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New Approach Towards the Development of Next Generation CNC

[1]Kamran Latif, [2]Yusri Yusof, [2]Qadir Bux Alias and [3]Imran Latif
[1]Faculty of Engineering, DRB-HICOM University of Malaysia, 26607 Pekan, Malaysia
[2]Faculty of Mechanical and Manufacturing Engineering,
University Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Malaysia
[3]Department of Civil and Environment Engineering, College of Engineering,
University of Nizwa, Nizwa, Oman

Abstract: Computer Numeric Control (CNC) machine has been widely used in the industries since its development. Today in industry CNC technology has been used for various operations like milling, drilling, packing, welding etc. With the rapid growth in the manufacturing world the demand of flexibility in the CNC machines had been increased. The commercial CNC was fail to provide flexibility because its structure was found to be of closed nature which does not provide access to inner features of the CNC. Apart from that the ISO data interface model of commercial CNC is found to be limited. In order to overcome these issues, Open Architecture Control (OAC) technology and STEP-NC data interface model was introduced. At present, the Personal Computer (PC) has been the best platform for the development of open-CNC system. In this study, a new approach of modern CNC development has been presented that utilized motion control card, universal motion control interface and various functional modules (developed on virtual componenet technology platform) for position, spindle and tool changer motion control. The system was experimentally tested on old 3 axis CNC milling machine and found to be useful to enable sustainable manufacturing environment.

Key words: Sustainable manufacturing, CNC, ISO 6983, ISO 14649, open architecture control, Soft-CNC, STEP-NC

INTRODUCTION

In the 1970's the major revolutionary change was occurred in machine tool automation with the development of the CNC where a computer replaced most of the electronic hardware and punch cards of the NC machine (Hecker and Landers, 2004). In the progression towards more modern systems, flexible manufacturing became dominant in 1970's and 1980's to enable low batch production of a wide range of parts. In order to realize flexible manufacturing, CNC machines became research manufacturing resource due to their capability for being reprogrammed to produce different parts (Xu and Newman, 2006). The CNC machines are operated by 50 years old language ISO 6983 commonly known as G-code, this standard is a well-accepted world-wide. This data interface is a low-level language mainly specifying the cutter motion in term of position and feed rate, due to the low level information this standard is not able to fulfil the requirements of the modern manufacturing environment. There were number of problems found in this data interface model such as: delivering limited information to CNC, transferring one-way information from (CAD)/(CAM)-CNC, unable to implement the seamless integration of the CAD-CAM-CNC, programs are huge very difficult to handle, last minute changes are very hard at shop floor, etc. (Suh and Cheon, 2002). Due to these limitations the ISO 6983 data interface model was unable to enable the modern features into the CNC systems.

In order to overcome ISO data interface problems a new Standard for The Exchange of Product Data (STEP) was introduced in 1990's. The objective of STEP is to provide a means of describing product data throughout the life cycle that is independent from any particular computer system. STEP has resolved the problems of interoperability between CAD systems but at the mean time it has created the requirement of new standard for the exchange of data between CAM and CNC systems. Based on that requirement, another standard was introduced in the 1999's known as STEP-NC (ISO, 14649) (Suh *et al*., 2002). The aim of STEP-NC standard is to use existing data models of STEP with NC system for the enabling of smooth and seamless exchange of the

Corresponding Author: Kamran Latif, Faculty of Engineering, DRB-HICOM University of Malaysia, 26607 Pekan, Malaysia

information between CAD, CAM and NC programming (Cai *et al*., 2005). The concept of STEP-NC is based on "Design anywhere, build anywhere and support anywhere" (Newman *et al*., 2008).

