the other in front) purpose in generate data. For top camera, data available in x (vertical line) and y (horizontal line) coordinates while front camera provides data in x (vertical line) and z (horizontal line) coordinates. By combining both images, 3 parameters can be calculated;

1. TopYCo     - object width at y axis.
2. FrontZCo    - object height at z axis.
3. MultFactor   - multiplication factor used to directly generate z coordinate from 2D images.

Procedures:

**Info 1**: For starting movement to run the Defect Shape Pointing application, click 'Load Image' button to activate the camera to capture images directly and display it into the display window through the system.

**Info 2**: Click on the 'XY Co' button, this activates the system pointing application which every edge occur in the system is show directly to the system with integration of mathematical equation (straight line equation) that generate x and y-coordinate based on pixel coordinate of the camera. The image used for this section is capture from top camera.

**Info 3**: Click on the 'XZ Co' button, this activates the front camera to capture image from front of the object in order to get information of x and z-coordinates. The algorithm to get the edge of image is same from the previous method by integrate the edge point occur with the equation of straight line.

**Info 4**: The integration of top and front camera pointing result produced the x, y and z-coordinates (3D transformation) that give exact location of each point occur in DSP application. This useful information will be used in gluing process using KUKA arm robot by sending the information via serial communication.

**Info 5**: Click button 'Gluing' to activate KUKA arm robot to glue the object according to the information data given. The complete gluing process will takes placed in all four gluing line. After the process complete, click button 'Defect' to run to next phases called as Defect Inspection Monitoring (DIM) application to classify the correct sequence of accepted or rejected object.

**Info 6**: The image display is using the HALCON window display known as WindowHandle to show all the process occur during every process. This application is

imported from HALCON software by using Visual Basic 6 library to integrate between them. It's also able to describe status of image being process by applying a simple algorithm in the display window.

**Info 7**: Shows the additional data occur from the difference between y coordinate (TopYCo) capture from the top camera and z coordinate (FrontZCo) capture from front camera to get the ration difference in order to locate z coordinate by using 2D images. The ration difference is known as 'MultFactor'.

**Info 8**: Display the information x, y and z coordinates occurs from pointing application based on pixels camera used.

## Third Processing GUI - Defect Inspection Monitoring (DIM)

This GUI created based on the specification of system in applying inspection system for gluing process. Creating model template is done by applying a real defect occurs in gluing such as gap and bumper. The characteristic of each defects are saved and stored in the system memory. System then immediately feed the model template as soon as the matching algorithm is takes placed.
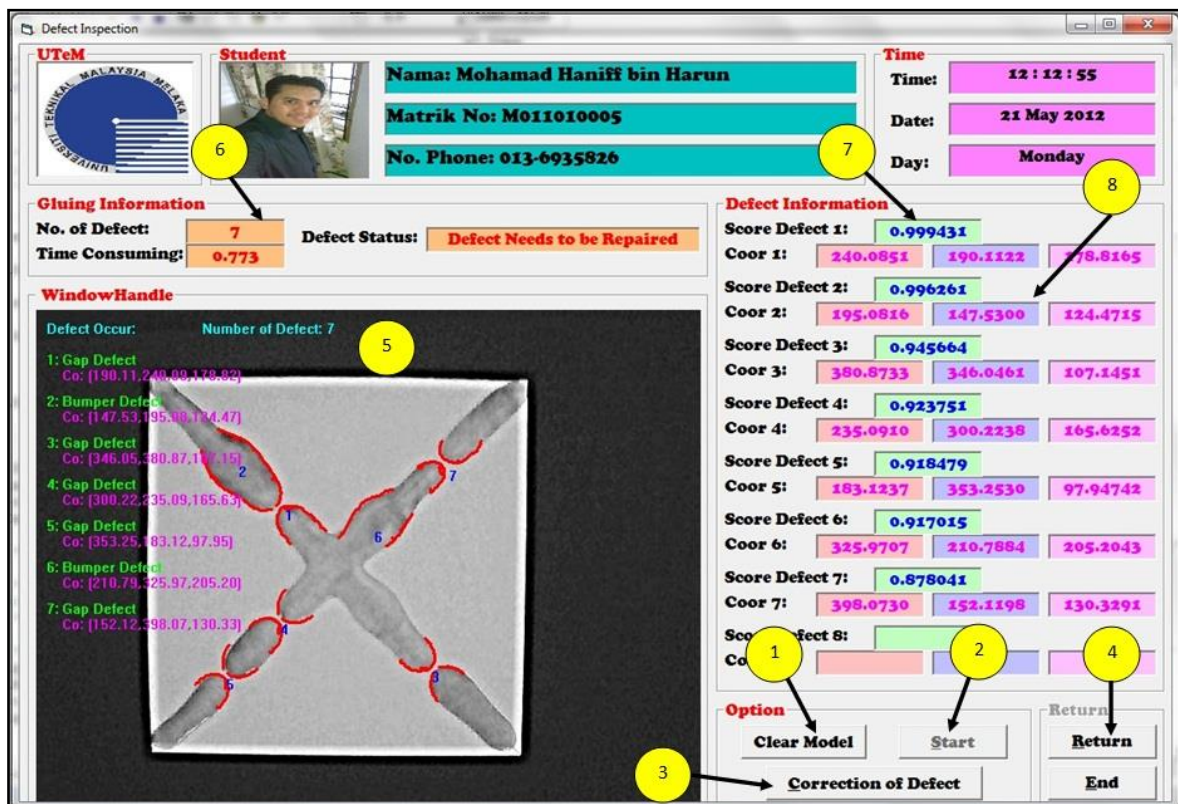


Procedures:

**Info 1**: Starting to run the system, click button 'Create Model' to create defect model template used to classify whether defect occur in the image or not. Creating image template based on the training phase as describe at chapter 2 and 3. After that, texts in the

button change from 'Create Model' to 'Clear Model' to provide option to clear the model template.

**Info 2**: Click on the 'Start' button, this activates the defect matching application which every defects occur being shown in the system with information of x, y and z coordinates. It also activates top camera to capture gluing image to process.

**Info 3**: Button 'Correction of Defect' known as CoD that functions to made correction where the defect occur in order to reduce the number of rejection product. This system linked with the KUKA arm robot in providing process data for the correction job. After that, click button 'Reinspection' to analyze whether the product is accepted or rejected.

**Info 4**: When the system finished with the inspection, button 'Return' is enabled to click where its directly through to the main system application known as Defect Shape Matching (DSM) to continue with another object.

**Info 5**: The image display is using the HALCON window display known as WindowHandle to show all the process occur during every process. This application is imported from HALCON software by using Visual Basic 6 library to integrate between them. It's also able to describe status of image being process by applying a simple algorithm in the display window.

**Info 6**: Gluing information gives data about the number of defects occur in the image, time consuming in detect all those defect and also defect status whether need correction or the product already in well-gluing.

**Info 7**: Every defect occur has their own recognition rate according to the defect template being created. So, this section provides data on recognition rate to each defect occur in the system.

