Faculty of Manufacturing Engineering

INTEGRATION OF G-CODE WITH POSITION CONTROLLER VIA INTERPRETER DESIGN USING MATLAB FOR MILLING MACHINE APPLICATION

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A thesis submitted
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DECLARATION

I declare that this thesis entitled “Integration of G-code with Position Controller via Interpreter Design using MATLAB for Milling Machine Application” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………...
Name : Norhidayah binti Mat Seman
Date : ……………………………...

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature : ……………………………………………….

Supervisor Name : Prof. Madya Dr. Zamberi bin Jamaludin

Date : ………………………………………………

DEDICATION

To my late father, beloved mother, and brothers

ABSTRACT

In precision machining, various classical and advanced feedback position controllers such as cascade, proportional-integral-derivative, and sliding mode controllers have been developed with the aim to meet the precision requirements of the machine tool controller. To-date, most of these position controllers are not well utilized in commercial CNC machine tools. This is due to the limitation of the input reference applied for the position controller structure. Commonly, input reference signals such as step, ramp, sinusoidal, and other waveforms are utilized in testing and verifying the efficiency and performance in design process of position controllers. In most cases, the position controllers rarely utilize geometrical drawing such as CAD/CAM trajectory as input reference without extensive programming or trajectory generation algorithm. Thus, this thesis aims to integrate directly the trajectory in G-code form of *.txt format as input reference for the position controller algorithm designed in MATLAB/Simulink via development of a system interpreter. A user interface of G-code-position controller (GPC) interpreter was designed using uicontrol objects in MATLAB GUI platform and Callbacks were programmed in Scripts Editor. The interpreter functions to extract and interpret the *x* and *y* data positions from the generated G-code. The input of the interpreter is the G-code generated from a standard three-dimensional geometrical CAD/CAM part production using CATIA software. Simulation of the interpreter was performed to compute the *x* and *y* data positions which were later validated experimentally by applying a cascade P/PI position controller for an XY positioning table of CNC milling machine. The success of the experimental validation proved the consistency of the interpreter to track three different shapes of geometrical objects in milling machining process. In simulation of the three G-code trajectories, the operation time to extract the data was recorded, whereby a 0.92%, 1.09%, and 1.35% efficiencies were achieved from extraction of 8429 data, 9514 data, and 12127 data, respectively. Based on the findings, it is concluded that more extraction time is required with increase in sample data size. The interpreted G-codes of random-curvy-shape, oval-shape, and circular-shape trajectories were validated experimentally on an XY milling machine positioning table resulted in RMSE values of respectively 0.0203mm and 0.0068mm, 0.0063mm and 0.0064mm, and 0.0057mm and 0.0064mm for *x* and *y* axes. As a conclusion, the realization of this interpreter has enabled seamless integration between a CAD/CAM trajectory and position controllers thus resulting in a reliable, accurate, and adaptable machining process to any desired specifications put forward by the part manufacturers. As a future recommendation, it is desired that the interpreter is tested and validated in real cutting experiments against the utilization of parts with complex shapes and processes to ensure its robustness and accuracy prior to commercialization.

