TOOL CONDITION MONITORING OF DRILL BIT WEAR USING CAMERA FOR COMPOSITE ASSEMBLY IN AEROSPACE MANUFACTURING SYSTEM

AHMAD RAIMINOR BIN RAMZI

UNIVERSITI SAINS MALAYSIA

2019

TOOL CONDITION MONITORING OF DRILL BIT WEAR USING CAMERA FOR COMPOSITE ASSEMBLY IN AEROSPACE MANUFACTURING SYSTEM

by

AHMAD RAIMINOR BIN RAMZI

Thesis submitted in fulfilment of the requirements
for the degree of
Master of Science

July 2019

ACKNOWLEDGEMENT

Praise be to Allah s.w.t for granting me the strength through this wonderful experience in life with full of blessing. First and foremost, I would like to express my greatest honour and gratitude to my supervisor, Associate Professor Dr. Elmi Abu Bakar for his supervision and guidance throughout this research work. Without his encouragement and motivation which inspires me, I would not be able to proceed and bring this research into completion.

It is also my pleasure to express my appreciation to all members of the Innovative System and Instrumentation (ISI) research team, especially Dr. Faisal Mahmod, Koo Yeong Chin, Muhammad Zaim Pauzi, Siti Nur Hanisah Umar and Muhammad Nizar Zukri who have been involved directly or indirectly into my study.

Special thanks to Spirit Aerosystem (M) Sdn. Bhd. which led by Dr Daniel Chin and his team, Luqman Baharudin, Rozaidi Salamon, Mohd Suhaimi, Mohd Faizuddin, and Azlaidi Abdullah for their supports in my research. Not to forget, undergraduate apprentice program (UGAP) students who offers their assistance during the data collection.

My heartfelt gratitude for my beloved parents, Mazura Ahmad and Ramzi Ahmad, my siblings, in-laws and relatives for their endless support. Also, I would like to express my special appreciation to my beloved wife, Nabila Huda Mansor and our lovely son, Ahmad Aisy Rayyan that gives me the spiritual strength along this journey. Finally, this dissertation is dedicated to my big family for their love and prayer.

