Design and Machining Control via Interoperable Function Blocks and STEP-NC Data Model

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Abstract: - This paper discussed about proposes an architecture and implementation of a controller via Function Block Development Kit (FBDK). It can be used to create an open CNC architecture on ISO 14649 and Function Block (IEC 61499). This offers interoperability, portability, and adaptability. The system framework consists of three main components: (1) STEP-NC Parser, (2) Tool Path Simulator, and (3) Communication. In order to optimise, the controller should incorporate with various technologies related to intelligent, such as kernel software, open communication port and open hardware design. The system has been implemented in CNC controller on an actual table 3-axis milling machine. It will simplify the design of a CNC machine controller with the architecture layers responsible for data processing, data storage and execution. This research also highlighted the requirements for global interoperable manufacturing for real-life machining system with the architecture layers responsible for data processing, data storage, execution and feedback.

Key-Words: - Interoperable, CNC controller, Function Block(FB) , STEP-NC

1 Introduction

Since the Computer Numerical Control (CNC) machine was introduced in the industrial sector and widely used in the manufacturing engineering around the world because of its efficiency in processing, accuracy of the machines and facilities in operation. So far, most of CNC machines using G/M codes, also known as ISO 6983 or RS274D and still utilised. G/M codes is current programming language used in CNC. The RS274D was developed by Electronic Industry Association since 1960s and became international standard ISO 6983 (1982) after approved in February 1980. Over 50 years CNC has gone into manufacturing industries, the way of their programming the used of low level language are unchanged for the most of CNC machine. In the future, technology involved in CNC will be more advanced, open system and flexible. No need for high-skilled operators to operate the machine.

On the other hand, ISO 14649 standards known as STEP-NC (Standard for Exchange of Product Data Numerical Control) presents a model for data transfer between the CAD / CAM and CNC. It is to overcome the lack of data exchange between Computer-Aided Manufacturing (CAM) and CNC in ISO 6983 such as geometry, tooling, features, tolerances, and machine parameters will be a bi-directional data flow. STEP-NC emphasizes the machining process, using object-oriented concepts and Workingsteps/ Workplans. Standard for the Exchange of Product (STEP) and STEP-NC are new ISO standard for manufacturing integration, and data exchange between CAD/CAPP/CAM/CNC (CAx) chain. CNCs are responsible for translating Workingsteps to axis motion and tool operation.

Existing system in CNCs is limited to low-level language and difficult to modify to be a flexible of data exchange and intelligent system. Controls system should be implemented in systems that can form a network that can absorb a variety of sources. CNCs must be integrated into automated systems, interoperating with Programmable Logic Controller (PLC), other CNCs, robots and embedded control devices. Vyatkin, [1] stated that IEC 61499 could meet the requirements of an open system design. The latest technology in the development of engineering technology can stimulate a good competition which aims to reduce design effort and allows configuration faster and easier. Function Block (FB) is one of the solutions in the realization of CNC control to be more portability, adaptability, flexibility and open system.

This paper proposes the architecture and prototype of CNC controller via Function Block Development Kit (FBDK). It can be used to create an open CNC architecture based on ISO 14649 and Function Block (IEC 61499) and offers interoperability, portability, and adaptability. The proposed framework consists of three main modules: (1) STEP-NC Parser, (2) Tool Path Simulator, and (3) Communication. The system has been implemented in CNC controller on the actual 3-axis milling machine.

Following chapter will discuss briefly about STEP (ISO 10303) and ISO 14649 standard, known as STEP-NC (Standard for Exchange of Product Data Numerical Control) presents a model for data transfer between the movement and operation tool axis.

1.1 STEP-NC AND STEP

Recently, CNC multi-workstation configuration process has been changed to support the manufacturing industry, particularly in automotive manufacturing from low-volume to high-volume of volatile production components. This configuration provides a more flexible production of larger quantities involving more complex geometries, from the smallest to biggest a part, from the various combinations of materials, and it is difficult to achieve through current standard. In future the manufacturing should more flexible and intelligent and with the concept found expression in DA-BA-SA (Design-Anywhere, Build-Anywhere, Support-Anywhere), which has become the catch phrase of e-Manufacturing [2].

