A HYBRID SYSTEM COMBINING RAPID PROTOTYPING AND CNC MACHINING OPERATION

BY

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ABSTRACT

At present, two important processes, namely CNC (Computer Numerical Control) machining and rapid prototyping (RP) are being used to create prototypes and functional products. CNC machining (subtractive method) is relatively more precise and accurate, but it is tough to create stuffs with complex features. RP (additive method), by contrast, is able to form parts with sophisticated features, that consents materials to be utilized more efficiently. Combining both subtractive and additive process on a single platform has significant advantages. However, there are two important aspects need to be taken into consideration for this process hybridization. First aspect is the integration of two different control systems for two processes and second aspect is maximizing workpiece alignment accuracy during the changeover step. This research attempts to assimilate both of these processes and propose a new design of hybrid machine with the purpose of overcoming the drawbacks related with different control panel and misalignment issues. Fused deposition modeling (FDM) is considered as the RP process in this study. A new innovative design for hybrid system, consisting of CNC machining and FDM, was proposed in this study. One of the aspects of the design consist of installing the CNC cutting spindle and the heat extruder of FDM on a rotary stage and using the IR sensors which makes the mechanism simpler and overcomes the problem of misalignment. The rotary stage has also given the advantage of using the 3-axis machine as a 4-axis machine. The other feature of this research was the single control panel for both CNC machining and FDM operation. The case studies undertaken in this research demonstrated that the proposed hybrid system can conduct three-axis machining on a completed FDM part or trim the surface of the parts with two different layers fabricated by FDM to achieve more accurate dimensions or better surface finish. Several objects were produced with different layer thickness for example 0.1 mm, 0.15 mm and 0.2 mm. About 99.87% accurate dimension was achieved after CNC grinding operation. Finally, dimensional accuracy was improved by 92% when the FDM part is compared with the final part after grinding operation. At the same time average surface roughness (R_a) was reduced by 90%. It was also observed that layer thickness plays a role on the dimensional accuracy and best accuracy is achieved with the minimum layer thickness (0.1 mm).

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خلاصة البحث

في الوقت الحاضر ، عمليتان مهمتان يستخدمان لصنع النماذج و المنتجات هما CNC Machining and Rapid prototyping (RP) . العملية CNC Machining هي عملية قطع باستخدام الآلة بحيث يكون القطع أو الحفر دقيق ومتقن. لكن هناك صعوبة بصنع النماذج المعقدة بهذه العملية. في المقابل عملية RP هي عملية إضافة قادرة على صنع النماذج الأكثر تعقيداً بكفاءة ودقة. بجمع العمليتين على منصة واحدة نحصل على إيجابيات كلتا العمليتين. ومع ذلك، هناك جانبان مهمان يجب علينا أخذهما بعين الاعتبار من أجل عملية الدمج أو التهجين. الأول هو دمج اثنين من أنظمة التحكم المختلفة للعمليتين والثاني هو زيادة دقة العمل أو الحفر خلال خطوة التحول. هذا البحث يدرس التخفيف أو الحد من هاتين العمليتين واقتراح تصميم آلة جديدة هجينة للتغلب على العيوب المتعلقة بالتحكم بالعملية وموضوع عدم الاتساق. عملية RP في هذا البحث هي Fused Deposition Modeling (FDM). تصميم نظام هجين يحتوي على CNC Machining and FDM هي ما سوف تناقشه هذه الدراسة. واحدة من الجوانب في التصميم هي برمجة وتنصيب CNC Machine وجعلها تعمل مع FDM في مرحلة الدوران واستخدام المستشعر IR التي تجعل العملية أبسط وتحل مشكلة عدم الاتساق. من ايجابيات الدوران هو جعل الآلة ثلاثية المحاور تعمل كأنها آلة رباعية المحاور. وهناك ميزة مبتكرة أخرى ألا وهي استخدام لوحة تحكم واحدة للعمليتين CNC and FDM. هذه الدراسة تبحث في النظام الهجين الذي يعمل على آلة ثلاثية المحاور و جعلها تعمل على نموذج FDM أو جعلها تقطع سطح النماذج مع اختلاف في سمك الطبقة المقطعة أو السطح باستخدام عملية FDMالعديد من النماذج قد انتجت قد انتجت مع اختلاف في سمك الطبقة ،على سبيل المثال0.1mm ,0.15 mm, 0.2 mm. نسبة دقة الأبعاد قد كانت% 99.87 بعد عملية CNC Grinding . أخيراً ،دقة الأبعاد قد زادت بنسبة%92 عند استخدام FDM بعد عملية CNC Grinding. بنفس الوقت متوسط خشونة السطح Ra قد خفض بنسبة% 90.لقد كان من الملاحظ أن سمك الطبقةالمقطعة يلعب دوراً مهماً بتأثيره على دقة الأبعاد وأن أفضل دقة يمكن الحصول عليها هوعند استخدام أقل سمك للطبقةالمقطعة0.1mm.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Mechatronics Engineering).