**Info 8**: Display the information x, y and z coordinates occurs from inspection based on pixels camera used.

# APPENDIX B


# EXPERIMENTAL GUIDE

# Experiment 1

# Defect Shape Matching (DSM)

**Appendix B - Experimental Guide**

## Experiment 1-1:

This experiment stressed on the creation of multiple object (template) creation and matching process in providing a valuable data about the process object. GUI display the image being capture using top camera and the object used is pyramid. Model template is then restored in the system memory to call back in recognition phase.
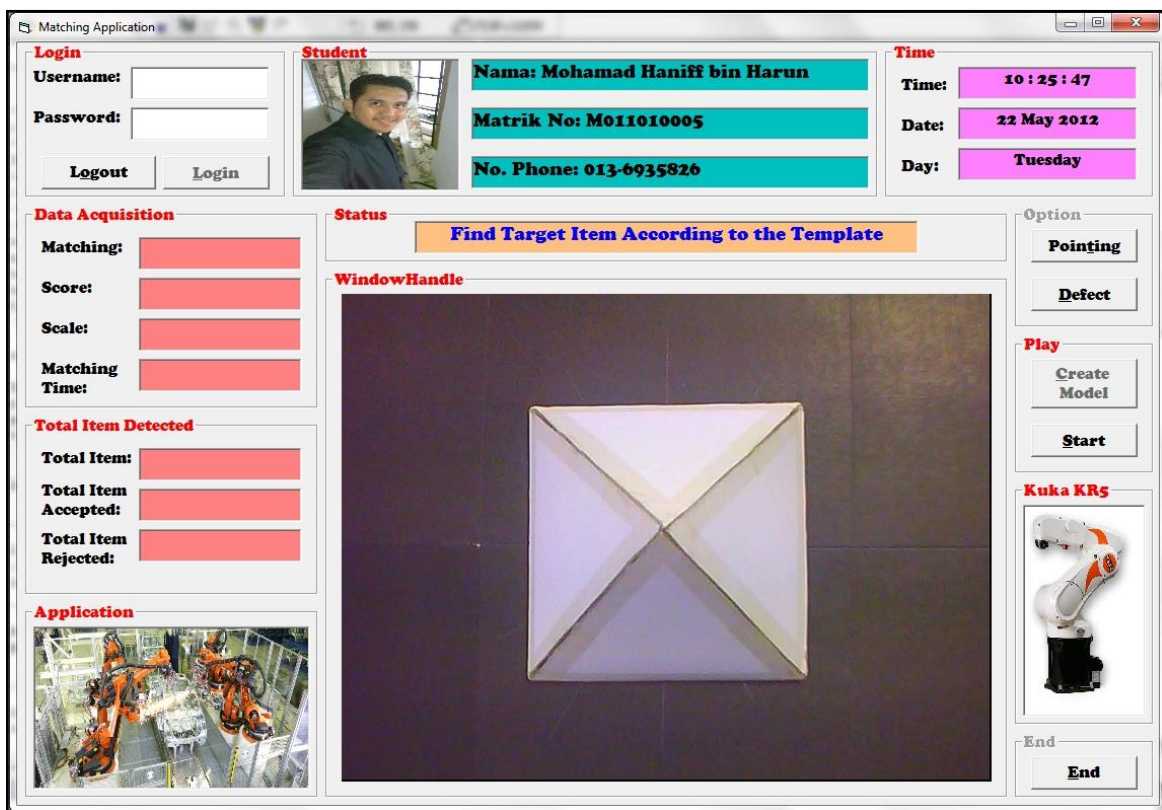
**Experiment 1-2:**

GUI display after the ROI was drawn automatically by assigning desired region of interest in algorithm when clicking Create Model. The purpose is limiting the process area by ignoring the background of the image. This helps in providing system with fastest processing time to cope with the type hardware being used.
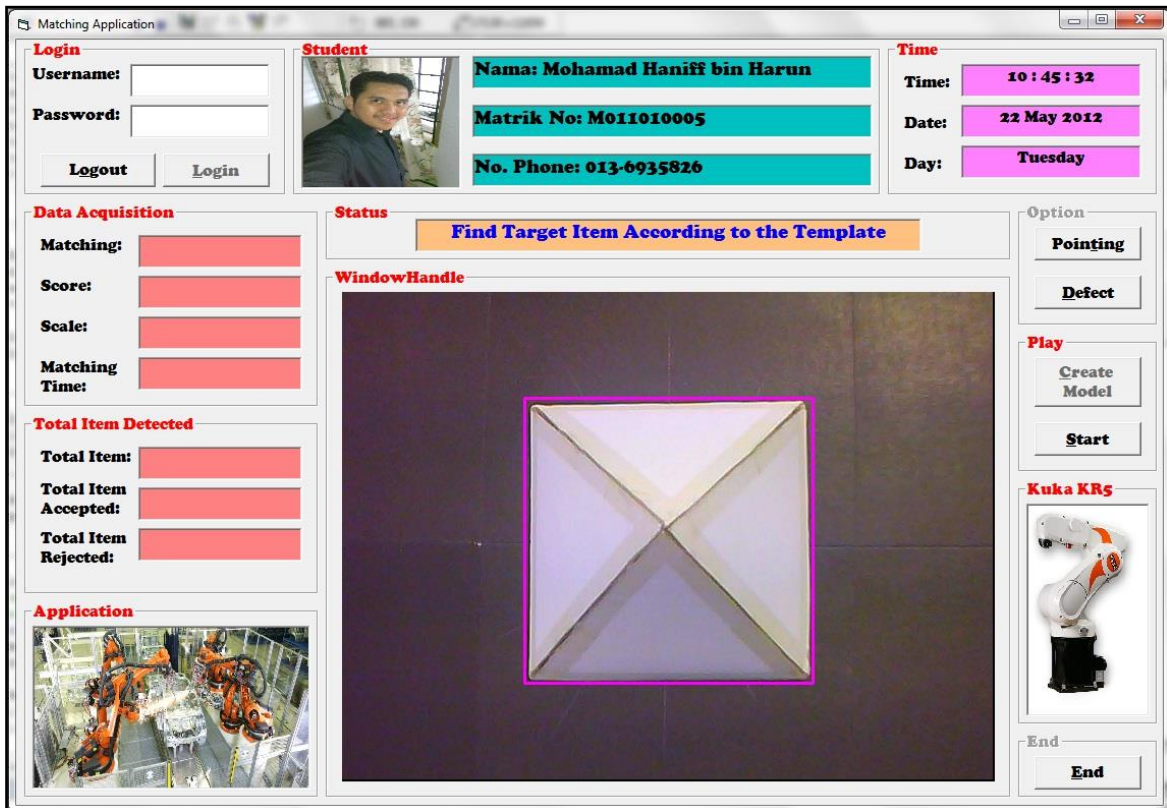
**Experiment 1-3:**

GUI display after the image was reduced by clicking Create Model before. The reduced images then being extract to identify their special characteristic then being restore in memory for later process. Each characteristic are saved according to the object used.
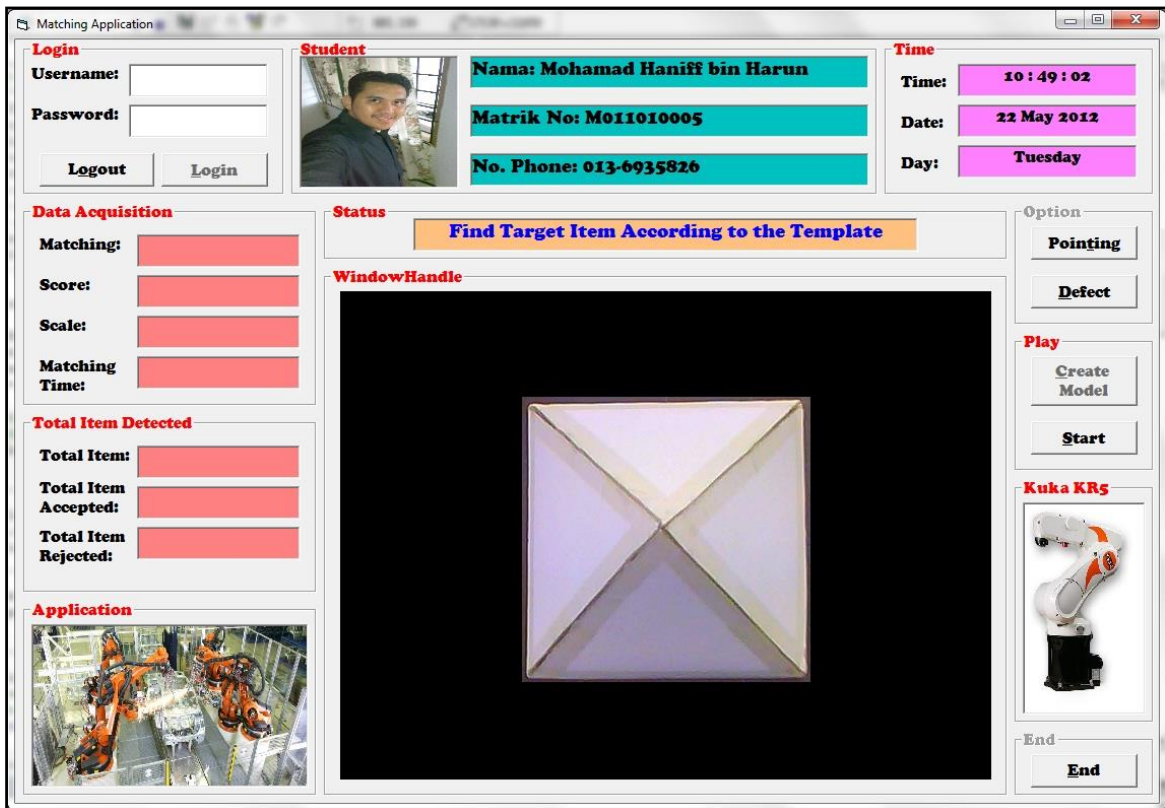
**Experiment 1-4:**

