A HEXAPOD ROBOTIC PLATFORM FOR MINIATURE DRILLING OPERATIONS

BY

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ABSTRACT

Product miniaturization is a key aspect of manufacturing nowadays. Computer numerically controlled (CNC) machine tools are the major tools used in manufacturing industries for producing miniaturized products. However, CNC machines are still big, bulky and stationary. This research is an effort to develop a robot which would be able to carry out machining operation as a mobile plaform. There have been several researches going on about the development and application of miniature multi legged robots. Hexapod robots are small and stable mobile robots which are developed having a lot of variety. But the main focus of researchers till now have been the structure and motion of hexapod robots. However, not much research has been conducted about the use of legged robot for machining application. In this project a Hexapod robot was designed and fabricated for machining operation. The research scope for this project is limited to 1-D machining i.e. drilling operation. This research demonstrates methodically for the first time the feasibility of meso-scale machining using linked mobile robotic platform. A suitable existing robot (hexapod) design was followed in this project. A drilling spindle was attached with the robot to carry out the machining operation. The robot was controlled using serial communication. A Graphical User Interface (GUI) was developed to control the Hexapod which had all the required algorithm inside. Machining operations were carried out with the prototype robot to test its performance. A new compensation algorithm has been proposed to improve the positional accuracy of the robot movement. The proposed algorithm takes into account spindle speed and linear velocity to compensate the positional error. The positional accuracy was improved by 85% after implementing the error compensation scheme. It was seen that for lowest spindle speed which is 2500RPM and point to point velocity 200mm/min the repeatability was the best which was less than 30µm. The positional accuracy of the robot movement was compared with that of an existing commercial micromachining system. The performance of the robot was found to be almost similar to that of the commercial machine. Finally, the machined hole quality was measured in terms of circularity and taperness. It was observed that at the best machining parameter setting, circularity deviation was as low as 0.016 mm and taperness was 0.547 degree.

خلاصة البحث

ان تصغير المنتج هو أحد الجوانب الرئيسية للتصنيع في الوقت الحاضر. ان أدوات التحكم العددي بالكمبيوتر (CNC) هي الأدوات الرئيسية المستخدمة في الصناعات التحويلية لإنتاج المنتجات المصغرة. ومع ذلك ، لا تزال آلات التصنيع باستخدام الحاسب الآلي كبيرة وكبيرة الحجم وثابتة. هذا البحث هو جهد لتطوير الروبوت من تشغيل الآلي إلى منصة الهاتف، هناك العديد من الأبحاث الجارية حول تطوير وتطبيق الروبوتات الصغيرة متعددة الأرجل. ان الروبوت سداسي الارجل هو روبوت نقال صغير ومتزن، والذي تم تطويره لانواع عديدة. ان التركيز الرئيسي للباحثين لحد الان ينصب على بنية وحركة الروبوتات سداسية الارجل. ومع ذلك ، لم يتم إجراء الكثير من الأبحاث حول استخدام روبوت ذو ارجل للتشغيل الآلي. في هذا المشروع تم تصميم وتصنيع الروبوت سداسي الارجل لتشغيل الآلات. ان نطاق البحث لهذا المشروع يقتصر على الآلات التي تتبع التشغيل الاحادي الاتجاه 1-D، على سبيل المثال عملية الحفر. ان هذا البحث يستعرض بشكل منهجي ولاول مره جدوى التشغيل متوسط النطاق للالات باستخدام الوسائل بمنصة هاتف الربوت. تم اتباع تصميم روبوت سداسي الارجل مناسب (هيكسابود) في هذا المشروع. تم إرفاق مغزل الحفر مع الروبوت لتنفيذ عملية التشغيل الآلي. تم التحكم في الروبوت باستخدام الاتصال التسلسلي.وقد تم تطوير واجهة المستخدم الرسومية (GUI) للتحكم في سداسي الأرجل (هيكسابود) التي كانت تحتوي على جميع الخوارزميات المطلوبة داخلها. وأجريت عمليات التشغيل مع روبوت النموذج الأولي لاختبار أدائها. تم اقتراح خوارزمية تعويض جديدة لتحسين الدقة الموضعية لحركة الروبوت. تأخذ الخوارزمية المقترحة في الاعتبار سرعة الدوران والسرعة الخطية لتعويض الخطأ الموضعي. تم تحسين دقة الموضع بنسبة 85٪ بعد تطبيق نظام تعويض الخطأ. لقد وجد بان أدنى سرعة للمغزل وهي RPM2500 و سرعة نقطة إلى نقطة mm / min200 كان التكرار الأفضل، حيث كان أقل من µm30. وتمت مقارنة الدقة الموضعية لحركة الروبوت مع نظام التصنيع الميكروميكانيكي التجاري القائم. واظهرت النتائج ان أداء الروبوت مشابه تقريبا لاداء الجهاز التجاري. أخيرا تم قياس جودة الثقب المصنوع من حيث الدائرية والسمك . لوحظ أنه في حالة أفضل معالم اعداد دوال كان الانحراف الدئري منخضا الى 0.016 ملم ، وكان السمك 0.547 درجة.

