Faculty of Manufacturing Engineering

NEW DATA PROCESSING STRATEGY FOR INTELLIGENT CNC MACHINE TOOL CONTROLLER USING FUNCTION BLOCK TECHNOLOGY

Muhammad Azri Bin Othman

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MUHAMMAD AZRI BIN OTHMAN

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DEDICATION

my beloved wife Nur Hayati Abd Rahman

my son Muhammad Akif hadif Muhammad Azri,

my family and my in-law family,

This humble work is dedicated for all of you who taught me to be patience in completing my work, who never fail to give continous support, du'as and encouragement during difficult time of this journey.

ABSTRACT

Enhancement in product data interoperability and flexibility of Computer Numerical Control (CNC) architecture to accommodate the trend toward digitalise industrial manufacturing in the era of Industry 4.0 are very much desired as key driven technologies for the development of new generation CNC systems. Large body of works to improve or even replace the existing CNC data model, that is, G-codes, have been reported by many researchers. It is well-known that this low-level coded data model technology has many limitations to achieving new CNC system especially where open, agile, distributed, interoperable and intelligent are required. The emerging standards like ISO 14649 and ISO 10303 (AP238), also known as STEP-NC, present an opportunity to revolutionize the way CNC machines are traditionally programmed and give promising alternatives to G-codes. Thus, this research proposed a direct integration of decision-making and control abilities of the CNC controller architecture. Therefore, a new data processing unit (DPU) architecture was developed using IEC 61499 function block technology. The role of the proposed DPU evolves from purely functional to decoded part program into flexible or even automatically reconfiguring its execution structures and provides intelligent functions in the case of occurrences of external user demands and/or internal faults. It works with STEP-NC data model and can automatically generate a set of required machining data to be executed on a machine tool. Three simple feature geometries consisting of planar face, closed pocket and round hole, with different machining strategies such as bidirectional, contour-bidirectional and contour milling that constitute a set of machining data were generated by the prototype systems. All sets of data were simulated using MATLAB developed interfaces and later validated on actual machining process using aluminium A6041 workpiece. Based on the machining product, all the desired features with their predetermined machining strategies were successfully machined and resulted in RMSE values of 0.0032mm and 0.0047mm, 0.0164mm and 0.0147mm, and 0.0020mm and 0.0037mm for x and y axes respectively. As conclusion, the system has a layered structure, making it easy to manage and extend. It has been proven that function block technology can provide enough intelligent functions to support the creation of next-generation CNC that is more open, adaptable, flexible, and interoperable.

STRATEGI BAHARU PEMPROSESAN DATA UNTUK PENGAWAL PEKAKAS MESIN CNC PINTAR MENGGUNAKAN TEKNOLOGI BLOK FUNGSI

ABSTRAK

Penambahbaikan dalam komponen kebolehkendalian data produk dan fleksibiliti seni bina kawalan berangka computer (CNC) kearah pendigitalisasi industri pembuatan di era Industri 4.0, dirujuk sebagai teknologi utama di dalam pembangunan sistem CNC generasi baru. Pelbagai gerak kerja untuk menambah baik atau bahkan mengantikan model data CNC sediaada, iaitu kod-G, telah dilaporkan oleh ramai penyelidik. Umum mengetahui bahawa teknologi model data berkod peringkat rendah ini mempunyai banyak batasan untuk mencapai tahap baharu sistem CNC, dimana keterbukaan ,ketangkasan, teragih, kebolehkendalian dan kepintaran sangat diperlukan. Kemunculan piawaian baru ISO 14649 dan ISO 10303 (AP238) yang juga dikenali sebagai STEP-NC telah membuka peluang dalam merevolusikan kaedah tradisi pengatucaraan program untuk mesin CNC dan menjanjikan alternatif kepada kod-G. Oleh itu, penyelidikan ini dicadangkan untuk mengintegrasikan secara langsung komponen kebolehupayaan membuat keputusan dan mengawal di dalam seni bina pengawal CNC. Untuk merealisasikannya, satu seni bina baharu bagi unit pemprosesan data (DPU) telah dibangunkan menggunakan teknologi blok fungsi IEC 61499. Peranan DPU yang dicadangkan berkembang daripada bahagian yang berfungsi menyahkod program semata-mata kepada bahagian yang bekerja secara fleksibel atau malah secara automatik dalam mengkonfigurasi semula struktur pelaksanaannya dan menyediakan fungsi pintar sekiranya berlaku permintaan luaran dan/atau kerosakan dalaman. Ia berfungsi dengan model data STEP-NC dan secara automatik boleh menjana satu set data pemesinan yang diperlukan untuk pengoperasian alatan mesin. Satu set data pemesinan bagi setiap tiga ciri geometri ringkas iaitu muka satah, poket tertutup dan lubang bulat dengan strategi pemesinan yang berbeza iaitu dwiarah, kontur dua arah dan lingkaran kontur telah dijana oleh sistem prototaip. Semua set data kemudiannya disahkan melalui simulasi menggunakan antara muka yang dibangunkan MATLAB dan kemudian diikuti dengan proses pemesinan sebenar menggunakan bahan kerja aluminium A6041. Berdasarkan produk pemesinan, semua ciri yang dikehendali dengan strategi pemesinan yang telah ditetapkan telah berjaya dicapai dan menghasilkan RMSE masing-masing 0.0032mm dan 0.0047mm, 0.0164mm dan 0.0147mm, dan 0.0020mm dan 0.0037mm untuk paksi x dan paksi y. Kesimpulannya, Sistem ini mempunyai struktur berlapis, menjadikannya mudah untuk diurus dan dilanjutkan. Telah terbukti bahawa penggunaan teknologi blok fungsi boleh menyediakan fungsi pintar yang cukup untuk menyokong pembangunan generasi baru CNC yang lebih terbuka, fleksibel, saling beroperasi.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF SYMBOLS