…………………………………..
Tanveer Saleh
Supervisor

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Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Mechatronics Engineering).

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External Examiner

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Erry Yulian Triblas Adesta
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently Submitted as a whole for any other degrees at IIUM or other institutions.

A N M Amanullah Tomal

Signature .... Date ....

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
AM	Additive Manufacturing
3DP	3D Printing
LM	Layered Manufacturing
LOM	Laminated Object Manufacturing
CNC	Computer Numerical Control
DED	Directed Energy Deposition
PBF	Powder Bed Fusion
FDM	Fused Deposition Modelling
IR	Infrared
LENS	Laser Engineering Net Shaping
PLA	Polylactic Acid
RP	Rapid Prototyping
SEM	Scanning Electron Microscope
SI	Solid Imaging
SLC	Selective Laser Cladding
SLS	Selective Laser Sintering
STL	STereoLithography
i.e	(id est) that is

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The objectives of manufacturing systems are more powerful now because of over-all competition in the development of product. Owing to spread the market rapidly, products that are commonly used to produce prototypes, need to be manufactured within scheduled time (Koren, 2010).Therefore, this development has appealed the attention of technology developers to bring change in the methods of manufacturing that are employed in producing prototypes. In the 1980s, RP- Rapid Prototyping technologies were introduced and were used to produce prototypes quickly with an automation process. RP is also known as 'Layered Manufacturing' (LM) and 'Additive Manufacturing' (AM). Additive mechanism which implies to build the part by combining layers of material (solid sheet, powder or liquid) until the whole product is produced (Wohlers, 2000). This additive manufacturing technology has drawn noteworthy interest due to its capability to overcome many drawbacks of traditional manufacturing techniques. Its ability to form almost any geometric feature or shape is a great advantage of AM (Hanser Gebhardt, 2003). RP technologies was introduced to assist the development of new product specially for evaluation processes and analysis. At early stages of product development, RP allows design changes and confirms product's validity before entering full scale production. With the time being RP technologies have advanced and their scope has been extended to create finished parts. Several techniques have been developed to establish RP technology as one of the most reliable manufacturing methods. More developments have invented some advanced techniques which are able to process metallic materials as well as to produce polymeric products.

However, this technology is still besieged with several limitations which restrict its abilities. Though this manufacturing technology is able to process metallic materials, may not be capable of solving several important issues including surface roughness, dimensional accuracy and final part properties (Campbell, Bourell, & Gibson, 2012; Wong & Hernandez, 2012). Figure 1.1 represents the qualitative assessment of different processes that are able to produce metal parts.