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).

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DECLARATION

I hereby declare that this thesis 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.

Murshiduzzaman

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LIST OF SYMBOLS

C#	C Sharp
E	Modulus of Elasticity
I	Moment of Inertia
kg	Kilo-gram
Kpa	Kilo pascal
L1,2,3	Length of link
mm	Millimeter
n	Number of leg
N1,2	Normal (reaction) force
P_{cr}	Critical Load
T1,2,3,4	Torque acting on joint
V	Voltage
W4	Weight of link
3-D	Three dimensional
β	Duty Factor
σ	Bending Stress
µm	Micro-meter
$\Theta_{1,2}$	Angle between leg links

LIST OF ABBREVIATIONS

CNC	Computer Numerically Controlled
CoM	Centre of Mass
Coxa	Co-Axial
DC	Direct Current
DOF	Degree Of Freedom
EKF	Extended-Kalman-Filter
GUI	Graphical User Interface
IC	Integrated Circuit
IK	Inverse Kinematics
Li-Po	Lithium Polymer
MDI	Manual Data Input
PCB	Printed Circuit Board
R/C	Radio Control
RFID	Radio Frequency Identification
USB	Universal Serial Bus
3D	Three Dimensional

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

A research in 2007 states that ,CNC machine tools have been in use in the manufacturing sectors for more than 50 years (Thomas, 2007). It is one of the key processes used for micro fabrication. Recently, demand of micro-fabrication has increased tremendously due to product miniaturization. CNC machines play a vital role to fabricate mini/micro parts. CNC machines can work very fast and effectively while the command is given by some G codes using a computer interface. The computer command controls all the features of the machining operation like machining speed, feedrate, velocity and so on. The modern researches about CNC machines usually focus on enhancing the performance of the CNC machining system. Some researches focus on the delivery of coolant at the place of machining (Robert Yellin, 2017). There are also a lot of researches which focus on making the CNC platform capable of doing multiple operation in the same platform. Some focus on using multiple axis (Gosselin, 2018) while some other researches focus on incorporating and improving different types of operations with CNC machining (Tomal et al., 2017).

In this research, a modular hexapod robot was used to carry out machining operation. Hexapod robots are used in different engineering applications. Many researchers have investigated kinematic and dynamic behaviour of the hexapods (Woering, 2011). There are various ways to design the motion patterns of the links of the hexapod (P. de Santos et al., 2007). Most literatures give wave gait examples of a rectangle shaped robots(Kimura et al., 2006). In the current research, a suitable method for the walking mechanism of the hexapod was considered based on the literature review and more focus was given on the development of hexapod assisted micro/mini machining technology.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

In different manufacturing processes CNC machining plays an important role. It provides a very useful way of automatically controlling different machining operations. However, for miniature product machining (feature size in mm range) conventional CNC machines are still used with significantly large work envelope. This is inefficient in terms of space utilization. Generally, CNC machines are bulky and very difficult to move from one place to another as they are not modular. As such, on site machining is not possible with current CNC machines.

1.3 RESEARCH OBJECTIVES

This project represents in detail about design and development of a Hexapod machine capable of machining for new engineering applications. The objectives of the project are presented below:

1. To develop a Hexapod robot based machining platform for micromachining operation on large work-piece.
2. To develop a control system for the Hexapod robot for precise machining operation
3. To design and develop a Graphical User Interface (GUI) for controlling the motion and machining parameters of the robotic machining platform
4. To evaluate the performance of the robot in terms of machining accuracy

1.4 RESEARCH METHODOLOGY

This research was carried out based on experimental design, development and control 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 mechanical design of the Hexapod was inspired from a previous design which consists of 6 legs with three degree of freedom in each leg. So, the total degree of freedom was 3(motor) X 6(legs) =18 DOF (Degrees of Freedom). The design of this hexapod was inspired from "Phoenix" hexapod of Lynxmotion.com("Lynxmotion"). This type of structure provided the platform ability to move over the work piece and do machining operation. There was another servo attached in the front middle area of the Hexapod which enabled, engage and disengage of the spindle motor. Skotch yoke mechanism was used to transform the rotary motion of the servo into z axis motion. The skotch yoke mechanism idea was followed from a CNC hexapod router. But detail research data were not found (Denton Matt).

