FEASIBILITY STUDY ON HANDHELD DEVICES-BASED AUGMENTED REALITY SYSTEM FOR IDENTIFICATION AND INSPECTION PROCESSES IN MANUFACTURING INDUSTRY

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**SUBMITTED TO THE
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Name of Candidate: Chiang Yoong Fatt

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Feasibility Study on Handheld Devices-Based Augmented Reality System for Identification and Inspection Processes in Manufacturing Industry

Field of Study: Augmented Reality

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FEASIBILITY STUDY ON HANDHELD DEVICES-BASED AUGMENTED REALITY SYSTEM FOR IDENTIFICATION AND INSPECTION PROCESSES IN MANUFACTURING INDUSTRY

ABSTRACT

The use of Augmented Reality (AR) in assisting inspectors during an identification and inspection tasks can be considered a practical and innovative method to reduce human error in reading mechanical drawing and improve productivity. This research project carries out a feasibility study of the implementation of handheld devices-based AR system in the manufacturing context, to support inspectors in carrying out quality inspection tasks. A feasibility study and its application to quality inspection has been carried on in collaboration with a Malaysia-based manufacturer of automated equipment. This case study targeted to a low-volume, high variation manufacturing company that is experiencing issues reducing its defects in incoming fabricated parts. Defects happened on fabricated parts such as missing important under-cut feature or engraving text. A prototype handheld device-based AR system is intended to be applied as effective tools to help inspector perform inspection tasks by viewing 3D model compared with the fabricated part. The expected pros or cons of its implementation and acceptance are discussed.

Keywords: feasibility study, augmented reality, quality inspection, low-volume, high variation manufacturing

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ABSTRAK

Penggunaan Reality Augmented (AR) dalam membantu pemeriksa semasa tugas pengenalpastian dan pemeriksaan boleh dianggap sebagai kaedah praktikal dan inovatif untuk mengurangkan kesilapan manusia dalam membaca lukisan mekanik dan meningkatkan produktiviti. Projek penyelidikan ini menjalankan kajian kebolehlaksanaan pelaksanaan sistem AR berasaskan peranti pegang tangan dalam konteks perkilangan, untuk menyokong pemeriksa dalam melaksanakan tugas pemeriksaan mutu. Kajian kebolehlaksanaan dan penerapannya untuk pemeriksaan kualiti telah dijalankan dengan kerjasama pembuat peralatan automatik yang berpangkalan di Malaysia. Kajian kes ini disasarkan kepada syarikat perkilangan yang bervolume rendah dan bervariasi tinggi yang mengalami masalah mengurangkan kecacatannya di bahagian-bahagian yang direka bentuk. Kecacatan berlaku pada bahagian fabrikasi seperti kehilangan ciri penting atau teks ukiran yang penting. Sistem AR berasaskan peranti pegang tangan direka untuk digunakan sebagai alat yang berkesan untuk membantu pemeriksa menjalankan tugas pemeriksaan dengan melihat model 3D berbanding dengan bahagian yang direka. Kebaikan atau keburukan yang diharapkan dari pelaksanaan dan penerimaannya dibincangkan.

Keywords: kajian kemungkinan, augmented reality, pemeriksaan kualiti, volum rendah, pembuatan variasi yang tinggi

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LIST OF SYMBOLS AND ABBREVIATIONS

AR	:	Augmented Reality
CNC	:	Computer Numerical Control
EDM	:	Electrical Discharge Machining
FBX	:	Filmbox
IQA	:	Incoming Quality Assurance
POC	:	Proof of Concept
QA	:	Quality Assurance
R&D	:	Research & Development
SLDPRT	:	Solidworks Part
SDK	:	Software Development Kit
STL	:	Stereolithography
WT3	:	Wikitude 3D
2D	:	Two Dimensional
3D	:	Three Dimensional

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

Identification and inspection processes play a crucial role in the manufacturing industry. Incoming Quality Assurance (IQA) team spend a lot of time to verify and conduct an inspection on incoming fabricated parts. An inspection is an action to check, measure, verify and validate the incoming fabricated parts whether conformity is achieved or not. Inspected fabricated parts can be the parts used for manufacturing directly or semi-finished goods of machines before shipping the goods to the end customers. Inspector needs to analyze the physical incoming fabricated parts and matching the physical part with specified technical requirements stated in the mechanical engineering drawing. Mechanical engineering drawings are technical drawings to represent a final design (Ullman et al., 1990). It consists of all the mechanical requirements and information that will allow a manufacturer to produce it. It includes information such as materials used, geometry with multiple views, dimensions used and others technical information.

Several studies across all manufacturers have been shown that there are a time and cost ratio for development: manufacturing: delivery of 1:10:100 ("Why Early Inspection is Generally Better," 2019). It means each part discrepancy will cost 10 times more (in time and in US Dollar) to fix in manufacturing that it would to fix in development, and 100 times more if the part discrepancy shipped to the customer as shown in table below: -

Table 1.1: Time and Cost ratio for development: manufacturing: delivery

Process	Cost Ratio
Development	RM 40
Manufacturing	RM 400
Delivery	RM 4000

This research project focuses on the new approach to assist inspectors identify and inspect incoming fabricated parts before manufacturing process. It proposes a feasibility study of the implementation of handheld devices-based augmented reality (AR) system to reduce the number of defects in carrying out quality inspection job. This case study aims to a high-mix, low-volume manufacturing company that is encountering issues reducing its number of discrepancies in incoming fabricated parts.

1.1 Background

The participating company is an automated machine vision equipment manufacturer with broad customers base around the world. It designs and manufactures innovative automatic vision inspection machine for the semiconductor industry. Figure 1.1 shows an overview of the machine vision hardware module for bottom vision inspection that installed in the test handler machine used in the semiconductor industry. A machine vision hardware module consists of a camera, lens, lighting, mechanical parts and 45-degree mirror block.