GUI image after the image was trained and the template is created (violet lines) by clicking Create Model. The special characteristic is being extracted as shown in the image according to the pyramid object.
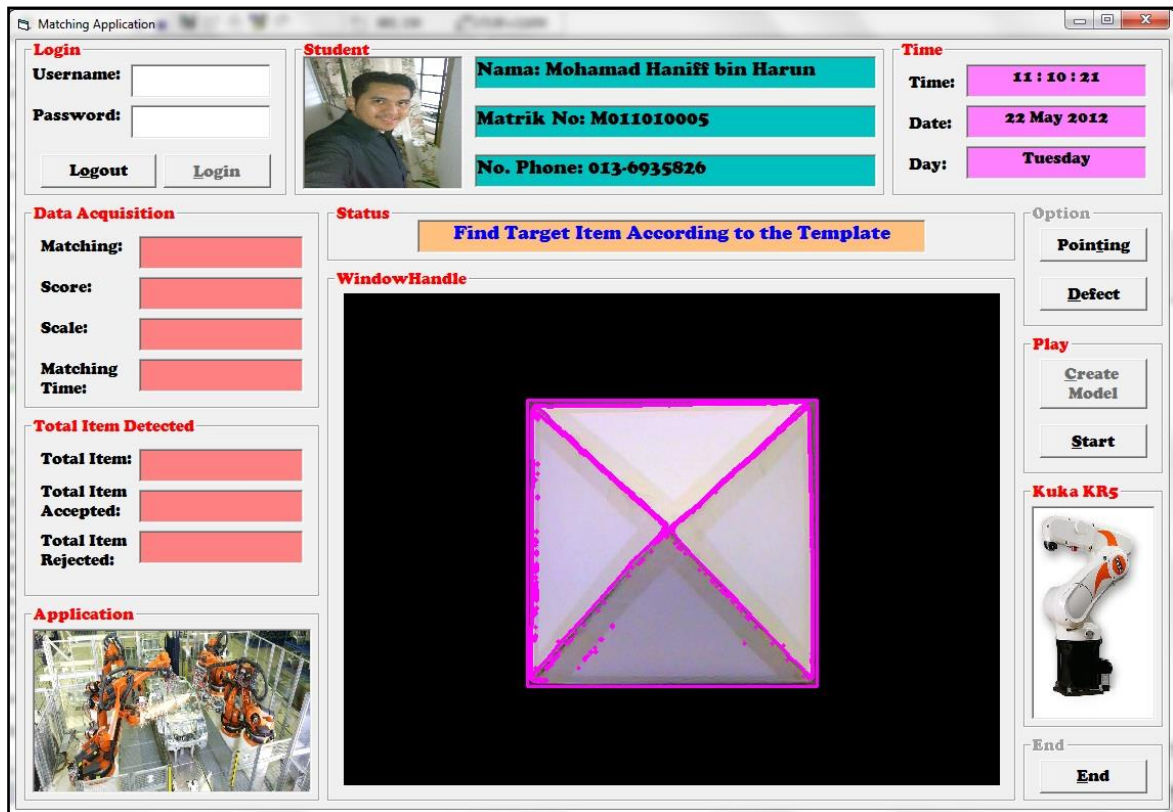
**Experiment 1-5:**

GUI display after the image being trained by clicking Create Model. The image shows the characteristic being saved in the system for recognition purpose. Each object has its own characteristic that need to be specified first before using it in matching process.
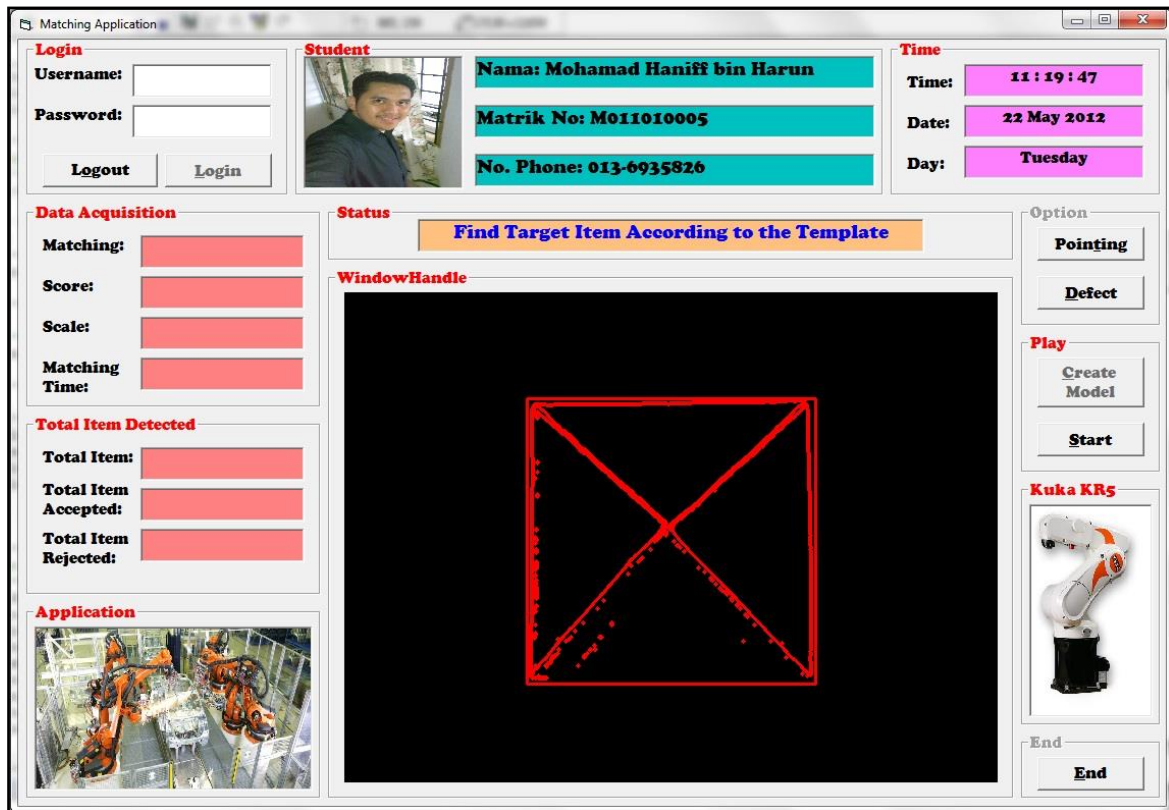
**Experiment 1-6:**