STEP-NC as a new language has a solution to replace the G/M codes that are used since 1950s in CNC. To overcome this problem from variety of standards, two different ISO subcommittees were developed a new standard known as ISO 10303(STEP) and ISO 14649(STEP-NC). ISO TC 184/SC4 subcommittees termed the Application Interpreted Model (AIM) are developing STEP-238 and ISO TC 184/SC1 subcommittees termed the Application Reference Model (ARM) or ISO14649. These two models represent the data model information to program intelligent CNC controllers, but the AIM is fully STEP compliant, whereas the ARM contains the information required to program a CNC machine. The ARM is to be used in an environment in which CAM systems have exact information from the shop-floor, whereas AIM is more suitable for a complete design and manufacturing integration [3]. Both standards are an international development aimed at achieving fully interoperability and bi-directional communication between CAx chain and shop floor [4].

1.2 IEC 61499 STANDARD

IEC 61499 encourages the development of new engineering technologies to reduce design effort and enables quick and easy configuration. This standard is something different compared to other standards used in the control and automation domain when it comes to architecture. Literally, it translates 'reference architecture' for software Distributed Process Measurement and Control System (DPMCS). The Standard incorporates advanced technology software, such as encapsulation functionality, component-based design, event-driven execution, and distribution. Therefore, the IEC 61499 architecture makes it portability, interoperability, and configurability.

FB is an open-source software unit that includes algorithms that can be designed as in an electronic circuit or electronic devices. This means that the FB can perform a task in the control of a process or combining several other elements that perform tasks more comprehensive. Unit, designed for a specific task, contains its own algorithm and a control process to accomplish specific tasks. In IEC 61499 standards, FB is defined in three main types: Basic FB, Composite FB, and Service Interface FB. Basic structure of the FB software is the intention to implement the basic functions of distributed control applications. A Basic FB with internal variables, more than one algorithms and Execution Control Chart (ECC). Implementation of execution control functions that the algorithm must be claimed after a certain input event in the particular circumstances of the ECC. Only one algorithm can be used at any one time, and Basic ECC FB has only one at a time.

2 Related Work

Matthieu [5] outlines three levels of method in order to achieve STEP-NC advanced programming: Indirect STEP-NC programming, Interpreted STEP-NC programming and Adaptive STEP-NC programming. The author also addresses on integration of simulation and optimization with

STEP-NC. A STEP-NC CNC Controller for industrial machines tools have been developed. For the future development platform, STEP-NC should enable multi-process manufacturing and validation tests to prove the efficiency of the system for industrial parts.

Xu et al. [6] discussed a work in which analyses of the roles that STEP-NC and IEC61499 standards are done based on their functionalities. These functionalities include CAD/CAM bidirectional flow information, data exchange through the internet, use of feature-based machining concept, modularity and reusability, intelligent and autonomous CNCs and portability through the resources. According to the authors, STEP-NC is good at supporting bidirectional information flow in CAD/CAM, while function blocks provide a useful tool for developing interoperable CNC controllers and the control strategies [6].

Wang et al. [7] proposed a system combination STEP-NC and function block. The system still using existing machine tools programming (G/M code). CNC should be operated by STEP-NC controller and not depending on existing code. Most of the research carried out is only a prototype. Minhat et al. [8], was developed a STEP-NC controller based on two standards, ISO 14649 and IEC 61499. The system offers full simulation and rendering of the CNC system using the concept of Model-View-Control (MVC). However, the system does not offer automatic process, and data exchange between STEP-NC and function blocks.

Wang et al. [9] proposed system for intelligent controller consists of five modules; STEP-NC parser, workingstep optimizer, knowledge base, machining parameter optimizer and tool path generator. Author also stresses on two major issues needs to be addressed, product data compatability /interoperability and adaptable CNC machines. The digital signal processor and complex programmable logic devices were developed for the controller, in order to transfer and interface the STEP-NC data with the machine motion units [9]. The object-oriented and features-based structure in the system, while tool paths generated based on workingstep. Meanwhile, in the challenge of STEP-NC is to convert the data model into axis data.