TABLE OF CONTENTS

ACKNOWLEDGEMENT .... **ii**

TABLE OF CONTENTS .... **iii**

LIST OF TABLES .... **vii**

LIST OF FIGURES .... **viii**

LIST OF SYMBOLS .... **xiii**

LIST OF ABBREVIATIONS .... **xiv**

ABSTRAK .... **xv**

ABSTRACT .... **xvii**

CHAPTER 1 INTRODUCTION **1**

1.1 Research Background 1

1.2 Problem Statement 5

1.3 Research Objective 7

1.4 Research Scope 7

1.5 Thesis Outline 8

CHAPTER 2 LITERATURE REVIEW **10**

2.1 Introduction 10

2.2 Composite Drilling in Aircraft Manufacturing Industry 10

2.2.1 Drill Bit Overview 12

2.3 Dominant Wear Mechanism in Composite Drilling Operation 14

2.3.1 Significant Effects of Flank Wear 16

2.3.2 Stages of Flank Wear 18

2.4 Review on Tool Condition Monitoring (TCM) 19

2.4.1 Comparison between Direct and Indirect Monitoring 20

2.4.2 Tool Rejection Criteria 23

2.5 Application of Image Processing Technique in TCM 24

2.6 Review on Image Segmentation 28

2.7 Review on Morphological Operation 32

2.8 Review on Image Registration 35

2.9 Summary 38

CHAPTER 3 METHODOLOGY 39

3.1 Introduction 39

3.2 Fundamental of Detection 41

3.3 Monitoring System Design 42

3.3.1 System Requirement 42

3.3.2 Proposed Monitoring System 43

3.3.3 Hardware Design 45

3.3.4 Illumination Condition 46

3.3.5 Subject Positioning 53

3.4 Flank Wear Detection 55

3.4.1 Region of Interest (ROI) 58

3.4.2 Image Acquisition Phase 59

3.4.3 Image Pre-Processing 60

3.4.4 Edge-Based Segmentation 61

3.4.5 Morphological Reconstruction of Flank Region 63

3.4.6 Positioning, Sizing and Orientation Correction 65

3.4.7 Measurement of Wear Percentage 67

3.5 System Graphical User Interface (GUI) 70

3.6 Monitoring System Testing 73

3.6.1 Principal Details of Drilling Operation 74

3.6.2 Testing Rejection Criteria 76

3.6.3 Data Collection Procedure 77

3.7 Summary 78

CHAPTER 4 RESULTS AND DISCUSSIONS 80
4.1 Introduction 80
4.2 Illumination Analysis 80
4.2.1 Effect of Light Source 81
4.2.2 Effect of Light Barriers 84
4.2.3 Effect of Brightness 88
4.2.4 Effect of Light Projection Angle 90
4.3 Comparison of Edge Detection Operators 93
4.4 Morphological Analysis 99
4.5 Image Registration Analysis 102
4.5.1 Interpretation of the Comparison Result 104
4.6 Flank Wear Monitoring Results 105
4.6.1 CFRP/Al Drilling using FLE 190 Drill Bit 106
4.6.2 GFRP/Al Drilling using FLE 193 Drill Bit 109
4.6.3 Comparative Study of Flank Wear Patterns 111
4.7 Wear Stages Analysis 114
4.8 Image Correction Analysis 118
4.9 Monitoring Precaution 121
4.10 Assumption 123
4.11 Summary 123
CHAPTER 5 CONCLUSIONS AND FUTURE WORKS 125
5.1 Conclusion of Research 125
5.2 Contribution of Research 126
5.3 Recommendation for Future Works 127
REFERENCE 129
APPENDICES
APPENDIX A : Orthographic Projection View of the Monitoring System

APPENDIX B : Matlab Source Code

APPENDIX C : Resulted Image of FLE 190 and FLE 193

APPENDIX D : Result of Flank Wear Percentages

LIST OF PUBLICATIONS

LIST OF TABLES

Page

Table 2.1 Description of Twist Drill Nomenclature *(Rao, 2013)* 12

Table 2.2 Application of different point angle. (Regal Cutting Tools, 2018).... 13

Table 3.1 Angle of light projection, β calculated for various drill bit point angle, α using Equation (3.7). 50

Table 3.2 Height of the light source, h calculated using Equation (3.11).......... 53

Table 3.3 RGB threshold values for both green and magenta colours............... 69

Table 3.4 Drilling operation specification for two different drill bit 74

Table 4.1 Default threshold values determine by MATLAB............................. 93

Table 4.2 Range of threshold for various edge detection operators................... 99

Table 4.3 Comparison of abrasive wear rates and the maximum values 112

Table 4.4 Comparison of flank wear rates and the maximum values 112

LIST OF FIGURES

Page

Figure 2.1 Drill bit nomenclature 12

Figure 2.2 Example of twist step drill bit with multi facet point......................... 13

Figure 2.3 Types of drill bit wear (Garg et al., 2014)... 15

Figure 2.4 Flank wear occur along the both side of the cutting lips region. 16

Figure 2.5 Stages of tool wear in machining (Sharif et al., 2012)....................... 19

Figure 2.6 Wear progression on primary face of micro drill bit measured up to 4000 holes (Fu et al., 2009) 26

Figure 2.7 Tool tip outlines extracted from side view (Atli et al., 2006)........... 27

Figure 2.8 Type of edge (a) step edge (b) line edge (c) ramp edge and (d) roof edge (Dharampal & Mutneja, 2015) 30

Figure 2.9 Mask used by Roberts operator... 31

Figure 2.10 Mask used by Prewitt operator.. 31

Figure 2.11 Masks used by Sobel operator 31

Figure 2.12 Comparison of dilation and erosion process (Jayaraman et al., 2009). 33

Figure 2.13 Comparison of original image (left) and transformed image (right) using the basic transformation such as (a) translation, (b) rotation, (c) scale and (d) shear (Mathworks, 2018).. 37

Figure 2.14 Generic geometric transformations. 38

Figure 3.1 Research overall flow chart... 40

Figure 3.2 Graphical illustration of (a) Reference image (b) Sample image of used drill bit (c) Fused image.. 41