1.4.2 Methodology for Objective 2

The whole control system for the Hexapod was developed through using a controller, circuitry and algorithm. SSC32u servo controller was used to control the position of servos. To communicate with the servo driver a GUI was developed. Point to point motion command could be given using the GUI within the workspace of 20mm x 20mm. The hexapod could do machining while standing at one place locally and also while it moves with moving its whole body and thus changing its global position.

1.4.3 Methodology for Objective 3

For controlling the Hexapod a GUI was developed using C# language. The Hexapod robot's various motions was given using the developed GUI. The GUI program helped to find out the required amount of rotation of each motor to move the Hexapod to an exact point where the machining is required. The GUI was capable of taking the input in three ways. Manual data input, button controlled movement and multiple data input by using text file. A compensation algorithm was adapted to reduce the positional error of the robotic platform. More about this controlling is discussed in chapter 3.

1.4.4 Methodology for Objective 4

The working ability of the Hexapod was studied. The machining that the Hexapod could do was checked by standard processes. Different operations was performed with the Hexapod by varying different parameters of the operation. Its movements was also checked to ensure that they are good enough and can correctly follow the given commands. The positional accuracy was measured in terms of distance in mm. The circularity and taperness was also measured. To find out the taperness, the following formula was used, $\theta = \ tan^{-1}(Entry\ hole - Exit\ hole/Thickness)$. And the hole circularity is measured by taking diameter from three places of the same hole and then calculating their standard deviation. If the standard deviation is high, then it means the hole circularity is less.