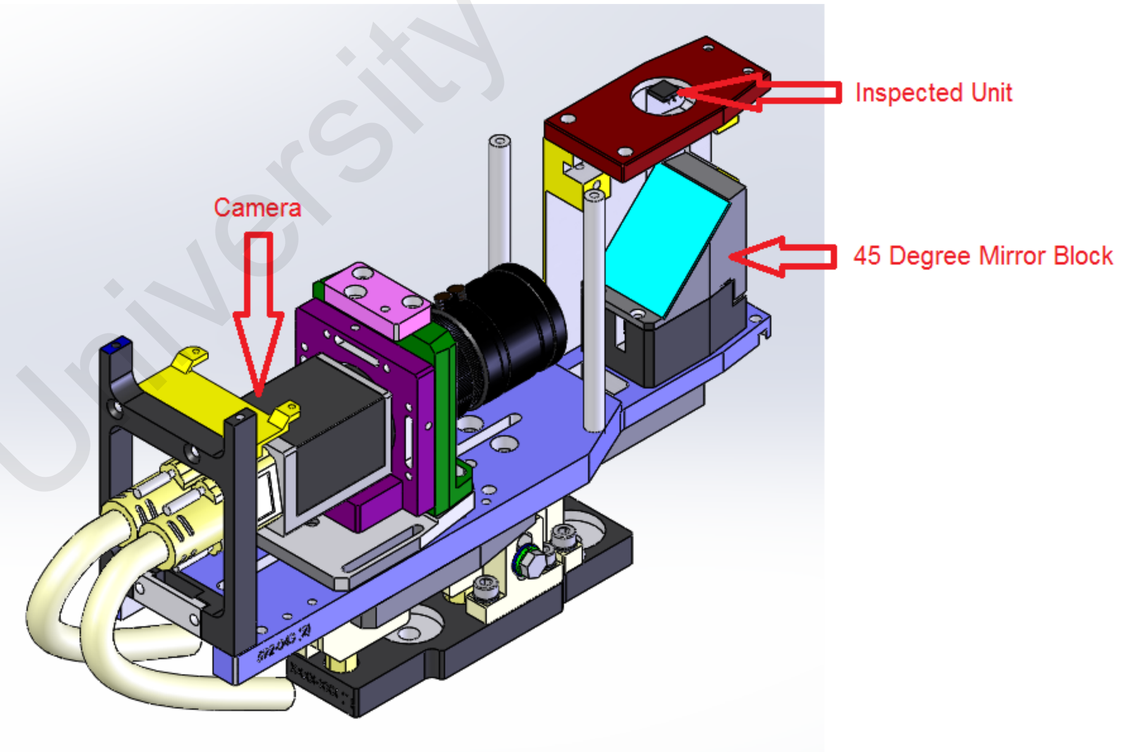


Figure 1.1: The overview of machine vision hardware module in CAD model

The 45-degree mirror block is the most critical part for the bottom vision inspection because it plays an important role to do a reflection for the inspected unit. To view an image of an inspected unit, light travels to camera along the path shown in the Figure 1.2 below: - The figure shows that the angle of the incident ray is same to the angle of the reflected ray. It is the ideal way the light reflects off the mirror when the angle is 45 degree.

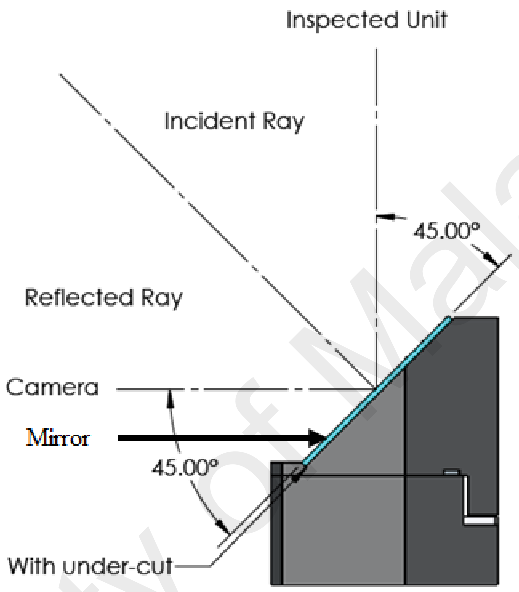


Figure 1.2: The role of the 45-degree mirror block

Its research and development (R&D) team constantly attempting innovation in their products. They always enhance its existing products and continue to expand their pipeline of new products. They want to launch at least six new or advanced products into the market every to capture the market's needs on time. Hence, there are thousands of new or improved fabricated parts purchased and assembled in the manufacturing and ship to customers.

1.2 Research Objective

The two objectives are shown below: -

- To implement 3D visualization and technical information through AR system on 2D mechanical drawing.
- To develop an assisted quality inspection prototype AR system for the incoming fabricated parts.

1.3 Problem Statement

Quality control in high-mix, low volume environment remains a challenges task. The complexity of the part inspection task increases due to the various types of products increases. In year 2018, there were total 1134 incoming parts consists of wire hardness and fabricated parts have been rejected in January due to the number of parts have been purchased were increase to 8411 parts as shown in Table 1.2 below.

Table 1.2: Total Incoming Parts Received Record in Year 2018

Month	No. of DMR (Cases)	Total Part IDs	1 - (DMR/Part IDs) (%)	Total Reject Qty	Total Received Qty	Good Qty / Total Received Qty (%)
January	311	8,411	96.30	1,134	64,474	98.24
February	222	5,181	95.72	784	48,192	98.37
March	210	5,287	96.03	659	40,711	98.38
April	214	3,960	94.60	536	20,944	97.44
May	173	4,283	95.96	569	27,884	97.96
June	103	3,480	97.04	343	40,361	99.15
July	129	3,281	96.07	436	31,728	98.63
August	122	2,982	95.91	395	21,991	98.20
September	96	3,118	96.92	213	20,609	98.97
October	183	3,749	95.12	891	23,024	96.13
November	130	2,800	95.36	389	17,214	97.74
December	68	1,942	96.50	217	12,133	98.21
Total:	1,961	48,474	95.95	6,566	369,265	98.22

The total incoming fabricated parts rejected was 1961 parts found in year 2018. Those parts have been rejected due to cosmetic, missing features, missing items, missing engraving text and missing finishing as shown in Figure 1.3 below.

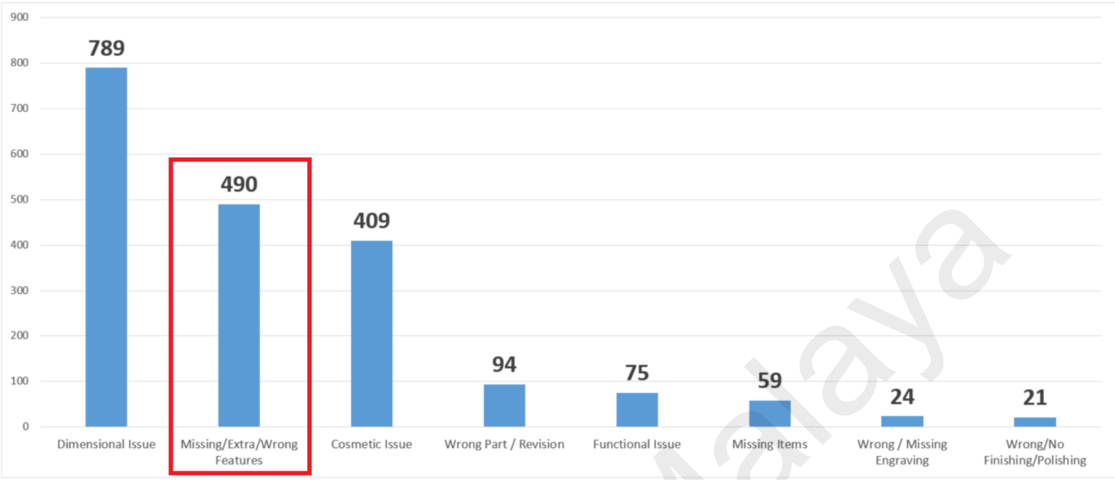


Figure 1.3: Total Incoming Fabricated Parts Rejected Record in Year 2018

This study focuses on the problem related to the missing features. As can be seen in Figure 1.3, there were 490 parts rejected due to missing important under-cut feature. An under-cut is an essential feature at the corner of the 45-degree mirror block as shown in Figure 1.3 and Figure 1.4 below.