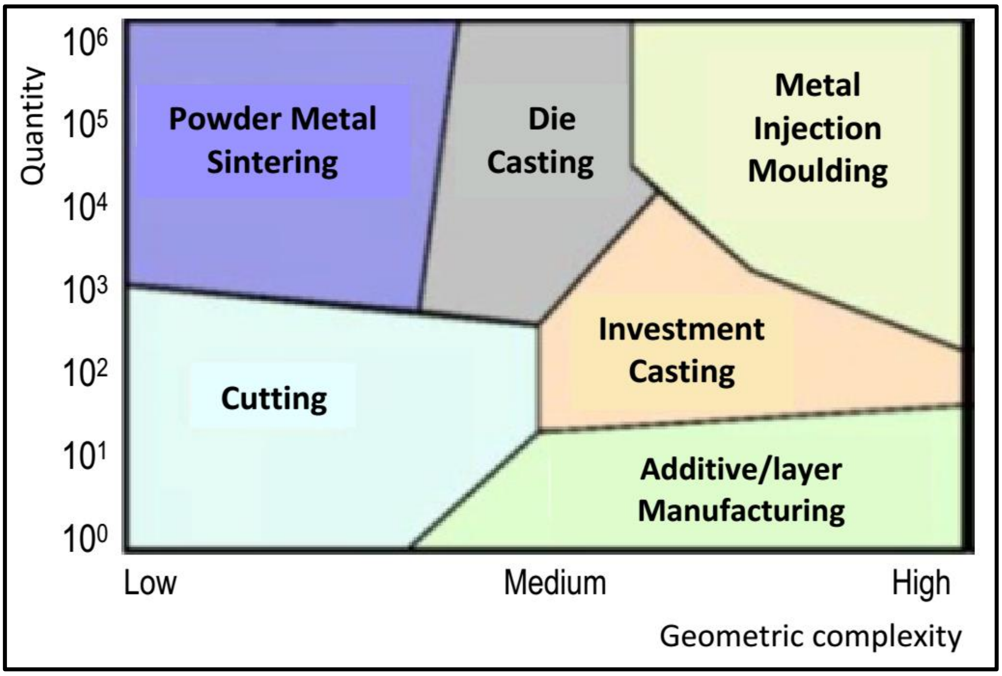

Figure 1.1 Involvement of various processes in metal parts production (Levy et al 2003)

According to Levy, Schindel, and Kruth (2003) only two processes are able to fabricate metal parts directly. The rest of the processes can be considered as indirect processes as they use different methods like as dies and moulds to createthe finished parts.

As the limitations of RP processes are still unsolved, other methods need to be considered to solve the issues such as cutting operations. However, there is a limitation in terms of part complexity despite the capability to handle low to medium production quantities. This method of manufacturing is categorized under subtractive manufacturing processes.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Both additive and subtractive approaches are important aspects of today's prototyping industry. Conventional CNC machining is a subtractive process. Subtractive processes, as the name implies, create objects by removing unwanted material from a large block or sheeting the form of chips. On the other hand, FDM is an additive process. It can't meet the need of subtractive approaches. In RP process though fast, easy of fabrication and process automation is obtained at the same time accuracy, good surface finish are not obtained which is possible in CNC machining. So the combination of FDM and conventional CNC machining will accumulate the advantages of the bost operation into a single work station. One system has been developed recently that is the combination of FDM and five-axis machining. But in this system stepper motors were used which creates a problem with less accuracy. Another remark is that in that system FDM extruder was installed on the opposite end of the cutter spindle that is a bulky mechanism. So, in this research, we will try to achieve better dimensional accuracy of the finished part with compact mechanism.

1.3 RESEARCH OBJECTIVES:

This project presents in detail a hybrid system combining FDM and CNC machining operation. The objectives of the project are as below:

1. To develop the mechanical system of the hybrid system.
2. To design and implement the graphical user interface based control system for the hybrid system.
3. To evaluate the performance of the system in terms of surface roughness and product accuracy by comparing with previous works.

1.4 RESEARCH METHODOLOGY:

This research has been carried out mainly based on experimental design, simulation and control system implementation of the developed system. The following section describes methodology for each objective of this proposed project.

1.4.1 Methodology for Objective 1:

The main structure of the machine was pre built with 3 servo motors for 3 axis. For that purpose, at first the properties of the motors were justified to confirm its ability to withstand with our newly developed hybrid system. For maintaining the alignment during changeover process, a rotary stage and two IR sensors wrer used. In front of the rotary sensor, there is an attachment where the CNC spindle and FDM heat extruder was attached respectively just parallel to the Rotary stage. An L bracket was fabricated to hold the FDM heat extruder. The IR sensors were attached to another attachment that is perpendicular to the rotary stage. The sensors were used to omit the problems of misalignment during exchanging the equipment of CNC milling and FDM process. Figure 1.2 and figure 1.3 shows the proposed 3D figure of the hybrid system with CNC spindle and heat extruder respectively.

