DESIGN OF AUTOMATED BOTTLE DEFECT DETECTOR FOR QUALITY INSPECTION

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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FACULTY OF INDUSTRIAL AND MANUFACTURING TECHNOLOGY AND ENGINEERING

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BORANG PENGESAHAN TAJUK INDUSTRI BAGI PROJEK SARJANA MUDA

Tajuk PSM: Design of Automated Bottle Defect Detector for Quality Inspection

Nama Syarikat: Tropical Bioessence Sdn. Bhd.

Sesi Pengajian: 2023/2024

Adalah saya dengan ini memperakui dan bersetuju bahawa Projek Sarjana Muda (PSM) yang bertajuk seperti di atas adalah merupakan satu projek yang dijalankan berdasarkan situasi sebenar yang berlaku di syarikat kami sepertimana yang telah dipersetujui bersama oleh wakil syarikat kami dan penyelia serta pelajar dari Fakulti Teknikal dan Kejuruteraan Industri dan Pembuatan, Universiti Teknikal Malaysia Melaka yang menjalankan projek ini.

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DECLARATION

I hereby, declared this report entitled "Design of Automated Bottle Defect Detector for Quality Inspection" is the result of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Industrial and Manufacturing Technology and Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The members of the supervisory committee are as follow:

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ABSTRAK

Dalam industri kosmetik yang sangat kompetitif, memastikan kualiti produk adalah penting untuk mengekalkan reputasi jenama dan kepuasan pelanggan. Salah satu masalah utama dalam industri kosmetik ialah memastikan botol plastik minyak wangi yang digunakan bebas daripada kecacatan permukaan dan struktur. Di industri tempat kajian ini dijalankan, iaitu di Tropical Bioessence Sdn. Bhd., isu utama bagi pemeriksaan kualiti botol ialah pemeriksaan manual oleh manusia yang lambat dan tidak tepat. Kajian ini mencadangkan kaedah berdasarkan visi mesin untuk mengenal pasti kecacatan permukaan dan struktur yang terdapat pada botol semburan pelbagai guna dan menyusun botol yang cacat. Industri juga menetapkan beberapa keperluan untuk sistem ini, iaitu sistem mesti mempunyai ketepatan tidak kurang daripada 95%. Objektif kajian adalah untuk pertama, mereka alat pengesan kecacatan botol automatik yang dapat membantu dalam mengenal pasti dan menyusun botol yang cacat serta menganalisis keberkesanan dan prestasi sistem yang direka. Projek ini dijalankan dalam skop ini di mana sistem pemeriksaan visi mesin untuk mengenal pasti kecacatan permukaan pada botol direka menggunakan MATLAB di makmal FTKIP dan analisis keberkesanan serta prestasi sistem akan dinilai di kemudahan industri tersebut. Sistem pemeriksaan menggunakan pengambilan imej dari kamera digital dan pemprosesan serta analisis imej dilakukan melalui perisian MATLAB. Kamera USB akan menangkap imej digital dan imej-imej digital ini akan ditentukan oleh MATLAB mengenai kriteria kecacatan botol menggunakan kaedah pengesanan hitam dan putih dengan ambang 0.5, 0.4, 0.3, 0.2 dan 0.1. Telah ditentukan bahawa ambang 0.2 adalah yang paling sesuai dan digunakan untuk ujian ketepatan. Alat pengesan kecacatan botol automatik berjaya mencapai ketepatan lebih daripada 95% untuk setiap kumpulan yang diperiksa. Walau bagaimanapun, jumlah proses pemeriksaan adalah sedikit lambat sebanyak satu minit berbanding pemeriksaan manual. Oleh itu, untuk meningkatkan kelajuan sistem, disarankan untuk menggunakan dua kamera USB untuk mempercepatkan proses pengambilan imej.

ABSTRACT

In the highly competitive cosmetic industry, ensuring product quality is paramount to maintaining brand reputation and customer satisfaction. One of the main issues in the cosmetic industry is to ensure the perfume plastic bottles used are free of surface and structural defects. At the industry the study is being conducted at, Tropical Bioessence Sdn. Bhd., the main issue for quality inspection of bottles is that manual inspection by humans is slow and is inaccurate. This study proposes a method based on machine vision for the identification of surface and structural defects present on multi-purpose spray bottles and sorting the defective bottles. The industry also set some requirements for the system to meet which is the system must have an accuracy of not less than 95%. The objectives are to first, design an automated bottle defect detector that can aid in identifying and sorting defective bottles as well as to analyse the effectiveness and performance of the system designed. The project is conducted within these scopes whereby a machine vision inspection system to identify surface defect on bottles is designed using MATLAB at the FTKIP lab and analysis of the system's effectiveness and performance will be evaluated at the industry's facilities. The inspection system utilizes image acquisition from digital cameras and the image processing and analysis is done via the MATLAB software. The USB camera will capture the digital images and these digital images will be determined by MATLAB regarding defects criteria of the bottles using black and white detection method using thresholds of 0.5, 0.4, 0.3, 0.2 and 0.1. It is determined that threshold 0.2 is the most suitable and is used for the accuracy testing. The automated bottle defect detector manages to obtain an accuracy of more than 95% for every batch inspected. However, the inspection total process is slightly slower by one minute compared to manual inspection. Therefore, to improve the speed of the system, it is recommended to use two USB cameras to speed up image acquisition process.

DEDICATION

Only

my beloved father, Ismail Bin Mohammad

my appreciated mother, Norriah Binti Mdshariff

my adored sisters, Siti Rohana and Nur Nadiah

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

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In the name of ALLAH, the most gracious, the most merciful, with the highest praise to Allah that I manage to complete this final year project successfully despite all the hardships and setbacks that I had during my Bachelor Degree studies. During the implementation of this study I learned a lot of new knowledge and valuable experience which I will use to help me in my career in the future.

I would like to thank my family for their undying support during this semester. I want to convey my appreciation and gratitude to my supervisor Dr. Aidawaty Binti Rafan, for her continuous support, valuable advice and guidance to which without it I will surely never be able to complete this Final Year Project.

I want to express my deepest appreciation towards Encik Khairil Bin Said the owner and founder of Tropical Bioessence Sdn. Bhd. for allowing me to conduct this study at his facilities. His unwavering support played a crucial role in shaping this work.

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LIST OF ABBREVIATIONS

FYP	-	Final Year Project
YOLO	-	You Only Look Once
OpenCV	-	Open Computer Vision
B&W	-	Black and White
FTKIP	-	Faculty of Industrial & Manufacturing Technology & Engineering

LIST OF SYMBOLS

°	-	Degree (angle)

CHAPTER 1

INTRODUCTION

This first chapter presents the introduction whereby the project background, problem statement, objectives and scope of study. The project background elaborates on the usage of multi-purpose spray and the means of quality inspection for it. The problem statement describes the issues faced by the industry that resulted in this study's creation. The objectives represent this study's aims and main goal while the scope of project identifies the project's focus and limitations. The summary of methodology explains about the system's components and how it will be implemented.

1.1 Project Background

Spray bottles are commonly used for spraying detergents, disinfectants and other liquids, including viscous liquids, into difficult to reach areas as well as perfumes. Spray bottles are made from clear polyethylene terephthalate (PET) material which lightweight, chemically resistant and has excellent durability (Briga-Sá et al., 2023). The bottles are commonly made from injection moulding or blow moulding process which are able to produce lightweight and durable plastic components suitable for the spray bottle application (Luo et al., 2022). However, this process is not perfect and some defects may be produced during the production process.

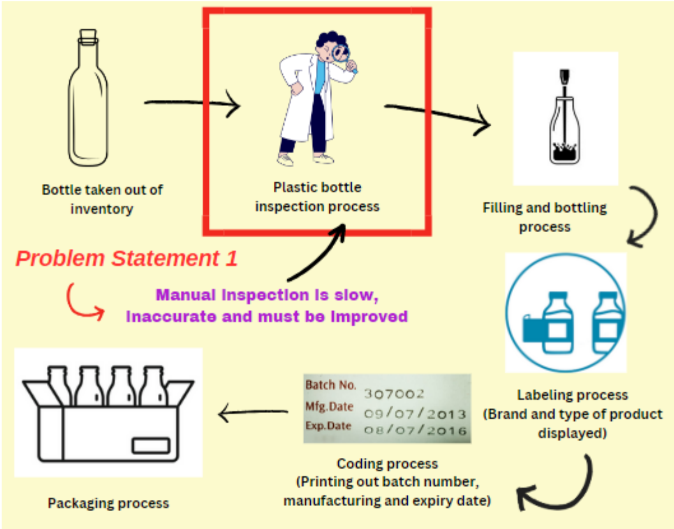


Figure 1.1: Overall multi-purpose spray bottling process

Figure 1.2: Multi-purpose spray bottle

At Tropical Bioessence Sdn. Bhd. the process of bottling multi-purpose spray is shown in Figure 1.1 while in Figure 1.2 shows the multi-purpose spray bottle used by the company. The bottling process starts off with retrieving the bottles from the inventory and then conducting manual inspection on the bottles to observe for any defects. Once determining all the bottles are checked properly for defects, the good bottles are then sent to the filling room. At the filling room, the bottles are filled with the aromatic spray liquid and are bottled (cap screwed on tightly). Next, the bottles are labelled with the company's brand and product name. Afterwards, bottles enter the coding room where the batch number, manufacturing and expiry date are printed on the labels. Lastly, the finished bottles are packaged accordingly, and waiting for delivery to customers. This study will on the plastic bottle inspection process.

1.2 Problem Statement

Some products use a standard 200ml spray bottle that is produced by local suppliers and sometimes have surface defect as shown in Figure 1.3.

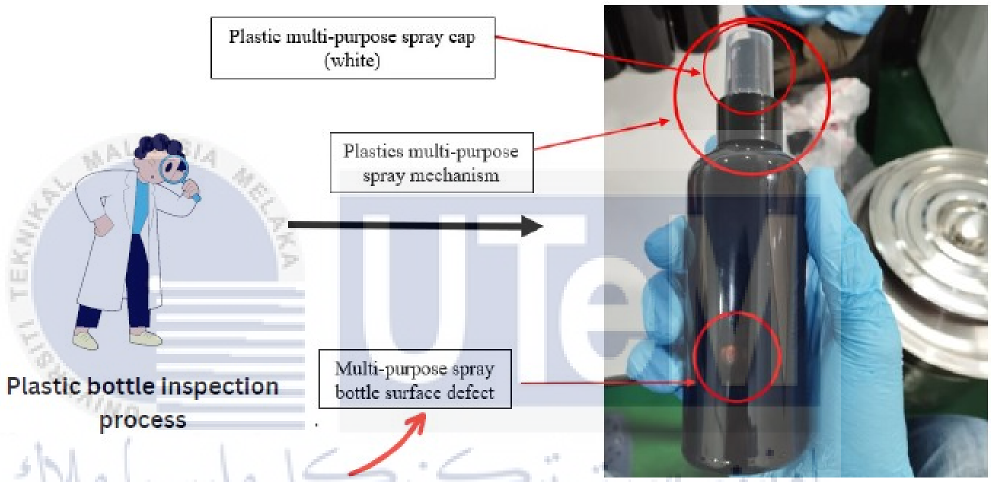


Figure 1.3: Current manual plastic bottle inspection process

Some companies employ manual inspection as a method to prevent defective bottle from entering the production line. This method takes time and can also be inaccurate at times which may result in potential customers avoiding purchasing the product or at worse the wholesaler of the product may reject the whole batch. Therefore, the automated bottle defect detector is aimed to ease the monitoring of defective bottles in order to increase quality control efficiency.

Other than that, the industry has laid out some criteria for the automated bottle defect detector to meet. It needs to be able to have an accuracy of more than 95% or only wrongfully detecting one bottle among a batch of 30 bottles. In short, these are the criteria for acceptance for the system or in other words the second problems statement.

1.3 Objectives

1. To design an automated bottle defect detector that can aid in identifying and sorting defective bottles.
2. To analyse the effectiveness and performance of the system designed.

1.4 Scope of Project

1. Design a machine vision inspection system using MATLAB at FTKIP lab in order to identify surface defects on bottles and indicate the location of defects.
2. The analysis of the system's effectiveness and performance will be evaluated at the industry (Tropical Bioessence Sdn. Bhd.).