Figure 3.3 (a) Conical region of the drill bit which is visible from the top view image (b) Plan view of the drill bit 43

Figure 3.4 Schematic of proposed monitoring system 44

Figure 3.5 3D rendering of monitoring system design using Solidworks Photo View 360. 45

Figure 3.6 Actual monitoring system during testing 46

Figure 3.7 Illumination setup with two light sources from different direction. .. 47

Figure 3.8 Law of reflection concept used for the illumination to ensure light rays enter the lens perfectly 48

Figure 3.9 Graphical illustration used to define the relation between angle α and β. 48

Figure 3.10 Light projection angle for drill bit with $\alpha > 90°$ 50

Figure 3.11 Light projection angle for drill bit with $\alpha = 90°$ 51

Figure 3.12 Light projection angle for drill bit with $\alpha < 90°$ 51

Figure 3.13 (a) Illustration to define the light source height, h (b) Right-angled triangle extracted to show the relation of k and β 52

Figure 3.14 Guideline application in the acquisition software. (a) unaligned. (b) aligned. 54

Figure 3.15 Drill bit position, size and orientation adjustment of the monitoring system 55

Figure 3.16 Image processing flow chart for wear detection algorithm. 57

Figure 3.17 ROI of the multi-facet drill bit point 58

Figure 3.18 Example of raw image taken using the developed hardware 59

Figure 3.19 Clean and smoothed background image after noise removal using Median filter 60

Figure 3.20 Flowchart of acquiring an ideal threshold for edge detection operators 62

Figure 3.21 An example of image resulting from edge detection process 62

Figure 3.22 Flow of morphological operators applied in the detection system 63

Figure 3.23 The 3-by-3 square structuring elements 64

Figure 3.24 Disk structuring elements with radius of 5 used for closing operation....64
Figure 3.25 Example of images resulting from the morphological operation (a) dilation (b) closing (c) flood-fill (d) erosion....65
Figure 3.26 Absolute comparison shows minor differences between the images 67
Figure 3.27 Variation of pixel intensities for (a) green and (b) magenta colour...68
Figure 3.28 Screen capture of the RGB thresholder application in used 69
Figure 3.29 Drill Bit Image Acquisition software....71
Figure 3.30 Drill Bit Wear Detection software developed using MATLAB. 72
Figure 3.31 Flowchart of system testing process 73
Figure 3.32 Semi-auto drill gun prepared for two different drill bit (a) FLE 190 (b) FLE 193....75
Figure 3.33 Sample of drill bit obtained from industry....76
Figure 3.34 Hole grading classified into four categories (a) grade A (b) grade B (c) grade C (d) grade D....77
Figure 4.1 Raw images of both drill bit model taken using the monitoring system (a) FLE 190 (b) FLE 193 81
Figure 4.2 Images captured at ambient light without any additional light sources (a) FLE 190 (b) FLE 193 83
Figure 4.3 Images captured by using built-in digital microscope light as the light source (a) FLE 190 (b) FLE 193....83
Figure 4.4 Images captured with customised illumination using barlight projected at angle of 45° (a) FLE 193 (b) FLE 193 83
Figure 4.5 Comparison of images captured without application of light barriers (a) FLE 190 (b) FLE 193 and with light barriers (c) FLE 190 (d) FLE 193....85
Figure 4.6 (a) – (d) Comparison of edge detection results for raw images shown in Figure 4.5 (a) – (d) respectively 86

Figure 4.7 (a) – (d) Grey level histogram of raw images shown in Figure 4.5 (a) – (d) respectively 87

Figure 4.8 (a) Over brightness at 1500 lux (b) normal brightness at 1100 lux (c) low brightness at 400 lux (d) inadequate lights at 150 lux 89

Figure 4.9 Raw images taken with different angles of light projection from 30° to 55° for FLE 190 drill bit 91

Figure 4.10 Raw images taken with different angles of light projection from 30° to 55° for FLE 193 drill bit 92

Figure 4.11 Comparison of edge detection using default threshold (a) Original image (b) Roberts (c) Sobel (d) Prewitt (e) Canny (f) LoG 95