ABSTRAK

*Dalam pemesinan jitu, pelbagai pengawal kedudukan maklum balas yang klasik dan maju seperti pengawal lata, derivatif integral berkadar, dan mod gelongsor telah dibangunkan bermatlamat untuk memenuhi keperluan pengawal mesin alat yang jitu. Setakat ini, kebanyakan pengawal kedudukan ini tidak digunakan sebaiknya dalam mesin alat CNC yang komersial. Hal ini disebabkan oleh limitasi input rujukan yang diaplikasi untuk struktur pengawal kedudukan. Biasanya, isyarat input rujukan seperti langkah, jalan, sinusoidal, dan bentuk gelombang lain digunakan untuk pengujian dan pengesahan kecekapan dan prestasi proses reka bentuk pengawal kedudukan. Dalam kebanyakan kes, pengawal kedudukan tersebut jarang menggunakan reka bentuk geometri seperti trajektori CAD/CAM sebagai input rujukan tanpa pengaturcaraan atau algoritma penjanaan trajektori. Oleh itu, tesis ini bertujuan untuk menyepadukan secara terus trajektori di dalam kod G dalam bentuk *.txt format sebagai input rujukan untuk algoritma pengawal kedudukan yang direka dalam MATLAB/Simulink melalui pembangunan sebuah sistem jurutafsir. Sebuah antara muka jurutafsir kod G – pengawal kedudukan (GPC) telah direka menggunakan objek "uicontrol" yang terdapat dalam platform MATLAB GUI dan panggilan balik telah diprogramkan dalam Editor Skrip. Jurutafsir ini berfungsi untuk mengekstrak dan menafsirkan data kedudukan x dan y daripada kod G yang telah ditafsir. Input jurutafsir tersebut adalah kod G yang telah dihasilkan daripada sebuah bahagian pengeluaran CAD/CAM yang piawai berbentuk geometri tiga dimensi menggunakan perisian CATIA. Simulasi jurutafsir tersebut telah dilakukan untuk mengira data kedudukan x dan y yang mana kemudiannya divalidasikan secara eksperimen dengan mengaplikasikan sebuah pengawal kedudukan lata P/PI untuk meja kedudukan XY mesin pengilangan CNC. Kejayaan validasi eksperimen tersebut telah membuktikan konsistensi jurutafsir tersebut bagi mengesan tiga bentuk objek geometri yang berbeza dalam proses pemesinan pengilangan. Dalam simulasi tiga trajektori kod G tersebut, masa operasi untuk ekstrak data telah direkodkan, di mana sebanyak 0.92%, 1.09%, dan 1.35% kecekapan yang telah berjaya diekstrak terhadap 8429 data, 9514 data, dan 12127 data. Berdasarkan penemuan tersebut, hal ini disimpulkan lebih banyak masa pengekstrakan yang diperlukan dengan peningkatan saiz data sampel. Kod G yang telah ditafsir yang mempunyai trajektori berbentuk rawak lengkung, bujur, dan bulatan itu juga telah divalidasi secara eksperimen di atas sebuah meja kedudukan mesin pengilangan XY memberi keputusan nilai RMSE masing-masing 0.0203mm dan 0.0068mm, 0.0063mm dan 0.0064mm, dan 0.0057mm dan 0.0064mm bagi paksi x dan y. Kesimpulannya, realisasi jurutafsir ini telah membolehkan persepaduan yang lancar antara sebuah trajektori CAD/CAM dan pengawal kedudukan seterusnya menghasilkan sebuah proses pemesinan yang dipercayai, tepat, dan bersesuaian dengan mana-mana spesifikasi yang dikehendaki yang dikemukakan oleh pengeluar bahagian. Sebagai saranan di masa hadapan, jurutafsir tersebut perlu diuji dan divalidasi dalam eksperimen pemotongan sebenar terhadap penggunaan bahagian-bahagian yang mempunyai bentuk dan proses yang kompleks untuk memastikan keteguhan dan ketepatannya sebelum dikomersialkan.*

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LIST OF SYMBOLS

Ø - Diameter

N - Spindle speed

V - Cutting speed

π - Pi = 3.142

D - Diameter

v_f - Feed rate

f_z - Feed per tooth

Z - Number of cutter teeth

K_p - Proportional gain (Velocity loop)

K_i - Integral gain (Velocity loop)

K_v - Velocity gain or proportional gain (Position loop)

LIST OF ABBREVIATIONS

API	-	Application program interface
APT	-	Automatically programmed tool
CAD	-	Computer-aided design
CAM	-	Computer-aided manufacturing
CATIA	-	Computer aided three-dimensional interactive application
CL	-	Cutter location
CNC	-	Computer numerical control
COM	-	Component object model
DAQ	-	Data acquisition
DFO	-	Disturbance force observer
EMG	-	Electromyography
FIR	-	Finite impulse response
FSM	-	Finite state machine
GMS	-	Generalised Maxwell-slip
GUI	-	Graphical user interface
GUIDE	-	Graphical user interactive development environment
HITCNC	-	Harbin institute of technology computer numerical control
HMI	-	Human-machine interface
IMBDO	-	Inverse-model-based disturbance observer
JOP	-	Japanese open promotion