CHAPTER 2

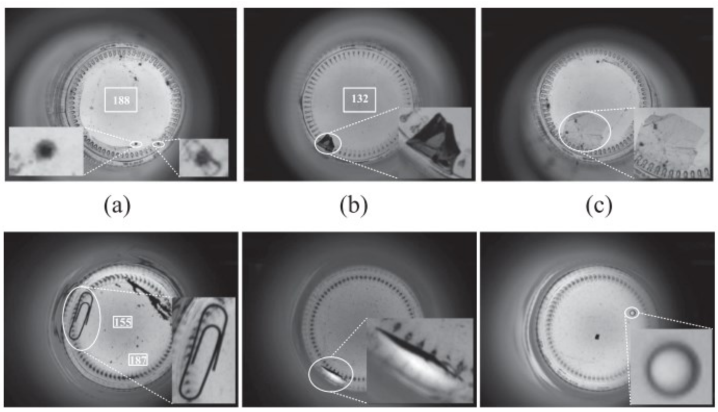
LITERATURE REVIEW

Chapter 2 presents a summary of current research papers, articles and journals regarding this study. It will mainly focus on these topics which are types of bottle defects present on bottles, advantages of machine vision system for quality inspection, comparison between manual inspection method and automatic inspection method and quality inspection process.

2.1 Types of Bottle Defects Present on Bottles

Due to blow moulding process, plastic bottles may have surface defects that such as discolouration (Rahman et al., 2018). This type of defects causes the walls of the bottles (where the discoloration occurs) to be thinner than other parts. This produces structural defects on the bottle thus weakening it.

Moreover, as stated by Zhou et al. (2020), there are many defects for glass bottles such as cracks, structural misalignment and bubbles as shown in Figure 2.1.



(a) (b) (c)

(d) (e) (f)

Figure 2.1: Typical defects of glass bottle bottoms. (a) Smudginess. (b) Glass detritus. (c) Transparent film. (d) Paperclip. (e) Damaged bottom. (f) Bubble. (Zhou et al., 2020)

These types of defects and errors plague the bottling industries that uses glass bottles. Thus, measures are needed to ensure they do not end up in the production line whereby this will cause problems during quality control or at worst may end up at consumer.

2.2 Advantages of Machine Vision System for Quality Inspection

Utilization of machine vision software/system is necessary in order to increase the accuracy and precision for the quality inspection for products in an industrial setting (Chang et al., 2021). Machine vision also aids in detail inspection for defects in quality control for printed circuit board (PCB) as the system is able to detect small defects that is difficult to observe through the naked eye as shown in Figure 4 (Zhang & Liu, 2021).

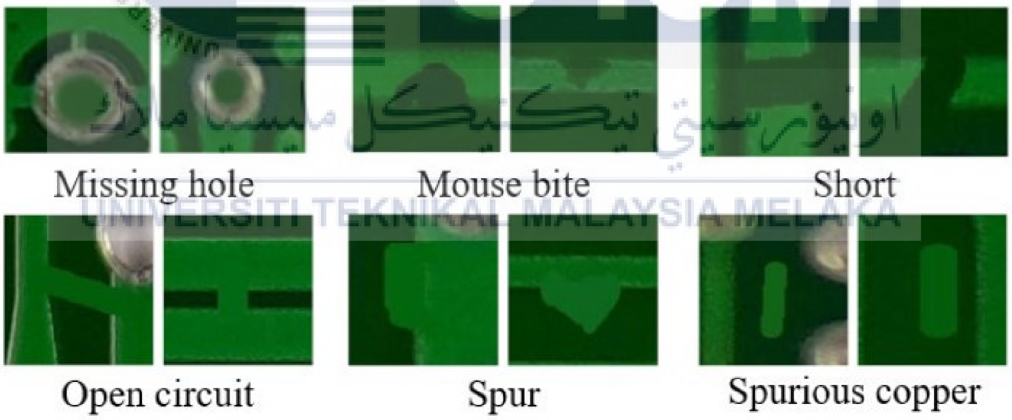


Figure 2.2: Types of defects present on PCB (Zhang & Liu, 2021)

These types of defects such as missing holes, mouse bites, short, open circuit and others are very small defects that occur on PCB which are really difficult to detect manually with the naked eye. Using machine vision systems for quality inspection helps maintain consistent inspection standards as the system can operate 24/7 or all day long without rest Chow et al. (2021) and Runji & Lin (2019).

Other than that, machine vision system for quality inspection has high adaptability and flexibility whereby the system can be programmed to accommodate new product design and variations in defects making it versatile for different manufacturing applications C. Li et al. (2023) and Wang et al. (2021).

Furthermore, machine vision system can be utilize to produce a quality inspection system that can constantly detect defects present on surfaces of products (Azamfirei et al., 2023). This inspection system is faster and can be used throughout the day and is a better option than relying on human inspection that is inefficient and oftentimes inaccurate (Lv et al., 2020).

Lastly, Figure 2.3 shows sets of images that shows the detection of surface defects present on a workpiece whereby (a) – represents the side view of the workpiece, (b) – represents the image pre-processed using grayscale, (c) – shows the regions of interest with threshold ranges and (d) – shows the defect detections (Xin et al., n.d.).

Figure 2.3: Workpiece surface detection with thresholding (Xin et al., n.d.)

2.3 Comparison Between Manual Inspection Method and Automatic Inspection Method

According to Song et al. (2022), the bearing surface defect detection based on machine algorithm have proven to be able to achieve an accuracy of 97.56% compared to using traditional methods. Utilization of machine vision system allows the researcher to be able to increase the quality inspection accuracy, and improve speed of quality inspection process. Using machine vision for detecting defects on surfaces such as steel will is able to improve quality inspection (Uraon et al., 2022).

Manual inspection of concrete structures is difficult due to a large area needed to be inspected. Therefore, an automated defect inspection system is produced to aid in improving inspection accuracy 50% compared to manual inspection that takes too much time and is inaccurate (Chow et al., 2021). The inspection system has been shown with the utilization of machine vision will improve accuracy for defect detection purposes.

Compared to manual methods, using an automated computer vision system to detect shape defects has the capability of achieving an detection accuracy of up to 100% (Norhashimah Mohd Saad et al., n.d.). In this study, the system is able to detect the defects very accurately however it did not mention about the how long each detection in terms of inspection time. Therefore, the proposed automated bottle defect detector needs to include inspection time to ensure not only a more accurate but also a faster defect detection is produced.

Manual method is costly and inefficient while the automated defect detection of steel is cheaper and has a mean average precision of 67.09% which strikes a balance between precision in detection and speed of detection (C. Li et al., 2021). This balance is crucial as it meets industrial needs for a fast and accurate defect detection system. Automatic inspection is able to save operation cost as the system is more efficient in inspection large batches of product (Lin et al., 2021).

Machine vision based defect detection system of defective straws can overcome the inaccuracy and inefficiency of manual inspection (Ying et al., n.d.). The authors managed to obtain a detection rate of 98.8% which shows the capability of machine vision technology for quality inspections.

2.4 Quality Inspection Process

2.4.1 Image acquisition

Image acquisition is used by machine vision system to capture images of the intended product or item whereby its quality will impact the accuracy of the defect detection by the image processor (Xia et al., 2020). The researchers used an Xiris camera to detect welds defect in tungsten inert gas or TIG welding as shown in Figure 2.4.

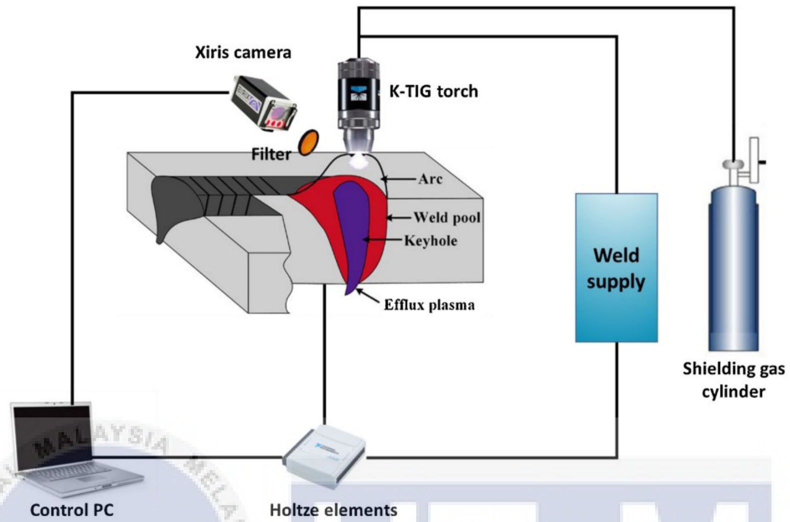


Figure 2.4: Schematic of experiment setup with the Xiris Camera (Xia et al., 2020)

Other than that, high resolution camera is used to ensure high quality digital images is captured in order to improve quality of defect detection (Ying et al., n.d.). High quality digital images ensure that small defects present on the workpiece is able to be detected by the inspection system. Having high quality camera helps increase accuracy and improves quality of data that will be analysed by the image processing software (Sharma et al., 2015).

Moreover, image acquisition for shape defect detection of bottles can be conducted using a 12-megapixel webcam as shown in Figure 2.5. The camera is setup to face only one side of the bottle. However, in real scenario, two or more cameras may be needed to give a 360° image of the bottle to ensure accurate defect detection is conducted.

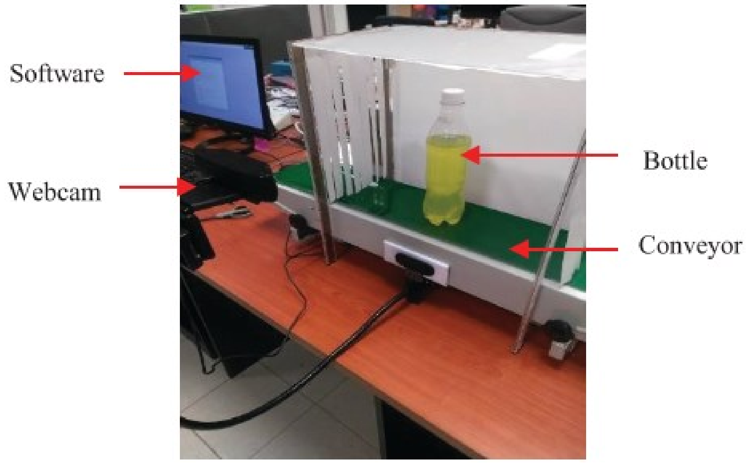


Figure 2.5: Setup of shape bottle defect detection system with 12-megapixel webcam (Rahman et al., 2018)

Furthermore, the researchers used a digital camera in order to capture weld penetration and send feedback to the controller unit (Peng et al., 2021).

The setup of the digital camera is placed under the workpiece in order to capture images of the weld penetration as shown in Figure 2.6. According to Peng et al. (2021), the reasoning behind the camera's placement is to ensure the system is able to detect weld penetration on the other side of the workpiece or in other words, opposite to the weld surface.

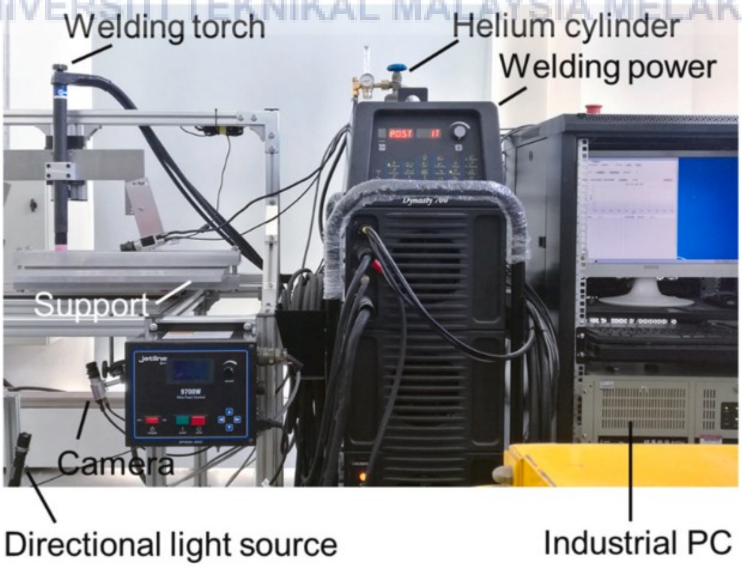


Figure 2.6: Weld penetration detection system with digital camera (Peng et al., 2021)

Figure 2.7 shows a 360° camera used for the purpose of capturing digital images of defects on concrete structures. The location of the camera is above the researcher as to not gain a better field of view (Chow et al., 2021).

Figure 2.7: Automated defect inspection of concrete structure setup with 360° camera (Chow et al., 2021)

Figure 2.8 shows the usage of industrial cameras in order to capture digital images of surface defects on workpiece. The setup used by the researcher uses up to seven Hikvision industrial cameras to ensure a complete image acquisition is produced.