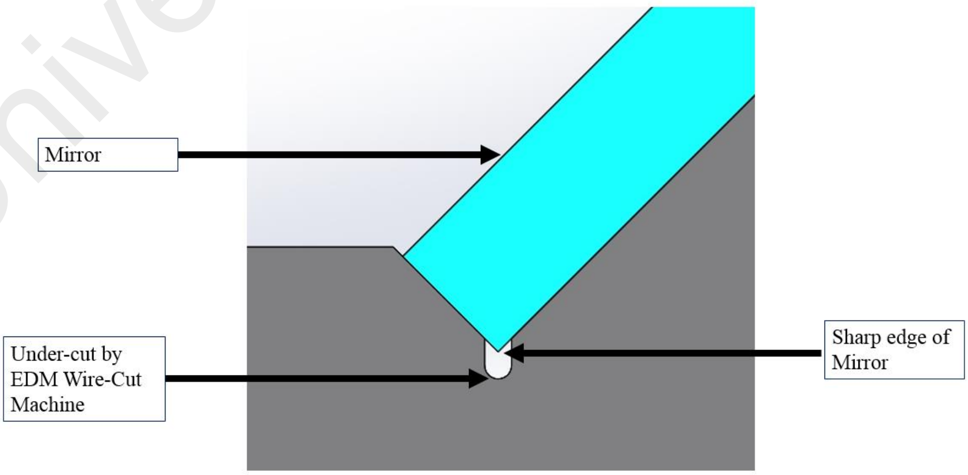


Figure 1.4: Under-cut by EDM Wire-Cut Machine

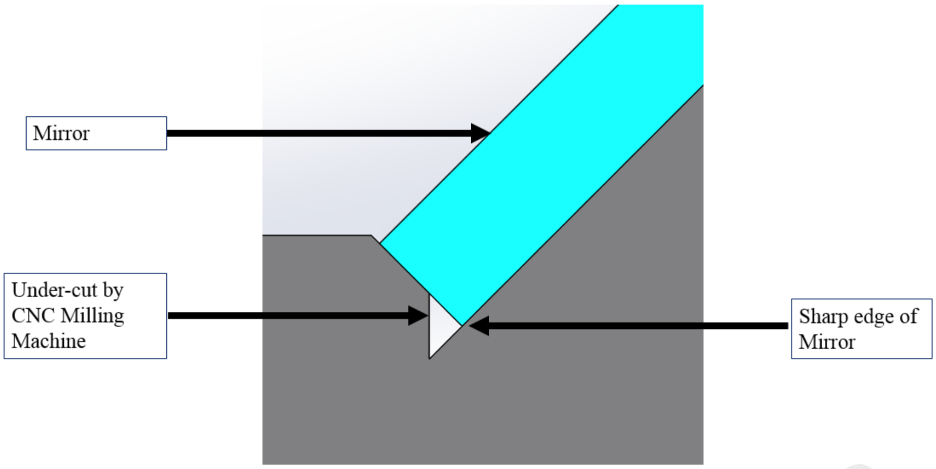


Figure 1.5: Under-cut by CNC Milling Machine

The under-cut feature made by EDM Wire-Cut or CNC Milling machine are to remove the radius of the 45-degree mirror block that is usually left by the milling tool as shown in below: -

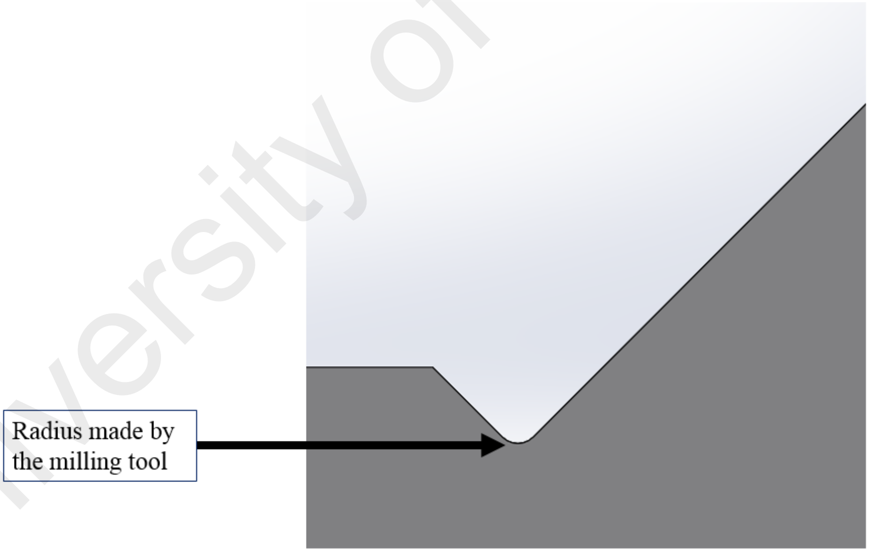


Figure 1.6: Radius made by the milling tool

Without an under-cut feature, the radius made by the milling tool will be caused a gap between the contacting surfaces during the assembly with mirror as shown in Figure 1.7 below.

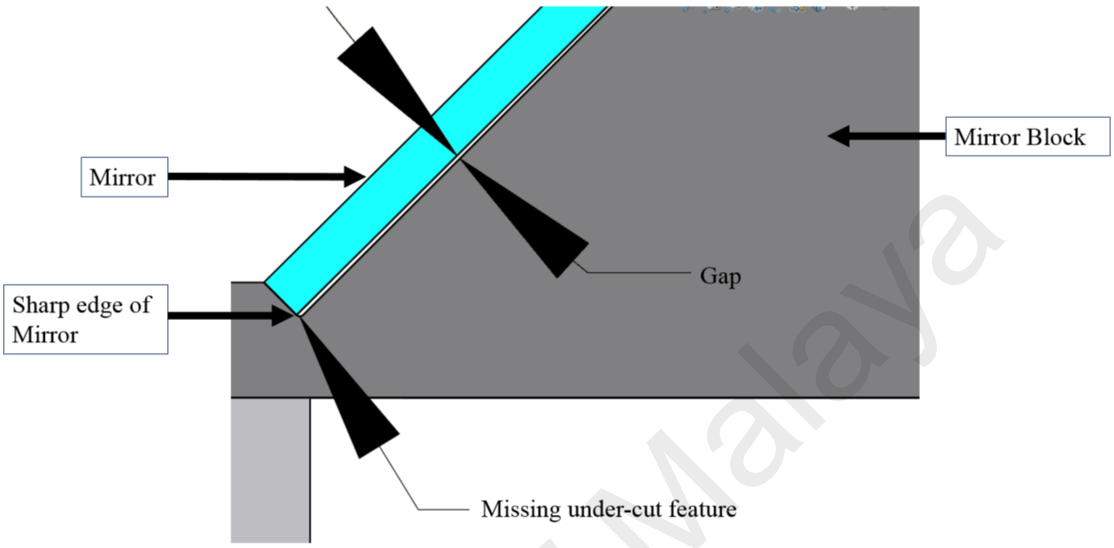


Figure 1.7: A gap between the contacting surfaces

A gap between the contacting mirror and mirror block surfaces may caused an angular deviation around 0.15 degree as shown in Figure 1.8. It will cause an image captured by camera looks skewed which is not acceptable by customer.