MATLAB	-	Matrix laboratory
NC	-	Numerical control
NCasFF	-	Nonlinear cascade feedforward
NI	-	National Instruments
NPID	-	Nonlinear PID
NURBS	-	Non-uniform rotational B-spline
OAC	-	Open architecture controller
OMAC	-	Open modular architecture controller
OSACA	-	Open system architecture for controls with automation systems
OSEC	-	Open system environment for controllers
P	-	Proportional
PI	-	Proportional-integral
PID	-	Proportional-integral-derivative
RAM	-	Random access memory
RMSE	-	Root mean square error
RTDLL	-	Real-time dynamical link library
SMC	-	Sliding mode controller
STEP	-	Standard for the exchange of product data
STEP-NC	-	Standard for the exchange of product data for numerical control
SOP	-	Standard operational procedure
SOSMC	-	Second order sliding mode controller
UML	-	Unified modelling language
VSS	-	Variable structure system

LIST OF APPENDICES

LIST OF PUBLICATIONS

Journal (Scopus)

1. Mat Seman, N., Jamaludin, Z., Minhat, M., and Junoh, S. C. K., 2018. Design of A CAD/CAM-Simulink Data Exchange System for Machine Tool Application. *Journal of Advanced Manufacturing Technology*, 12(1(2)), pp. 1–14.

Book Chapter (Scopus)

1. Mat Seman, N., Jamaludin, Z., and Minhat, M., 2020. Analysis of Interpreted CAD/CAM Trajectory as Alternative Input Reference for Control System. In: Jamaludin, Z., Ali Mokhtar, M., *Intelligent Manufacturing & Mechatronics, SympoSIMM2019. Lecture Notes in Mechanical Engineering*. Melaka, 8 July 2019. Springer Nature Singapore Pte Ltd., pp. 186-194.
2. Mat Seman, N., Jamaludin, Z., and Minhat, M., 2018. System Interface Design for CAD/CAM-Simulink Data Exchange System using MATLAB. In: Hassan, M. H. A., *Intelligent Manufacturing & Mechatronics, Lecture Notes in Mechanical Engineering*. Pekan, Pahang, 29 January 2018. Springer Nature Singapore Pte Ltd., pp. 639–647.

Conference

1. Mat Seman, N., Jamaludin, Z., Minhat, M., and Othman, M. A., 2017. A Conceptual Design of an Interpreter for an Open Architecture Control System. *In Proceedings of Innovative Research and Industrial Dialogue'16*. Melaka, Malaysia: Advanced Manufacturing Centre, pp. 107–108.

CHAPTER 1

INTRODUCTION

This chapter introduces the research background on the topics of this thesis that centers on the integration of a CAD/CAM system with a position controller via an interpreter system for the application of an XY positioning table of CNC milling machine. Among the topics introduced are the problem statement, research questions, objectives, scopes, and significances. The thesis organization is presented at the end of this chapter.

1.1 Background

Computer Numerical Control (CNC) machine tool plays a major role in the manufacturing industry. The milling process is a famous manufacturing process in manufacturing production. Radeaf (2010) mentioned that CNC milling machine is equipped with components which include: (i) part program, (ii) input device, (iii) machine control unit (MCU), (iv) feedback system, (v) drive system, and (vi) machine tool as depicted in Figure 1.1. Nowadays, the commercial CNC machine utilizes standard and ready-made machine control unit. For example, CNC machines by Siemens utilized Sinumerik 808 as its controller package for perfectly preconfigured CNC systems (Sinumerik 808, 2019). However, this commercial product normally limits where its controller package is closed and only compatible with the selected machine tool. The simple meaning is that the controller unit cannot be used in other machine tools. Thus, arising the need for flexibility of the controller in terms of open systems. Nonetheless, the flexible controller systems are rarely adaptable to new applications that can be overcame by the concept of open architecture systems (Ford, 2002).