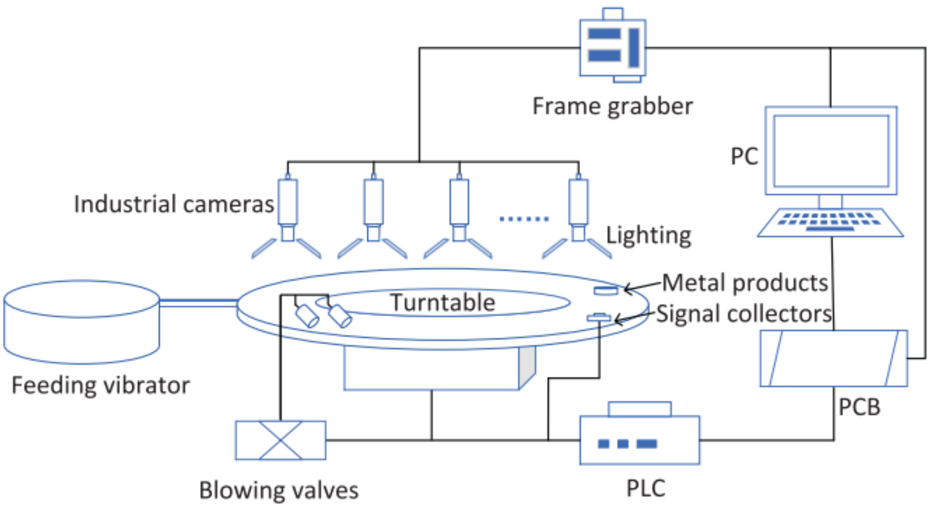


Figure 2.8: Surface defect detection system using seven Hikvision industrial cameras (Xin et al., n.d.)

Figure 2.9 shows the setup for a detecting empty and filled bottle using 3 cameras. Three cameras are used to observe the water level inside the bottles whereby cameras 1 and 3 are used to observe if the bottle is empty or not while camera 2 is used for observing the water level of the bottle (Sharma et al., 2015).

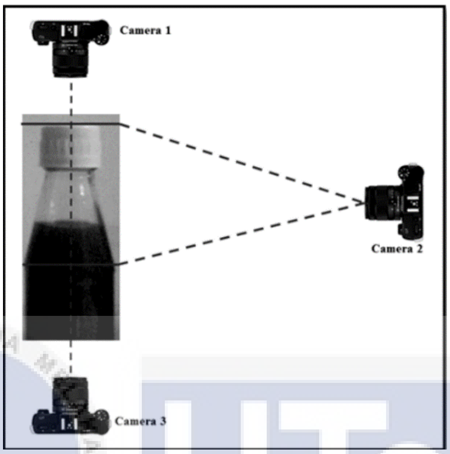


Figure 2.9: Setup for empty and filled bottle detection system with 3 cameras (Sharma et al., 2015)

2.4.2 Image processing

2.4.2.1 MATLAB

Figure 2.10 shows the hardware system process of the shape defect detection system used by the researchers in (Rahman et al., 2018). This system uses MATLAB as an image processing software whereby it will analyse the images captured by the webcam and identifies the defectives bottles.

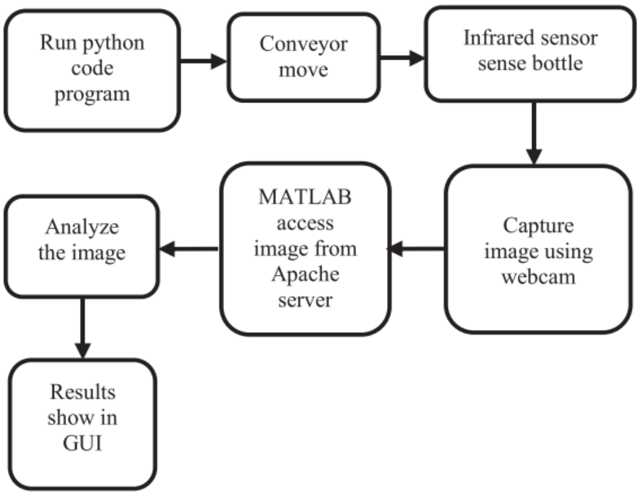


Figure 2.10: Hardware system process with MATLAB (Rahman et al., 2018)

Moreover, MATLAB can be utilized to identify defects on digital images of glass bottles as shown in Figure 2.11. Grayscale technique is used to isolate defects (white colour – 3(d)). This enables the system to quickly identify the defective bottles. This shows that the MATLAB software is capable to be used for the proposed system.

Figure 2.11: Defects identified using gray scaling through MATLAB software (Fu et al., 2019)

2.4.2.2 YOLO system

The YOLO system in image processing allows the user to produce an algorithm to serve their purpose, be it image detection, object detection, colour detection and especially defect detection on objects. Figure 2.12 shows the results of utilizing the YOLO v4 variant of the software whereby the software is able to detect a variety of defects such as scratches, patches, inclusions and others. This shows that YOLO software is a candidate to be used in the proposed system.

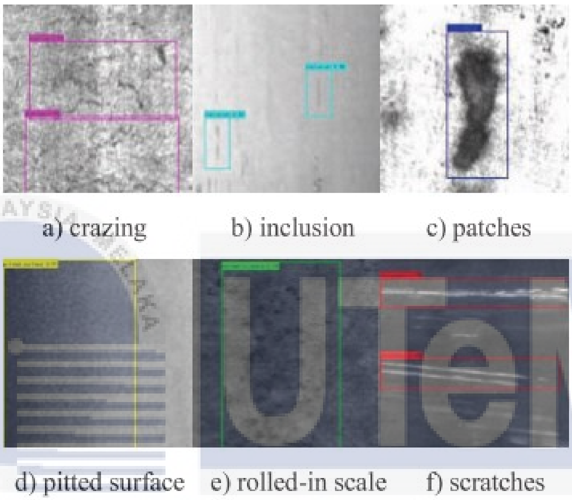


Figure 2.12: Results of surface defects on steel via YOLO v4detection system (C. Li et al., 2021)

Next, the YOLO v5 variant of the YOLO system is also used in detection of defects occurring on steel workpiece as shown in Figure 2.13 whereby there are many samples of metal material used to test the algorithm out in order to improve the detection system.

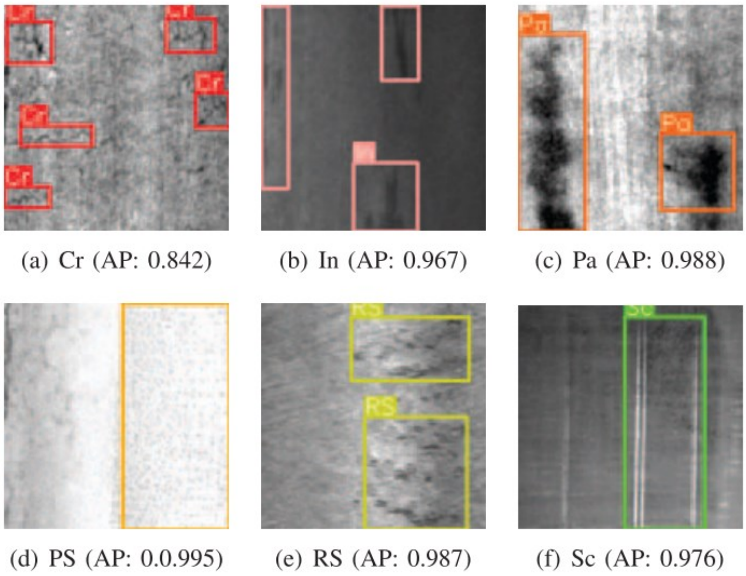


Figure 2.13: Defects detected on many samples of metal (Huang, 2023)

2.4.2.3 OpenCV

For OpenCV software, there many papers that uses this software in order to detect defects on products or workpieces that require quality inspection. According to (Hang et al., 2020), the researcher used edge detection and grayscale in order to teach the algorithm to detect defects on surfaces of sanitary ceramic products. This shows that OpenCV is also a candidate that can be used for the proposed system.

Figure 2.14 shows the process of the system used by the researchers in order to identify the defects occurring on the sanitary ceramics.

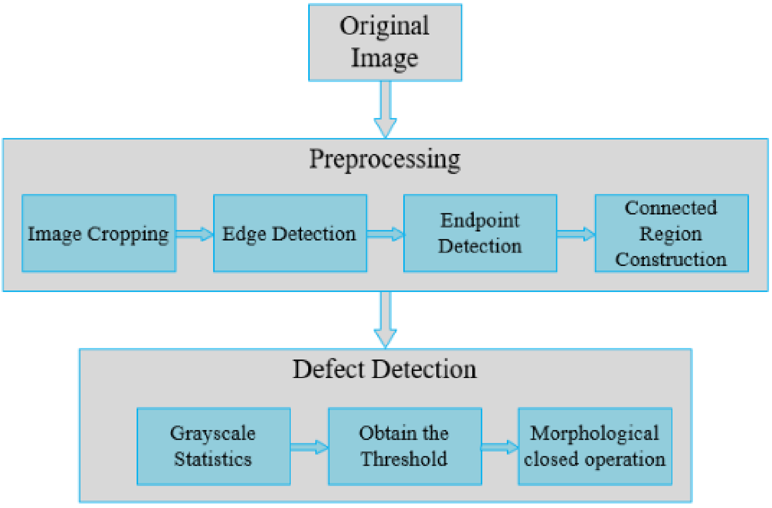


Figure 2.14: Process used defect detection (Hang et al., 2020)

Figure 2.15 shows the overview of the research conducted regarding an automated defect detection of gas turbine blades that uses OpenCV as an image processing system (Aust et al., 2021). The study obtained an accuracy of 83% for a test sample size of 60 turbine blades.

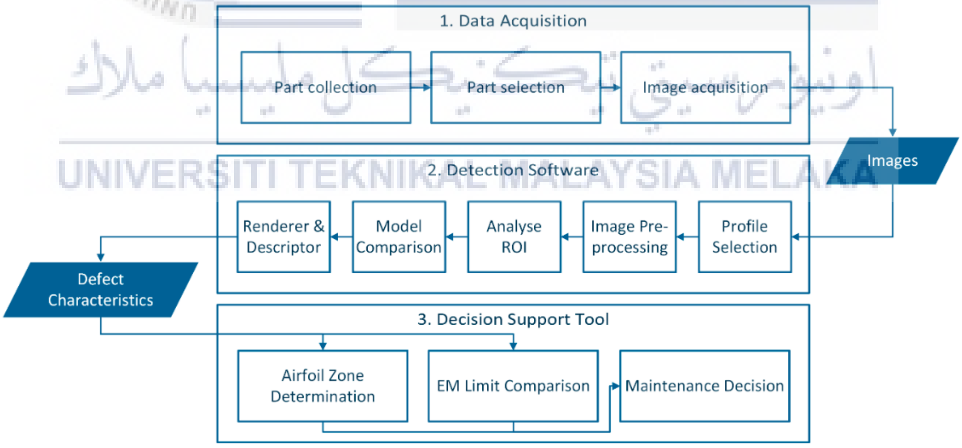


Figure 2.15: Overview of research used in (Aust et al., 2021)

MATLAB is preferably used for this project as it is available for students to use in the FTKIP lab and is complete with multitude of functions that can aid in the development of the defect detection system based on machine vision.

2.4.3 Lighting

Figure 2.16 shows the setup for a defect detection system that utilizes an industrial camera that is used to detect bubble defects in glass. Lighting is important as the camera requires adequate lighting to be able to capture quality digital images that will be used for image analysis by the image processor Zheng et al. (2021) and Z. Li et al. (2018). If lighting is neglected, errors and inaccuracies will occur in defect detection as the camera is not able to capture detailed images of defects (Chen et al., 2021).

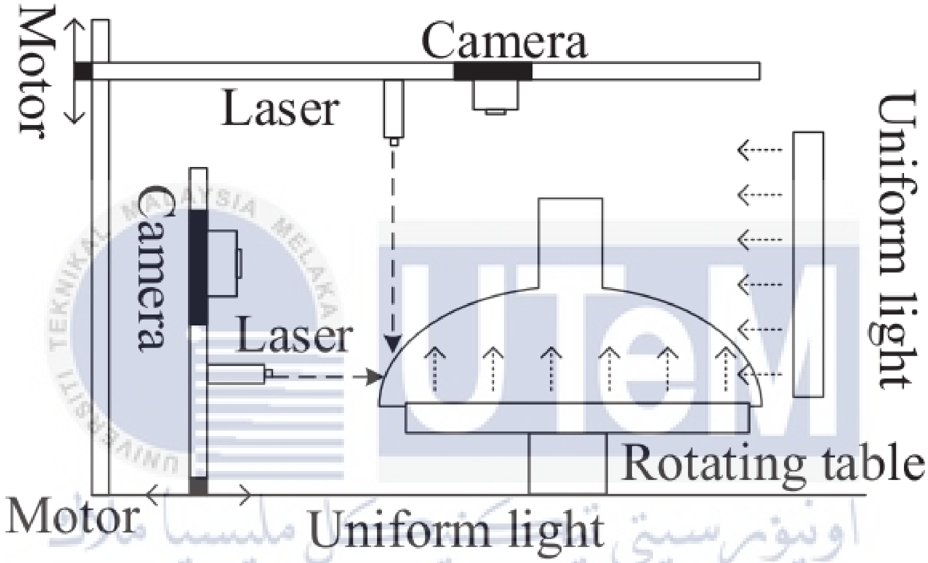


Figure 2.16: Setup for bubble defect detection system with industrial camera (Zheng et al., 2021)

Lighting structure for machine vision is important as lighting or intensity of light can effect quality of digital image captured for image processing purposes (Yi-Fan et al, n.d.). Figure 2.17 shows the lighting system used by the authors utilizes light bars arranged in square circle that will ensure proper illumination for image acquisition process.