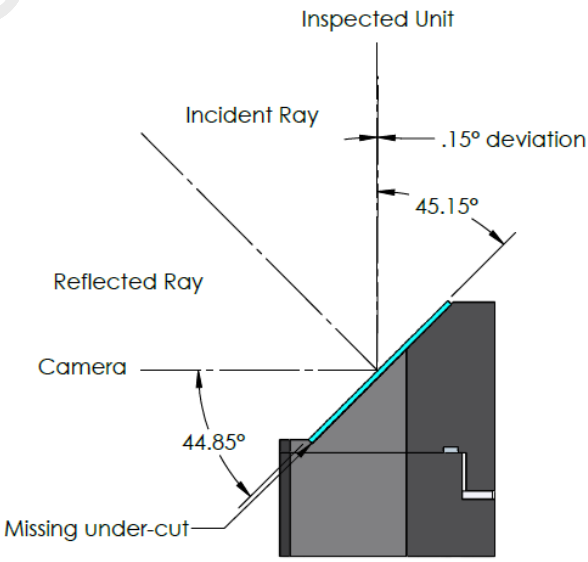


Figure 1.8: Missing under-cut feature in the 45-degree mirror block

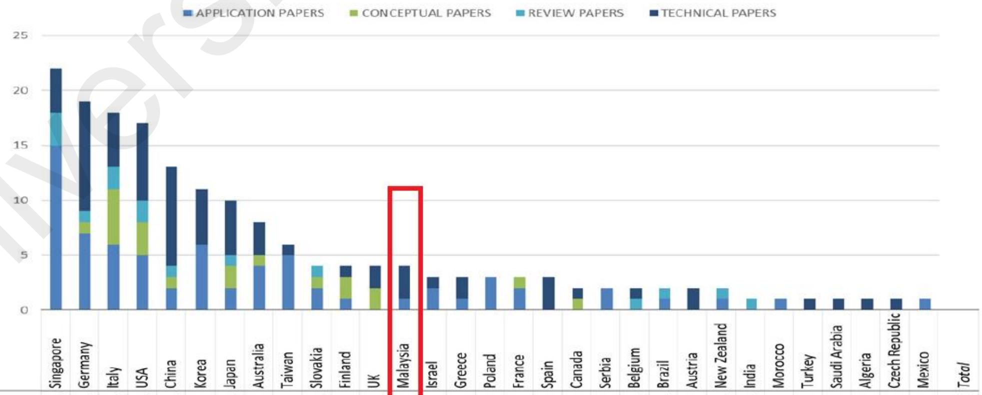
1.4 Scope of Work

Negligence of important features in the 2D mechanical drawing is the most possible root causes of incoming fabricated parts been rejected. The human factor has considered an important role in the quality inspection.

This work aims to deliver a prototype AR system as a proof of concept (PoC) that demonstrates how QA team reduce human mistake and improve their productivity through the utilization of Handheld Device-Based Augmented Reality System concepts. The scope of the study is limited to the manual visual inspection through 2D mechanical drawing and handheld-devices. It suggests the use of AR technology for supporting inspectors in visual inspection process.

CHAPTER 2: LITERATURE REVIEW

Bottani and Vignali (2019) have studied and analyzed various papers related to the AR application in the manufacturing industry. AR application was initially used as a training device for the aerospace manufacturing sector (Frigo, M. A et al., 2016). The number of these studies has incremented since the year 2006, and it covered applications such as quality control, training/learning, 2D/3D CAD, product design, facility inspection, remote assistance and others. Figure 2.1 shows the number of published papers from different countries from the year 2006 to 2017. Most of the application papers were contributed from Singapore, Germany, Italy, USA, China, Korea and Japan. These countries are active in examining the use of AR system for the manufacturing industry. As can be seen in Figure 2.1, Malaysia has carried out 3 technical papers and 1 application paper on AR system. It demonstrates that AR system is still in its early stage of usage and adoption in Malaysia as compared to the Singapore that has carried out 4 technical papers and 15 application papers about AR technology.



CLASSIFICATION	Singapore	Germany	Italy	USA	China	Korea	Japan	Australia	Taiwan	Slovakia	Finland	UK	Malaysia	Israel	Greece	Poland	France	Spain	Canada	Serbia	Belgium	Brazil	Austria	New Zealand	India	Morocco	Turkey	Saudi Arabia	Algeria	Czech Republic	Mexico	*Total*
Review paper	3	1	2	2	1		1			1											1	1		1	1							*15*
Conceptual paper		1	5	3	1		2	1		1	2	2					1		1													*20*
Technical paper	4	10	5	7	9	5	5	3	1		1	2	3	1	2			3	1		1		2				1	1	1	1		*69*
Application paper	15	7	6	5	2	6	2	4	5	2	1		1	2	1	3	2			2		1		1		1					1	*70*
Total	*22*	*19*	*18*	*17*	*13*	*11*	*10*	*8*	*6*	*4*	*4*	*4*	*4*	*3*	*3*	*3*	*3*	*3*	*2*	*2*	*2*	*2*	*2*	*2*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*174*

Figure 2.1: The number of published papers from different countries from the year 2006 to 2017. Retrieved from 'Augmented reality technology in the manufacturing industry: A review of the last decade' by Bottani, E., & Vignali, G. 2019, IISE Transactions, 51(3), 284-310.

Bottani and Vignali (2019) have found out that quality inspection in AR application considered as intermittent research topic whereby the first paper was published since the year 2010, and the last article was published since the year 2016. Authors found that quality control can benefit from quicker execution of daily tasks and improve the effectiveness of quality inspection in the which involve in the manufacturing and processing of parts.

The practice of AR to find defects has been suggested by Franceschini et al., (2016). The authors studied how AR can reduce the risk of mistakes due to distress and lack of adequate training (Franceschini et al., 2016). Authors also discussed critical parameters that affecting the performance of the assisted quality inspection AR prototype system.

In this chapter, the handheld devices were reviewed to identify the suitable hardware of AR application. The concept of AR techniques and quality inspection were discussed systematically.

2.1 Handheld Devices

A Handheld device is an electronic device which is small and portable with an operating system, display screen, camera, powerful processors, large storage capacity, RAM and lightweight battery. Smartphones and tablets are considered as handheld devices. In the past decade, handheld devices have increased the number of users due to it has become more available to the people around the world. Users need to hold them with appropriate position and orientation to work correctly for AR applications (Moller et al., 2014). This requirement is important because it may impact user-friendliness and visualization accuracy.

AR system for quality assessment in the construction industry have been implemented on handheld devices and evaluated in previous studies (Lee, S. Y. et al., 2017). In this study, it found that the AR system by using a handheld device equipped with a digital camera able to provide 3D visualized information and help user understanding of construction phase based as-built model.

2.1.1 Smartphone

Smartphone is a computing phone with advanced features such as high processor power, high camera resolution, low power consumption and equipped with various types of sensors to support gaming and motion-based navigation. According to the Osman, M. A et al., (2012) study, smartphone is altering young adults' behaviors in Malaysia because they addicted it. Most of the young adults use smartphone as multi-function devices for calling, texting, gaming and internet browsing. The use of smartphone in manufacturing industry is still in its early adoption.

2.1.2 Tablet

Tablet is a portable device with operating system and touchscreen. It has larger touchscreen display as compared to smartphone. Generally, it has not equipped with advanced camera systems and high-resolution display.

Smartphone was selected for this prototype system because it has more powerful processors, high-quality camera and high-resolution display as compared to tablet.

2.2 Augmented Reality System

Augmented Reality (AR) is what we see could be improved and enhanced with additional virtual annotation or information in the real scene (Azuma et al., 2001). AR is named as the augmentation of physical reality by superimposing layers of computer-generated information (Carmigniani et al., 2011). AR system can be used in numerous types of applications with digitally produced sensory inputs such as sound or visual (Richardson et al. 2014). Additional computer-generated details could be any virtual content such as 3D model, label, image and video. It represents a real-time user interface for human with actual parts and digital devices like a smartphone or tablet. Basically, AR consists of four basic operatives (Glockner et al., 2014) as shown in Figure 2.2: -

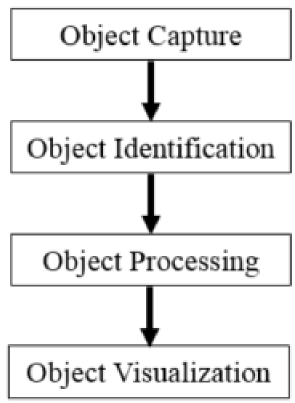


Figure 2.2: Four basic functional block diagram of Augmented Reality

1. **Object Capture:** Firstly, the object in engineering drawing is captured using handheld-devices with camera such as smartphone, tablets or laptop.
2. **Object Identification:** The captured object needs to be scanned to determine the location where the virtual object should be set. The location could be defined by markers or images.
3. **Object Processing:** Once the object becomes clearly identified and known, the corresponding virtual object is requested from the cloud database.
4. **Object Visualization**: Lastly, the AR system presents a mixed real-time image with the combination real environment and virtual object.