3 STEP-NC Controller

The STEP-NC and IEC standards are based on an open architecture that is designed to control the CNC system. STEP-NC data model is used as a data source to perform the machining process, while FB as a controller for the motion control. Physical file part 21(.stp format) is generated by MasterCam software and converted into Java's classes using ST-Developer V14. It will be developed next through Java's platform for an interpreter to produce the tool path for the FB execution.

3.1 System Structure And Hardware

Fig.1 shows the system structure consists of a PC to design an interpreter and controller, in form of programming, based on several software such as Java, FB, Java 3D etcetera. Signals are sent through the communications port LPT1 25 pins to the switch board to raise the voltage up to 5V. The motor controller then will receive the signal and give the instructions to the motor for motion control in order to start the machining processes.

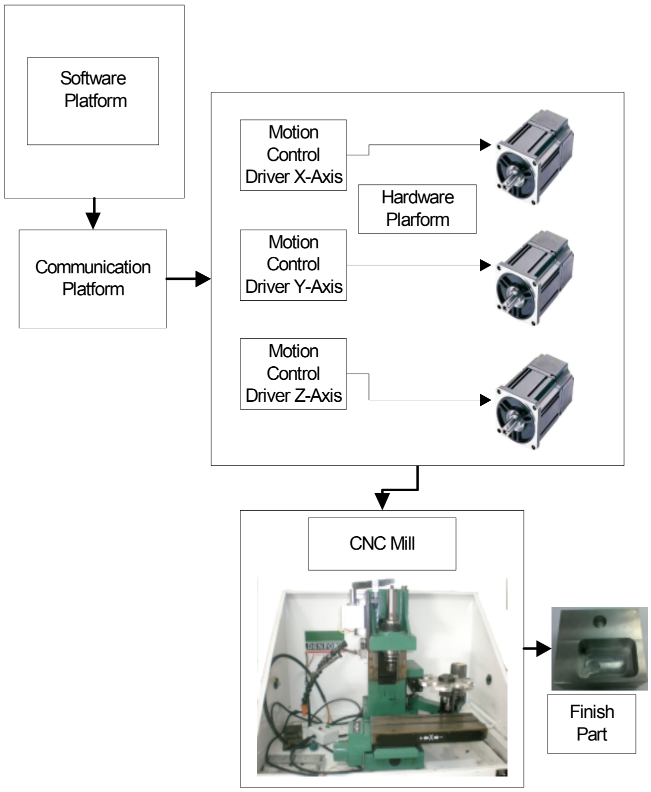

Figure 1: The System Structure

3.2 STEP-NC Parser

In the STEP-NC control system, it has a STEP-NC interpreter designed to process data from the physical file part 21 in ISO 14649 to generate the tool-path for machining. Which is, this file then will be uploaded in FB interface. The Interpreter is designed by using Java and NetBeans software .

The project commenced by developing a model-view-control based on a testbed, and concluded by conducting a verification model. The Model-View-

Control (MVC) design patterns are adopted as the resource tool for verifying the STEP-NC controller. The layered architecture responsible for data processing, data storage and program execution. Separation of the functions into layers enables interoperability of the controller. The Layered MVC has methodology [10] to perform from sketching to physical hardware.

Fig.2 shows the construction of a tree diagram for STEP-NC controller comprising: Interface 3D, machining data, STEP-NC Control and signal mapping. All these networks generated by the FB editor. The sequence defined by the Workplan implementation of STEP-NC program defines the order of the generated code, and consequently, the sequence of execution of the FB. Initially, updated data into the FB, if there is any data input on the event. Meanwhile, FB algorithm also can generate tool paths corresponding to the current situation and update the position in the output. Where each block has a network, and the respective algorithm based on the specified functions.

3.3 Communication

In this research, the communication between PC and controller is using a parallel port LPT1. The parallel port LPT1 25-pin connector is used in the most previous computer to connect to printers or other equipment. A benefit of this type of connection is that it will send the right data and constant, while it limited the number of pins available only and difficult for feedback execution for the controller. An action that will occur will be determined by the controller (computer-based), and the signal will be sent to a certain point to implement the tasks.