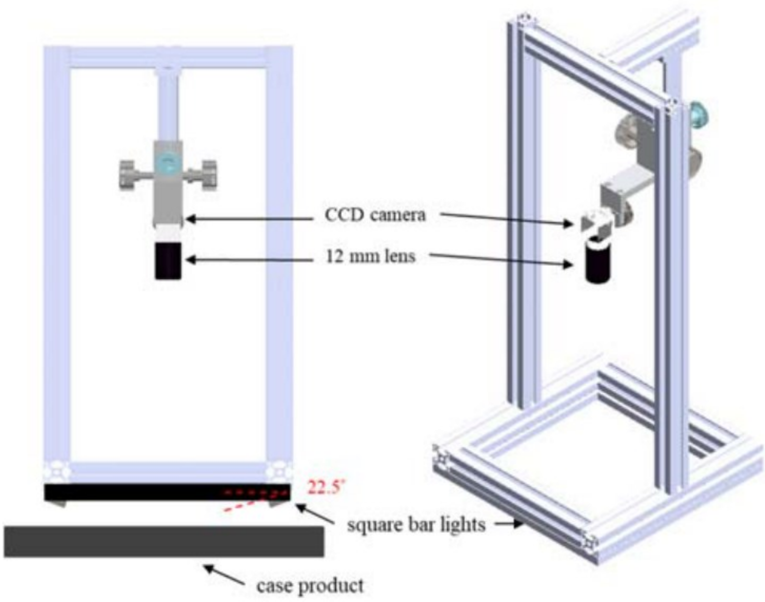


Figure 2.17: Lighting structure (Yi-Fan et al, n.d.).

CHAPTER 3
METHODOLOGY

Chapter 3 presents the methodology of this study which will consist of the project process flow, project timeline, methods to collect data, experimental design and analysis.

3.1 Project Planning

This section of the methodology details the steps involved in completing the Final Year Project or FYP 1. This includes the flowchart of study, time line for FYP 1 and FYP 2 in a form of a Gantt Chart, system requirements, experimental design, experimental setup and expected outcome.

3.2 Flowchart of Study

Figure 3.1 shows the project flowchart that involves identifying problem statements, conducting literature review and developing methodology which consists of identifying tools, equipment and software to be used for the systems. Afterwards, the creation of the automated bottle defect detector will be conducted while the inspection system via MATLAB will be done. Then, preliminary testing will be done to ensure the inspection system's readiness for industry trial testing. When the preliminary testing is done, the inspection system is tested out at the industry to see its feasibility. The inspection system is considered acceptable according to the industry's set requirements.

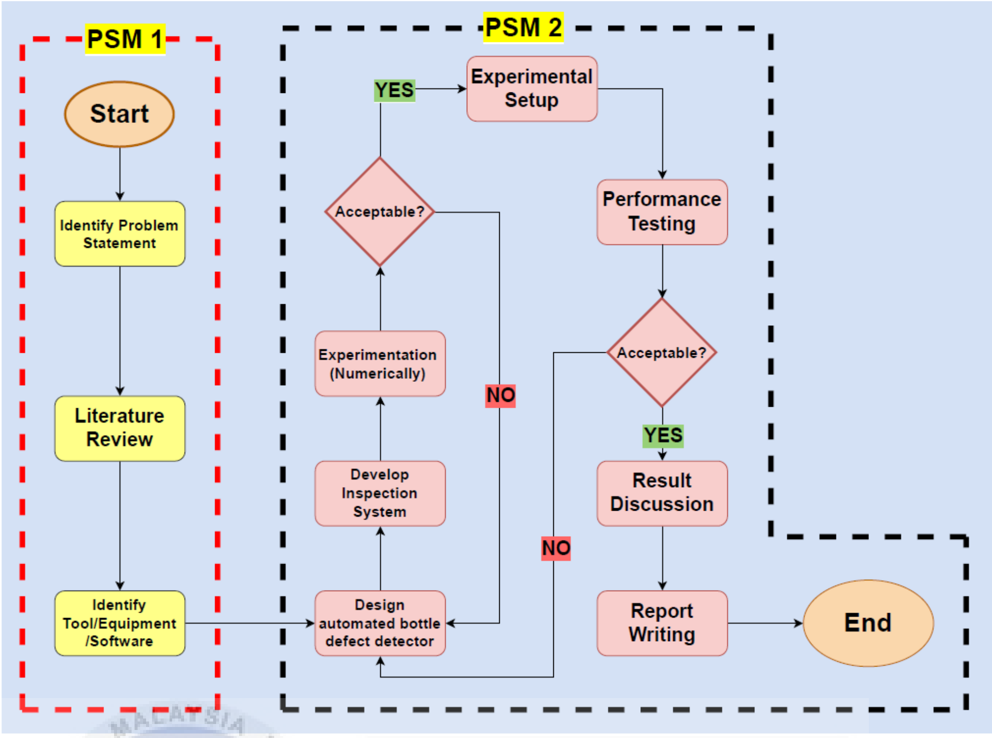


Figure 3.1: Flowchart of study

3.3 Gantt Chart

The Gantt Chart in figure 3.2 shows the timeline for Final Year Project 1 and 2. The duration is of the project is illustrated in order to ensure that the project is conducted in a timely manner and without delay.

1	**Bachelor Degree Program 1 & 2 (PSM1 & PSM2) Automatic bottle defect detector**	**185 days**	**Mon 10/9/23**	**Fri 6/21/24**	
2	**Start of PSM 1**	**75 days**	**Mon 10/9/2:**	**Fri 1/19/24**	
3	Research and Literature Review	20 days?	Mon 10/9/23	Fri 11/3/23	
4	Methodology & Feasibility Study	10 days?	Mon 11/6/23	Fri 11/17/23	3
5	Design product concept	20 days?	Mon 11/20/23	Fri 12/15/23	4
6	Documentation	15 days?	Mon 12/18/2	Fri 1/5/24	5
7	Finished Product Presenation and Final PSM Report 1 Submission	10 days?	Mon 1/8/24	Fri 1/19/24	6
8	Milestone: End of PSM 1	0 days	Fri 1/19/24	Fri 1/19/24	7
9	Semester Break & Material Purchase	37 days?	Fri 1/19/24	Mon 3/11/24	
10	**Start of PSM 2**	**74 days**	**Tue 3/12/24**	**Fri 6/21/24**	
11	Project Making	30 days	Tue 3/12/24	Mon 4/22/24	
12	Testing	15 days	Tue 4/23/24	Mon 5/13/24	11
13	Analysis	13 days	Tue 5/14/24	Thu 5/30/24	12
14	Evaluation and Improvement	10 days	Fri 5/31/24	Thu 6/13/24	13
15	Supervisor & Panel Approval	5 days	Fri 6/14/24	Thu 6/20/24	14
16	Finished Product Presentation & Final Report Submission Day	1 day	Fri 6/21/24	Fri 6/21/24	15
17	Milestone: End of PSM 2	0 days	Fri 6/21/24	Fri 6/21/24	16

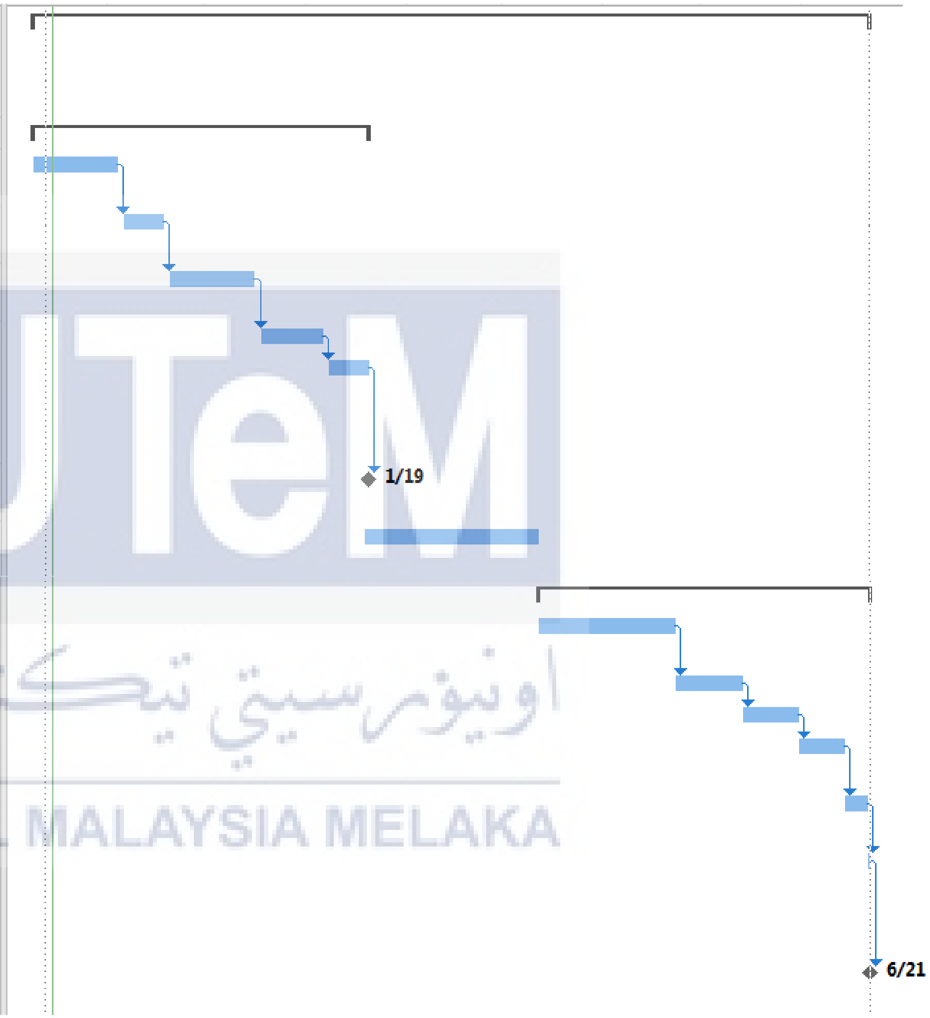


Figure 3.2: Gantt Chart of FYP 1 and FYP 2

3.4 System Requirements

Table 3.1: Table of System Requirements

No.	Equipment/Components/Software	Description
1.	Arduino UNO	This microcontroller is used to control the servomotor so that it rotates 180° (back and forth).
2.	5MP USB CMOS with Varifocal lens or the USB camera	The USB camera will be used to obtain 360° digital image of the multi-purpose spray bottle.
3.	Laptop and MATLAB software	Laptop that is installed with the MATLAB software will be used to initiate image processing functions for the inspection system.
4.	MG995 servomotor (Rotary Mechanism)	This servomotor will be used to rotate the bottles so that the USB camera can capture a 360° image of the multi-purpose spray bottle.
5.	Rechargeable light bar	This light bar will provide the adequate lighting/illumination for the USB cameras.
6.	White wall	The white walls are made from three pieces of white coloured mounting boards. They serve to provide a white backdrop to ease image processing.
7.	Power bank	To provide power for the Arduino UNO and the servomotor.

The first objective of this study is to design an automated bottle defect detector that can aid in identifying and sorting defective bottles. To achieve this, an automated inspection system is designed using these components which are one 5MP USB CMOS with Varifocal lens (USB camera), laptop, rechargeable light bar, rotary mechanism (MG995 servomotor controlled by Arduino UNO), white wall made from white coloured mounting board and power bank. This system is setup as shown in Figure 3.3.

Moreover, the second objective is to analyse the effectiveness and performance of the system designed. Here, the inspection system utilizes MATLAB to conduct the defect detection for the bottles using the black and white method to segment the image of bottles and utilize a bounding box to locate and determine a defect on the bottle.