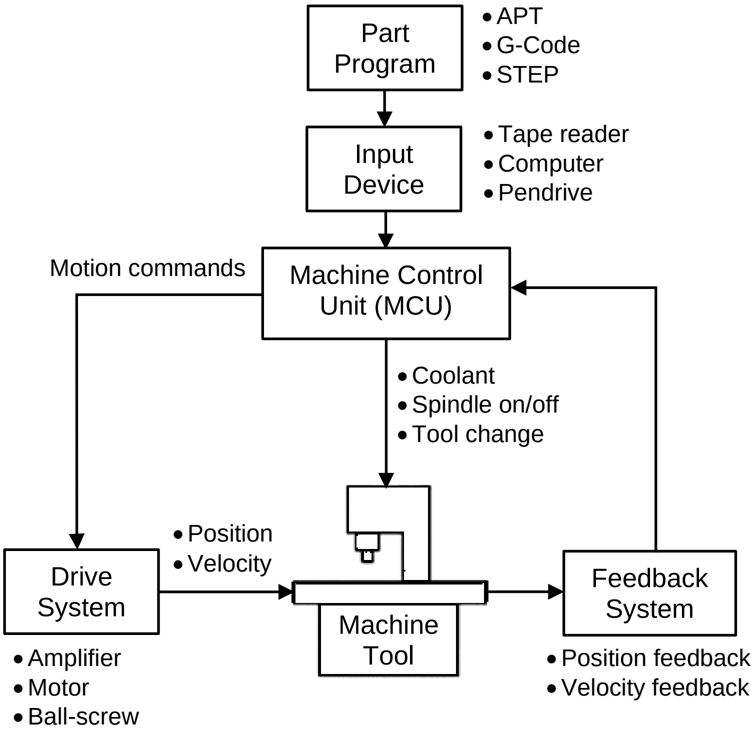

Figure 1.1: Basic components in CNC milling machines

An open architecture controller is known as a flexible version of the machine control unit in an open architecture system. The controller can be utilized as a part of the integration of multiple different software and machine tool for different control requirements and applications. Koren (1998) defined open architecture control as “a controller that is designed and constructed for integration of new monitoring and control devices and software modules by permitting access to a given set of internal controller variables” with advantages of: (i) enhancing part quality, (ii) increasing machine productivity, (iii) shortening time, and (iv) lowering cost. The open architecture controller is one module from an open system. The open architecture system mainly consists of four component modules which include: (i) input/output module, (ii) interpreter module, (iii) controller module, and (iv) hardware module. Figure 1.2 takes an example of the Open Modular Architecture Controller API structure by Pritschow et al. (2001) to illustrate the main components of the open architecture control system.