GUI display after the object was found during matching phase. Matching Object is display at the display windows known as WindowHandle. In this process, the model template created before is calling back to the system in finding whether the object is pyramid or not. Each matching process has it recognition rate (also known as Score) and its scaling ration between process images with template image.
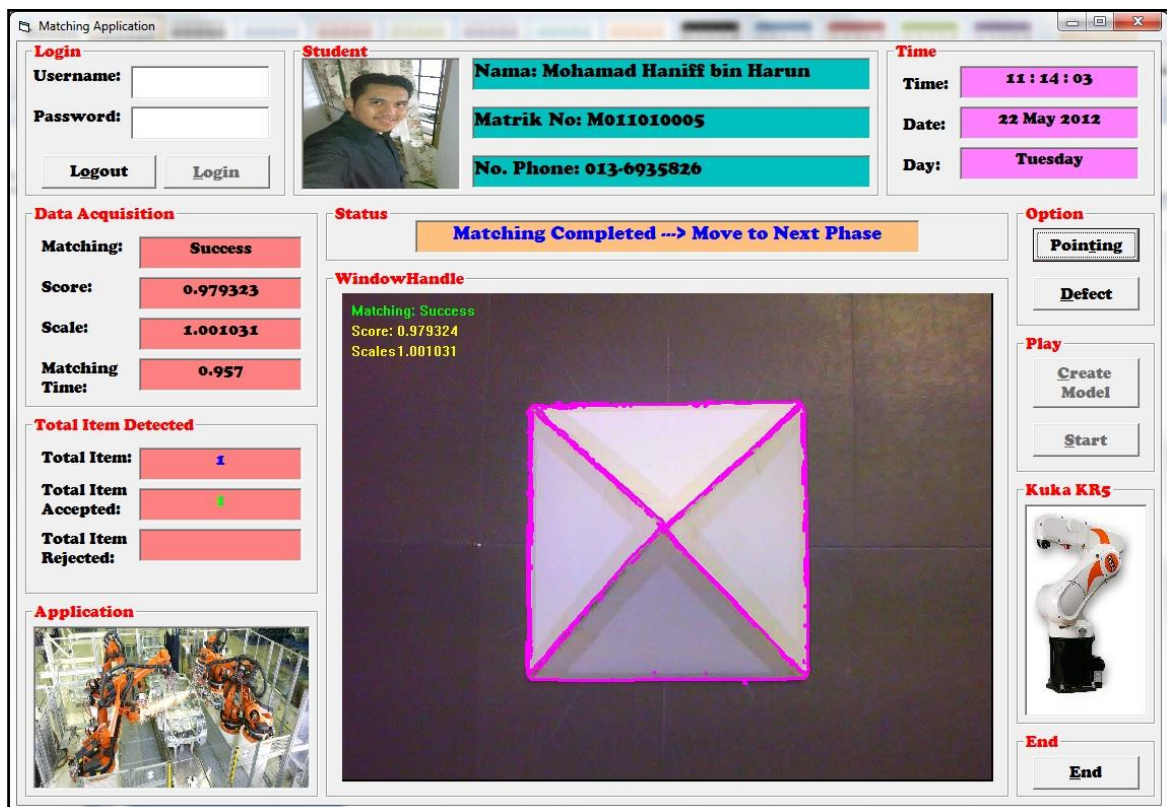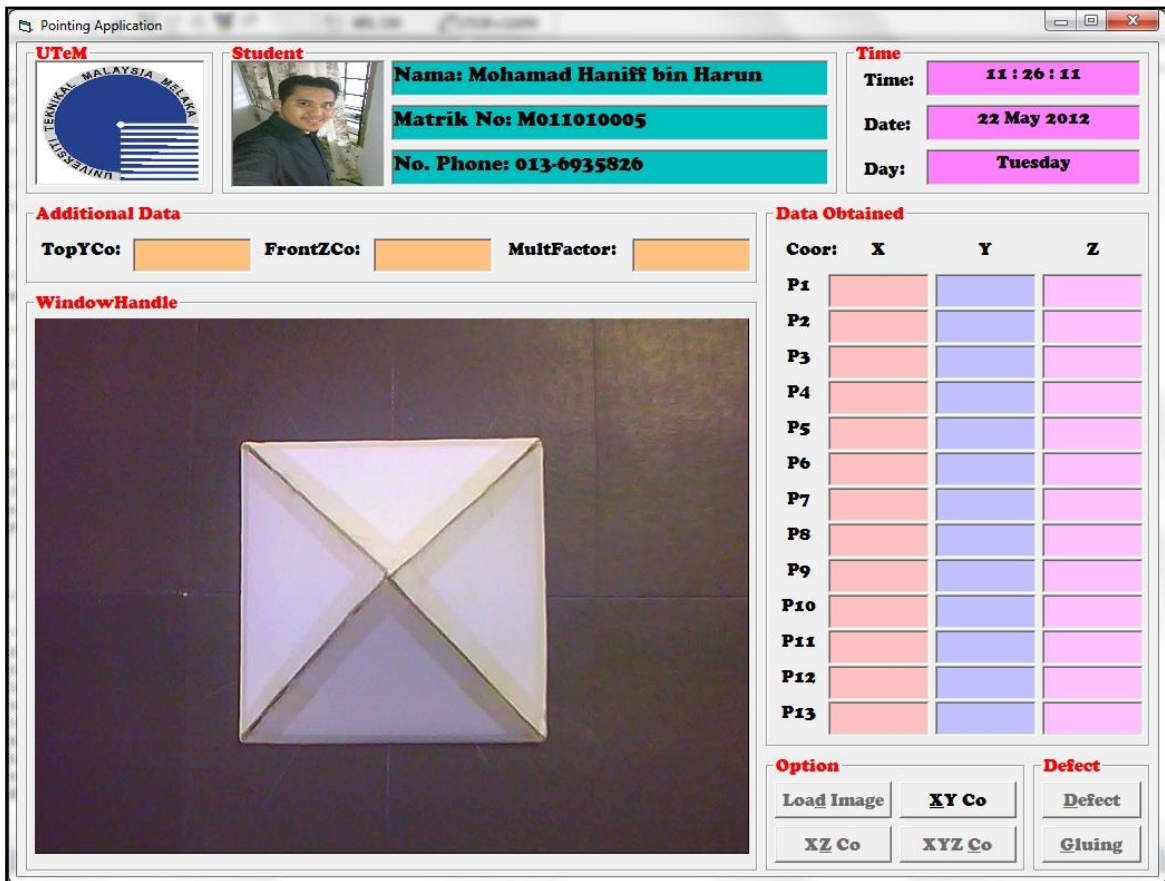
# Experiment 2

# Defect Shape Pointing (DSP)

**Experiment 2-1:**

GUI shows the image display capturing from top camera. By clicking 'Load Image' image will taken directly through the system. This image used to find the edges around the image in order to generate data for gluing process.

**Experiment 2-2:**

GUI displays the image that already through process Harris Corner Detector (HCD). HCD used to identify edges occur in the image. Each edges occur has shown in the image and its data is collected and saved in memory. This data will be used to generate additional data for assisting KUKA in gluing the object.

**Experiment 2-3:**

The GUI showed the image with complete additional data for giving information for KUKA arm robot to glue according to the data given. Before that, the data generated only in 2D transformation image (capture from top camera) without the information of z coordinate.

GUI display after the image was captured from front camera. This application used to generate 3D transformation image in findings the z coordinate based on two 2D image transformation. Before that, HCD is used to identify the edges of the image. Data gathered will be used to generate additional data according to the data from top images.

**Experiment 2-5:**

GUI display after the image through the system to generate additional data. Data gathered will be compared with results from top camera in identifying z coordinates based on both results images. The thorough explanations about this feature refer to Chapter 3.

**Experiment 2-6:**

GUI image after the image was through 3D transformation system based from two 2D images. The data generated will be used in assisting KUKA arm robot in gluing the object based on data given.

**Experiment 2-7:**

By clicking button 'Gluing', data sent to the robot directly and gluing process start automatically after sending data is completed.

**Experiment 3**

**Defect Inspection Monitoring (DIM)**

## Experiment 3-1:

GUI display the template creation of Defect Gap 1 captured from top camera. This model template is saved in the system for inspection system later on.
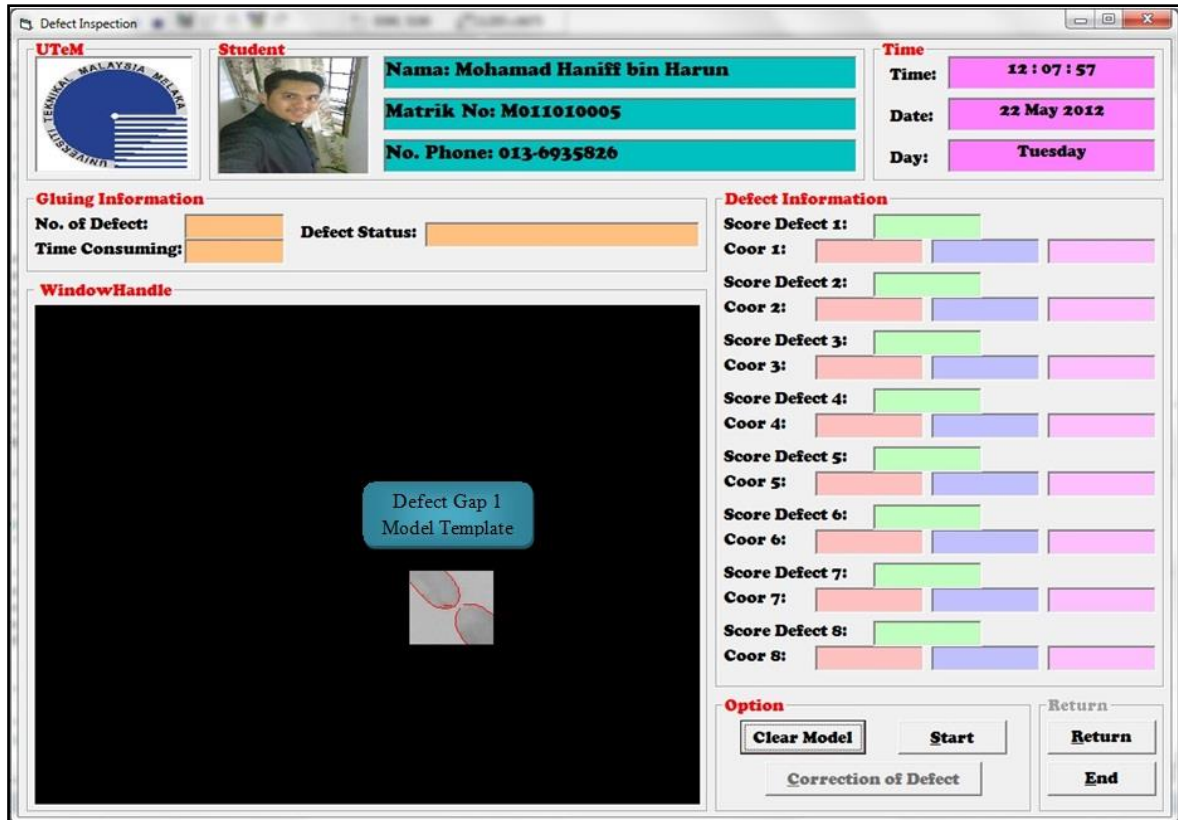
**Experiment 3-2:**