3.5 Experimental Design

Figure 3.3 shows the experimental design setup for the automated bottle defect detector, the USB camera or the 5MP USB CMOS with Varifocal lens is connected to the laptop and linked with the MATLAB software. Here, the MATLAB software is able to capture images of the multi-purpose spray bottle through the USB camera and process the images according to the experiment parameters shown in Figure 3.5. The USB camera can be calibrated accordingly so that a clear and crisps image of the bottle is obtained. The rechargeable light bar is placed atop the white wall with the purpose of providing adequate illumination for the USB camera to capture quality images. The electronic case holder in Figure 3.4 shows the Arduino UNO and power bank which will control the servomotor for the rotary mechanism. The rotary mechanism is used to rotate the bottle 180° back and forth in order for the USB camera to capture the images of the bottle. Each bottle will have two images (front and back) and these images will be processed by MATLAB in order to determine the presence of surface defects. The bottles will be placed and removed from the rotary platform after two images (front and back) are captured. The system will indicate the presence of defects by using bounding box.

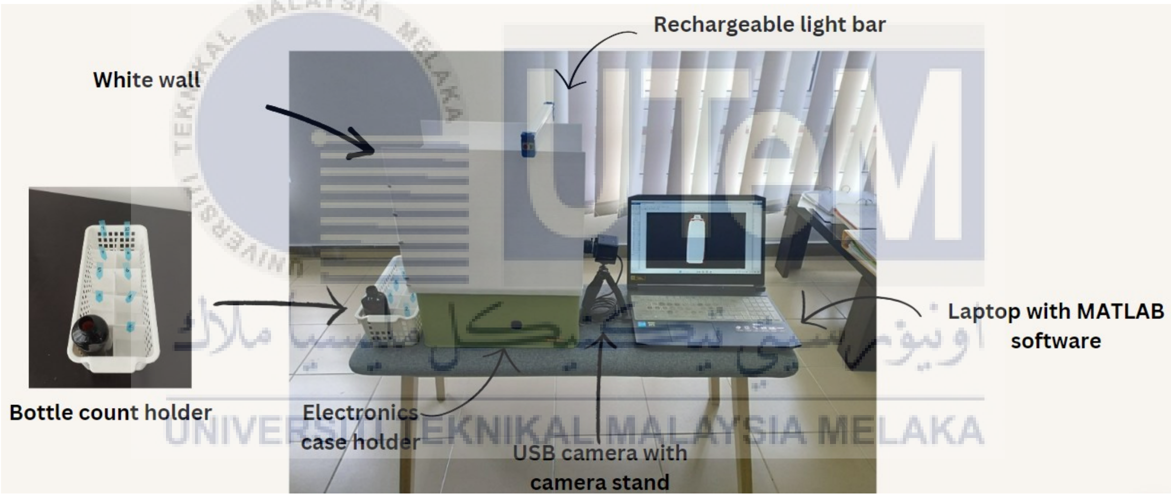


Figure 3.3: Experimental design setup

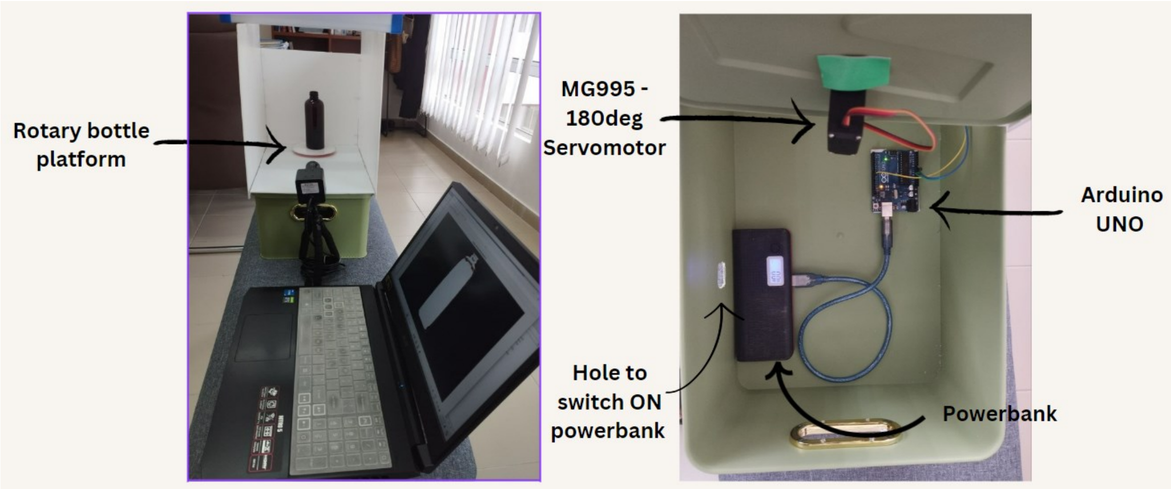


Figure 3.4: Rotary platform and internals of the electronic case holder

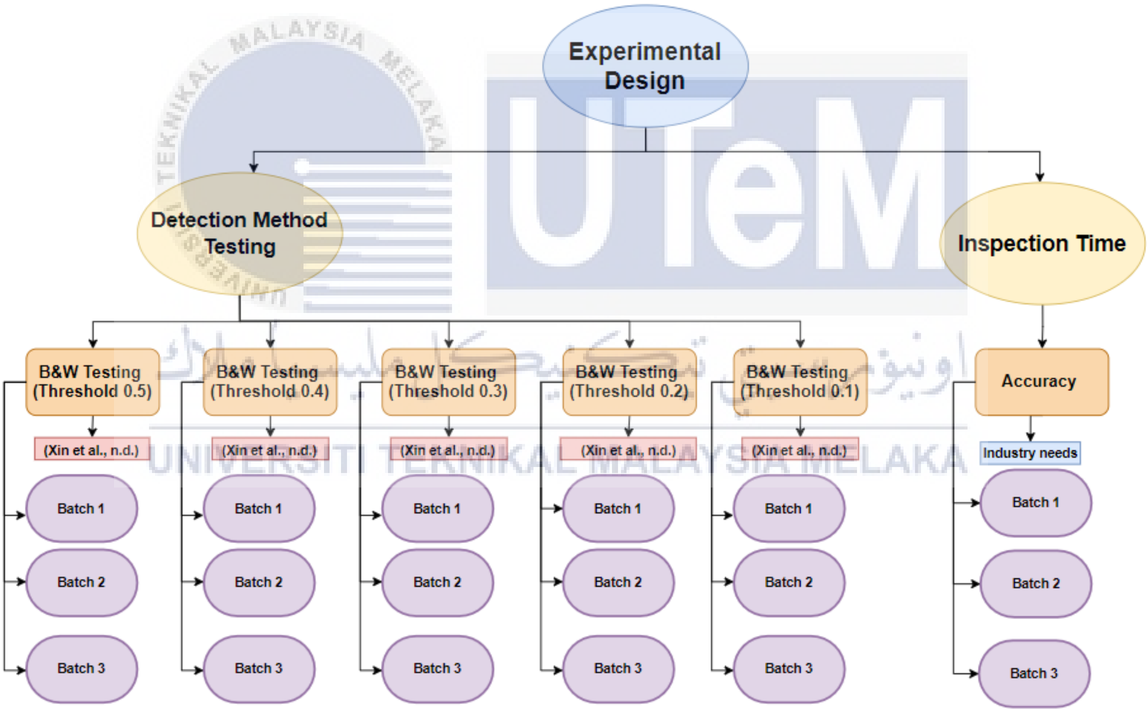


Figure 3.5: Experimental design for study

Figure 3.5 shows the experimental design for the study. The inspection system will utilize the black and white (B&W) testing method to detect and distinguish defects on bottles' surfaces. The threshold used are based on a study by Xin et al.(n.d.), whereby it uses a threshold with ranges from 0.5 to 0.1 for image processing and defect detection on workpiece surfaces. A threshold value between 0 and 1 is chosen. This value represents a fraction of the maximum intensity (255). For example, a threshold of 0.5 corresponds to an intensity value of 127.5 (0.5 * 255). Each batch contain a number of defective bottles and good bottles. The total number of bottles per batch is 30 bottles each.

The best threshold will then be selected for usage in the accuracy test whereby the aim is to have an accuracy of not more than one wrongful detection or above 95% accuracy and to be faster than manual testing. 95% accuracy means that the inspection system does not wrongfully identify bottles by not more than one time. If the inspection system produces errors of more than one per batch, that means the system need further development as the system does not meet industry requirements.

3.6 Quality Inspection System Procedure

The automated bottle defect detector utilizes the combination of USB camera with image processing software (MATLAB) to inspect surface defects on multi-purpose spray bottles. The USB camera captures the front and rear images of the bottle and these two images are processed by the software to check for defects. The rotary platform rotates the bottle so that the camera can take two 180° images (front and back) of the bottle. This pairing the inspection system (USB camera and MATLAB software) with the rotary mechanism allows for a more efficient image capturing process for a batch of bottles (30 bottles per one batch). Figure 3.6 shows the inspection process for the multi-purpose spray.

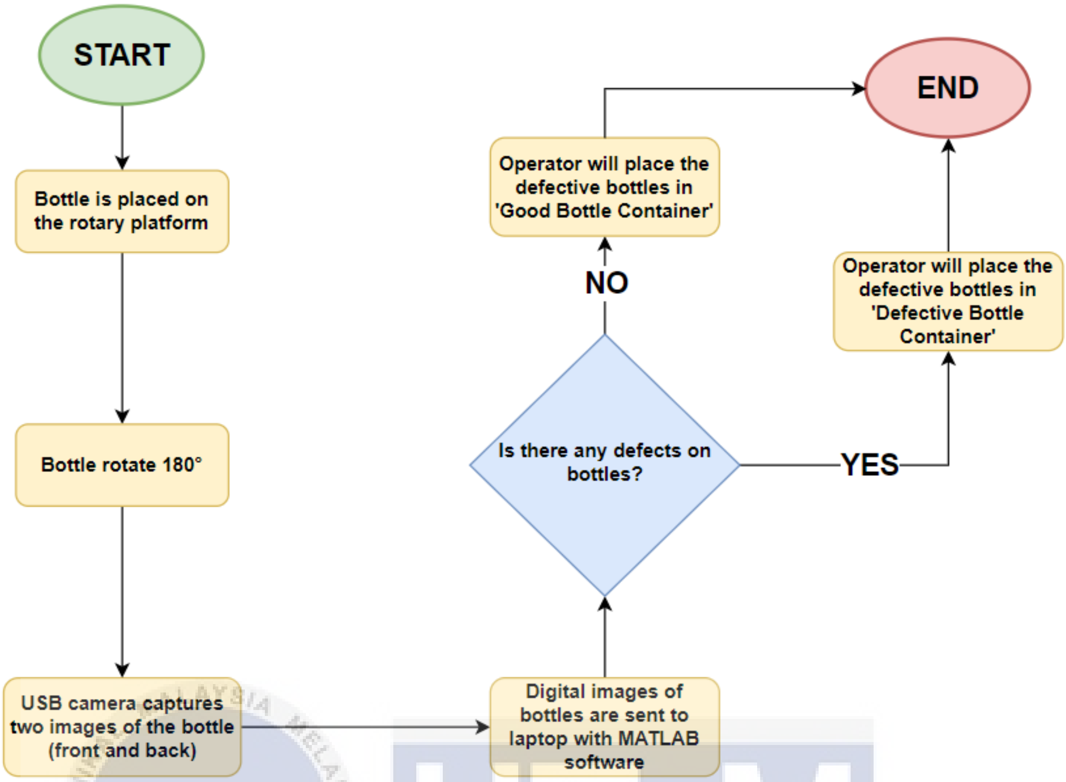


Figure 3.6: Flowchart of inspection process.

3.7 Development of MATLAB Programming

This part will discuss more on the programming or coding side of this project. The MATLAB software starts with image acquisition through the USB camera, then it pre-processes the images and perform feature extraction according to the threshold needed and lastly it detects the defects presence on the bottle images.

3.7.1 Image Acquisition

The image acquisition code is shown in Figure 3.7 whereby the code tells the USB camera to take 20 images in an interval of 5.2 seconds per image. The image capture is aligned with the rotation timing of the rotary platform of 5 seconds for every 180°. The delay in image capture of about 0.2 seconds allows the operator time to remove the old bottle and replace them with new bottle for inspection. After the front and back images of a bottle is captured, it is removed from the rotary platform and a new bottle is placed on the platform. This is done until all images of 10 bottles are captured and this will be repeated twice with 20 more bottles to complete one batch or inspection of 30 bottles.

