DEVELOPMENT OF OPEN PLATFORM CONTROLLER FOR STEP-NC COMPLIANT CNC SYSTEM

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To my beloved wife **Sabrina Khoo** and my parents, thank you.

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ABSTRACT

The Computer Numerical Control (CNC) machines have gone through tremendous upgrades along the years. However, conventional CNC machines could not find its place in the new era of machining under the conventional standard of ISO 6983 due to its limitation in compatibility, language difference and control has caused increase in terms of repurchase cost, reinstallations, reconfigurations and also training of operators. Therefore, this study covers the system which has been designed and developed from outdated and conventional PROLIGHT 1000 Milling CNC machine from Light Intelitek as the lesser cost solution which further discussed in detail based upon upgrades of hardware, architecture, and algorithm design. The hardware of the system was upgraded with the new servo system combined with SSCNET implementation to improve the functionality and efficiency of the new system. Meanwhile the PC-based software internal structure was developed and categorized under six modules which are Menu, Interpreter, 3D Simulation, Machine Motion System, Drill Bit Monitoring and Live Thermal Monitoring. The designed system software is established as UTHM Open CNC Controller (UOCC). It shows that the retrofitted CNC machine has successfully manufactured “Example 1” (STEP-NC) and “13 Drill Hole” (G-Code) files from the UOCC system which indicates that modules in the UOCC system are able to communicate with the CNC machine thus validating the workability of the controller. Moreover, UOCC system has been extended to online environment via Wi-Fi which utilizes Transmission Control Protocol (TCP) Socket in Java which used the PC as server to create socket thus establishing bind connection between UOCC RM mobile phone and the UOCC system, allowing users to remotely monitor the machining process on mobile platform. While the UOCC AR mobile application allow users to view machining setup process through Augmented Reality guide therefore improving the average operating time for experienced users (42.46%) and non-experienced (28.36%). Moreover, the averaged users’ rating shows 93.3% of overall satisfactory from the users which shows that the addition of AR in the system is well received and accepted by the operators of the UOCC.

ABSTRAK

Mesin Computer Numerical Control (CNC) telah mengalami peningkatan yang luar biasa selama ini. Namun, mesin CNC konvensional goyah di era pemesinan baru di bawah standard konvensional ISO 6983 kerana keterbatasan dalam keserasian, perbezaan bahasa dan kawalan telah menyebabkan kenaikan dari segi kos pembelian,pemasangan dan juga latihan pengendali. Oleh itu, kajian ini merangkumi sistem yang telah dikembangkan dari mesin CNC Milling 1000 PROLIGHT yang sudah usang dan konvensional dari Light Intelitek sebagai penyelesaian kos yang lebih rendah yang dibincangkan lebih lanjut secara terperinci. Perkakasan sistem ditingkatkan dengan sistem servo baru yang digabungkan dengan pelaksanaan SSCNET untuk meningkatkan fungsi dan kecekapan sistem baru. Struktur dalaman perisian berasaskan PC dikembangkan dan dikategorikan di bawah enam modul iaitu Menu, Interpreter, 3D Simulation, Machine Motion System, Drill Bit Monitoring dan Live Thermal Monitoring. Perisian sistem yang dirancang ditetapkan sebagai UTHM Open CNC Controller (UOCC). Ini menunjukkan bahawa mesin CNC yang dipasang semula berjaya menghasilkan fail "Example 1" (STEP-NC) dan "13 Drill Hole" (G-Code) dari sistem UOCC yang menunjukkan bahawa modul dalam sistem UOCC dapat berkomunikasi dengan CNC mesin mengesahkan kebolehlaksanaan pengawal. Malah, sistem UOCC telah diperluas ke lingkungan dalam talian melalui Wi-Fi yang menggunakan Transmission Control Protocol (TCP) di Java yang menggunakan PC sebagai pelayan untuk mewujudkan hubungan antara telefon bimbit UOCC RM dan sistem UOCC, yang memungkinkan pengguna untuk memantau proses pemesinan dari platform mudah alih. Aplikasi mudah alih UOCC AR membolehkan pengguna melihat proses penyediaan pemesinan melalui panduan Augmented Reality yang meningkatkan purata masa operasi untuk pengguna berpengalaman (42.46%) dan bukan berpengalaman (28.36%). Penilaian pengguna rata-rata menunjukkan 93.3% keseluruhan memuaskan dari pengguna yang menunjukkan bahawa penambahan AR dalam sistem diterima dengan baik dan diterima oleh pengendali UOCC.