GUI display the template creation of Defect Gap 2 captured from top camera. This model template is saved in the system for inspection system later on.
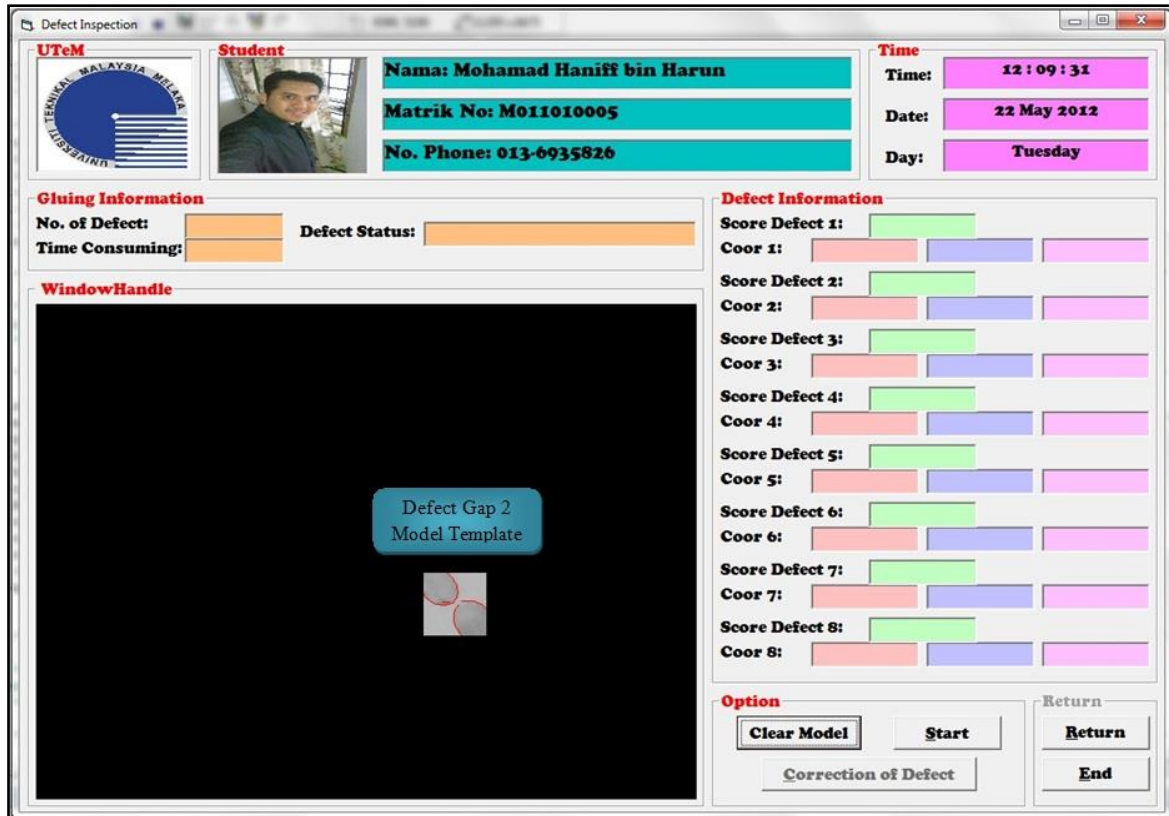
**Experiment 3-3:**

GUI display the template creation of Defect Gap 3 captured from top camera. This model template is saved in the system for inspection system later on.
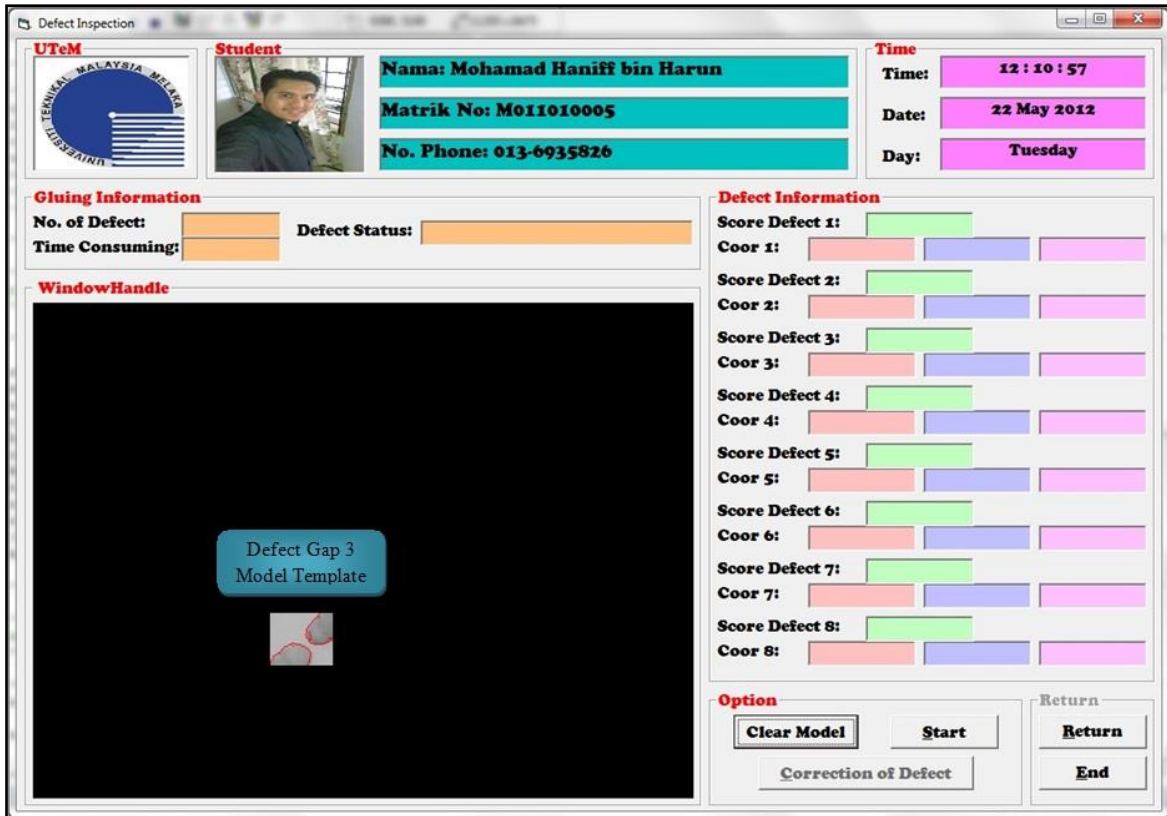
**Experiment 3-4:**

GUI display the template creation of Defect Bumper 1 captured from top camera. This model template is saved in the system for inspection system later on.
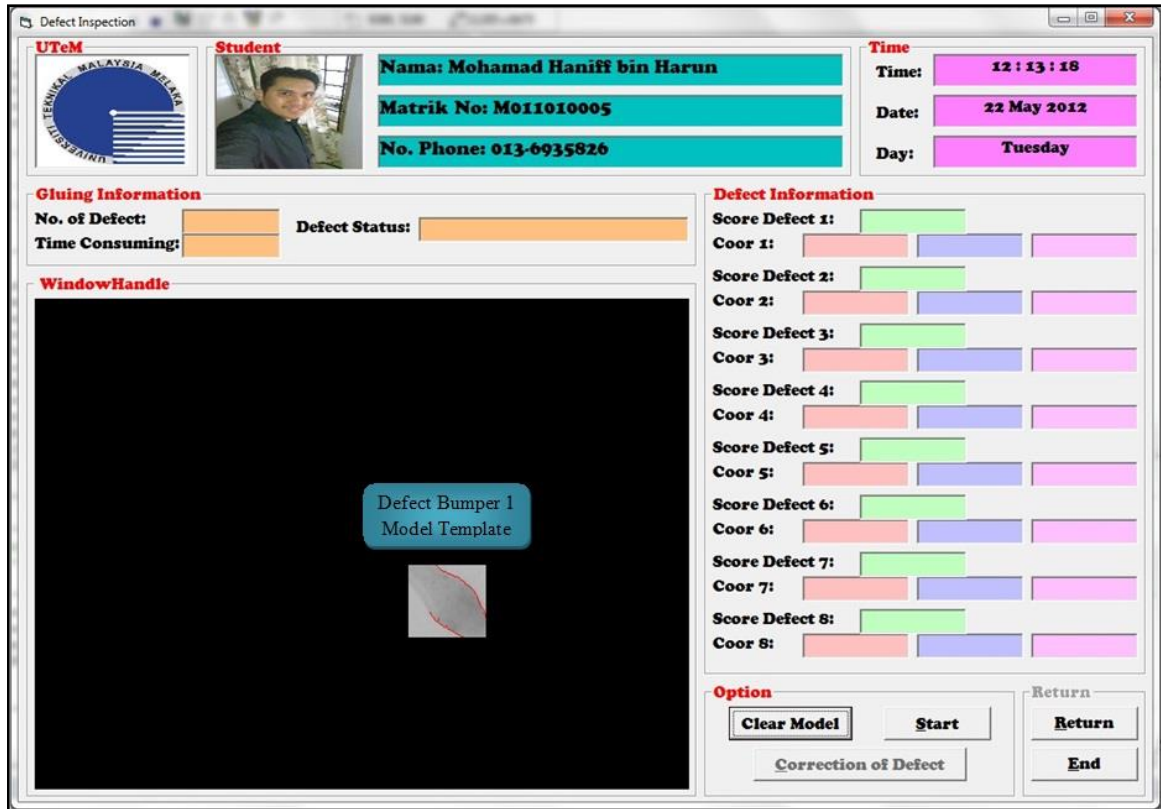
**Experiment 3-5:**