Figure 4.12 Sobel edge detector with threshold values of (a) 0.1 (b) 0.2 (c) 0.3 ..96

Figure 4.13 Canny edge detector with threshold values of (a) 0.5 (b) 0.6 (c) 0.9 97

Figure 4.14 LoG edge detector with threshold values of (a) 0.010 (b) 0.015 (c) 0.0020...98

Figure 4.15 Comparison of a gap between disconnected lines (a) before and (b) after morphological dilation 100

Figure 4.16 Comparison of image resulted from (a) before and (b) after closing operation..101

Figure 4.17 Flank region filled by the flood-fill operation..................................101

Figure 4.18 Comparison of edge boundary affected (a) with and (b) without morphological erosion..102

Figure 4.19 (a) Absolute comparison of the drill bit flank without any correction made (b) Similarity transformation tends to align the images inaccurately..104

Figure 4.20 Example of image registration result showing the green and magenta region 105

Figure 4.21 Exit hole conditions on the test panel for (a) brand new drill bit (b) FLE 190 after 1000 holes (c) FLE 193 after 3000 holes..................106

Figure 4.22 Wear contribution of abrasive and adhesive wear mechanism in CFRP/Al stacks drilling operation for (a) FLE 190 A and (b) FLE 190 B 107

Figure 4.23 Flank wear percentage of FLE 190 A drill bit and FLE 190 B drill bit 108

Figure 4.24 Wear contribution of abrasive and adhesive wear mechanism in GFRP/Al stacks drilling operation for (a) FLE 193 A and (b) FLE 193 B 110

Figure 4.25 Flank wear percentage of FLE 193 A drill bit and FLE 193 B drill bit 111

Figure 4.26 Comparison of flank wear pattern for all drill bits monitored 113

Figure 4.27 Three stages of flank wear for FLE 190 drill bits 115

Figure 4.28 FLE 190 A wear area after (a) 100 (b) 400 (c) 700 and (d) 1000 holes 116

Figure 4.29 Three stages of flank wear for (a) FLE 193 A and (b) FLE 193 B drill bits 117

Figure 4.30 FLE 193 A wear area after (a) 300 (b) 1500 (c) 2100 and (d) 3000 holes 118

Figure 4.31 Image aligned perfectly using the proposed method........................119

Figure 4.32 Rotational correction made to the drill bit orientation for (a) FLE 190 and (b) FLE 193 120

Figure 4.33 Scaling correction made to the drill bit sizing for (a) FLE 190 and (b) FLE 193 121

Figure 4.34 Example image of (a) unclean drill bit and (b) its edge detection result..122

LIST OF SYMBOLS

A_g	Amount of green area (pixels)
A_m	Amount of green area (pixels)
A_{ref}	Reference area of the cutting lips (pixels)
B	Structuring element
$\hat{B}$	Reflection of image B about origin
h	Height of light source
i	Incident angle
k	Distance between drill bit tip and light source pivot
r	Reflective angle
W_{abr}	Percentage of abrasive wear
W_{adh}	Percentage of adhesive wear
W_f	Total percentage of flank wear
X	Reference image
x	Angle between flank surface and reflection line
Y	Boundary image
y	Angle between flank surface and normal line
z	outcome element
α	Drill bit point angle
β	Angle of light source projection

LIST OF ABBREVIATIONS

AE	Acoustic Emission
ASM	Active Shape Model
BoSS	Bag of Shape Segment
CAD	Computer-Aided Design
CCD	Charge-Coupled Device
CFRP	Carbon Fibre Reinforced Plastic
CFRP/Al	Carbon Fibre Reinforced Plastic - Aluminium
DEFROL	Deviation from Linearity
FLE	Fixed Leading Edge
FML	Fibre Metal Composite Laminate
FN	False Negative
FP	False Positive
FRP	Fibre Reinforced Plastic
GFRP	Glass Fibre Reinforced Plastic
GFRP/Al	Glass Fibre Reinforced Plastic - Aluminium
Gr/Bi-Ti	Graphite/Bismaleimide-Titanium
GUI	Graphical User Interface
HSS	High Speed Steel
HSS-Co	High Speed Cobalt
LoG	Laplacian of Gaussian
MRI	Magnetic Resonance Imaging
PCB	Printed Circuit Board
PCD	Polycrystalline Carbide
RGB	Red Green Blue
RLD	Randomised Line Detection
ROI	Region of Interest
TCM	Tool Condition Monitoring
USB	Universal Serial Bus