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LIST OF ABBREVIATION

3D	Three Dimensional
AP	Application Protocol
APT	Automatically Programmed Tool
AR	Augmented Reality
ATC	Automatic Tool Changer
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CAPP	Computer Aided Process Planning
CNC	Computer Numerical Control
GUI	Graphical User Interface
IGES	Initial Graphics Exchange Specifications
IoT	Internet of Things
IMAQ	Image Acquisition
I/O	Input/Output
IPIM	Integrated Product Information Model
IR 4.0	Industrial Revolution 4.0
ISO	International Standard Organisation
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
MCC	Machine Control Card
NC	Numerical Control
NI	National Instrument
OS	Operating System
OWL	Web Ontology Language
PC	Personal Computer
PCI	Peripheral Component Interconnect
SOP	Standard Operating Procedure
SSCNET	Servo System Controller Network

STEP	Standard of The Exchange of Product
STEPcNC	Step-compliant NC
STEP-NC	Standard of The Exchange of Product Data Numerical Control
UMI	Universal Motion Interface
VDA	Verband derAutomobilindustry
VDAFS	Verband derAutomobilindustry Flachenschittelle
XML	Extensible Markup Language

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In the manufacturing sector, the CNC machine plays a significant role for the last five decade (Yusof & Latif, 2015b). In this research, a new platform for the development of sustainable platform controller based on STEP-NC technologies is introduced. The new platform provides an online experience with live monitoring for CNC machining. The system will be implemented on an old 3 axis CNC milling machine.

In modern era of productions and fabrications, Computer Numerical Control (CNC) machine has become an essential tool to machine high-precision products (Ridwan & Xu, 2013). With G-Codes (ISO 6983) as the conventional programming of numerical controlled machine, it only does simple commands for single movement and switching operations (Weck, Wolf, & Kiritsis, 2001) supported by sequential programming language. Hence, a new ISO standard was developed; Standard for the Exchange of Product Data (STEP) or ISO 10303 by the STEP committee to provide means of describing product data through any desired computer system (Latif & Yusof, 2016). The standard then changed to ISO 14649 for further development. ISO 14649 is basically an improvement of ISO 10303 which focusses on the machining process rather than only the tool motion. These systems are an essential part of future manufacturing. In the urge towards the development of next-generation manufacturing systems, various technologies have been introduced. Moreover, based on those technologies, numerous systems have been developed all around the world (Latif, Adam, Yusof, & Kadir, 2021). At present, many manufacturing enterprises have been equipped with a large number of high- grade machine tools and numerical control systems, forming a considerable scale of numerical control workshops (Ridwan & Xu,

2013). However, most of the machines run in an isolation environment, which gives rise to information occlusion and lack of monitoring. Although some of the newly developed control systems provide data acquisition interfaces, they are often ignored in practical product and haven't fully play their roles (W. Liu, Kong, Niu, Jiang, & Zhou, 2020). To achieve this aim, communication in real time with surroundings, people, machines, devices, and products during production must be outstanding. It is important for every country to adopt and adapt the IR 4.0 trend by meeting the challenges and capitalizing on the advantages of the economic globalization opportunities (Iliyas Ahmad et al., 2020).

Thus, Yusri Yusof, (2015a) from Universiti Tun Hussein Onn Malaysia (UTHM) is contributing for ISO 14649 (which is also known as STEP-NC) manufacturing from Malaysia with his 2009 proposed system of "STEP-NC Code Generator" to generate STEP-NC file from the user inputs for turning application. An open architecture CNC controller based on LabVIEW software is introduced by Yusof, (2013) which has developed modules to interpret STEP-NC and ISO 6983 format files to contribute to the system. Modules are further divided into three via, which are reading input, processing data and data extraction output file generation in text or XML formats (Yusof, 2010).

Therefore, the platform is now further developed in this research to run on android software which adopts intelligence into the CNC to enable the system to be accessed anywhere, at any time. The system relies on communication between android software and CNC hardware that specifically operates through ISO 14649 which will enhance the capability of CNC machine in terms of cloud computing (Kao, Lin, & Yang, 2016) and remote computing (Lutovac Banduka, 2015). The new platform is developed through LabVIEW software that implemented on a 3 axis CNC milling machine. A prototype implementation of the proposed model is based on STEP-NC interpretation, 3D simulation, machine motion control, and real-time thermal monitoring with mobile platform extension adopting features such as remote monitoring and Augmented Reality which has been used in conjunction with Industry 4.0 in manufacturing.

1.2 Problem statement

As announced by former Prime Minister of Malaysia, Dato' Seri Najib bin Razak in Malaysian Budget 2017, the government is looking forward to implement and support the advancement of technology especially those relating to IoT (A. Kumar, 2017), where the government believes that in order for this country to move forward , the nation must be capable of producing mobile-based innovation.

Hence, in the manufacturing sector, where the CNC machine plays a significant role for the last five decades (R. Y. Zhang, Ma, & Cheng, 2014), new platform for the development of sustainable platform controller based on STEP-NC technology is introduced (Yusof & Latif, 2015c). The platform has successfully interpreted the STEP-NC information and enables modern functionalities into the CNC system. In this research, it is also suggested that STEP-NC should be implemented in an online environment.