GUI display the template creation of Defect Bumper 2 captured from top camera. This model template is saved in the system for inspection system later on.
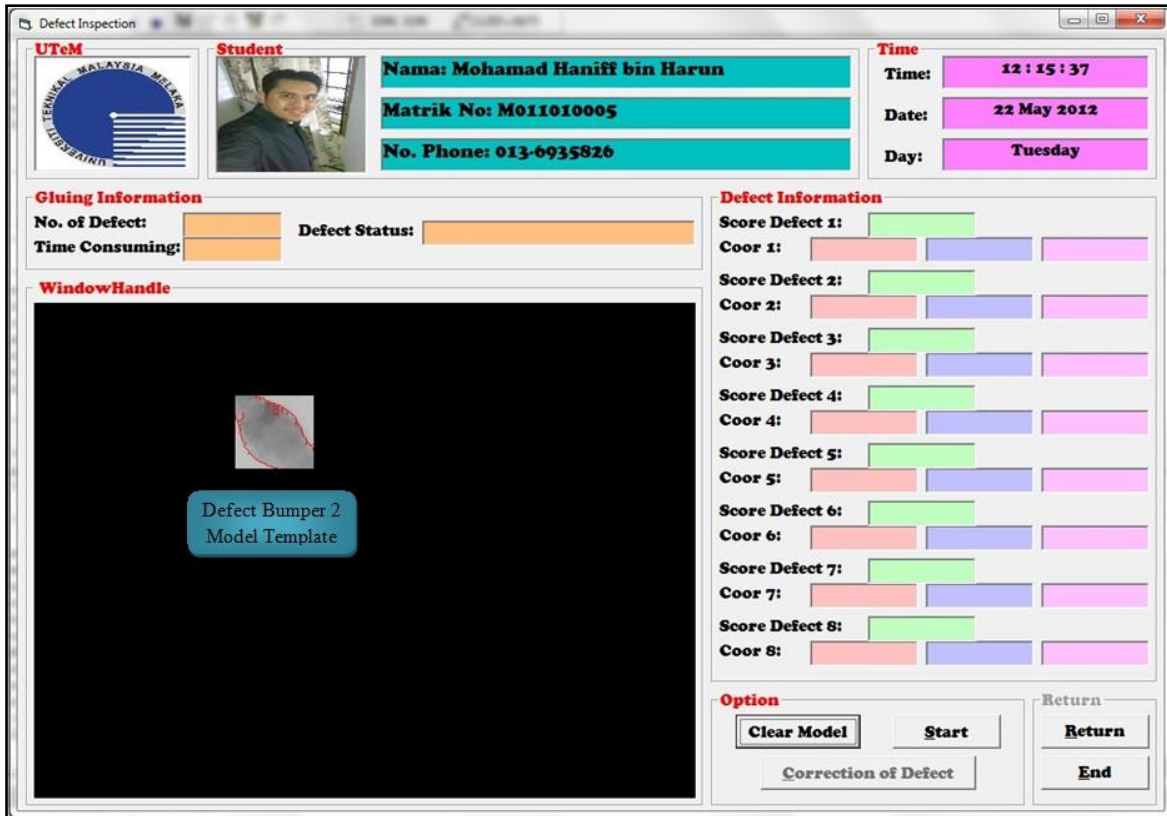
**Experiment 3-6:**

GUI display the template creation of Defect Bumper 3 captured from top camera. This model template is saved in the system for inspection system later on.
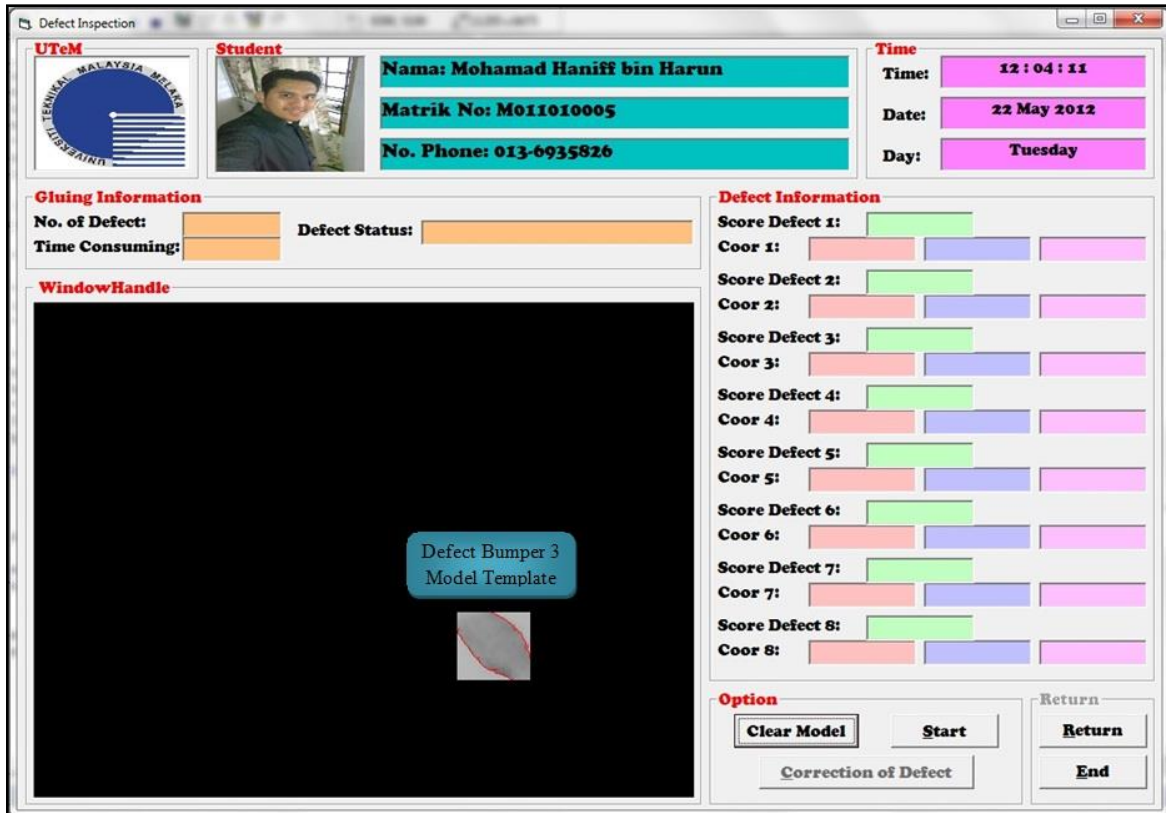
**Experiment 3-7:**

GUI image after the image was complete with inspection system. According to the image, each defect occur along gluing line will be detected based on the model created. Better model template created, better the results obtained (recognition rate). Each defect occurs comes with the data about x, y and z coordinates (length, width and height). Every defect will go through Correction of Defects (CoD) to alter the defects.

**Experiment 4**

**Correction of Defect (CoD)**

**Experiment 4-1:**

After the Defect Inspection Monitoring (DIM) is completed, the system will checked whether the object need to rechecked or accepted as a quality product. If the systems find a defect, supposedly it should be corrected to ensure that the product still can be used as a quality product. By clicking button 'Correction of Defect' data of the defects will be sent directly to the robot for made it a correction.

**Experiment 4-2:**

After the correction has been done, the system must be rechecked to identify that the system is gluing perfectly without any defects. By clicking button 'Reinspection', the system used algorithm of DIM to identify any defects in the object. If there is still has defect, it must be through the correction algorithm once again. If not, the system will classify the object as perfectly gluing.