PEMANTAUAN KEADAAN ALAT TERHADAP KEHAUSAN MATA GERUDI MENGGUNAKAN KAMERA UNTUK PEMASANGAN KOMPOSIT DALAM SISTEM PEMBUATAN AEROANGKASA

ABSTRAK

Sifat kebolehmesinan bahan komposit yang lemah menjadikan sistem pemantauan keadaan alat (TCM) sangat diperlukan untuk operasi menggerudi dalam industri pembuatan kapal terbang. Sifat ini telah menyebabkan mata gerudi haus dengan lebih cepat, mengurangkan jangka hayat alat dan meningkatkan kos pembuatan. Ia adalah penting untuk menggantikan mata gerudi pada masa yang tepat sebagai amalan pencegahan untuk mengelakkan bahan komposit yang mahal ini daripada dirosakkan oleh mata gerudi yang tumpul. Oleh itu, sistem TCM menyediakan satu penyelesaian yang padat dalam memantau, mengawal dan mengoptimumkan penggunaan mata gerudi yang akan meningkatkan kualiti pemesinan secara tidak langsung. Penyelidikan ini mencadangkan satu sistem untuk memantau keadaan haus mata gerudi yang digunakan dalam pemesinan komposit yang merangkumi pengesanan dan pengukuran kehausan. Konsep pengesanan pada dasarnya membandingkan imej mata gerudi yang tumpul dengan imej rujukan mata gerudi yang baru. Perubahan pada bahagian mata pemotong yang menunjukkan jumlah kehausan diukur dalam bentuk peratusan menggunakan pendekatan pemprosesan imej. Dua sampel daripada industri sebenar, FLE 190 dan FLE 193 telah digunakan dalam pengujian sistem pemantauan. Berdasarkan keputusan, mata gerudi FLE 190 yang digunakan untuk menggerudi tindanan plastik bertetulang gentian karbon-aluminium (CFRP/Al) tumpul pada peratusan kehausan rusuk maksimum sebanyak 24.84 %. Sementara itu, mata gerudi FLE 193 dianggap tumpul pada 19.58 % apabila menggerudi tindanan plastik bertetulang gentian kaca-aluminium (GFRP/Al). Analisis menunjukkan bahawa mata gerudi FLE 190 mengalami kadar kehausan dengan lebih cepat pada purata 2.12 % setiap 100 lubang manakala mata gerudi FLE 193 tumpul pada kadar kehausan purata yang lebih perlahan sebanyak 0.46 % setiap 100 lubang kerana perbezaan kekuatan bahan kerja. Sistem ini mampu untuk memantau kehausan rusuk mata gerudi dan mengklasifikasikannya kepada mekanisma kehausan lelas dan perekat. Di samping itu, teknik pencahayaan yang digunakan membolehkan sistem ini digunakan untuk pelbagai mata gerudi dengan ketinggian dan sudut hujung mata yang berbeza. Hasil dan sumbangan penyelidikan ini membuktikan bahawa sistem pemantauan optik langsung yang dicadangkan ini boleh digunakan untuk aplikasi perindustrian.