Editor - C:\Users\NZND 101020\OneDrive\Documents\MATLAB\MATLAB Scripts\MATLAB

+17 | BoundingBoxes_forLighterColour.m | Test1.m | Test2.m | Test3.m

```
cam = webcam('USB Video Device');
preview(cam)
for i=1:20
    img=snapshot(cam);
    fname=['Image' num2str(i)];
    imwrite(img,fname, 'jpg');
    pause(5.2);
end
```

Figure 3.7: Image acquisition code

The 'img=snapshot(cam)' commands MATLAB to take pictures while the rest of the code assigns a name, number and type format (jpg) for every image captured and the intervals are of 5.2 seconds.

3.7.2 Threshold Testing

The code shown in figure 3.8 shows the coding to convert the images captured by the USB camera to B&W (black and white) with the threshold range (from 0.5 to 0.1) in this case a of 0.5 value. The function 'im2bw(A, t)' where 'A' is the image front side and 't' represents the threshold value converts a normal bottle image into B&W image. The defect detection uses bounding boxes to show the defects in the which is shown in the next lines of code. The software will draw a red rectangular box around the bottle's silhouette. If the number of red rectangular boxes is more than one per image, then the bottle is considered defective. Meanwhile, if the number of red rectangular boxes is only one per image then it is a good bottle. The threshold values that are tested will be 0.5, 0.4, 0.3, 0.2 and 0.1. these ranges of values will be tested with good bottles and defective bottles in order to determine the most suitable threshold that is going to be used for the accuracy testing.

```
t=0.5;
A=imread("Image1");
A1=im2bw(A,t);
A2=imcomplement(A1);

figure, imshow(A2), title('Original image in BW 1');
[L, ~] = bwlabel(A2);

bboxes = regionprops(L, 'BoundingBox');

figure, imshow(A2), title('Image with Bounding Boxes 1');
hold on
for k = 1: length(bboxes)
      CurrBB = bboxes(k).BoundingBox;
      rectangle('Position', [CurrBB(1), CurrBB(2), CurrBB(3), CurrBB(4)], 'EdgeColor', 'r', 'LineWidth', 2)
end
hold off
```

Figure 3.8: Code for defect detection using thresholding

3.8 Accuracy Testing

After determining the best threshold to be used for the accuracy testing, two inspection methods will be tested against each other, manual inspection versus automatic inspection. For the accuracy testing, two type of data is to be acquired and analyzed. Firstly, the time taken for manual inspection and automatic inspection to finish inspecting the three batches of bottles (one batch equals 30 bottles). Secondly, is the accuracy of the inspection between the two methods (manual and automatic). The inspection system will utilize the best threshold

3.8.1 Manual Inspection

Figure 3.9 shows the operator inspecting a batch of multi-purpose spray bottles. here the operator will manually retrieve and sort the good bottles form the defective bottles. The operator will conduct the inspection in three batches whereby each batch contains 30 bottles. The inspection time of the operator (manual inspection) to inspect each batch will be recorded and tabulated. The average inspection time per batch and accuracy of the manual inspection by the operator is calculated using the formula [1] and [2] respectively. Equation [3] shows method to calculate the average accuracy per batch for manual inspection.

Figure 3.9: Manual inspection of bottles

Calculation for average time taken for manual inspection for each batch;

$$[1] \quad Average\ time\ taken = \frac{(Batch\ 1\ time + Batch\ 2\ time + Batch\ 3\ time)}{Total\ number\ of\ batches}$$

Accuracy of manual inspection calculation for each batch;

$$[2] \quad Batch\ number = \frac{(Total\ number\ of\ bottles - number\ of\ wrongful\ detection)}{Total\ number\ of\ bottles}$$

Average accuracy for manual inspection

$$[3]\ Average\ accuracy = \frac{(Batch\ 1\ accuracy\ (\%) + Batch\ 2\ accuracy\ (\%) + Batch\ 3\ accuracy\ (\%)}{3}$$

3.8.2 Automatic Inspection

Figure 3.10 shows the automatic inspection process being conducted for three batches of bottles. The automatic inspection is tested with inspecting three batches of bottles (30 bottles per batch) and the time take to inspect each batch and the accuracy are collected and tabulated. The inspection system will utilize MATLAB's black and white method to process the image and use bounding boxes to draw on the silhouette of the bottle and the defects. If there is more than one bounding box, that means there is a defect present on the bottle's surface. The value of threshold used for this test is determine during the detection method testing.

The steps to conduct this test starts with the operator placing the bottle on the rotary platform and then running the MATLAB program to begin the image acquisition. The USB camera will capture the front image of the bottle and the rotary platform will rotate 180° so that the back image of the bottle can be captured. After two images (front and back) of the bottles are captured, the operator will remove the first bottle and will place a new bottle on the rotary platform. These steps are repeated for up to 10 bottles, then, the inspection system will determine the good and defective bottles which the operator will sort themselves. Following this, the operator will continue with the next 20 bottles. Inspection is done with 10 bottles each time per one batch or 3 times inspection for one batch of 30 bottles. This is done to ensure that the operator is able to keep track of good and defective bottles. Here, the bottle count holder in Figure 3.3 will be used.

The average inspection time per batch and accuracy of the automatic inspection by the inspection system is calculated using the formula [4] and [5] respectively. Equation [6] shows method to calculate the average accuracy per batch for automatic inspection.

Figure 3.10: Automatic inspection is being conducted

Calculation for average time taken for automatic inspection for each batch;

$$[4] \quad Average\ time\ taken = \frac{(Batch\ 1\ time + Batch\ 2\ time + Batch\ 3\ time)}{Total\ number\ of\ batches}$$

Accuracy of automatic inspection calculation for each batch;

$$[5] \quad Batch\ number = \frac{(Total\ number\ of\ bottles - number\ of\ wrongful\ detection)}{Total\ number\ of\ bottles}$$

Average accuracy for automatic inspection

$$[6]\ Average\ accuracy = \frac{(Batch\ 1\ accuracy\ (\%) + Batch\ 2\ accuracy\ (\%) + Batch\ 3\ accuracy\ (\%)}{3}$$

CHAPTER 4

RESULT AND DISCUSSION

Chapter 4 presents the result and discussion of the study which will consist of image processing, defect detection, data analysis. First, the bottles are tested with the B&W method of image processing with various ranges of threshold which are 0.5, 0.4, 0.3, 0.2 and 0.1. A bounding box command is used to indicate the presence of defects on the bottle's surfaces. The best threshold is later used for the accuracy test whereby the time taken and percentage of accuracy are tabulated and analysed.

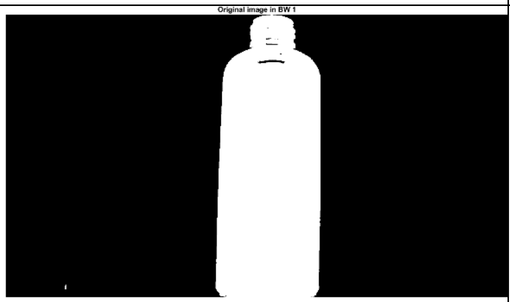
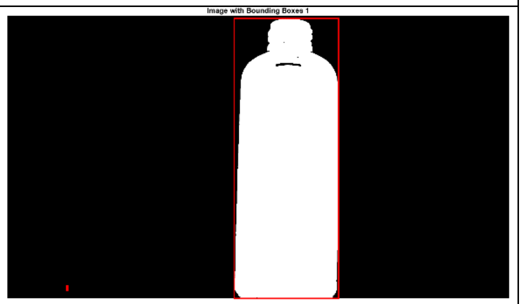
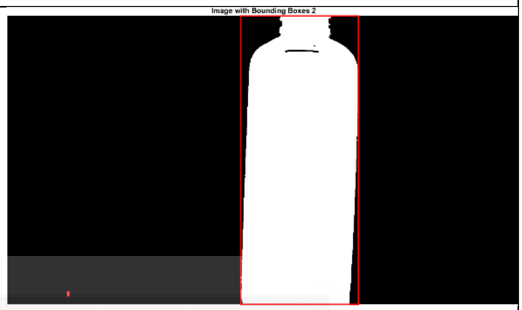
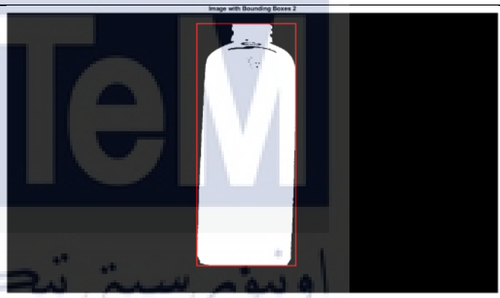
4.1 Detection Method Testing

The B&W or black and white threshold testing is conducted in order to determine the most suitable threshold for surface defect detection on the multi-purpose spray bottles. A good bottle and defective bottle are tested each with varying thresholds of 0.5, 0.4, 0.3, 0.2 and 0.1. Here, the bounding box (red rectangular box) determines the presence of defects. If the number of bounding boxes is one, then, the image has no defects. If the image has two bounding boxes, the bottle is considered to have defects.

4.1.1 B&W Testing with Threshold of 0.5

As shown in Table 4.1, the threshold of 0.5 is too large as it is not able to detect the presence of defects at all. Therefore. Threshold 0.5 is unsuitable.

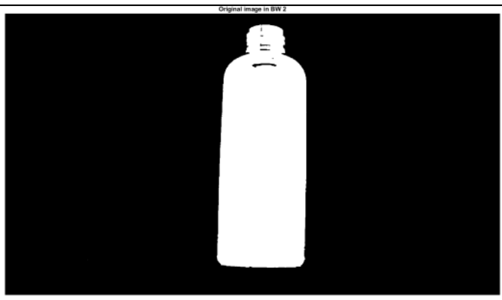
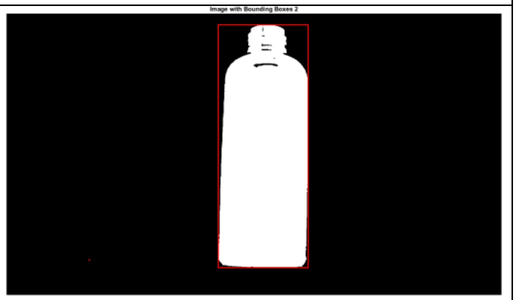
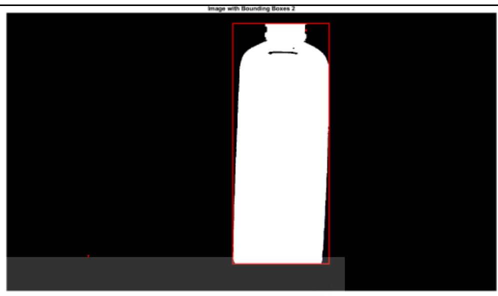
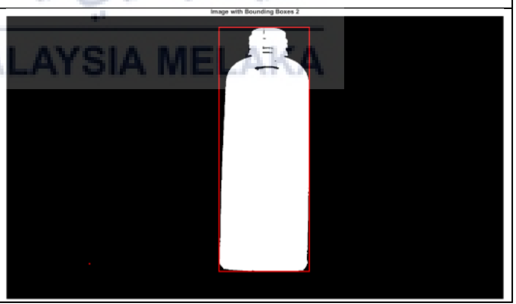
Table 4.1: Threshold 0.5 pre-processing images

Type of Bottle	B&W image	Bounding Box
Good bottle (front)		
Good bottle (back)		
Defective bottle (front)		
Defective bottle (back)		

4.1.2 B&W Testing with Threshold of 0.4

Table 4.2 shows that the threshold of 0.4 is also too large as it is not able to detect the presence of defects at all. Thus, 0.4 will not be used for accuracy testing.

