An overview of the current status on step-nc

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Abstract. STEP-NC is known as a Standard for Product Model Data Exchange which aims to be the next generation for Computer Numerical controller. It provides a new breed of intelligence to the CNC controller in terms of interoperability, flexibility, adaptability, and extensibility. Based on that capability, the conventional programming standard known as International Standard Organization data Interface (ISO 6983) needs to be replaced with the STEP-NC ISO14649. This article presents an overview of work done to capture the trend of Closed-loop machining (CLM) based on the application of STEP-NC standard. A study stated that CLM improves the machining process and enables a part to be manufactured accurately and efficiently through optimization.

1. Introduction

The world is rapidly progressing and changes are ubiquitous. The changes start from natural environment to building environment and now to the real-time environment or digital environment [1]. These three phases of environment changes affect the society and economy evolution. The evolution results in market competition and globalized trends. The current global market wishes to offer the customer a reasonable cost of product, good quality of product, customization, and responsiveness in terms of development and production time [1-2]. To keep up with the market trend, the manufacturing process trend must be modified from conventional to modern. Modern manufacturing process trend will lead to an increase in the speed and control of the cost of production cycles [3]. The modification can be done through embedding intelligent system and highflying the control technique based on the standard data exchange and programming [4]. Machine tool control is considered as one of the most important manufacturing activities which end the manufacturing process chain.

Since the 1950s, the machine tool control movement was controlled by the International Standard Organization data interface ISO 6983 called G-Code programming[5]. G-code is considered as an old and low-level programming standard that only delivers minimum information to the CNC. G–code also breaks the information to be flown between the CAx chain [6]. Moreover, G-Code programming describes the movement of a tool based on the individual brand of CNC machine. Due to the fluctuation in market needs and trends, CNC industrial companies are facing a big challenge to integrate all levels in product lifecycle management. To respond to the CNC industrial companies challenge, the old CNC standard needs to be replaced with the most powerful standard called Standard for Product Model Data Exchange STEP-NC or
more commonly known as ISO 14649 and ISO10303 AP238 and proven by ISO TC184 SC1 and SC4[7]. STEP-NC allows data to be seamlessly exchanged between CAx chains without any information loss.

Figure 1. Flow chart for data filtration.

Many studies have been conducted to promote STEP-NC as an upcoming generation of data model interface for CNC system. Based on the data gathered from eight different databases (Academic Search Primary, ACM Digital Library, Applied Science and Technology, IEEE, SAE Mobilus, Science Direct, Scopus, and Springer Link), a total of 708 publications comprising of books, book chapters, conference proceedings, industry research reports and journal articles was published. The flowchart for data filtration from Universiti Tun Hussein Onn Malaysia databases is depicted in figure 1.

So far, a majority of the publications have specifically reviewed the topic of STEP-NC. However, no studies have captured the trend of closed-loop machining based on the application of STEP-NC standard. This study aims to identify the gap for future research on the above matter.

2. Overview of current data model interface of CNC system
The current data model interface of Computer Numerical Control system for making a part or product starts with a detail drawing of a part which is designed in a 3D model via a CAD system. This 3D model is then converted to IGES files format. IGES file is a natural data format used to translate CAD data. It was published by the American National Standards Institute (ANSI) in 1980 until the final version was published in 1996 [8]. In 1994, STEP, ISO standard data took place [9]. The data from CAD were then converted into the STEP format. STEP enables standardized product data exchange between Product Lifecycle management systems unlike IGES format which was only designed for geometrical information exchange and is not able to fulfill the industrial needs [10]. The IGES/STEP file is then sent to the job shop. In the job shop, the CAM operator refers to the files and the process is defined in CAM. The CAM system translates the process as defined by the operator in G-code programming. Finally, the G-code programming is then sent to CNC based on vendor specific format. Figure 2 illustrates the current data model interface of CNC system.
3. Drawback of current data model interface of CNC system

Although the current data model interface of CNC machine was designed to make a product, the problem of data exchange still remains unsolved. The problem exists between CAD/CAM and CNC system data exchange. Since the introduction of CNC system, G-code remained the dominant code and is used as an output from CAD/CAM to CNC system. G-code enables information to flow in one direction from design to manufacturing only. Moreover, G-code contains a list of instruction which consists of hundreds of thousands codes telling the CNC system where to move the cutting tool to make a part. To overcome the barrier of G-code, an international team of expert made an effort to extend STEP to STEP-NC. STEP-NC is defined as a free bi-directional information standard for Computerized Numerical Control (CNC) system. STEP-NC aims to represent a standard data model which was specially created for NC programming and as an effort to realize the objective of standardizing controller of CNC and NC code generation into reality [10].

Table 1 lists G-code programming drawback and STEP-NC capability. From the list, a conclusion can be made that replacing the old standard of CNC controller with new high-level standard STEP-NC is the right decision and is sufficient to be a new standard for the next generation of CNC controller.