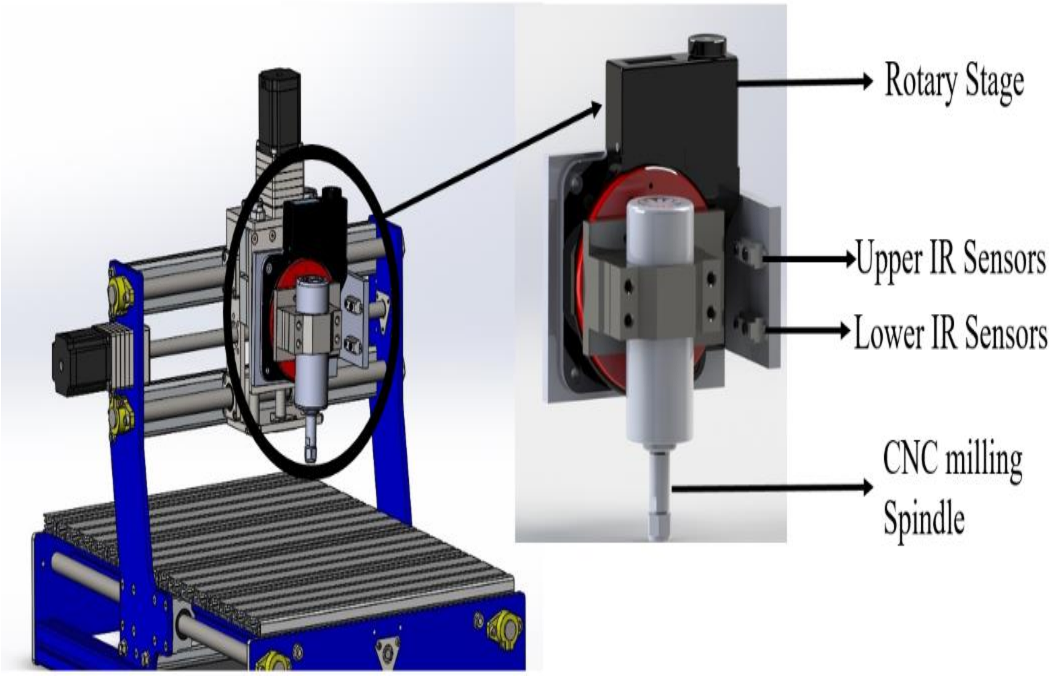

Figure 1.2 Proposed design of the system with CNC spindle

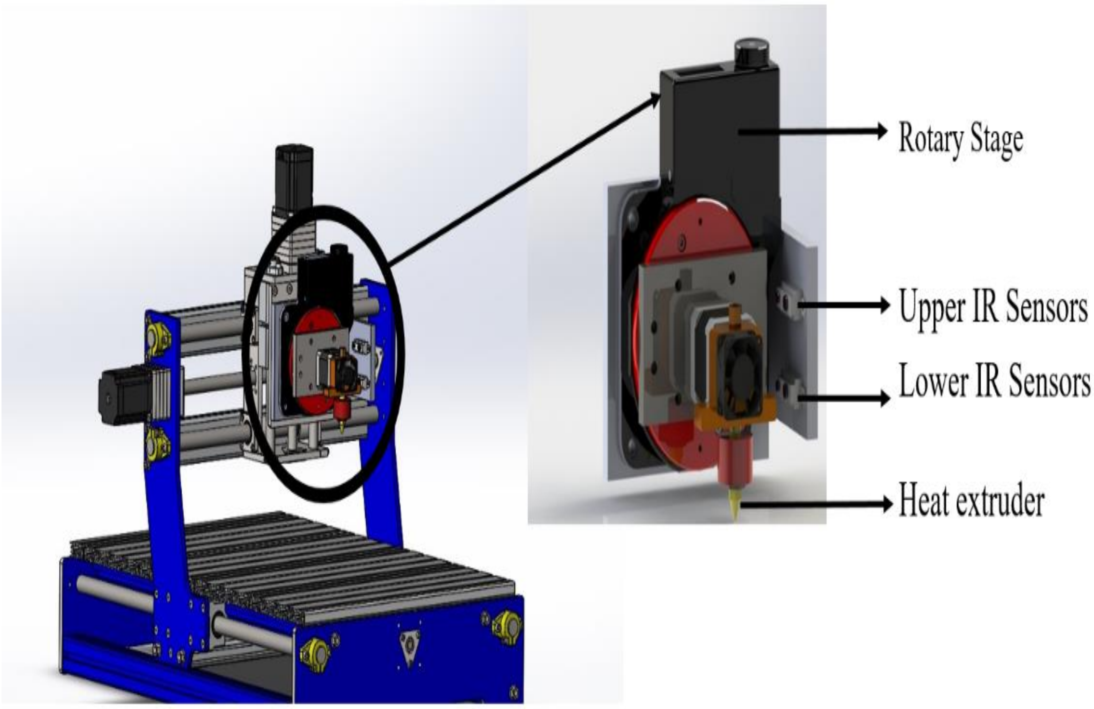

Figure 1.3 Proposed design of the system with heat extruder

1.4.2 Methodology for Objective 2:

The whole control system for the machine was developed using separate controller and circuitry to handle the CNC machining and FDM process. For our research purpose, we have used LabVIEW 2014 to create the Graphical User Interface (GUI) for the newly developed system. For controlling the whole process we have used NI PCI-7344, UMI-7764. To perform the FDM operation, at first, we needed to draw the 3D figure of the desired object. As most of the RP processes use the CAD file in STL (stereolithography) format (Fadel & Kirschman, 1996), the 3D figure was converted into STL format .To do these operations we used SolidWorks 2014. After that we sliced the CAD file into layers with Slice3R software and we got the G codes for the FDM operation. Finally we did the FDM operation. During the changeover process we controlled the signals coming from the IR sensors to eliminate the misalignment issue. For this issue we have used the NI DAQ USB 6211. The analog signals were coming from the IR sensors and in the GUI it was represented as voltage. After that, we adjusted the position of the CNC spindle by rotating the rotary stage according to the signal information from the sensors. When the misalignment issue was eliminated we started the CNC grinding operation.

1.4.3 Methodology for Objective 3:

To investigate the performance of the machine the dimensional accuracy, surface roughness and effect of layer thickness on the produced parts were studied. We have used PLA (Polylactic Acid) material to produce several cubic parts with different layer thickness. After doing the FDM operation, we replaced the FDM heat extruder with CNC spindle with grinding stone. Figure 1.4 describes the process of methodology flow for objectives of the research work.