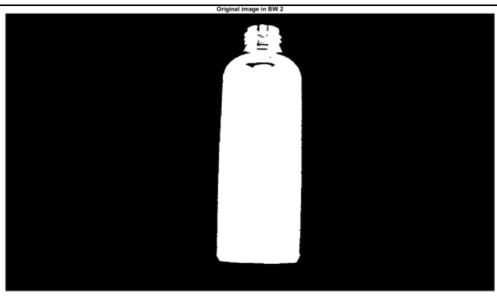
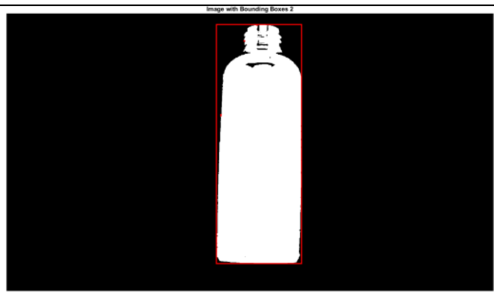
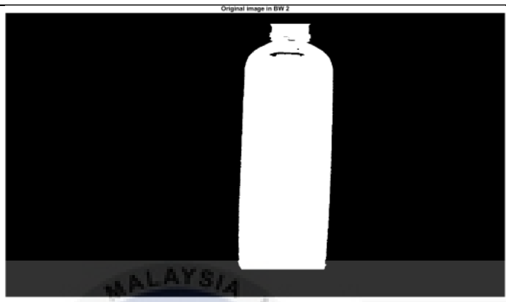
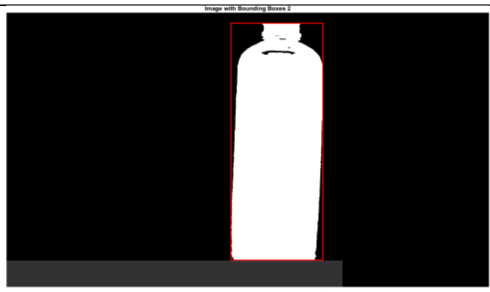
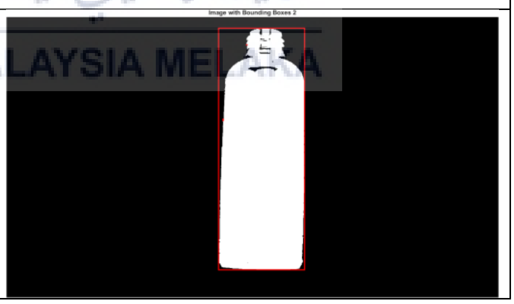
Table 4.2: Threshold 0.4 pre-processing images

Type of Bottle	B&W image	Bounding Box
Good bottle (front)		
Good bottle (back)		
Defective bottle (front)		
Defective bottle (back)		

4.1.3 B&W Testing with Threshold of 0.3

As shown in Table 4.3, the threshold of 0.3 is also too big as it is not able to detect the presence of defects at all even though the B&W image shows the defects of the bottle. Hence, the threshold 0.3 is eliminated for accuracy testing.

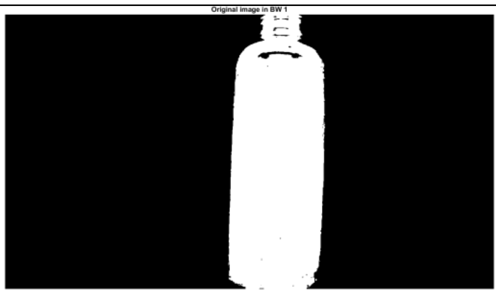
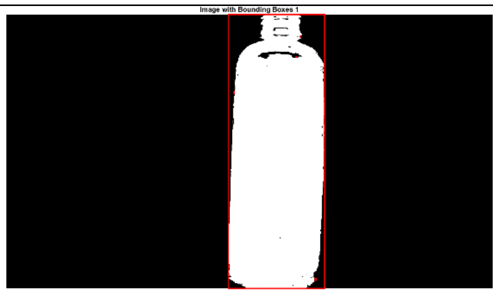
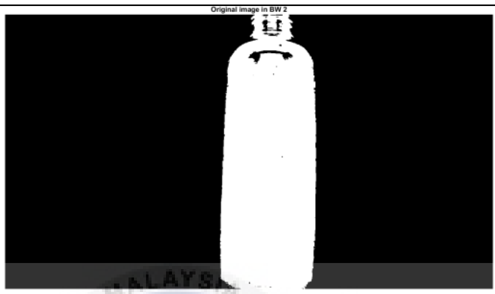
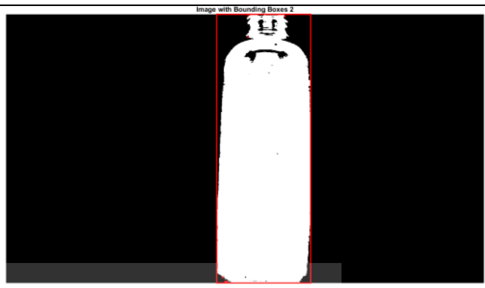
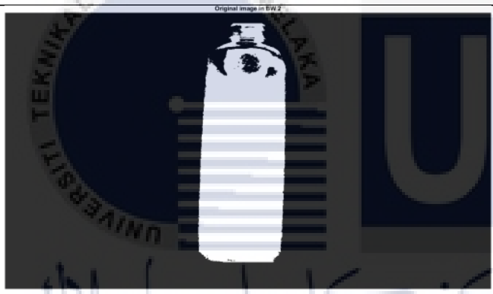
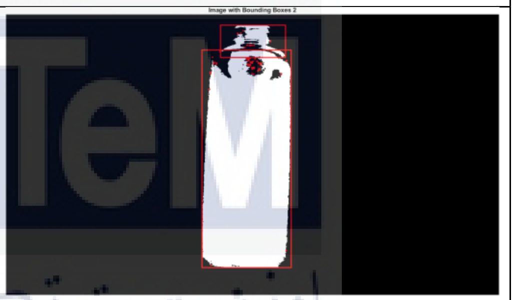
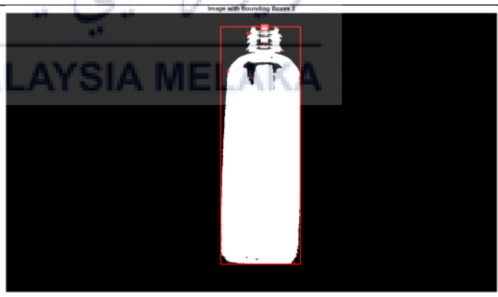
Table 4.3: Threshold 0.3 pre-processing images

Type of Bottle	B&W image	Bounding Box
Good bottle (front)		
Good bottle (back)		
Defective bottle (front)		
Defective bottle (back)		

4.1.4 B&W Testing with Threshold of 0.2

As shown in Table 4.4, the threshold of 0.2 is able to detect the presence of defects with the presence of two bounding boxes on the front image of the defective bottle. Hence, the threshold 0.2 is considered for the accuracy testing.

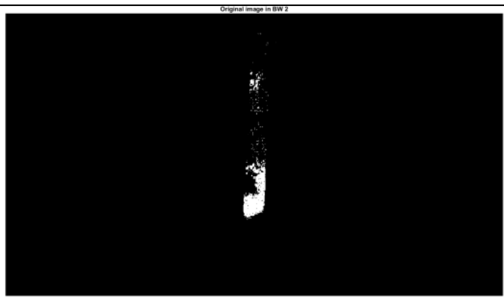
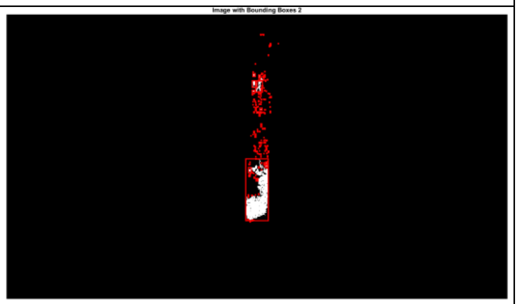
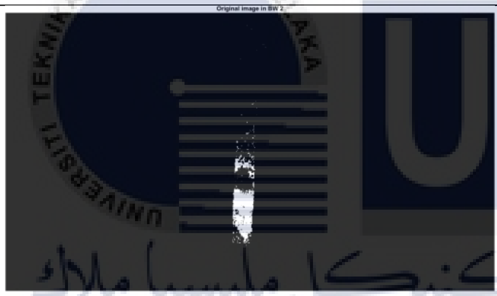
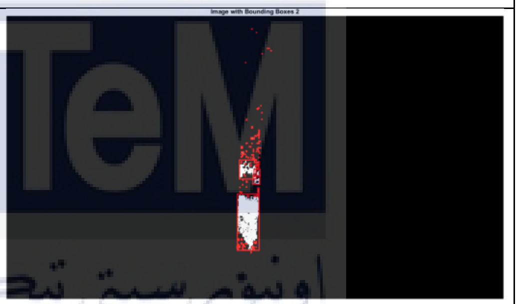
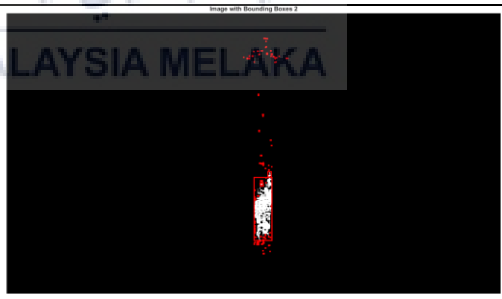
Table 4.4: Threshold 0.2 pre-processing images

Type of Bottle	B&W image	Bounding Box
Good bottle (front)		
Good bottle (back)		
Defective bottle (front)		
Defective bottle (back)		

4.1.5 B&W Testing with Threshold of 0.1

Table 4.5 shows that the threshold of 0.1 is also too little as it is not able to detect a good bottle as well as a bad bottle. Too little information is processed due to the small threshold value thus, 0.1 will not be used for accuracy testing.

Table 4.5: Threshold 0.1 pre-processing images

Type of Bottle	B&W image	Bounding Box
Good bottle (front)		
Good bottle (back)		
Defective bottle (front)		
Defective bottle (back)		

Based on threshold 0.5, 0.4 and 0.3 are not suitable to be used for the accuracy testing as the system is not able to detect the defects on the defective bottle. Meanwhile, the threshold value of 0.1 is not able to detect good and defective bottles at all as too little information is processed due to the small threshold value. On the other hand, the threshold value of 0.2 is able to correctly detect good and defective bottles hence threshold 0.2 is chosen to be used for the accuracy testing.

4.2 Accuracy Testing

This part will show the recoded data in a table form with the necessary calculations.

4.2.1 Accuracy Results for Manual Inspection

Table 4.6: Time taken for manual inspection for each batch

Batch no.	Time taken for manual inspection
Batch 1	6 minutes 45 seconds
Batch 2	7 minutes 5 seconds
Batch 3	6 minutes 58 seconds

Calculation for average time taken for manual inspection for each batch;

$$Average\ time\ taken = \frac{(Batch\ 1\ time + Batch\ 2\ time + Batch\ 3\ time)}{Total\ number\ of\ batches}$$

$$Average\ time\ taken = \frac{(6\text{ min }45\text{ sec} + 7\text{ min }5\text{ sec} + 6\text{ min }58\text{ sec }))}{3}$$

$$= 6\text{ min }56\ sec\ \ per\ batch$$

Table 4.7: Accuracy of manual inspection

Batch no.	Accuracy of manual inspection
Batch 1	Three bottles wrongfully inspected
Batch 2	One bottle wrongfully inspected
Batch 3	Two bottles wrongfully inspected

All the bottles that were wrongfully inspected are attributed to human error.

Accuracy of manual inspection calculation for each batch;

$$Batch\ number = \frac{(Total\ number\ of\ bottles - number\ of\ wrongful\ detection)}{Total\ number\ of\ bottles}$$

$$Batch\ 1 = \frac{(30-3)}{30} = 90\%$$

$$Batch\ 2 = \frac{(30 - 1)}{30} = 96.67\%$$

$$Batch\ 3 = \frac{(30 - 2)}{30} = 93.33\%$$

$$Average\ accuracy = \frac{(90\% + 96.67\% + 93.33\%)}{3} = 93.33\%\ accuracy\ per\ batch$$

4.2.2 Accuracy Results for Automatic Inspection

Table 4.8: Time taken for automatic inspection for each batch

Batch no.	Time taken for automatic inspection
Batch 1	7 minutes 50 seconds
Batch 2	8 minutes 7 seconds
Batch 3	8 minutes 20 seconds

Calculation for average time taken for automatic inspection for each batch;

$$Average\ time\ taken = \frac{(Batch\ 1\ time + Batch\ 2\ time + Batch\ 3\ time)}{Total\ number\ of\ batches}$$

$$Average\ time\ taken = \frac{(7\,\mathrm{min}\ 50\,\mathrm{sec} + 8\ \mathrm{min}\ 7\,\mathrm{sec} + 8\,\mathrm{min}\ 20\,\mathrm{sec}\ ))}{3}$$

$$= 8\,\mathrm{min}\ 5\ sec\ \ per\ batch$$

Table 4.9: Accuracy of automatic inspection.

Batch no.	Accuracy of automatic inspection
Batch 1	One bottle wrongfully inspected
Batch 2	One bottle wrongfully inspected
Batch 3	Zero bottles wrongfully inspected

For batches one and two, the reason the inspection system missed the defective bottles are attributed to lighting error. Due to uneven lighting, the system was not able to detect the defects of these particular bottles. In order to rectify this, the light bar is adjusted slightly so that the USB camera is able to obtain better images.