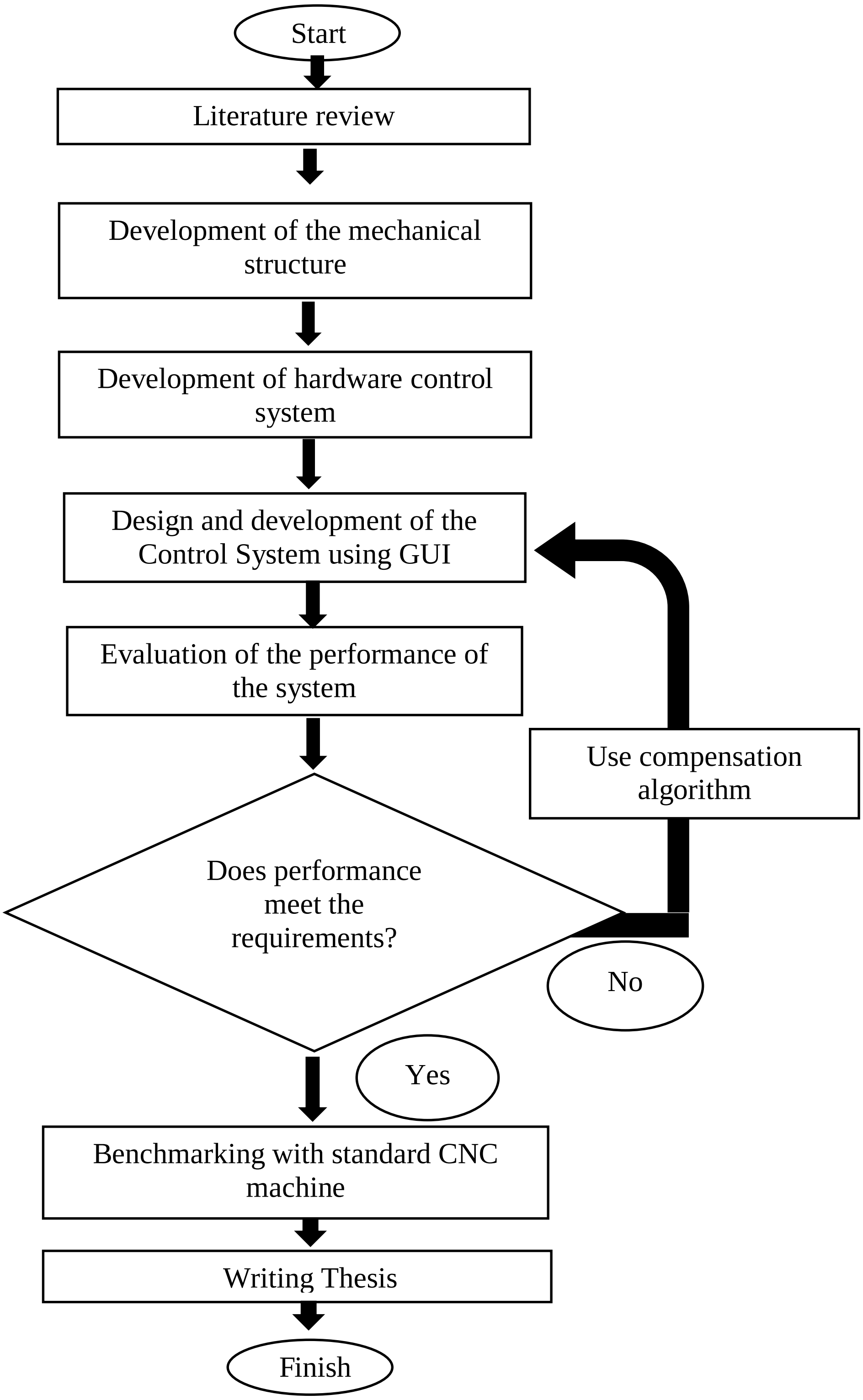

Figure 1.1 Complete Research Flow Chart

The complete research flow chart is shown in the Fig 1.1 above. From this flow chart, the steps followed to do this research can be understood.

1.5 RESEARCH SCOPE

In most researches, CNC machining and Hexapod robot had been usually two separate themes. In the research of hexapod robots, machining operations like CNC machining has not been thought of. Mostly the Hexapod robot research work focus on different designs, models and movements. In some recent researches, CNC machining is done by big size Hexapods (Tunc & Shaw, 2016). This mobile hexapod gives certain mobility and ease of movement of the CNC machining tool. Still the machine is somewhat heavy and bulky. This research can be thought of as the fusion of mini hexapod robots and CNC machining. The size of the machine tool was small because of using mini size Hexapods. Adjusting movement of the robot for rough terrain or obstacle was not covered in this research.

1.6 THESIS ORGANIZATION

The thesis has been organized in 6 chapters which have highlighted the total research work in details. The 6 chapters are described briefly as below.

Chapter 1: As described in the previous sections, this chapter provides a brief product. The last section highlights the research scope of this study technology.

Chapter 2: The literature review starts with introducing different types of Hexapods and different method of locomotion. Then, different configurations and walking styles of hexapod robots are discussed. Existing mobile machines and existing hexapod models are discussed as well.

Chapter 3: The design and development of the whole Hexapod based machining system is discussed in this chapter. The mechanical development, required stress and torque analysis, electrical components and their application, control algorithm, GUI instruction all these topics are discussed in this chapter.

Chapter 4: The arrangements required for the experimental procedures are discussed in this chapter. A wooden block was used as sacrificial material which gave support and elevated the workpiece. And 3mm Perspex was used to test drilling. Dino-lite was used for measuring accuracy.

Chapter 5: The data collected from the experiments were shown in this chapter. Comparison were also shown among use of various parameters.

Chapter 6: The whole work discussed in this thesis is summarized in this chapter. 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.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Research about hexapod robots started approximately around late 80's. Since it is not a very old research topic, researchers started to create some movement sequences and structure which can be used effectively as per requirement. Still, there are many research work going on to optimize the functionality of hexapod robots. At the university of Duisberg, the department of Mechanics started to develop a hexapod named Tarry I in 1992, which followed the structure of stick insect (*Carausius morosus*) (Buschmann., 2000). Later on there were some research work which considered different movement and structure of hexapod robots. Cockroach like structure was followed in a research in 1997 (Nelson et al., 1997). In the year 2000 some research works were done on a robot called RHex by Uluq Saranli', Martin Buehler and Daniel E. Koditschek' (Koditschek et al., 2000). In 2012 some work on a hexapod robot called "HITCR II" by Jie Zhao, He Zhang, Yubin Liu, Jihong Yan, Xizhe Zang and Ziwei Zhou(Zhang et al., 2014) . This robot was designed in a way so that it was capable of walking on an unstructured surface. A hexapod robot which was smaller than 9 cm in terms of length, width and height, was developed by Mayo Funatsu, Yushi Kawasaki, Soichiro Kawasaki and Koki Kikuchi in 2014. This robot had claws which assisted it to climb concrete wall (Funatsuat et al, 2014).

The first industrial robot which was commercially available, was made by the father of industrial grade robotic arm, Joseph Engelberger. He along with his colleagues designed the first autonomous mobile robots to be used in hospital. Later on there had