NEW TECHNIQUE FOR THE DEVELOPMENT OF OPEN CNC CELL CONTROLLER BASED ON ISO 14649 and ISO 6983

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I would like to dedicate this thesis to

**Almighty "Allah"**

*(Who gave me strength, knowledge, patience and wisdom)*

**My "Parents"**

*(Their pure love, devotion, cares and prays helps me to achieve this target)*

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## ABSTRACT

The aim of modern Computer Numerical Control (CNC) is to be more flexible, interoperable, adoptable, open and intelligent. In the projection towards the development of the next generation of CNC systems, the problem of current International Standards Organization (ISO) data interface model (ISO 6983) limitations was encountered. A new ISO standard known as Standard for The Exchange of Product Data (STEP) or ISO 10303 was introduced to overcome the issues of current data interface model in Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM) systems. After that successful implementation, the standard was further extended to implement the STEP features on the CNC by introducing a new standard known as STEP-Numeric Control (NC) or ISO 14649. The implementation of STEP-NC was firstly initiated on the commercial CNC units by In-Direct STEP-NC programming approach. However, that approach failed to enable all the features of modern CNC systems due to the translation of data from high to low level and vendor specifications dependency of the commercial CNC units. A new controller is need to be developed in order to overcome these issues. In this study a new cell controller has been developed based on Open Architecture Control (OAC) technology and Interpreted STEP-NC programming approach. The aim of the developed system is to provide new techniques for both ISO data interface models (14649 and 6983) interpretation, along with its graphical verification, execution, monitoring and report generation functionalities into the CNC core. The implied system is composed of *ISO data interface models interpretation*, *3D simulation*, *machine motion control*, *live video monitoring* and *automatic document generation* modules. The system has also been validated through manufacturing of case study components. Corresponding experimental results verified the proposed technique with satisfactory outcomes.

# ABSTRAK

Pembangunan Mesin Kawalan Berangka Komputer (CNC) yang moden adalah untuk menjadi lebih fleksibel, boleh beroperasi, boleh beradaptasi, system terbuka dan pintar dengan kehendak semasa. Standard Organisasi Antarabangsa (ISO) untuk model antaramuka data sediada yaitu ISO 6983 tidak dapat menampung keperluan sistem CNC di masa depan. Standard ISO baru, yang dikenali sebagai *Standard for The Exchange of Product Data (STEP)* atau ISO 10303 telah diperkenalkan untuk mengatasi masalah penukaran model antaramuka data yang digunakan sekarang kepada sistem dalam Rekabentuk Berbantu Komputer (CAD)/ Pembuatan Berbantu Komputer (CAM). Kejayaan perlaksanaan STEP telah membawa kepada pengembangan penggunaannya kepada CNC dengan memperkenalkan satu standard baru yang dikenali sebagai *STEP-Numerical Control (NC)* atau ISO 14649. Perlaksanaan STEP-NC telah mula digunakan untuk unit CNC komersil secara tidak langsung dalam pengaturcaraan STEP-NC. Walaubagaimanapun, pendekatan tersebut gagal mengataptasi kesemua ciri-ciri yang terdapat dalam sistem CNC moden kerana tidak boleh menterjemahkan data daripada tahap tinggi kepada tahap rendah dan terlalu bergantung kepada spesifikasi pembekal mesin CNC. Sistem kawalan yang baru telah dibangunkan berdasarkan teknologi Kawalan Rekabentuk Terbuka (Open Architecture Control, OAC) dan menggunakan pendekatan pengaturcaraan pentafsiran STEP-NC. Tujuan sistem ini dibangunkan adalah untuk menggunakan teknik baru model antaramuka dan tukaran data dari ISO 14649 ke ISO 6983, berserta verifikasi grafik, operasi pemesinan, pemantauan dan berfungsi untuk penyediaan laporan. Sistem yang dimaksudkan terdiri daripada modul interpretasi antara muka data ISO, simulasi 3D, kawalan pergerakan mesin, pemantauan video secara lansung dan penghasilan dokumen secara automatik. Sistem ini telah disahkan melalui penghasilan komponen dalam beberapa kajian kes. Keputusan eksperimen yang dijalankan telah mengesahkan sistem yang dibangunkan ini mengasilkan keputusan yang sangat memuaskan.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| 2.5D | Two-and-a-half Dimensional |
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| 3DS | Three Dimensional Simulation |
| AAM | Application Activity Model |
| AB-CAM | Agent Based Computer Aided Manufacturing |
| AD | Analog to Digital |
| ADG | Automatic Document Generator |
| AI | Artificial Intelligent |
| AIM | Application Interpreted Model |
| AM | Application Module |
| AO | Architecture Object |
| AP | Application Protocol |
| API | Application Program Interface |
| ARM | Application Reference Model |
| ASC | American Standard Code |
| ASIC | Application Specific Integrated Circuit |
| ATC | Automatic Tool Changer |
| CAA | Component Application Architecture |
| CAD | Computer Aided Design |
| CAM | Computer Aided Manufacturing |
| CAPP | Computer Aided Process Planning |
| CAx | Computer Aided Systems |
| CC | Conformance Classes |
| CCC or $C^3$ | Conical Code Converter |
| CE | Compact Edition |
| CMM | Coordinate Measuring Machine |