3.4 Machine Commissioning

Execution of the manufacturing process starts with the tool machining and work-piece setup on the machine manually. Once a file is loading in the system and compiles it, two options either to do a simulation or loading to the machine to perform the machining process are available. If the process is not successful (Fig.3), then the execution must be restarted by closing all programs.

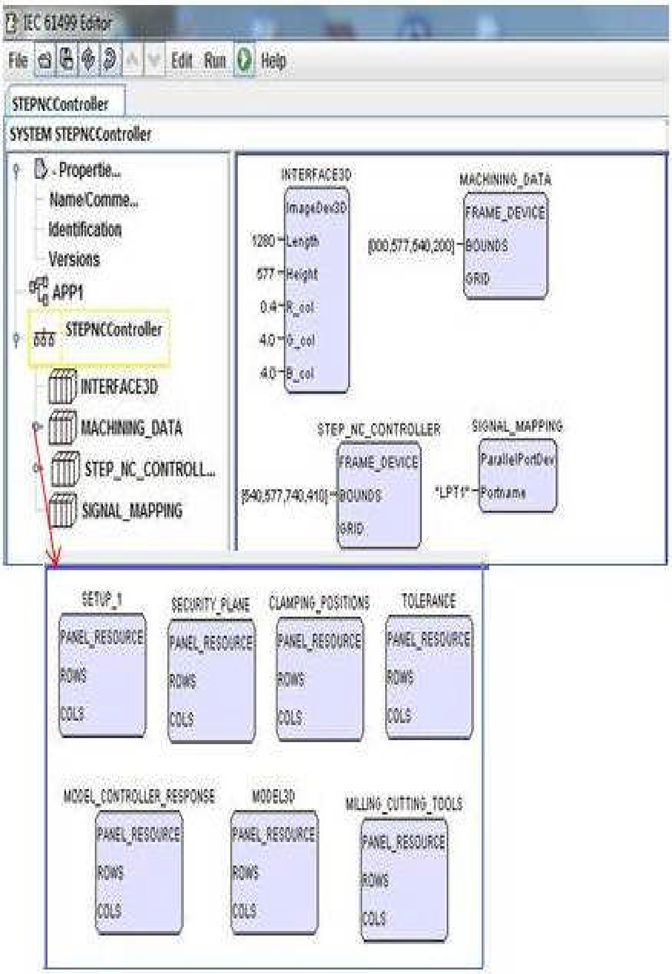

Fig.2 : STEP-NC Controller (FB Editor)

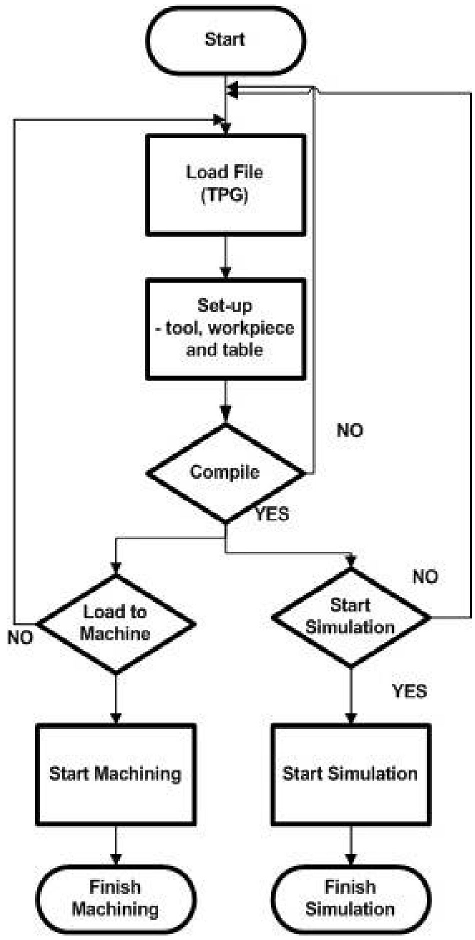

Fig.3 : The Flow Chart of Machining Process

The Feed-rate on the machine is done by calculating the feed-rate for each individual axis, using a feed- rate vector. Feed-rate vector resolved into three components and is used to generate vectored movement and mapping signal. Signal device mapping using raw data calculated by the STEP-NC controller to control machine tools, producing signals required to drive the motor. Each axis of movement of the machine is controlled by a servo motor to move the axis X, Y, Z, or spindle. Electric servo motor is to perform the incremental movement in response of current pulses. Therefore, to achieve precise control, control of motion sequence must be taken into account. When programs implemented on the machine, STEP-NC controller revealed similar performance to the simulation model. Moreover, the actual machine will be tested so that it is consistent with the simulation.