While the implementation of STEP-NC data interface model, the one of the major problem of current commercial CNC machines closeness had been found. According to (Mori *et al*., 2001) "most of the today's CNC machine tool systems are being equipped with CNC controller supplied by controller vendors as a "black box" and that makes it difficult for the machine tool builder to quickly develop and implement the new/custom control functions". In order to overcome the shortcomings of vendor's dependency an Open Architecture Control (OAC) technology based machine controllers need to be developed. Open controller means "controllers independent from manufactures technology, allowing the user to buy hardware and software from several different manufacturers and freely assemble the acquired piece of equipment" (Asato *et al*., 2002). OAC is a concept derived from the flexibility requirement based on computer integrated technology. Some hardware reconfiguration and communication as well as advanced NC programming technology are involved in the new generation development of the CNC system (Park *et al*., 2006).

There had been a various efforts done all around the world for the development of open environment in shape of different projects such as: OSACA, PLCopen, OMAC, OSADL, OROCOS, AUTOSAR, EMC, Global HMI, IEC61499, OCEAN, FAOP, JOP, OSEC, SOFIA, etc. (Brecher *et al*., 2010; Nacsa, 2001; Pritschow *et al*., 2001). Overall state that "Personal Computer (PC) has been one of the preferred hardware platform for open CNC system because of its good openness and high performance to price ratio". With the development of manufacturing world (Han *et al*., 2007) highlights that the current trend of CNC machines is towards the development of PC based soft-CNC systems. Based on this technology there had been various efforts done by scholar, however in this study a method of modern CNC system has been introduced that is based on the virtual component technology. A virtual instrumentation is a software used for developing a computerized test system, a measurement system, a calibration system, a control system for an external measurement hardware device and a display system for test or measurement data. In this approach, a National Instruments (NI) Laboratory Virtual Instrument Engineering Workbench (LabVIEW) platform has been chosen for the development soft-CNC system. Before this some scholars (Rocha *et al*., 2010; Elias *et al*., 2013; Yang and Zhanbiao, 2010) had used this platform for CNC motion control but their approaches were limited to 3 axis and spindle motion control in open loop system environment. So in comparison to those approaches in this study a new technique has been proposed to enable three axis, spindle and automatic tool changer motion control in close loop system environment in soft-CNC systems.

The LabVIEW, platform was chosen because it is an application development program that was developed by National Instruments in 1986 to integrate science and engineering tasks by interfacing computers with instruments for collecting, storing, analyzing and transmitting data while at the same time, providing an effective user interface. Different from other development software such as C/C++, FORTRAN, Basic, etc., LabVIEW utilizes its own integrated programming language known as the graphical programming language which uses graphics as code sequences in the application being developed, making the software development process significantly easier it is very popular and proved to be a very useful tool in control, display, analysis and data acquisition applications. LabVIEW is powerful programming software that can interface with over 7,000 instruments to provide data acquisition, industrial measurement, automated testing and instrument control. LabVIEW contain a rich sets of tool kits to provide a single platform for various activities. LabVIEW features includes libraries of reusable code, support for building GUIs, use of the dataflow paradigm and automatic memory management (Yang and Zhanbiao, 2010). As ISO 14649 data model contains a rich set of information, LabVIEW can be very useful platform to provide all in one unit for CNC operation by utilizing that high level information. The major advantage of LabVIEW is that it provides wide range of connectivity in hardware and software terms that makes an open environment for CNC.

MATERIALS AND METHODS

System development: The system has been developed in two phases: hardware and software.

Hardware configurations: The hardware configuration is based on the interaction of CNC machine with PC. In this study an old 3 axis Denford NOVAMILL has been converted into a PC based CNC system to make an open CNC environment. To do this a PCI 7334 motion control card has been installed in PC that controls the motion of X-Z axis and spindle. Each of the axis contains a rotatory encoder (ENC-7742) that are connected to the I/O card (PCI, 6221) for feedback of data. The automatic tool changer of the machine has been operated by through pneumatic valves which are connected with the air compressor. The system also contains limit switches and sensors for automatic tool changer that are also connected to I/O card. The connection between PC and CNC machine has been done by using UMI 7764 connector block via serial communication port this installation made the vendor specific free CNC controller.