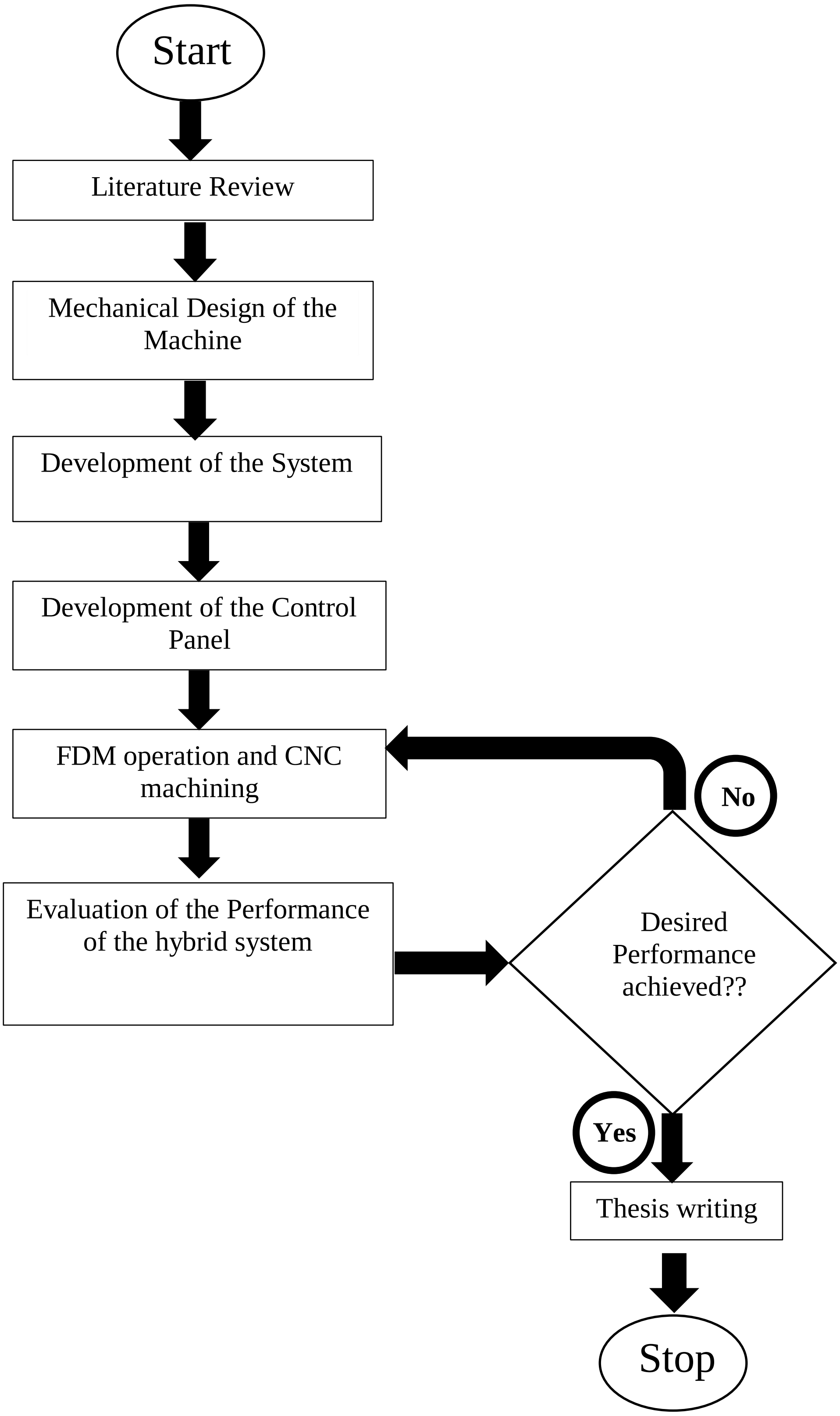

Figure 1.4 The complete research plan of methodology

1.5 RESEARCH SCOPE

This research represents the development of a new hybrid system integrating two processes namely CNC machining and FDM operation. We have developed the system with simple mechanism with compared to other existing systems. The alignment issue during the changeover process was eliminated by using Rotary stage and IR sensors. The single control panel for the whole system was also a great achievement. The technique requires a set of process parameters for experimental verification to achieve the best parameter for the sensor fabrication. Primarily, the justification of the selection of different motors investigation was carried out. Consequently, several cubic parts with different layer thickness were produced to assess the system performance. Next, dimensions were measured to test the dimensional accuracy of the both produced parts with and without machining. Thereafter, the produced parts were investigated in SEM so that we could get better idea about the surface finishing before machining and after machining. Finally, the effect of layer thickness on thermoplastic parts was described.

1.6 THESIS ORGANIZATION

The thesis has been organized in 5 chapters which have highlighted the total research work in detail. The 5 chapters are described briefly as below.

Chapter 1: As described in the previous sections, this chapter provides a brief insight into CNC machining and RP technology along with the importance of hybrid manufacturing system combining these two operation into a single workstation. It also highlighted the developments that enable the RP process to manufacture finished products. The last section highlights the research scope of this study technology.

Chapter 2: The literature review starts with introducing the Additive Manufacturing Technologies along with its classifications and its usage in different sectors. After that, the existing post processing techniques of additively manufactured parts are described in briefly. Several processes are also described based on subtractive