| | |
|---|---|
| CNC | Computer Numerical Control |
| COM | Component Object Model |
| CPU | Central Processing Unit |
| DA | Digital to Analog |
| DBC | Drill Bit Changer |
| DH | Drill Head |
| DIO | Digital Input Output |
| DLL | Dynamic Link Library |
| DNC | Direct Numerical Control |
| DRC | Distributed Reconfigurable Controller |
| DSP | Digital Signal Processing |
| EMC | Enhanced Machine Controller |
| ESPRIT | European Strategic Program on Research in Information Technology |
| EtherCAT | Ethernet for Control Automation Technology |
| EtherMAC | Ethernet for Manufacturing Automation Technology |
| EU | European Union |
| FBICS | Feature Based Inspection and Control System |
| FBMash | Feature Based Machining |
| FBTol | Feature Based Tolerancing |
| FDL | Flowchart Description Language |
| FM&T | Federal Manufacturing and Technologies |
| FMS | Flexible Manufacturing System |
| FPGA | Field Programmable Gate Array |
| FSMC-OA | FoFdation Smart Machine Controller-Open Architecture |
| GD&T | Geometric Dimensioning and Tolerancing |
| GUI | Graphical User Interface |
| HMI | Human Machine Interface |
| I/O | Input/Output |
| IDEF | Integrated DEFinition for function modeling |
| IEEE | Institute of Electrical and Electrons Engineers |
| IGES | Initial Graphics Exchange Specification |
| IIMP | Intelligent and Interoperable Manufacturing Platform |
| IMAQ | IMage AcQuisition |

| | |
|---|---|
| IMS | Intelligent Manufacturing System |
| IMSCMI | Intelligent Manufacture for STEP-NC Compliant Machining and Inspection |
| IP3AC | Integrated Platform for Process Planning And Control |
| IPC | Intrinsically Passive Controller |
| IPIM | Integrated Product Information Model |
| ISO | International Standards Organization |
| ITP | Integrated Test Platform |
| JIS | Japanese Industrial Standard |
| JOP | Japanese Open Promotion group |
| LabVIEW | Laboratory Virtual Instrument Engineering Workbench |
| LVM | Live Video Monitoring |
| MADCON | Multi Agent Distributed Controller |
| MATLAB | MATrix LABoratory |
| MCC | Motion Control Card |
| MDICM | Model Driven Intelligent Control of Manufacturing |
| MFA | Manufacturing Feature Agent |
| MIM | Module Integrated Model |
| MMC | Machine Motion Control |
| MMI | Man Machine Interface |
| MPU | Micro Processing Unit |
| NC | Numerical Control |
| NCC | NIST-SAI Conical Code |
| NCK | Numeric Control Kernel |
| NI | National Instruments |
| NIST | National Institute of Standards and Technology |
| NN | Neural Network |
| NRL-SNT | National Research Laboratory for STEP-NC Technology |
| NT | New Technology |
| NURBS | Non Uniform Rational Basic-Spline |
| OAC | Open Architecture Control |
| OCEAN | Openness, Conscientiousness, Extroversion, Agreeableness and Neuroticism |
| OMAC | Open Modular Architecture Control |

| | |
|---|---|
| ORCOS | Organic Reconfigurable Operating System |
| OS | Operating System |
| OSACA | Open System Architecture for Controls within Automation Systems |
| OSEC | Open System Environment for Controllers |
| OWL | Ontology Web Language |
| PAPI | Principal Application Programming Interface |
| PC | Personal Computer |
| PCI | Peripheral Component Interconnect |
| PIC | Peripheral Interface Controller |
| PLC | Programmable Logic Control |
| PMAC | Packet Media Access Controller |
| RAMP | Rapid Acquisition of Manufactured Parts |
| RT | Real Time |
| RTAI | Real Time Artificial Intelligent |
| RTOS | Real Time Operating System |
| SAI | Stand Alone Interpreter |
| SC | Sub Committee |
| SDAI | STEP Data Access Interface |
| SERCANS | Module of Master SERCOS interface-A product from Bosch Rexroth |
| SERCOS | SErial Real-time COmmunication System |
| SFP | Shop Floor Programming |
| SIM | System for Interconnecting of Media |
| SMS | STEP Manufacturing Suite |
| SPAIM | STEP-NC Platform for Advance and Intelligent Manufacturing |
| STEP | Standard for The Exchange of Product Data |
| STEPcNC | STEP-compliant NC |
| STEP-NC | Standard for The Exchange of Product Data-Numerical Control |
| TC | Technical Committee |
| TPG | Tool Path Generator |
| TPV | Tool Path Viewer |