Software configurations: The function of this module is to control the motion of the CNC machine, it is based on machine axis motion control technique introduced by (Elias *et al*., 2013) but that approach was only for 3 axis and spindle motion control of open loop system. Proposed approach extends the motion control with tool changer and enables closed loop control enviornment. The software configurations of this module are composed of three sub modules: axis control, tool control and accuracy control which contains various functional blocks. The axis control sub module contains functional blocks for each axis movement, jog movement for each axis, machine home position, machine origin, maximum values and spindle motion. The each axis movement functional block controls the motion of 3 axis CNC machine in X-Z co-ordinates, jog movement for each axis sets the jog movement of X-Z axis of CNC machine, machine home position sets and moves the machine at its defined home position, machine origin sets and move the machine at defined origin point, maximum values defines the maximum range of machine axis, spindle and tool changer movements to avoid accident and the last spindle motion functional block controls the motion of the spindle of the CNC machine.

The tool control sub module is composed of tool+1 rotation, tool chamber, tool lever movement, tool home position, tool move to previous position, tool+half rotation, move Z-LO, move Z-HI, check tool registry, teach tool, axis jog and tool head functional blocks. The tool+1 rotation functional block controls the rotations of the tool changer the tool chamber valve functional block controls the clamping (open) and un clamping (close) of tool, the tool lever movement functional block control the linear movement of the tool changer motion in both directions: in and out, the tool home position functional block moves all the axis back to user defined home position for avoiding any collision while tool changing, the tool move to previous position functional block return back the machine to the previous position after tool changing operations, the tool+half rotation functional block rotates the tool changer drive at short turns for alignment settings, the move Z-LO functional block brings the Z-axis at the position of tool picking or dropping, the move Z-HI functional block moves the machine at the highest value of Z-axis in positive direction for avoiding accident at the time of tool changing, the check tool registry functional block searchs for the installed tool information and matches with the tool changer sub module database for automatic tool changing operations, the teach tool functional block tells the system regarding the changes made by the user while setting, the axis jog functional block sets the jog movement of the tool changer in rotational and linear motions and the tool head functional block highlights the tool that is already installed in the chamber.

This sub-module is working on a principle for proper operations as the time of tool change occurred in the machining process this sub module will be activated and initiated by the tool home sequence function block and followed by check tool registry functional block. At this moment the sub-module makes a decision regarding Tool Head (TH) status, if the Drill Head (DH) contains a tool that indicates the DH is occupied. Whereas, if there is no any tool installed in DH that indicates it is empty, these DH status decides the working principle of this sub module. The sub-module will combined at tool chamber (close) functional block after performing various functions and continue its operations by utilizing tool home sequence, tool movement and tool move to previous position functional blocks.

The accuracy control sub-module contains functional block (each axis real time movement) for each axis of the CNC machine that reads the actual position from rotatory encoders and shows the actual machine movement in real time.

Graphics User Interface (GUI): The GUI of the system is composed of two tabs: Main and settings. The main tabs contains load file control function that provides a platform for uploading the ISO data interface model file (STEP-NC or G code) that uploaded information has been shown in the tabular form at the main tab in shape of separate columns for easily understanding. The main tab also contains spindle on/off control function for powering on/off spindle motor drive, coolant on/off control function to start and stop coolant lubricant, start control function is for to execute the machine, step control function is responsible for the execution of machine in step by step directions, stop control function for stopping the machine execution and end control function is responsible to end the complete execution, these functional modules ease the motion execution and control operations. Apart from that the main tab also contains home control function that