**Experiment 4-3:**

GUI displays the object without any defect known as perfectly gluing and can further to another object to be glue.
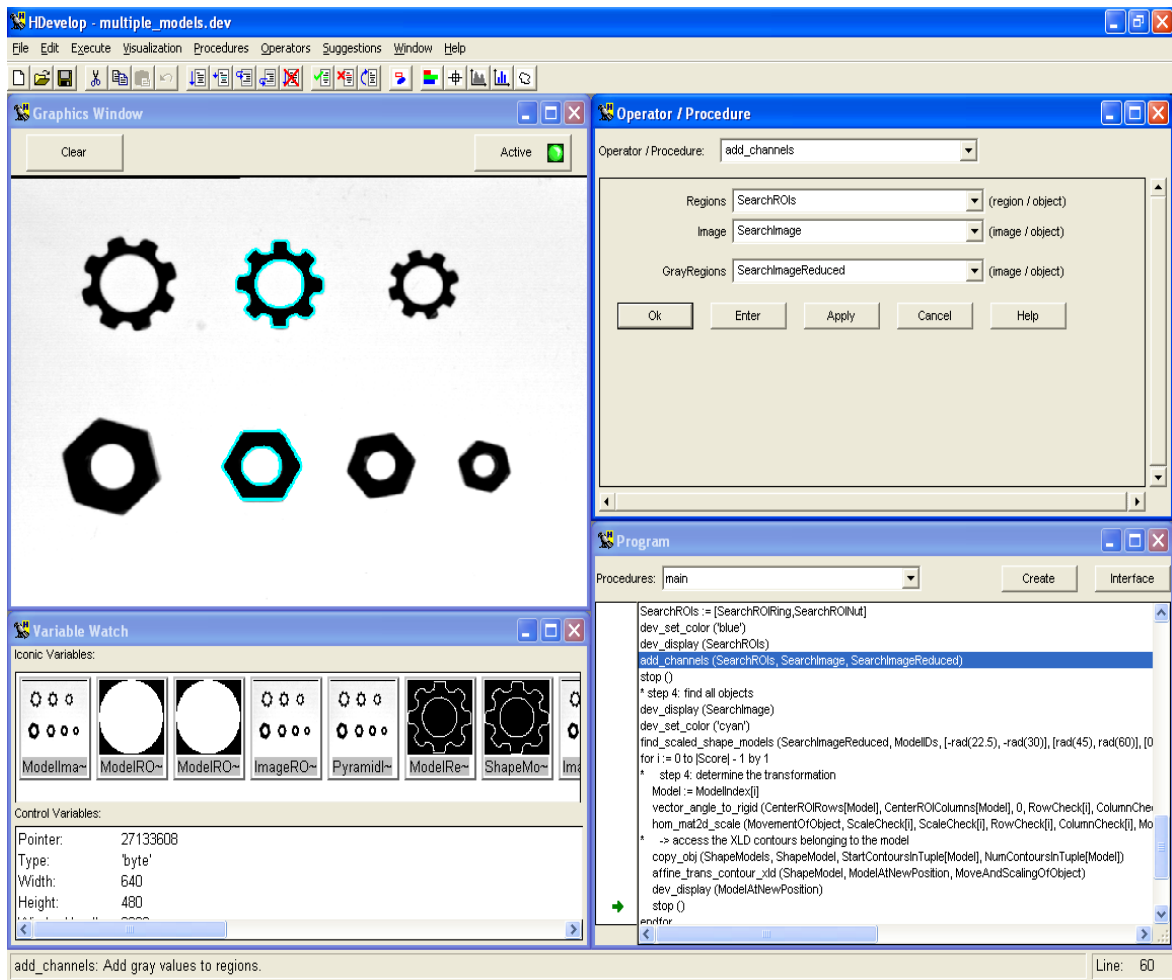
# APPENDIX C


# SOFTWARE GUIDE

**Appendix C1 – Software Guide (HALCON)**

HALCON is software specifically used for image processing design and development. It consists of four main windows, Graphic Windows for image display, Program Windows for main program arrangement, Operator / Procedure Windows for program details and modifications, and Variable Watch Windows to show the detail values of the related variables.
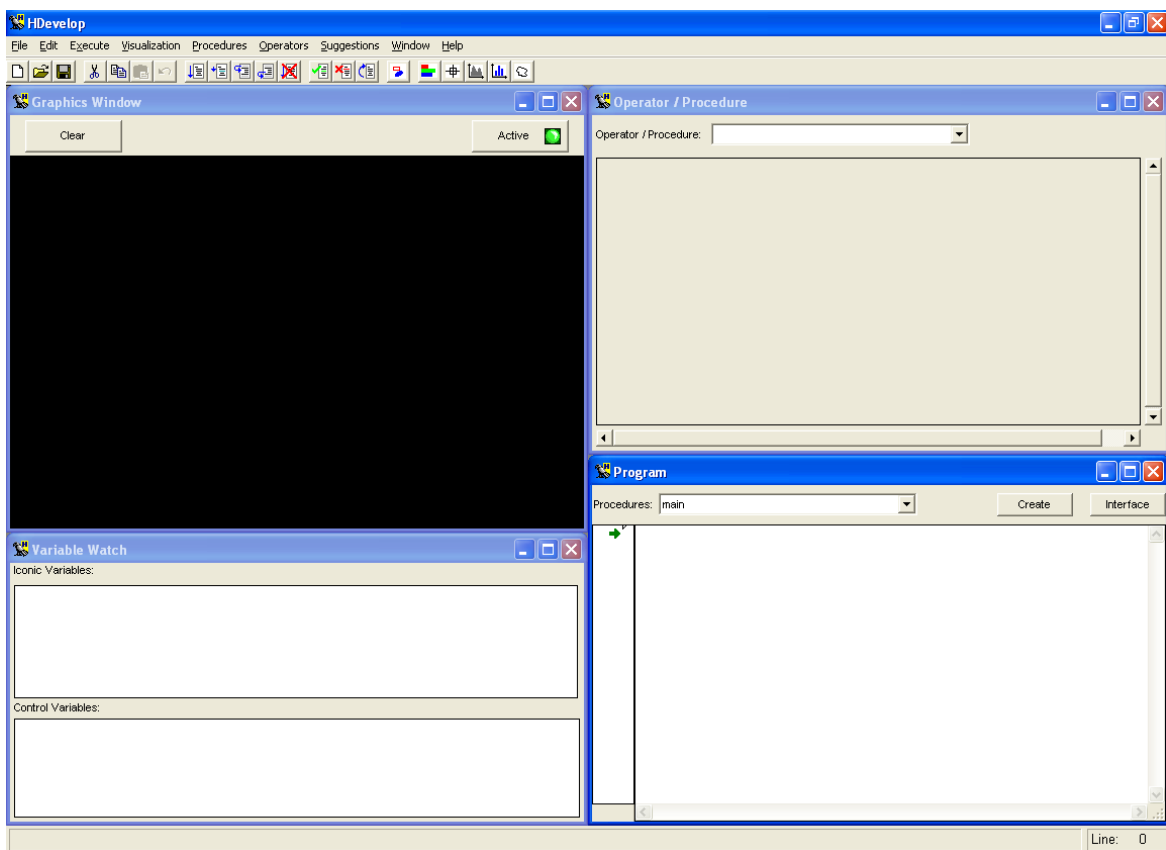


An example is shown; there are lines of programs and libraries available to be chosen from depending on users' requirements. All programs are written at the Program windows and each program lines can be modify by just double-clicking it, the details of each program lines or library can be then modified in the Operator / Procedure Windows. The Graphic Windows and Variable Watch Windows are mainly output of the resultant

programs. For detail explanations and guide, users are advised to refer to the users' guide

provided by HALCON.