processes. Next, a comparison is shown between CNC machining and additive manufacturing processes. Advantages and limitations of each process are described specially to fortify the argument for implementing RM applications and CNC machining. Finally, several sections cover the developments that have been carried out in hybrid manufacturing systems combining CNC machining and RP technology.

Chapter 3: The design and development of the whole hybrid system is described in this chapter. Firstly, the mechanism of the total mechanical structure of the hybrid system is described. After that, the justification of the existing servo motors to withstand with the new system is validated. Later on, the mechanism behind using the IR sensors is described. Along with these sections, the selection of several parts such as rotary stage, IR sensors, is also described. Next, the whole control system is described along with all sub control panels for different operations involved in the hybrid system such as: jog and home operation, CNC machining operation, FDM operation, and alignment operation.

Chapter 4: Performance of the newly developed hybrid manufacturing system is evaluated in this chapter by producing several cubic parts with different layer thickness. Firstly, the dimensional accuracy test is described showing the differences of different layer thickness for both machined and un-machined parts. Secondly, the roughness study is highlighted elaborately. In which, the comparative study of the surface profile of each parts is described. During the production of the cubic parts and

CNC machining on them several problems raised. The problems are also highlighted in this chapter with providing the possible actions to resolve them.

Chapter 5: The whole work discussed in this thesis is summarized in this chapter. The findings of the previous studies related to hybrid manufacturing system are highlighted. Furthermore, the shortcomings of this research work is highlighted and recommendations are also included to give proper direction for future works that will further improve this hybrid manufacturing system.