TOOL CONDITION MONITORING OF DRILL BIT WEAR USING CAMERA FOR COMPOSITE ASSEMBLY IN AEROSPACE MANUFACTURING SYSTEM

ABSTRACT

The poor machinability of composite materials makes the tool condition monitoring (TCM) system is highly demanded for the drilling operation in aircraft manufacturing industry. It caused the drill bit to wear faster, reducing the tool life expectancy and increasing the manufacturing cost. It is important to replace the drill bit on time as the precautionary practice to avoid the expensive composite material from being damaged by the blunt drill bit. Therefore, TCM system provides a compact solution in monitoring, controlling and optimising the drill bit usage which will improve the machining quality indirectly. This research proposed a system to monitor the wear condition of drill bits used in composite machining which includes detection and measurement of wear. The detection concept is basically comparing the image of worn drill bit with the reference image of a brand new drill bit. The changes in the cutting edge region which indicating the amount of wear is measured in term of percentage by using image processing approach. Two samples of drill bits from real industry, FLE 190 and FLE 193 were used in the monitoring system testing. Based on the result, FLE 190 drill bit which is used to drill carbon fibre reinforced plastic - aluminium (CFRP/Al) stacks worn out at maximum flank wear percentage of 24.84 %. Meanwhile, FLE 193 drill bit is considered worn at 19.58 % when drilling glass fibre reinforced plastic - aluminium (GFRP/Al) stacks. The analysis shows that FLE 190 drill bit experienced a faster wear rate at average of 2.12 % per 100 holes while FLE 193 drill bit worn out at slower average rate of 0.46 % per 100 holes due to the

different strength of the workpiece. The system is capable to monitor the drill bit flank wear and classify it into abrasive and adhesive wear mechanism. Besides, the illumination technique used enables the system to be used for various drill bit with different height and point angle. The output and contribution of this research proving that the direct optical monitoring system proposed is applicable for the industrial application.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Composite materials present superior mechanical properties such as high strength to weight and stiffness to weight ratio. For past decades, it is widely used in various industries such as marine, aerospace, automobile, sporting goods and chemical processing equipment. In aerospace industry, the demand is increasing due to its lightweight, high strength, nonconductive, corrosion resistance and excellent fatigue resistance properties (Dandekar & Shin, 2012). The first significant use of composite material in commercial aircraft was in 1983 in the rudder of Airbus A300 and A310. The usage of composite materials is increasing by years as it constitutes almost 50% of Boeing 787 in 2009 with average weight reduction of 20 % (Quilter, 2001). These hybrid properties of the material help the manufacturers to compete in building strong and lightweight aircrafts to improve the fuel efficiency and flight endurance. Thus, composite materials offer a better fuel economy and a lower operating cost for the airlines.

However, the usage of composite material in aircraft manufacturing increased the production cost and leads to a higher aircrafts price. Apart from the rising of material prices, the composite machining process also contributes to the increasing production cost. In aircraft manufacturing, composite drilling is the major machining operation involves and it is different and quite challenging compared to the drilling of conventional metallic materials. This is due to the non-homogenous, anisotropic and highly abrasive characteristics of the composite materials (Teti, 2002). The cutting tool life will be reduced as it tends to worn faster due to the poor machinability of the composite material. This causes the manufacturing process to require more cutting tools in order to assemble the same amount of the aircraft components. Furthermore, the drilling process also may cause severe damages to the composite panel such as delamination and fibre pull-out (Liu et al., 2012). In the past, this problems is very common in composite drilling as it was reported that 60% of the composite laminates rejected parts are due to delamination damages during final assembly (Stone & Krishnamurthy, 1996). It is very crucial for the manufacturers to minimise the waste as the rising material prices are making the cost of scrapped component higher. This loss can be avoided by reducing or even eliminating the delamination during drilling process.

Delamination depends on feed rate, cutting speed, drill geometry, tool wear and tool material (Iliescu et al., 2010). The tendency of the delamination can be minimised during high speed drilling of the composite laminates by using the combination of high cutting speed and low feed rate. Selecting the suitable drill geometry and material also can enhance the quality of the hole making process. These factors can be controlled once the right selection is made before drilling operation except for tool wear which occurs progressively during the drilling. The level of tool wear should be monitored and keep under control to avoid the machined workpiece from being damaged.