**Appendix C2 – Software Guide (Visual Basic 6.0)**

Visual Basic is a C based language programming tools that are more oriented towards block by block programs that can be represented visually. It is a two layer programming method where one layer consists of line by line program instructions and the other layer is the visual representations of those programs. For example, first select the Command Button located in the tools workspace on the left hand side and draw it on the Form Window. Double click the button and the program instructions for that button will be shown, program specifications will depends on users' requirement. Plenty of detail guide and instructions can be found easily in books and internet.
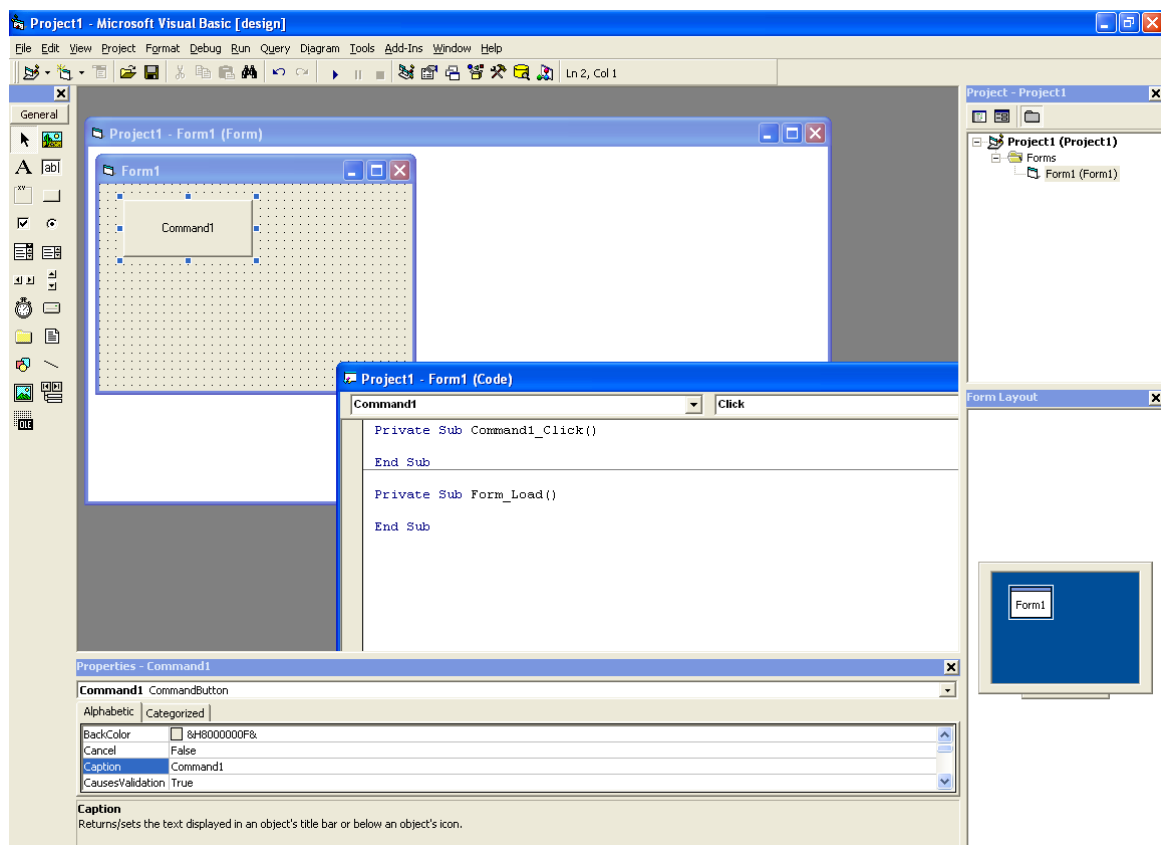
In order to incorporate HALCON's libraries into Visual Basic environments, first click on the project tab on the top of the Visual Basic Program and select the component tab. A window of the components tab will be shown.
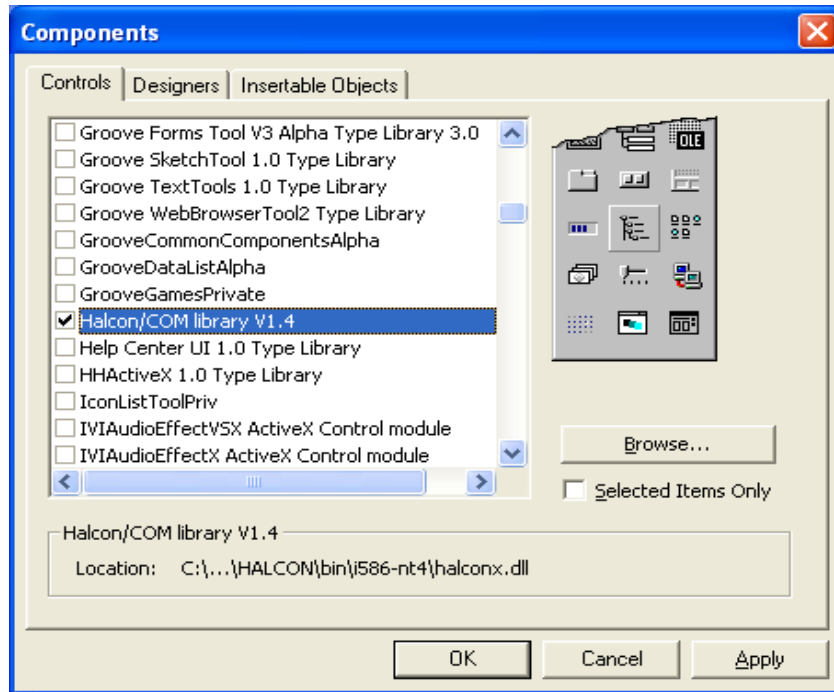


Select the Halcon/COM library tick box, press Apply and Close. An Additional Icon named HWindowXControl will then appear, this icon will be used to create the image display windows that are compatible with the HALCON library.
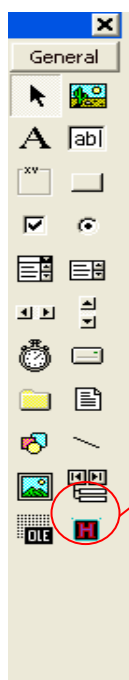
HWindowXControl

# APPENDIX D


# HARDWARE SPECIFICATIONS

# Appendix D - Hardware Specifications

| | |
|---|---|
| Camera | Samsung SDC-410 |
| Framegrabber | Matrix Vision, SIGMA-SLC |
| Computer | Intel® Core 2 Duo CPU 2.2 GHz<br><br>1 GB RAM |
| Robot Arm | 1. KUKA KR5 sixx R650 Robot Arm<br><br>2. Katana 6M Robot Arm |
| USB to Serial Converter | Any Brand |
| Necessary Connection Cables | Banana Plug Cable, Two Core Cable. |
| Power Supply | DC Power Supply (12V for cameras) |

Specification of Katana 6M Robot Arm

| Item | | | Specifications |
|---|---|---|---|
| Construction | | | Anodized aluminium |
| Degree of freedom | | | 6 axes |
| Drive system | | | DC motors with integrated digital position encoder |
| Maximum Speed | Arm | Axis 6 | 90°/sec (1.571 rad/s) |
| | | Axis 5 | 90°/sec (1.571 rad/s) |
| | | Axis 4 | 90°/sec (1.571 rad/s) |
| | Wrist | Axis 3 | 90°/sec (1.571 rad/s) |
| | | Axis 2 | 90°/sec (1.571 rad/s) |
| | | Axis 1 | 90°/sec (1.571 rad/s) |
| Payload | | | 400 g including gripper |
| Repeatability | | | ±0.1mm |
| Force | | | 4 N (in all direction) |
| Weight | | | 4.8 kg |
| Operating range area | | | 517 mm (without gripper) |
| Installation method | | | Floor, wall |
| Connection | | | Max 96 W (24V, 4A) |
| Standard Interfaces | | | Digital I/O, Ethernet, Modbus TCP/IP (additional I/O and PLC connection), USB, LAN, Soft Stop, UPS, C++ interface, support for Python |
| Software | | | Visual Basic 2008 |

Specification of KUKA KR5 sixx R650 Robot Arm

| Item | | | Specifications | |
|---|---|---|---|---|
| Maximum Reach | | | 653 mm | |
| Degree of Freedom (DOF) | | | 6 axes | |
| Mounting Position | | | Floor, ceiling | |
| Maximum Speed and Range | Arm | Axis 6 | 660°/sec (11.520 rad/s) | ±358° |
| | | Axis 5 | 410°/sec (7.156 rad/s) | ±120° |
| | | Axis 4 | 410°/sec (7.156 rad/s) | ±190° |
| | Wrist | Axis 3 | 375°/sec (6.545 rad/s) | +165°/-119° |
| | | Axis 2 | 300°/sec (5.236 rad/s) | +45°/-190° |
| | | Axis 1 | 375°/sec (6.545 rad/s) | ±170° |
| Payload | | | 5 kg | |
| Repeatability | | | ±0.02 mm | |
| Operating temperature | | | 0 $^0$C to +40 $^0$C | |
| Weight | | | 28 kg | |
| Noise level | | | <75 dB | |
| Connection | | | 2.5 kVA | |
| Software | | | KUKA Software | |

# APPENDIX E

# LIST OF PUBLICATION

1. M. H. Harun, M. Sulaiman, H. N. M. Shah & L. W. Teck, **"Shape-based Matching: Defect Inspection of Glue Process in Vision System**", in IEEE Symposium on Industrial Electronics and Application (ISIEA), Langkawi, Malaysia, Sept 2011.

2. M. H. Harun, M. Sulaiman & H. N. M. Shah, **"Shape-based Matching: Application of Edge Detection Using Harris Point"**, in International Conference on Robotic Automation System (ICORAS), Kemaman, Malaysia, May 2011.

**3.** M. H. Harun, M. Sulaiman & H. N. M. Shah, **"Shape-based Matching: Application of Defect Detection"**, in Malaysian Technical Universities International Conference on Engineering & Technology (MUICeT), Batu Pahat, Malaysia, Nov 2011.

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