Fig. 1: The main and setting tabs of GUI

moves the machines at home position, origin control function that moves the machine at origin, stop all motors or X-Z control functions that stops X-Z axis motor drives one by one or at all a time, axis X-Z control functions that shows the real time movement of the CNC machine calculated from rotatory encoders. The second tab (settings) of GUI includes home X-Z axis, origin X-Z and movement settings control functions. The home X-Z axis control functions are responsible for the setting of machine home position, whereas the origin X-Y control functions sets the origin point of the CNC machine. The movement settings control functions is responsible for settings of maximum and minimum movements of machine tool, this modules sets the maximum movements of positions axis, spindle, etc. Figure 1 shows the snap shots of the proposed system GUI tabs.The main tab also contains functional modules of automatic tool changer settings in "manual function", this function is composed of drill bit changer, drill bit clamper, tool change, teach tool mapping and tool change half control functions. The drill bit changer control function is responsible for the linear movement of the tool changer, this control function is connected with the limit switch that helps and guides the tool changer regarding its movements to avoid collision. The drill bit clamper control function is responsible for the picking and dropping of the cutting tools, it utilizes compressor for clamping and un-clamping of cutting tool. The status of clamping has been indicated by the clamp status indicator function. The tool change control function rotates the tool changer motor drive for setting cutting tools order as per requirements. The tool teach mapping control function teach the machine controller regarding tool at head and tool sequence. The tool change half control function sets the alignment between drill chamber and cutting tool by rotating the motor drive at short rounds as per requirements. Figure 2 shows the GUI of the automatic tool changer, all of these control and indications functions has been done by utilizing developed functional blocks in a proper sequence as per operation requirement.