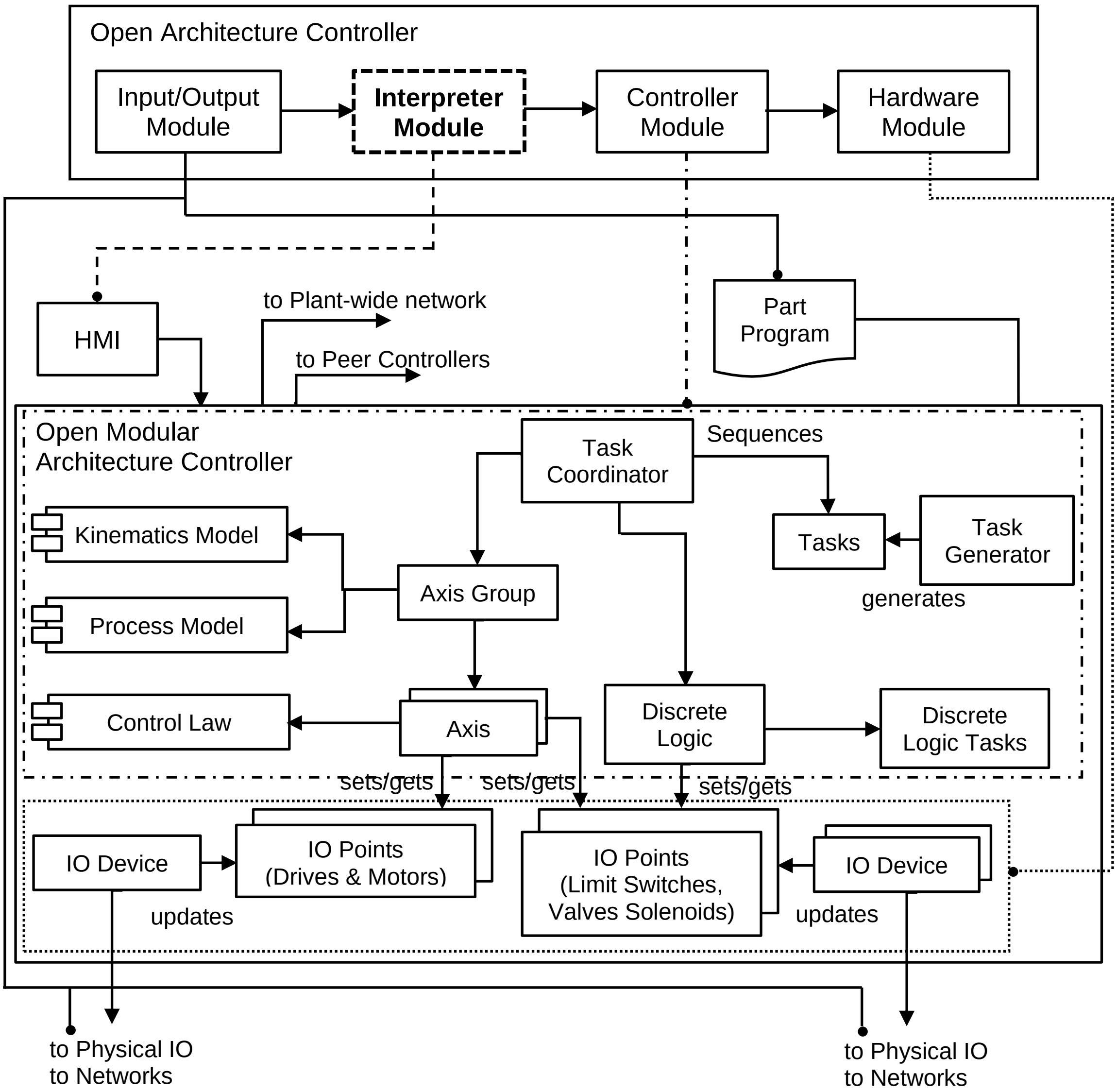

Figure 1.2: Main components of OAC based on OMAC API

Control systems are designed for various distinct requirements based on different applications and limitations. Fundamentally, the control system utilizes a common wave signal (for example step, ramp, and sinusoidal) as the reference input for controller testing purposes. For example, Niranjan et al. (2016) used semi-ramp signal, Kühne et al. (2018) used step signal, and Junoh et al. (2016) and Guo et al. (2018) used the sinusoidal signal as reference input with the purpose of testing their developed controllers. However, rather than having a typical wave signal as the reference input for the controller, this thesis proposes CAD/CAM trajectory as an alternative reference input for the position controller.

CAD/CAM is well known in the manufacturing industries where CAD designs a product and documents the process of design such as materials, tolerances, and dimensions, and processes while CAM utilizes computer-driven manufacturing processes software to automate the manufacturing processes (Zeid and Sivasubramanian, 2006). The application of CAD/CAM geometrical data as an alternative reference input for a flexible position controller of machine tool motivates the use of a position controller which is capable to control the machine tools according to the desired pathway of parts and products designed in CAD/CAM. However, G-code generated automatically from post-processor software has a limitation where it cannot directly become the reference input of the position controller designed in MATLAB/Simulink software. This is where the interpreter is desired. This thesis aims for the development of the interpreter module for the application of a flexible control system. The interpreter will encourage the openness, adaptability, and compatibility of the non-real-time software to be used in flexible real-time control systems in the CNC milling machine.

Yadav and Ramesh (2011) described the functions of an interpreter in information technology are translating each source code line by line and then executing the source code immediately. An interpreter is beneficial since it is memory efficient, easy debugging application, and takes less time to analyse the source code. However, the overall execution time is slow. Wu et al. (2014) designed an interpreter by using concepts in software engineering but experienced the challenges hence proposed the utilization of graphical user interface (GUI) for having a more interactive interpreter. In this thesis, the interpreter bridges CAD/CAM trajectory and position controller of a CNC milling machine as conceptualized in Figure 1.3. This thesis declares the development of a G-code position controller (GPC) interpreter as a software application that has the functionality to execute directly G-code which consists of CAD/CAM geometrical trajectory into the desired output data. In this case,