| | |
|---|---|
| TTL | Transistor Transistor Logic |
| UK | United Kingdom |
| UMI | Universal Motion Interface |
| UNL | Universal Logic Network |
| USA | United States of America |
| USB | Universal Serial Bus |
| VB | Visual Basic |
| VDAFS | Verband der Automobilindustri Flachenschnittstelle |
| VISA | Virtual Instrument Software Architecture |
| VS | Visual Studio |
| WEDM | Wire Electric Discharge Machine |
| WZL | Laboratory for Machine Tools and Production Engineering |
| XMIS | eXtended Manufacturing Integrated System |
| XML | Extensible Markup Language |

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# LIST OF AWARDS AND ACHIEVEMENTS

(i). **Silver Medal** in Research and Innovation Festival 2014 [R&I 2014]: Yusri Yusof and Kamran Latif "New ISO 14649 and 6983 based Open CNC Controller".

(ii). **Malaysian International Scholarship (MIS)** under Ministry of Education (MOE) Malaysia.

(iii). **Patent** application in process with ID (PI2014702363) by TRADEMARK2U INTELLECTUAL PROPERTY SDN BHD.

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# CHAPTER 1

# INTRODUCTION

In this chapter, the basic concept of the traditional Computer Numerical Control (CNC) and its systems are discussed. Then, the shortcomings of the commercial CNC system in terms of modern manufacturing are highlighted. Followed by general discussion about possible remedies over these shortcomings with some previous efforts and proposed approach introduced. At the end of the chapter, the problem statement, aim, scope, objectives and further design of thesis are given.

## 1.1 Research Background and Motivation

The CNC machine plays a vital role in the growth of manufacturing since its development. This technology uses computers and Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM) software for the generation, parsing and execution of the sequential control. Today, CNC machines are employed in many industries with different controllers and multiple abilities for various applications such as: turning, drilling, milling, packaging, tube welding and robotic cutting (Groover, 2007). The CNC is composed of many parts whereas, the controller is the heart of a CNC unit that is composed of two parts: hardware and software. The hardware part contains various types of hardware namely motor drives, motion control card and others. While, the software part consists of Programmable Logic Control (PLC) and interpreter for executing machine hardware. The interpreter of the CNC controller acquires the International Standards Organization (ISO) data interface model instructions and translates it into internal commands for moving tools and executing auxiliary functions in a CNC system (Ertell, 1969). CNC machines utilize ISO 6983 data interface model, formally known as G M codes, for their operations. The ISO 6983 data interface model program codes are generated by CAM systems that use CAD information. This model defines the information by numerical codes (G, T, M, F, S etc) indicating the movement of a machine and an axis to the controller (ISO 6983-1, 1982).

The demand of flexibility in the CNC systems was increased in the late 1970's and early 1980's. Because of the rapid growth in the manufacturing world to enable low batch manufacturing of the extensive variety of parts. In the progression towards the realization of the flexible manufacturing environment, the CNC machines were found to be a critical resource because of their capability of being reprogrammed to produce different parts (Xu & Newman, 2006). However, in the development of the flexible CNC systems, a number of limitations were found in ISO 6983 data interface model such as: delivering limited information to CNC, transferring one-way information from CAD/CAM to CNC, unable to implement the seamless integration between CAD-CAM-CNC, programs are huge and very difficult to handle and last minute changes are very hard at shop floor (Suh & Cheon, 2002). Apart from that, different manufacturers had also added new supplement commands into G codes for enabling more facilities into the systems but these extensions are not a part of ISO 6983. Due to these additions, the part programs cause interchangeability problems between different machines, which make the G code more machine specific (Xu & Newman, 2006).

In order to overcome these issues, a new ISO standard was developed which is formally known as Standard for The Exchange of Product Data (STEP) or ISO 10303 (ISO, 1991; ISO, 1994b). The objective of STEP is to provide the means of describing product data throughout the life cycle that is independent from any particular computer system. ISO 10303 significantly improved the interoperability between CAD systems and had also created the need of a similar standard for exchange of information between CNC machines as well as CAM systems. Consequently, in 1999 an international project was started to specify a new standard entitled ISO 14649 formally known as STEP-(Numerical Control) NC to bring the benefits of STEP to CAM and CNC (Suh *et al.*, 2002). The ISO 14649 standard is an extension of ISO 10303. It allows the connections between STEP based Computer Aided Systems (CAx) and CNC machines. The concept of Standard for The

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