2.2.1 Types of Augmented Reality (AR)

AR based on image recognition technology (Kato, H. et al., 2011) has two types of AR system, marker-based and markerless-based.

2.2.1.1 Marker-based AR

Marker-based AR means a user needs to use a handheld device with a camera to scan an image or 2D code. Once the handheld device with a camera recognizes the marker, it produces a result with AR features that enhancing the things we see (Craig, A. B. (2013)). In general, marker-based AR divided into a black and white image or colour image as a trigger to present an AR object. Marker-based AR is the most widely used in a smartphone because its processing time is shorter, and the decoded time is fast (Henrysson, A. et al., 2005). However, the effectiveness of marker tracking still depends on lighting conditions especially in outdoors conditions (Kasapakis, V. et al., 2018).

2.2.1.2 Markerless-based AR

Markerless-based AR is based on position or orientation tracking of an object using smartphone (Kato, H. et al., 2011). It also called location-based or GPS-based because it uses an accelerometer, GPS or digital compass to accurately detect and map the real scene which is integrated in the handheld device.

2.2.2 Augmented Reality SDK

There are many types of Augmented Reality Software Development Kit (SDK) available in the market as shown in figure 2.2. A comparative analysis for two augmented reality SDK is carried out: Wikitude and Vuforia.

	Wikitude	ARKit	ARcore	Vuforia
Maximum distance capture (m)	2.4 / 5	1.5 / 5	1.0 / 3	1.2 / 3.7
Recognition stability of immovable marker	6	9	9	10
Recognition stability of movable marker	6	7	6	6
Minimum angle recognition	10	30	50	30
Minimum visibility for recognition overlapped marker	100%	50%	75%	20%
2D Recognition	✓	✓	✓	✓
3D Recognition	✓	✓	✓	✓
Geo-Location	✓	✓	✓	–
Cloud Recognition	✓	✓	✓	✓
SLAM	✓	✓	✓	✓
Total (rating)	**8.0**	**7.5**	**7.7**	**7.7**

Figure 2.3: Augmented Reality SDK Comparison Table. Retrieved from “n.d., https://thinkmobiles.com/blog/best-ar-sdk-review/’

2.2.2.1 Wikitude

Wikitude is one the world's leading augmented reality (AR) application provider for handheld-based devices such as smartphones, tablets and head-mounted display. It implements algorithms for the image recognition as a image tracker for rendering of AR objects. Wikitude is a powerful SDK which it contains 3D object loader and renderer. It supports Android and iOS operating system. Its Wikitude Studio only supported .wt3 file format.

2.2.2.2 Vuforia

Vuforia is one of the most popular in the world providers of augmented reality. It allows recognition of various types of text and the environment, visual objects such as cube, cylinder and plane. It supports Extended Tracking for recognizing 3D objects and supporting Virtual Button.

Based on the above analysis, the choice of Wikitude Augmented Reality SDK and Wikitude Studio are made. This platform is the highest rating among others AR SDK.

2.3 Quality Inspection

Quality inspection is an action to check, measure, verify and validate the incoming fabricated parts whether conformity is achieved or not (QC Basics: What is a Quality Inspection? Context, Tools & Template, 2019). The quality inspection is performed once the fabricated parts are received from the supplier before the fabricated parts delivered to the manufacturing team as shown in Figure 2.3 below: -

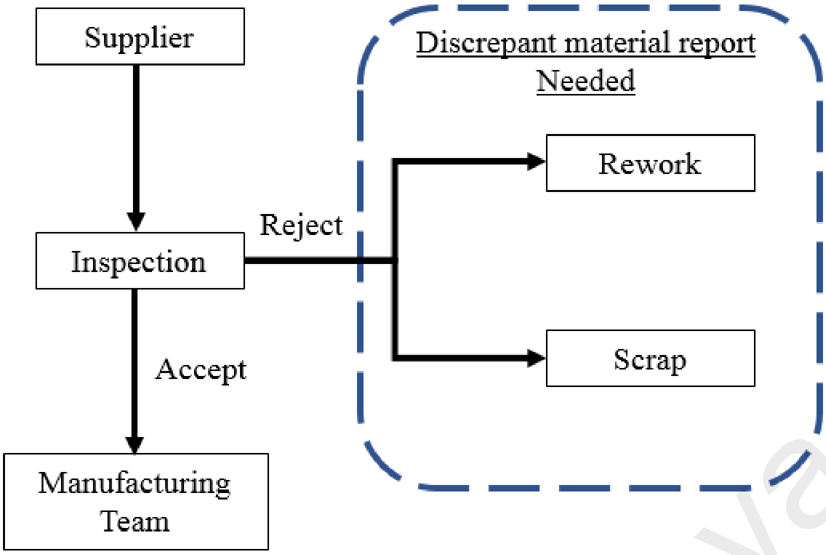


Figure 2.4: Flow Chart of the Incoming Inspection Process

The incoming fabricated parts may either be accepted or rejected. Fabricated parts in a rejected lot are either scrapped, reworked or replaced with good items. A discrepant material report (DMR) will be sent to supplier. One of their performance will be evaluated based on the number of DMR. The targeted number for the DMR is single digit for every year.

CHAPTER 3: METHODOLOGY

The overview of the prototype AR system as shown in Figure 3.1. The component of this architecture is the assisted quality inspection prototype AR system module.

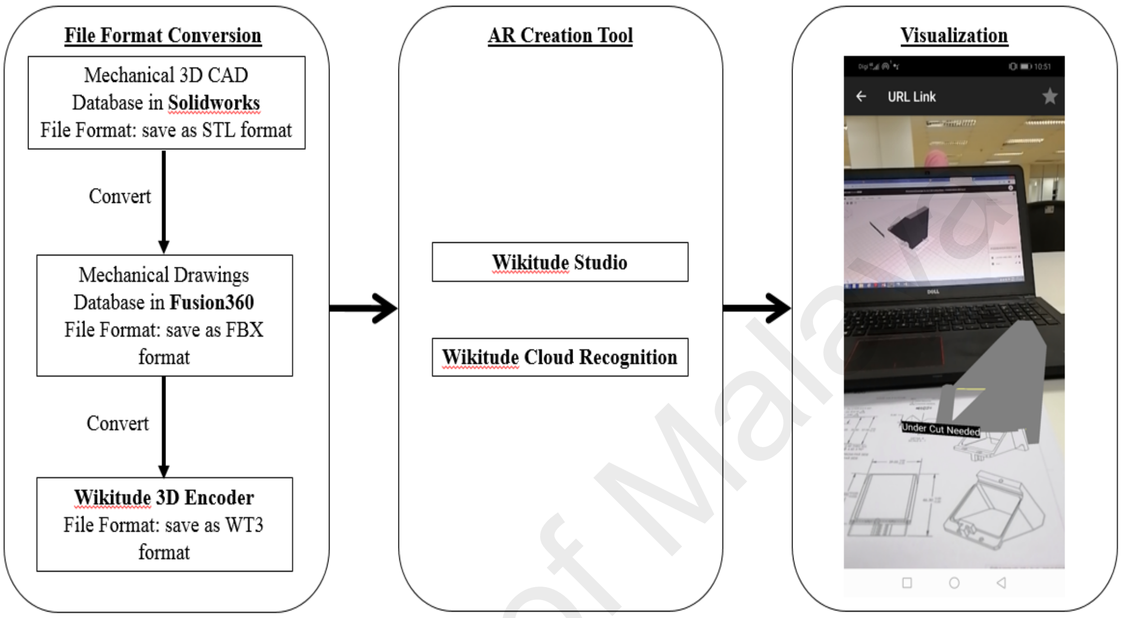


Figure 3.1: The overview of the Prototype AR System

3.1 File format conversion from SLDPRT to WT3

All the mechanical parts file from the participating company are in SLDPRT format. The SLDPRT format is a Solidworks part file that contains a 3D CAD model. For storing the 3D CAD model into the Wikitude 3D encoder, the first step is to use Solidworks CAD software that will allow the conversion of the file from SLDPRT format to STL format. The STL format is a universal file format for the 3D CAD model. Figure 3.2 shows the system options for the conversion of SLDPRT to STL format.