Generally, the procedure for cutting tool replacement is depending on the value of workpiece material. If the workpiece value is lower than the cost of tool replacement, the production will keep using and change the cutting tool only after the workpiece is rejected. On the other hand, if the workpiece is more valuable, the tool must be replaced on time as the preventive measure to avoid any undesirable results

(D'Addona & Teti, 2013). In aerospace manufacturing, the composite material is very expensive and any damaged that leads to scrap would be a huge loss to the industry. Thus the preventive measures are very crucial. It is extremely essential to replace the worn tool in time to avoid downtime and scrapped component. Worn or blunt drill bit must be avoided as it may damage the surface finish of the machined part. On top of that, excessive wear and tool breakage also may cause downtime which is unfavourable in any manufacturing industries. Malaysia has been a major player in aerospace industrial hub by providing final stage services such as assembling the aircraft parts. In this circumstances, any rejection of the composite panels will be huge loss for the industry to bear. The loss is not primarily contributed by the expensive composite material only but also because of the whole processes involved before and until the final tier of assembly. Therefore, tool condition monitoring (TCM) would be beneficial for the aircraft assembly line in optimising the usage of the drill bit, improving the quality of the machining process and achieving the high quality of the final product.

In metal cutting process, TCM is inevitable as it also helps in reducing the machine tool downtime which improves production rate significantly. Dimla Snr. (2000) stated that TCM is important to metal cutting process as it can provide an advance fault detection system for cutting and machine tool, check and safeguard machining process stability and machine tool damage avoidance system. Historically, human operators performed TCM process by using the senses of sight and hearing which is subjective and flexible but inaccurate. Nowadays technology is very advanced in replacing the method through various approaches. Principally, TCM can be divided into two categories which is direct sensing method and indirect sensing method. Direct method measures the wear directly while indirect method measures the parameters that correlate the wear and tool condition.

Researchers have been looking into the possibility of implementing the TCM system into the real industrial application whether through direct or indirect monitoring method. Optical measurement approach is reported as the only reliable direct monitoring while for indirect monitoring, measurement through thrust force, machining temperature, vibration signal and acoustic emission (AE) are the preferable methods (Siddhpura & Paurobally, 2013). From the publications reviewed, these indirect methods pose some limitation which is a significant drawback in tool wear monitoring. For example, the force sensors are sensitive to the machine vibration and the high frequency force is unable to be measured by dynamometer. Besides, temperature monitoring also unable to measure the exact machining temperature due to the difficulties in accessing the cutting zone (Dimla Snr., 2000). Vibration signal may be distracted by the environmental noises but AE is a better approach as it does not interfere with machining operation due to its higher operational frequency than environmental noise. However, AE is only effective in detecting tool breakage or fracture as it generates larger AE signals during breakage and fracture (Jantunen, 2002).

Most of the indirect methods has the capability to perform online monitoring but the direct methods is hardly to be applied online due to the inaccessibility of the cutting area and continuous contact between the tool and workpiece during cutting process (Waydande et al., 2016). Apart from that, the direct optical method requires an appropriate illumination for the monitoring system to eliminate the nonlinear illumination from the ambience. A robust algorithm is vastly demanded in achieving a reliable monitoring process. However, this direct optical method provides an advantage of capturing the actual geometrical changes of tool condition. The optical approach is practically reliable in industrial environment as it offers a non-contact measurement of the tool wear which deliver a reliable, accurate and quickest results through the direct measurement. In addition to this, Siddhpura and Paurobally (2013) stated that the optical measurement methods have a promising future in terms of industrial application if this method can be continuously developed to monitor the tool wear. Practically, this approach is applicable to industrial environment despite of the limitations.

1.2 Problem Statement

Tool replacement is a process that should not be underestimated especially in composite machining of the aircraft assembly. It is very important to maintain the productivity of the manufacturing process, avoid scrapping expensive composite component and assure the product of high aerospace standard quality. In Malaysia, the current practise in cutting tool replacement for composite machining is by depending on the number of tool usage. This parameter is highly inconsistent even for the same machining process. For example, two identical drilling processes would yield a different number of tool usage even both processes are using the same drill bit type, workpiece material and the same semi-automatic drill gun model with constant drill speed and feed rate. The number of tool usage is affected by the efficiency of the semi-automatic drill guns. This shows that the number of tool usage is not a consistent parameter to be depending on for the tool replacement process. A new consistent parameter is required to represent the condition of the drill bit which could be done by applying an optical TCM system into the manufacturing process.