Figure 2. Current Data Model Interface of CNC system.
Table 1. G-code programming Verses STEP-NC standard[11][12][13][14]–[18] [19]–[22][23], [24].

| G-code adapted from                      | STEP-NC                                      |
|-----------------------------------------|----------------------------------------------|
| Low level Programming language         | High level Programming language              |
| Limited of Information                  | Rich of Information                           |
| Limited Control of Program              | Easily Control of Module                     |
| Vendor Specification Code               | Standard Data Model                           |
| Unidirectional flow of Information      | Bidirectional flow of Information.            |
| Vendor Specify architecture             | Standard architecture                         |
| Limited optimization support            | High optimization support                    |
| Complex and difficult task to realized close loop machining | Support close loop machining |

4. Overview to overcome drawback of G-code

A huge number of effort was done by vendor, researchers, and academic institutions from all corner of the world to replace the old standard with a new breed of intelligent CNCs. Based on the roadmap proposed by a STEP-NC International committee members [25], the CNC controller had gone through three levels of control. The first level involves STEP-NC files being interpreted through a post-processor in generating toolpaths and controlling information in the form of G and M codes and passed to a conventional controller. Research works related to the first level of control include [13-14]. The second step directly interpret the information of STEP-NC on the machine tool. Research works related to the second level of control include [3], [28]–[34]. The third step embeds a new intelligent algorithm in the STEP-NC files. The feature of intelligence is embedded to the CNC system based on different approaches. One of it involves closed-loop machining.

The first demonstration of closed-loop machining approach was conducted in the United States by a group of industry partners in the year 2005. The demonstration was focused on CLM to support probe capabilities via STEP-NC (ISO 10303 AP 238) [35]. The development includes Conformance Classes 1 and 2 of AP238 while the other two Conformance Classes will be developed next. Furthermore, AP238 takes more storage space and is more complex in programming as compared with ISO14649.

The next research was conducted in 2006 at Aachen University, Germany in the Laboratory for Machine Tools and Production Engineering (WZL) by [17]. The research was focused on incorporating inspection into STEP-NC data flow based on the concept of the closed-loop process chain. Through the closed-loop
process chain, the inspection result responds back to the planning process. However, the tolerance models of every single existing standard should be harmonized with a specific end goal to have the capacity to translate and exchange measure and overcome the problem of data conversions in CMM (coordinate measuring machine). Moreover, the optimization is offline due to the research being limited to CMMs usage.

In 2007, [36] proposed CNC manufacturing intelligent process control system. The framework is based on a STEP-NC-oriented knowledge-based for discrete components. Three types of process control explained in the proposed framework are simulated process control, product control, and machine control. Simulation process control is done before the manufacturing process while product control and machine control are done during machining. Through that, the proposed framework permits the manufacturing system to make use of the data feedback during machining via a self-learning mechanism, produces quality product consistently and enables real-time closed-loop machining. However, the process control is based on knowledge-based analyzer feedback where knowledge is extracted from a large number of machining operation experiment data.

Another research that enables real-time closed-loop machining was proposed by [18] in 2008. The author proposed a framework on-machine inspection (OMI). Based on that feature, automated and seamless data feedback can be achieved. However, the research only considers on-machine touch probe and is not implemented in reality. Other recent research on CLM is summarized in table 2.

| CLM system | Feature | Limitation |
|------------|---------|------------|
| [37] Proposed a solution for manufacturing technology and CAx application, interoperability<br><strong>Solution:</strong> Knowledge Capitalization | Provided guideline for a CAM programmer to manufacture excellent product quality for the first time | Tested based on case study and for simple shape (pocket) only. Data were manually filled to a database. Future work recommended to create an inquiry to pop-up automatically based on CAD design manufacturing feature and coupled with Computer Aided Process Planning and optimization program. |
| [38] Proposed an open and intelligent platform for advanced AM<br><strong>Solution:</strong> Inspection, Optimization, Simulation and Cloud knowledge database | Suitable for any AM system. Enables simulation and monitoring | Inspection module, optimization module, and cloud knowledge database are under development |
| [39] Proposed a solution to support closed-loop machining by extending STEP-NC data model via aligning and laser tracker measuring for machining assembly interfaces of large size of component | Proposed a high level controller for STEP-NC with 2 important function. First, STEP-NC codes is translated into executable CNC code. Second, realized close loop optimization on-line. The proposed method contributes to future development of STEP-NC for machining large size components | The extension is more suitable for large and complex component |
5. Conclusion
This article summarized the third control type of CNCs based on CLM approach to enable intelligent feature to be embedded to the CNC system via STEP-NC. The work on CLM started since 2005 and is still currently progressing. Based on the observation, to prepare for a new breed of CNC controller, data feedback based on real-time and on-machine inspection must be embedded into CNC machining system via STEP-NC information flow. Based on that effort, issues on bad quality of machining parts, wastage, and time-consuming machining will be solved. Furthermore, the availability of data feedback function enables on-machine inspection and optimization of setup adjustment. Furthermore, the data can be saved in the cloud storage and the integration of cloud manufacturing can be realized. In the future, it is recommended for CAM programmer to manufacture any part well the first time through cloud integration. By considering the benefits of CLM, future work on CLM is must.

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