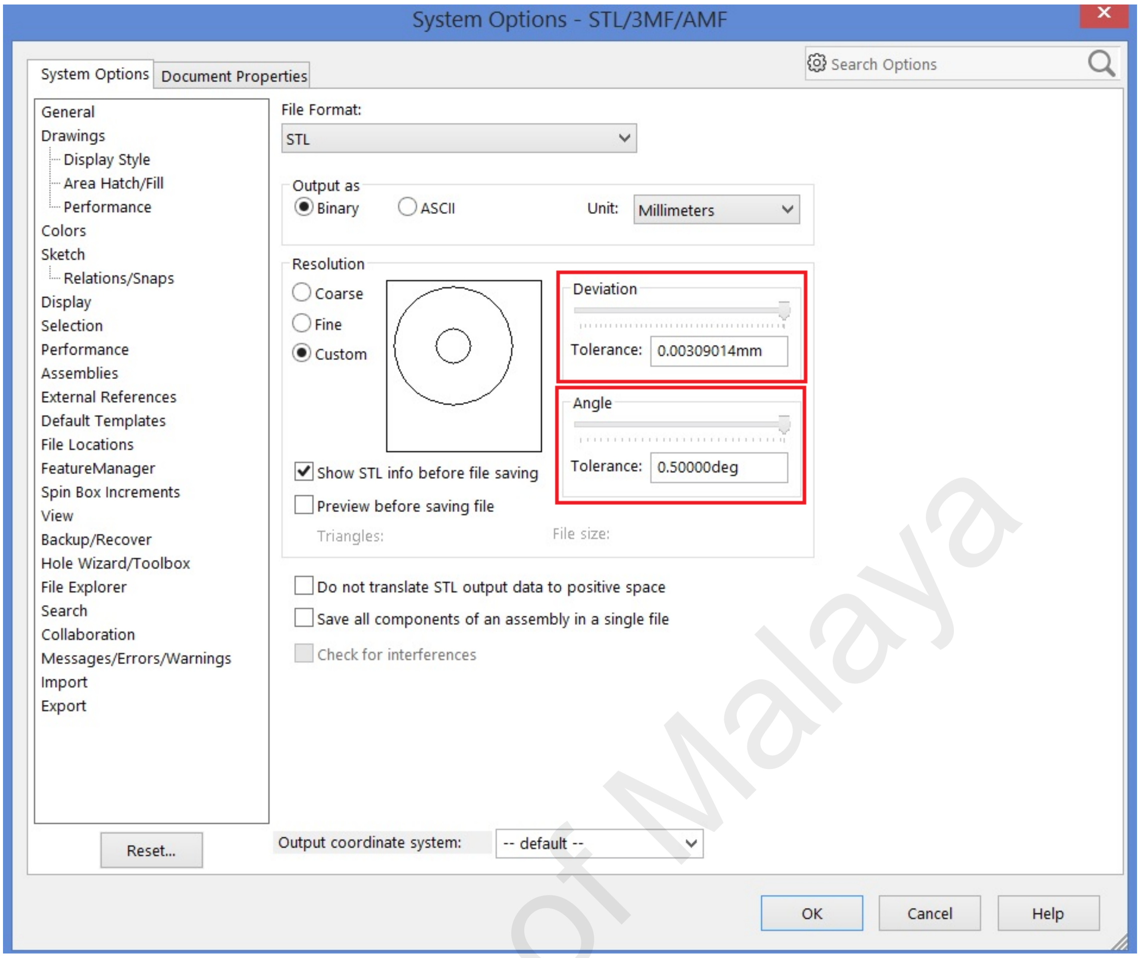


Figure 3.2: System Options for the conversion of SLDPRT to STL format

As can be seen in Figure 3.2 under resolution section, the custom mode has been selected. The deviation and angle have been adjusted to the right of the slider. The lower numbers of deviation will generate STL format with greater part accuracy while the smaller numbers of angle will generate STL format with greater detail accuracy.

Fusion 360 software is used to convert the STL to FBX format. The FBX file is an Autodesk part file that contains a 3D CAD model. Figure 3.3 shows the conversion of STL to FBX format in Autodesk Fusion 360.

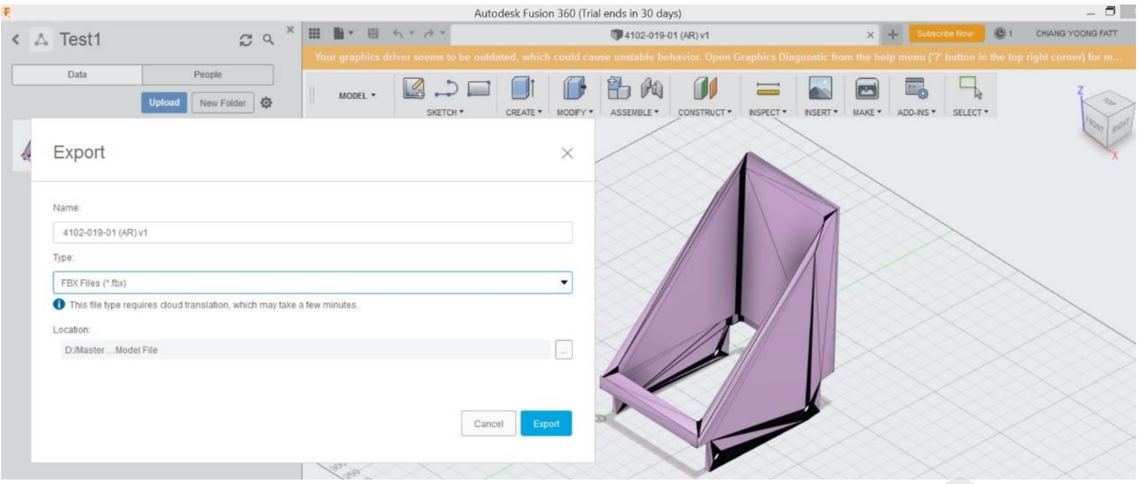


Figure 3.3: The conversion of STL to FBX format using Autodesk Fusion 360

The next step would be to convert the FBX to WT3 format using Wikitude 3D Encoder, as shown in Figure 3.4. The WT3 file is a compressed binary file for fast loading of 3D CAD model on a smartphone.