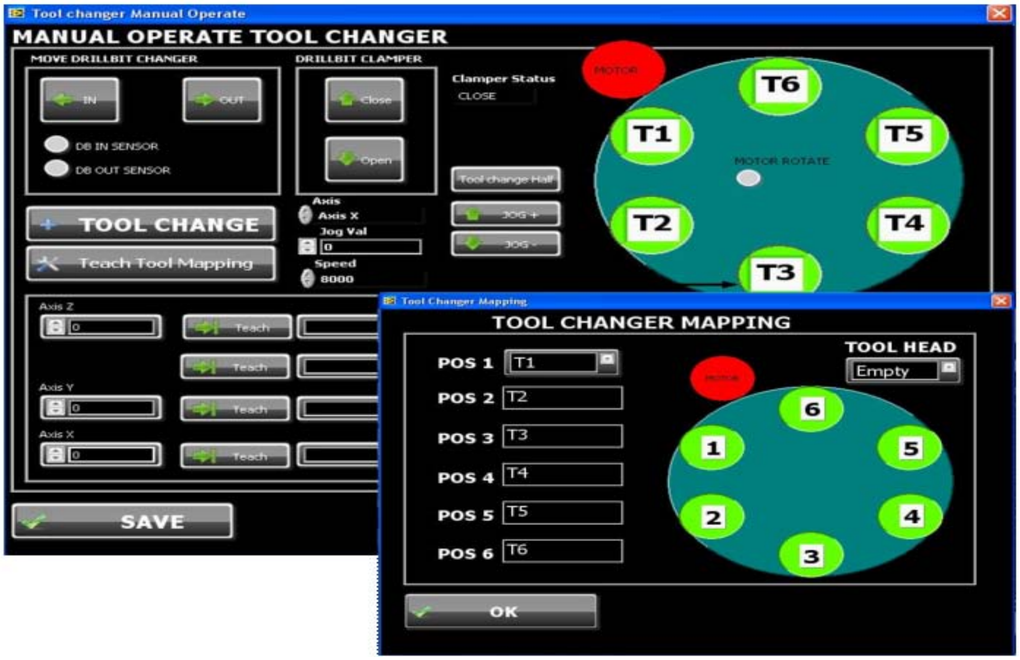

Fig. 2: Tool changer GUI

RESULTS AND DISCUSSION

Algorithm design: The proposed system algorithm has been designed in NI LabVIEW which initiated by moving the machine at home position by utilizing home functional block. At this position the algorithm contains a decision module for setting of home by utilizing machine home position functional blocks. After home position setup, the tool change sub module has been activated with teach tool mapping functional block for setting of cutting tools sequences, alignment, tool head, etc. After the tool changer settings, the load file control function has been executed that provides a platform to upload ISO data interface model file into the system. After that the start control function has been executed that moves the machine at the origin position, at this moment the algorithm contains a decision module regarding origin point setting by utilizing machine origin functional block. After that the machine execution has been started as per input ISO data interface model instructions by utilizing axis control, tool control and accuracy control sub modules. After all, the operations has been done the algorithm ends the script and stop the machine by utilizing stop control function and also moves the machine back to home position by utilizing home control function. Figure 3 shows the flow chart of the proposed system algorithm design.

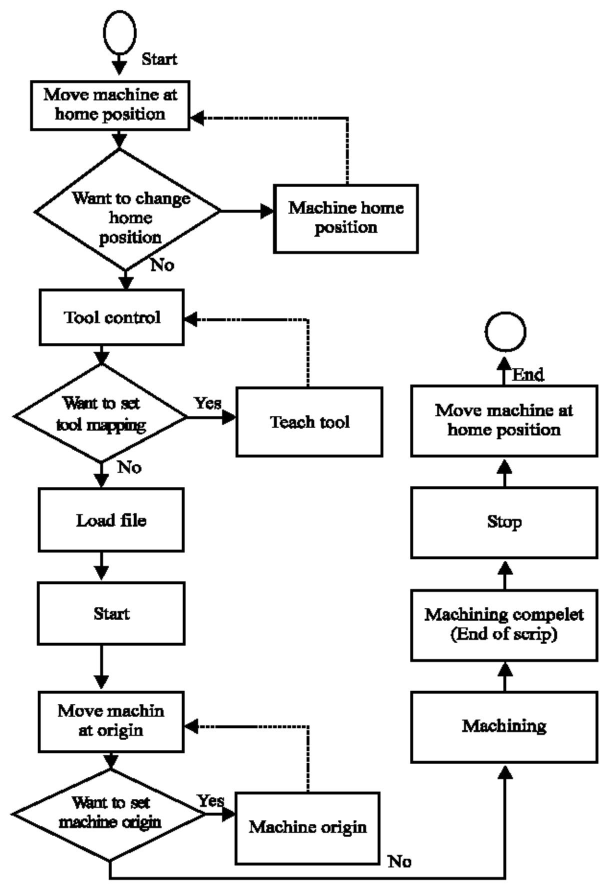

Fig. 3: Flow chart of developed system algorithm design

CONCLUSION

Today's conventional controllers of CNC machines are found to be close in nature, i.e., they do not facilitate access to the inner features of the CNC controllers and axis control systems. These systems are closed in both aspects: hardware and software. In other words they are closed in terms of Human Machine Interface (HMI) platform, input and output functions, connectivity, data interface model, etc. To overcome these problems open architecture control technology was introduced, the aim of this technology is to develop controller which are independent from the manufactures technology, allowing the user to buy hardware and software from several different manufactures and freely assemble the acquired piece of equipment. With the development of manufacturing world the development of PC based soft-CNC systems has been the hot topic of the research because the system are of low cost, good for sustainable manufacturing environment, provides flexibility, more openness etc.

Based on this technology a new approach of PC based open CNC system has been presented in this study. The proposed system based on the PC, motion control card, universal motion interface, LabVIEW and windows environments. The system is able to control position axis, spindle and tool changer motion control by utilizing various functional blocks such as load file, spindle on/off, coolant on/off, start, step, stop, end, home, origin, stop all motors or X, Y and Z motors, axis X, Y and Z, tool+1 rotation, tool chamber, tool lever movement, teach tool mapping, tool+ half rotation, tool head, tool home position etc functional blocks. The development of these kind of system enable more functionalities into the CNC at very low cost because it minimize the use of hardware and software. The proposed system was tested experimentally and found to satisfactory, it was implemented on old CNC machine by converting it into new PC based modern CNC system to make sustainable CNC environment.

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