3.5 Tool Path Simulation

The simulations are intended to ensure that the data model has been loaded from FB library to perform a machining as required. Simulation built in FB is a combination with Java 3D to create a simulation model. Where, it shows the real situation on the machine process, and features formed. The simulation model showed graphically the tool movement of a machine that would eventually produce the desired work-piece.

In Fig.4 shows the simulation form in wire-frame Java3D and to get 3D visualisation, more layers are needed in FB to be generated. In order to create 3D components that can be rendered in Sample Frame3D, function blocks representing manufacturing features were developed to form a library of function blocks that is accessible by the ImageDev3D device. Another way for visualization uses software such as MTConnect, MATLAB Simulink etcetera.

4 Conclusion

The Combination this two standard, ISO 14649 and IEC 61499 will generate a better user interface to improve functionality and operation mechanism. The system architecture framework of control system offer interoperability, portability and adaptability. It is also able to perform the simulation and actual machining by using the of Model-View-Control (MVC) concept. Due to the flexible design structure,

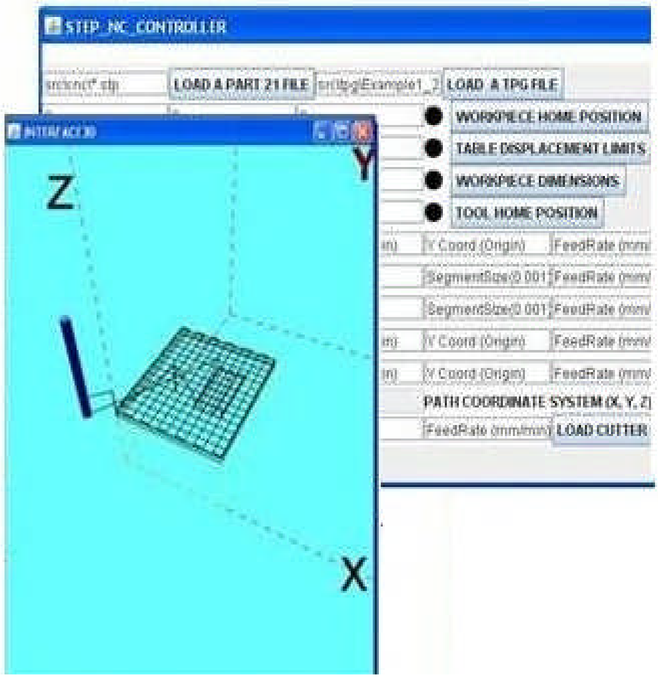

Fig.4 : The Tool Path Simulation

hardware/software computer so that the structural design can be arranged in operation or hierarchy layer. This allows the modification of control to be done easily and effectively.

The machining process starts by converting a physical file part 21 that has been converted earlier by the interpreter into tool-path generation code. It will be processed then in the control system and allowing the signal to be driven by the STEP-NC controller located on the CNC machine tool. The system successful implemented on the machine tool controller for the actual 3-axis CNC milling machine. Feedback element and online control for the control system should be developed in future, and it is a key for global interoperable manufacturing of the real-life machining system. In order to realise intelligent controller for STEP-NC, machine tools and LabView (Laboratory Virtual Instrument Engineering) is incorporated and will be implemented as a platform in next research.

The major challenge to researchers for the development of this type of intelligent controller is the barrier of the software/hardware vendors. The vendors are seeing the lack of standards for manufacturers to take the opportunity to maintain their market advantage through the open architecture control system structure. Hopefully, in future, FB and STEP-NC are considered one of the enabled controllers sooner or later.

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