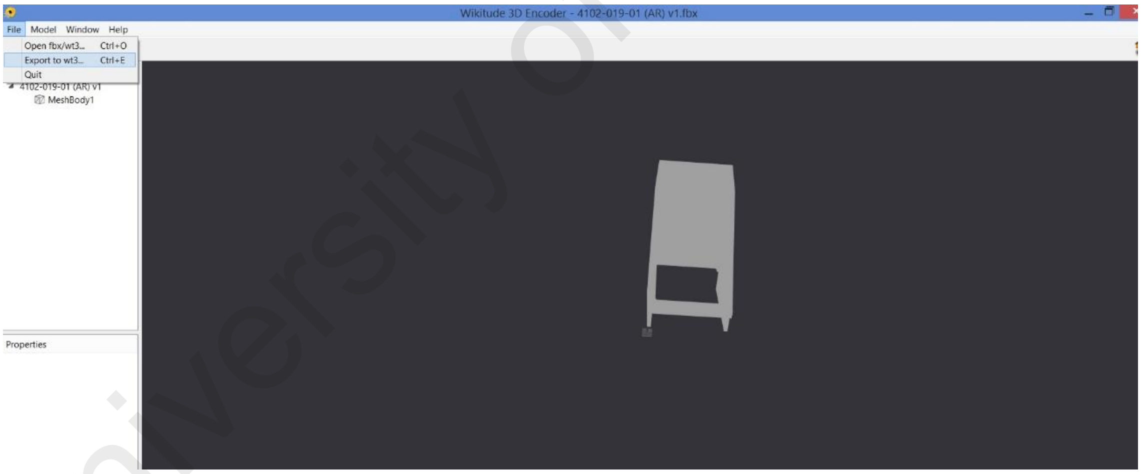


Figure 3.4: The conversion of FBX to WT3 format using Wikitude 3D Encoder

3.2 AR Creation Tool

The Wikitude Studio can render the WT3 file and it does not require programming knowledge. The Wikitude Cloud Recognition service provide a cloud server to store images as AR marker.

3.3 Visualization

The prototype AR system using isometric view as the AR marker for the Smartphone as shown in Figure 3.5 below:

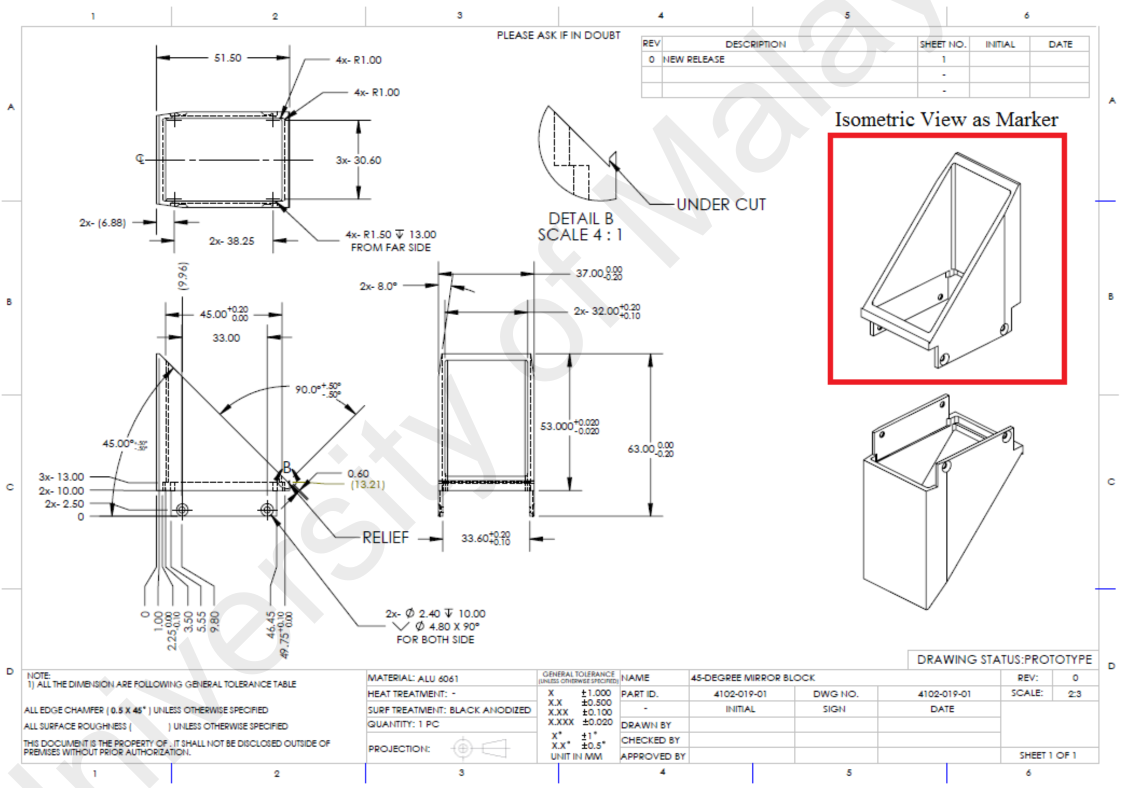


Figure 3.5: The Isometric view in mechanical drawing as AR marker

The isometric view has advantage to be a marker because it is unique without any additional information such as dimension, tolerance control and annotation as compared to the other projection view in the mechanical drawing.

CHAPTER 4: RESULTS AND DISCUSSION

To explore the benefits of AR in the quality inspection process, the 3D visualization and technical information on 2D mechanical drawing was developed in Figure 4.1 and Figure 4.2 below: -