Accuracy of automatic inspection calculation for each batch;

$$Batch\ number = \frac{(Total\ number\ of\ bottles - number\ of\ wrongful\ detection)}{Total\ number\ of\ bottles}$$

$$Batch\ 1 = \frac{(30-1)}{30} = 96.67\%$$

$$Batch\ 2 = \frac{(30-1)}{30} = 96.67\%$$

$$Batch\ 3 = \frac{(30-0)}{30} = 100\%$$

$$Average\ accuracy = \frac{(96.67\% + 96.67\% + 100\%)}{3} = 97.78\%\ accuracy\ per\ batch$$

4.3 Comparison of Manual Inspection and Automatic Inspection

Table 4.10: Manual inspection vs automatic inspection time taken in minutes

Batch number	**Time in minutes for manual inspection (min)**	**Time take in minutes for automatic inspection (min)**
Batch 1	6.75	7.83
Batch 2	7.08	8.12
Batch 3	6.97	8.33

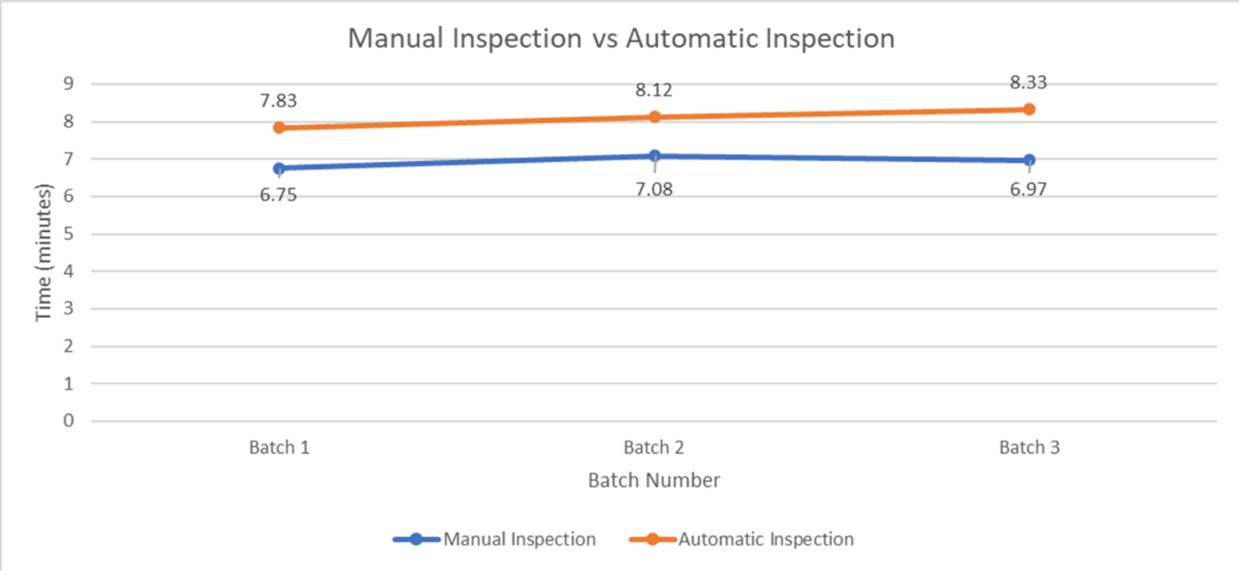


Figure 4.1: Graph of manual inspection time vs automatic inspection time

Based on figure 4.1, it shows that the automatic inspection takes longer time to complete one batch by about one minute compared to manual inspection. For the first batch, the manual inspection managed to complete the inspection in 6.75 minutes while automatic inspection took 7.83 minutes. Likewise, for batch 2, automatic inspection took 8.12 minutes while manual inspection only took 7.08 minutes. Lastly, the automatic inspection took 8.33 minutes to complete inspection of batch 3 while it only took 6.97 minutes for manual inspection method.

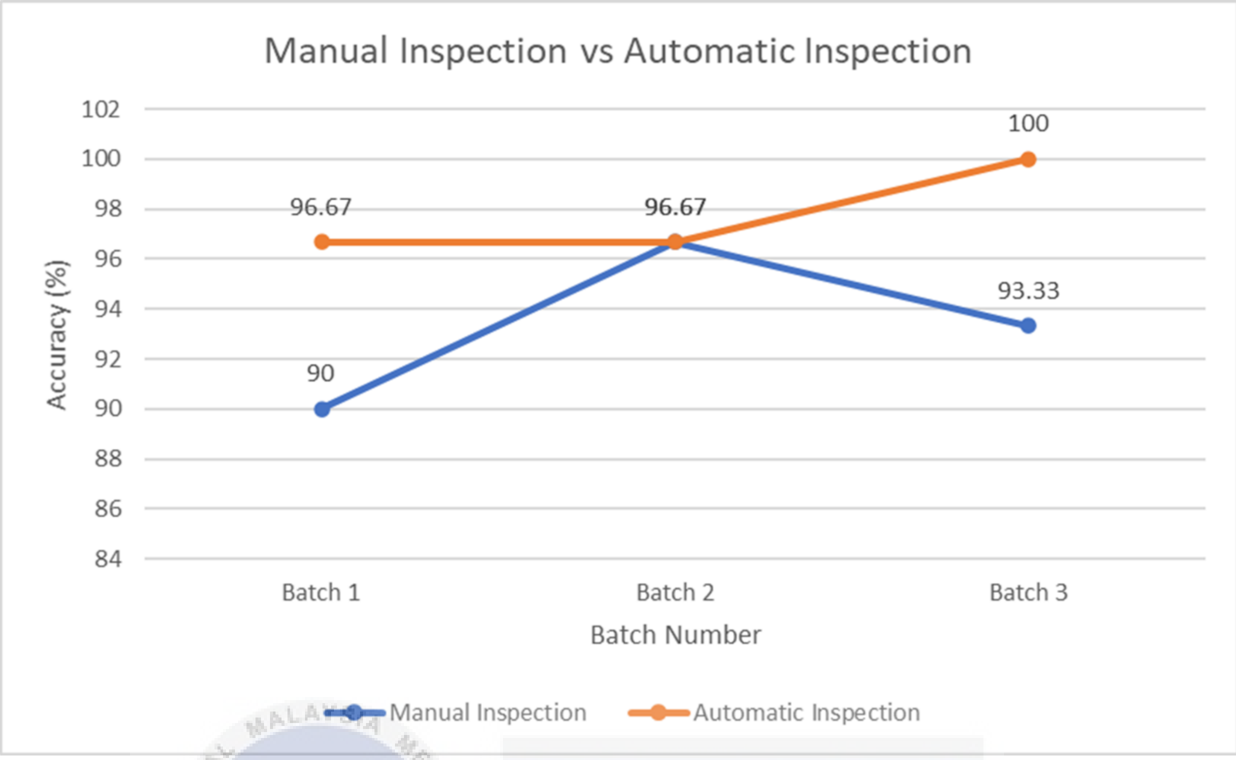


Figure 4.2: Graph of manual accuracy vs automatic accuracy

From the figure 4.2, it is observed that automatic inspection has higher accuracy compared to manual inspection. For batch 1, automatic inspection managed to obtain an accuracy of 96.67% compared to 90% accuracy achieved by manual inspection. For batch 2, both inspection methods managed to obtain the same accuracy which 96.67% accuracy. Lastly, the automatic inspection managed to achieve a 100% accuracy for batch 3 while manual inspection obtained only a 93.33% percentage accuracy.

CHAPTER 5

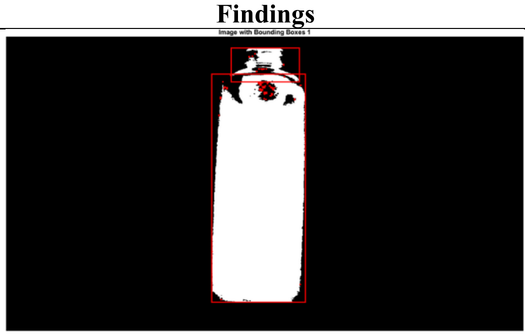
CONCLUSION AND RECOMMENDATION

This chapter dives into the year long project, detailing its scope and accomplishments. It also showcases the project's most significant achievements and offers valuable insights gained throughout the process. To ensure even greater success in the future, the chapter concludes with recommendation and ideas for future initiatives.

5.1 Conclusion

In conclusion, the objectives are partially achieved during this project. The problem statements for this project are that manual inspection is slow and inaccurate while the company has set a requirement target for the inspection system whereby the accuracy must be above 95% and faster than manual inspection. The automated bottle defect detector is more accurate compared to manual inspection with an average accuracy of more than 95% while manual inspection has an average accuracy of 93.33% per batch. However, it is slower by one minute at inspecting one batch of 30 bottles compared to the manual inspection. Table 5.1 shows the relationship between problem statement, objectives and findings during testing.

Table 5. 1: Relationship between problem statement, objectives and findings during testing

No.	Problem statement	Objective	Findings
1.	Manually identifying and sorting defective bottles takes too much time and the results are not that accurate.	To design an automated bottle defect detector that can aid in identifying and sorting defective bottles.	 The program developed in the MATLAB software is able to detect defects present on the bottle by drawing two bounding boxes in the image as indication of defects being identified successfully.
2.	The industry needs the system to be able to have an accuracy of more than 95%.	To analyse the effectiveness and performance of the system designed.	i. Automatic inspection takes longer time to complete one batch by about one minute compared to manual inspection. ii. Automatic inspection has higher accuracy compared to manual inspection.

5.2 Sustainability

Most of the main electronic components used in this project such as the USB camera, the Arduino UNO, the power bank, connector wires and the MG995 servomotor which rotate the rotary platform are reused from previous projects. Hence, not many new components are purchased just for this project which helps reduce the impact towards the environment. Electronic components require intensive resource extraction that are polluting and the manufacturing of the components consume a lot of energy and water.

Purchasing new components and discarding used components will lead to the accumulation of e-waste whereby harmful toxins may leach into the environment leading to harming human health. Proper handling of electronic equipment and components is needed to preserve the environment. Other than that, the white walls of the projects use white coloured mounting boards that are able to be reused or recycled after it reaches its lifespan or gets damaged. The boards can easily be replaced with another mounting board that is used or comes from another project.

5.3 Complexity Engineering

The complexity present in this study is the integration of MATLAB, the USB camera and the rotary mechanism so that it can detect defects on bottle's surface accurately and within a timely manner. Lighting control is paramount for this type of project as uniform and adequate lighting is required so that the camera is able to capture clear images for image processing. Isolating the bottles from the background using the white walls ensures accurate defect detection and reliable system.

The USB camera used fits the job as it is able to capture sharp and clear images for more quality image processing. It has a special 5MP lens that delivers a suitable field of view, focal length and aperture. All of this is critical in ensuring the right focal length is used in the project.

The method of defect detection such as using the B&W detection method requires the understanding of threshold and how they can impact the project either positively or negatively. Using the correct threshold will enable the developed program to be able to detect the defects present on the bottles more reliably.

5.4 Lifelong Learning

Lifelong learning in image processing refers to the continuous study, information gathering and reading about knowledge regarding the many aspects of image processing. Image processing is used everywhere, on smartphones, television, computers or laptops and etc. By learning image processing, an individual can expand their capability and use this to climb the corporate ladder (for engineers) and be able to design solutions for image processing related problems that could benefit humankind.

Other than that, there are many types of image processing software available for use other than MATLAB such as OpenCV and YOLO V3. These software can be learnt through many mediums such as online or through mentoring with experts of the stated software. By delving into these new image processing software can expand one's horizons as not every company uses MATLAB. Familiarizing with these software will help increase versatility and capability in this field and also help to stand out in the ever competitive job market.

Finally, by adopting lifelong learning in the field of image processing, individuals may stay up to date with current trends regrading this subject such as the new advancements in space or deep sea imagery. These may contribute to an individual's growth and help advance their careers.

5.5 Recommendation

The automated bottle defect detector is a more accurate method but its slower compared to manual inspection. The slowness in the inspection time is attributed to still having high human interference even though visual inspection is taken over by the MATLAB image processing software. High human interference is present during placing and removing the bottles on the rotary platform, this takes time and reduces efficiency. Sorting the good and defective bottles adds to the inspection time. Therefore, I would recommend using a conveyor belt and an automatic sorting machine so that the operator would only need to load or place the bottles on the conveyor belt and let the machine handle the rest.

Other than that, the usage of only one camera hinders efficiency of the system. It takes about 10 seconds to capture a 360° image of one bottle (two 180° images). The long time is to ensure a smooth transition of placing and removing the bottles on the rotary platform (void mistakes during image acquisition). Hence, using two cameras instead of one in order to capture a 360° image of the bottles thus reducing the image capture time of one bottle by half.

Lastly, considering the image processing software used is MATLAB which requires a license to utilize, I would suggest using an open source image processing software such as OpenCV so that the company does not need to pay monthly or annual installments to continue using the inspection system.

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