$\varnothing$	-	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
k_i	-	Integral gain
k_d	-	Derivative gain

LIST OF ABBREVIATIONS

AB-CAM	-	Agent-based CAM system
AIM	-	Application interpreted model
AP	-	Application protocol
API	-	Application program interface
APT	-	Automatically programmed tool
ARM	-	Application reference model
CAD	-	Computer-aided design
CAM	-	Computer-aided manufacture
CAPP	-	Computer-aided process planning
CAx	-	Computer-aided
CL	-	Cutter location
CLU	-	Control loops unit
CNC	-	Computer numerically controlled
COM	-	Component object model
DAQ	-	Digital acquisition
DC	-	Direct current
DNC	-	Direct numerical control
DPU	-	Data processing unit
DXF	-	Drawing interchange format
FB	-	Function block
GPC	-	G-code position controller

GUI	-	Graphical user interface
G2STEP	-	G-codes to STEP-NC converter
HITCNC	-	Harbin Institute of technology computer numerical control
HMI	-	Human-machine interface
HSS	-	High speed steel
ICT	-	Information and communication technology
IEEE	-	Institute of electrical and electronics engineers
IGES	-	Initial graphics exchange specification
IPQC	-	In process quality control
IR4.0	-	Industrial revolution 4.0
ISO	-	International standard organization
MATLAB	-	Matrix laboratory
MCU	-	Machine control unit (
NC	-	Numerical control
NURBS	-	Non-uniform rotational B-spline
OA	-	Open architecture
OAC	-	Open architecture controller
OMAC	-	Open modular architecture controller
OSACA	-	Open system architecture for controls with automation systems
OSEC	-	Open systems environment for controllers
PC	-	Personal computer
PDES	-	Product Data Exchange Standard
PosSFP	-	Shop floor programming system

POSTECH	-	Pohang university of science and technology
PPS	-	Process planning system
RMSE	-	Root mean square error
RO	-	Research objective
RP	-	Research problem
RPM	-	Revolution per minute
RQ	-	Research question
SC	-	Subcommittees
STEP	-	Standard for the exchange of product data
STEP-NC	-	Standard for the exchange of product data for numerical control
STEPNCMillUoA	-	STEP-NC milling open architecture
STEPNCFB-DPU	-	STEP-NC/function block data processing unit
TC	-	Technical committee
UTHM	-	Universiti Tun Hussein Onn Malaysia
UPCi	-	Universal Process Comprehensive interface
XML	-	Extensible Markup Language

LIST OF PUBLICATIONS

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1. **Othman, M.A.**, Jamaludin, Z. , Minhat, M. , Patwari M.A.U., 2020. Design and development of a 3-axis vertical milling machine control logic architecture using IEC 61499 function Block. Journal of Advanced Manufacturing Technology, 14(1). pp 61-73.

2. **Othman, M. A**., Minhat, M. Jamaludin, Z.,(2019) A Framework of Next Generation Adaptive CNC controller. *International Journal of Innovative Technology and Exploring Engineering*, 8(11 special issue 2), pp 288-293.

3. **Othman, M. A**., Jamaludin, Z. , Minhat, M. (2019) Design of Intelligent CNC system using IEC61499 Function Block. International Journal of Innovative Technology and Exploring Engineering, 8(10), pp 2114-2118.

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1. **Othman, M.A**., Jamaludin, Z. , Minhat, M., 2020. Intelligent control of CNC system based on IEC 61499 function block technology. *Lecture Notes in Mechanical Engineering,* pp. 176-185.

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