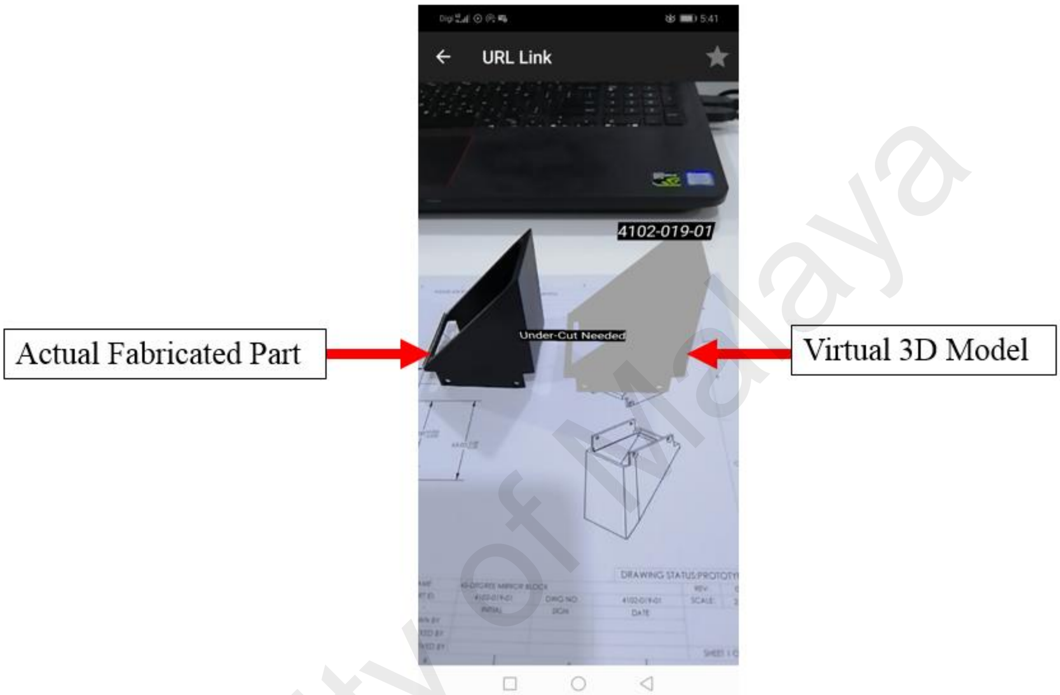


Figure 4.1: 3D visualization on 2D mechanical drawing

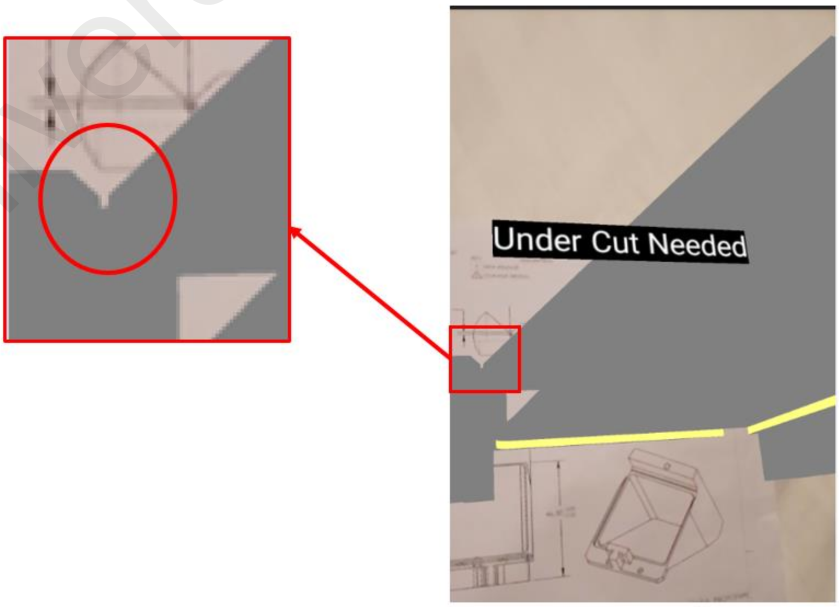


Figure 4.2: 3D visualization about under-cut feature

Few inspectors visualize with the 3D models using the prototype system. The prototype AR system seems able to offer an interactive method to let inspector perceive the technical information like under cut feature from the engineering drawing. It provides better understanding on the engineering drawing.

An assisted quality inspection application (see Figure 4.2) is aimed at overcoming the limitations of the conventional quality inspection. In conventional quality inspection context, inspector only referred to the 2D mechanical drawing for the important features such as undercut, chamfer, engraving text and etc. In an assisted quality inspection context, the inspector is guided in his specific 2D mechanical drawing providing real-time important feature, undercut process needed (see Figure 4.3).

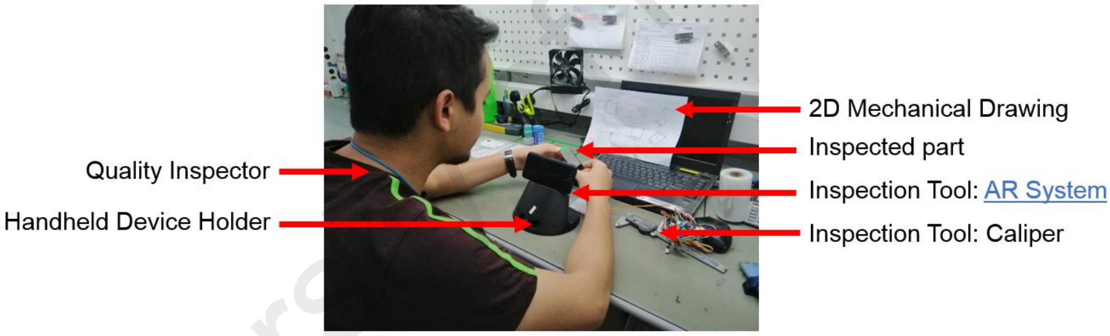


Figure 4.3: An assisted quality inspection application

Step 1 (Scanned Isometric picture) Step 2 (Visualized Virtual Model)

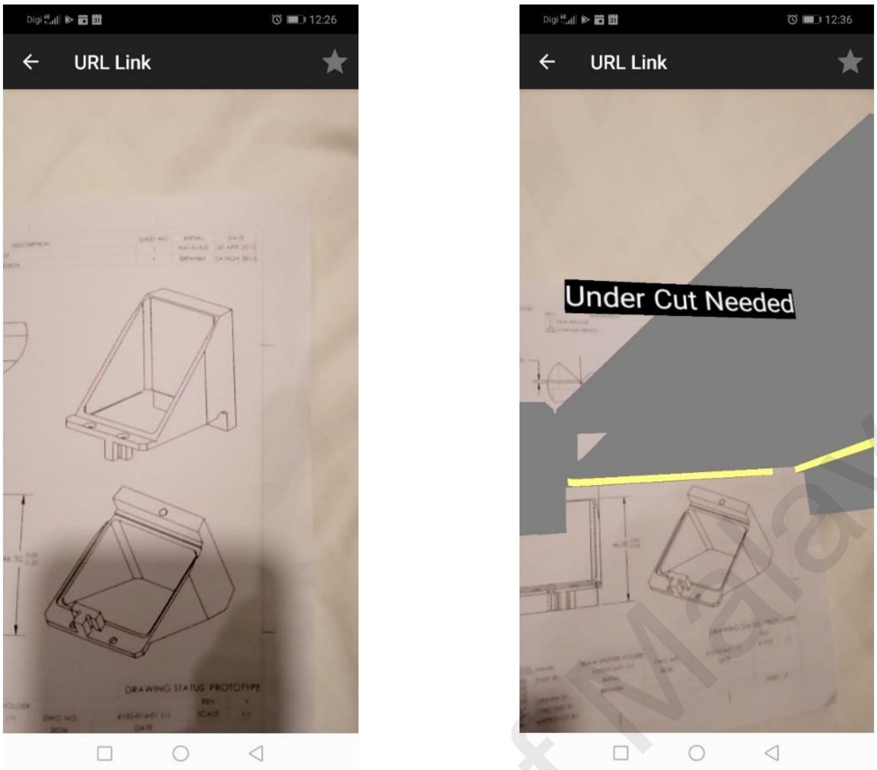


Figure 4.4: Image Visualization in AR system

The advantages of the developed prototype AR system are to reduce the time needed and provides better understand on technical information in mechanical engineering drawing as shown in Figure 4.5.

Pro	Cons
- Provides better understanding on technical information in Mechanical Engineering Drawing (3D Visualization)	- Ergonomic Issue (Non-portable holder)
- Can be implemented as 1st Fault Inspection model	- Unable to use it for bigger inspected parts (> 150 mm
	- Unable to use it for the assembly part

Figure 4.5: The Pro and Cons of assisted quality inspection prototype AR system

The prototype AR system also acts final gate inspection tool to avoid any missing feature or important annotation needed on the physical parts.

CHAPTER 5: CONCLUSION

A Smartphone-based Augmented Reality (AR) System is proposed for application in quality inspection for the manufacturing industry. This work focuses on the 3D visualization in AR to provide a better visual representation of critical information or features that in the 2D mechanical engineering drawing. The inspector can carry out inspection tasks, comparing immersive AR model with a fabricated part. The inspector appears to have a better understanding of the critical requirements when using AR prototype system. The prototype AR system seems to provide more perception or insights to inspector especially for the complex fabricated parts with few critical features and engraving texts. In the future, it is planned to develop the visualization of all mechanical drawings to promotes a better understanding of the important requirement for the mechanical drawings and targeted to reduce the number of discrepant material report (DMR).

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