However, the users' experience to modify and adapt to meet the various needs are suspended by the basic function nature of the CNC software applications in conventional CNC machine which requires to sustain with the function of current technology (Newman et al., 2008; M.A Othman, Jamaludin, Minhat, & Patwari, 2020; Tan, Zhang, & Liang, 2009; Yusof & Kamran, 2013) which becomes the aim contribution to the research of manufacturing for CNC machine to be achieved in this study. Today's industries are equipped with many types of CNC machines with different controllers and multiple abilities to fulfil customer demands. However, the structure of commercial CNC systems are of closed nature that makes CNC unsuitable for modem manufacturing environment (B. Li, Zhou, & Tang, 2004) and the prices for the CNC machines are expensive (Khechekhouche, 2021; Pan & Wang, 2021) to be afforded especially by the Small and Medium Entrepreneurs (SME) and education industries. Furthermore, the CNC machine tool systems are being equipped with CNC controller supplied by the control vendor as a "black box" which makes it difficult for machine tool builder to quickly develop and implement the custom control functions and the vendors specification dependence makes CNCs less adaptable (Cha, Suh, Hascoet, & Stroud, 2016).

Therefore, a new platform controller is introduced to merge with the existing IS0 14649 based technology along with the implementation of IR 4.0 element (real-time monitoring) through retrofitting of conventional CNC machine. The development of

controller of the machine would require a lesser cost than a new purchase of the CNC machine. However, as consequence of the implementation of IR 4.0 to the platform controller, new skills are demanded to operators thus increasing the machining operational time (Lai, Tao, Leu, & Yin, 2020). The operators are required to be more flexible and adaptable in dynamic manufacturing industry ergo requiring higher level of training is needed which consumes more times in the industry especially in manufacturing sector. Thus with the adaptation of Augmented Reality (AR) it works as guides not just to the non-experienced users but as well as the experienced ones to further improve their time through avoiding rework and redundant inspections (Adam, Yusof, & Latif, 2021).

1.3 Aim and objectives of research

The aim of this research is to develop a newly functional platform controller on STEP compliant CNC system. In order to achieve it, few objectives are formulated as follows:

i. To adopt ISO 14649 in a new platform controller based on interpretation of developed software.
ii. To develop a real time manufacturing controller with online environment for STEP-NC platform controller application with process monitoring and Augmented Reality feature.
iii. To validate the workability of the developed platform controller through manufacturing of case study components.

1.4 Scope of study

The study focuses on the development of new STEP-NC online platform controller for retrofitted 3-axis CNC milling machine available in Universiti Tun Hussein Onn Malaysia (UTHM). It is based on development of system controller between desktop computer though software LabVIEW with android application to CNC machine by using interpreter with bi-directional flow between interpreter and machine motion control for ISO 14649-21 (pocket). The development of the controller contains

modules such as menu interface for selection, 3D simulator for graphical verification data, machining process controller, real time thermal monitoring, drill bit for tool monitoring with remote monitoring through mobile platform which uses Android as its main platform with additional feature of augmented reality via wireless as part of advancement on the CNC functions. The validation is done through manufacturing case study using 'Example 1' (Pocket Drill) and '13 Drill Hole' to verify the functionality of the newly developed platform controller.

1.5 Limitation of study

For this study, several limitations are identified as following;

i) The ISO 6983 limited for linear motion control commands only.
ii) The IS0 14649-21 interpretation limited to facing, pocketing, and drilling processes only.
iii) The workability testing is limited to the functionality and performance of the enhanced system functions through interpretation between the CNC machine to the developed system.

1.6 Outline of thesis and summary

The thesis consists of six chapters which build up to the development of the new STEP-NC platform controller and its validation process, for conclusion. After brief introduction for the thesis, Chapter 2 highlights the reviews and discussions for current related technology to illuminate the basis for selected methods and equipment. Through that, Chapter 3 illustrates the methodology applied to complete the research, with clarification of the development process in Chapter 4. Later, Chapter 5 highlights on the experimental validation of the developed system. Finally, the research conclusions and recommendations are presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers the system of Computer Numerical Control (CNC) and STEP-NC using ISO 14649. The research targets to develop ISO 14649 controller which connected to conventional PROLIGHT 1000 Milling CNC machine from Light Intelitek which is used as the base for the research to be retrofitted. The controller developed by (Yusof & Latif, 2015c) and (Mohd Elias, 2014) functioned as guideline for the research. In attempt to extend the research, the use of advanced numerical control system is also reviewed, which highlights the previous methods and approaches applied for the development of this particular technology advancement. The research also studies the implementation of augmented reality as the way to adopt elements of Industrial Revolution (IR) 4.0 in the research.

2.2 NC Overview

Numerical Control (NC) is the term used to describe the control of machine movements and various other functions by instructions expressed as a series of numbers and initiated via an electronic control system (Pritschow et al., 2001; Yusof, Kassim, & Tan, 2011). In the 1950's a revolutionary change takes place in the manufacturing world with the establishment of Numerical Control (NC) machine tools which then in the 1970's a next important development in machine tool automation occurred, that was the introduction of Computer Numerical Control (CNC) machines (Liang, Hecker, & Landers, 2004).

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