Towards cloud-based STEP-NC to enhance interoperability in global manufacturing

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Abstract. STEP-NC has been under research for several years, and its manufacturing interoperability is still considered in its infancy. Until recently, seldom STEP-NC compliant CAD/CAM/CNC systems were commercially materialized. The reasons why the CAD/CAM and CNC vendors have not been interested in becoming STEP-compliant are diverse. One of the major is the unmatured interoperability in handling uncertainty in highly dynamic production contexts. STEP-NC requires enormous manufactured data being exchanged among different STEP-compliant systems, whereas little lack of consistency may course the failure of final manufacturing results. The low-volume volatile component production and the complexity of STEP-NC data bring much more risks of uncertainty and unforeseen events, which generally propagate across the different stages of production. The authors believe that the combination of STEP-NC and cloud manufacturing will be the key solution for dealing with the current dilemma of STEP-NC and can promote the intelligent manufacturing into reality. This research proposes a framework of the STEP-NC compliant manufacturing in a cloud environment.

1. Introduction
Modern industry has made an increasing necessity for manufacturing companies to support low-volume volatile component productions and handle the uncertainty from highly dynamic production contexts [1]. Since the inception of STEP-NC, it has been continuously considered as a competitive tool to research and improve different elements of the CAx chain. Thus, it has turned into the main condition for manufacturing businesses to be strategically proactive and competitive [2] on the global scale. In spite of the tremendously encouraging advantages of STEP-NC, its manufacturing interoperability is still related to a number of issues [2-4]. Comparing to the G-code (ISO 6983) based on CNC programming, STEP-NC (ISO 14649 or AP238) offers much more abundant manufacturing data for the use of object-oriented manufacturing tasks, while it also brings a lot of complexity and difficulties in handling the high-level data models in various CAx systems and realization of the interoperability. The STEP-NC provides the possibility of bidirectional flow of data between CAD/CAM and CNC without any information being lost. It also brings sufficient advancements inside CAD, CAM and CNC systems and the bidirectional data flow of information, which cannot endure any breach or incapability of the CAD-CAM-CNC chain of data [5, 6]. There are numerous hinders in the headway of developing commercialized STEP-compliant CAx systems; the underdeveloped
interoperability is nonetheless one of the major issues. Several inconveniences affecting the interoperability of STEP-compliant CAx systems can be presented as follow:

- The STEP-compliant CAD system requires correct understandings of manufacturing features.
- The STEP-compliant CAM system needs enormous non-geometric data inputs.
- The STEP-compliant CNC system has to transfer the machine tool status upwards to designers.

The introduction of cloud computing into cloud manufacturing gives a reasonable solution to reducing the complexity of handling STEP-NC data and enhancing its interoperability. In cloud-based computing, everything is interpreted as a service (XaaS), e.g. SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service) [7]. ISO 14649 or STEP-NC is free of the STEP design data, or technically it was worked out with an objective not to contain the full-fledged design data. This paper presents the STEP-NC based services that facilitate the convenience for both designers and operators.

2. Framework and architecture of global manufacturing cloud

Global Manufacturing Cloud (GMC) is proposed and conceptualized to have the following features throughout the platform. Figure 1 shows the semantic model of GMC. Consumers get access to the GMU via a multi-platform application, browser, computer or mobile device. Multi-platform applications or browsers use a secure Hypertext Transfer Protocol (HTTP) based communication protocol [8].

![Figure 1. Conceptual model of Global Manufacturing Cloud.](image)

GMC is hosted in the Web-Server. GMC communicates with the manufacturer via the Internet to transmit tasks and to monitor and manage machines. Customers and Administrators connect to the web-server, which then connects to the manufacturer via TCP/IP (Transfer Control Protocol/Internet Protocol), RESTful MTConnect. Each factory has its own local server. The computer is used to manage the machines through controllers through the local network. Local servers send the received data from the cloud and command the controller to perform the manufacturing operations.
2.1. Framework
In this section is the proposed architecture of GMC. The framework is presented in figure 2. The diagram presents a hierarchical view of communication services and GMC.

![Figure 2. Architecture of Global Cloud Manufacturing Platform.](image)

2.1.1. Physical resource layer
This layer includes physical structures of NC machines, motors, drives, Electronic hardware (embedded systems with microprocessors, microcontrollers, memory, input/output), circuits and power supplies. It treats the warehouse facility as a hardware to store software or any future versions of it. Advanced embedded systems of this layer make it possible to have intellectual manufacturing. Manufacturers can publish their resources in the GMC because such resources have Internet access and computational abilities. Manufacturing resources are connected to virtualization resources and can be used for remote monitoring and management throughout the cloud. The TCP/IP Protocol and MTConnect are used to connect manufacturing resources and virtualization resources. MTConnect transfers data for monitoring and collecting data in XML format. TCP/IP communication Protocol is used to interact with the cloud layer.

2.1.2. Virtual resource layer
The ‘Virtual resource layer’ has an advanced operating system, which includes several technologies to identify physical resources (Machines), virtualize and identify them in CMfg service as Infrastructure as a Service (IaaS) [8]. This layer uses resource identification, resource accessing, remote accessing, sharing technologies, along with IoT, and embedded technologies. The virtual resource layer virtualizes the manufacturing resources and represents them in GMC. GMC virtualizes manufacturing resources by publishing accessible RESTful web services across the Internet, refer to figure 2. Manufactures develop and deploy RESTful web services within the servers of the virtual resource layer, which is provided by a local server figure 1. In addition to virtualization, the resource virtualization layer protects production resources by confirming Internet access requests and verifying incoming operations requests from the cloud. This layer uses HTTP-based REST Protocol to interact with the cloud layer.

2.1.3. Cloud service layer
The present GMC is not designed to develop any business model but to provide the services primarily for Cloud users instead. The role of the platform administrator is to...
overlook the entire manufacturing cloud i.e. to integrate and deploy a specific set of functions for the needs of cloud users such as subscription manager of the cloud layer [9] as CMfg services.

For inter-component communication, these cloud services are designed as RESTful web services using HTTP-based REST Protocol. The application layer also interacts with a cloud layer through HTTP based REST protocol. The layer services are presented below.

**Subscription Service:** This component grants authentication for the user to manage machining tools across the internet when permission is requested. In addition, this service creates a database of user settings and subscriptions.

**Cloud Repository Manager** stores web virtualization services data and applications. Every announced RESTful virtualized web service has a URL, and these URLs are stored in a database with the required information about the settings. Manufacturers can configure access to web services. Below is the description of published web services.

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**The Monitoring API Manager** provides manufacturers with information how to run published web services from applications. All Internet users have full access to published web services.

**The Private API Manager** is developed to provide an access to manage and use published web services. For each case publishing manufacturers specify the limits of access. This type of web service provides access for application development and for internal maintenance of production environments.

**Security Manager:** In order to improve the security of the platform to GMC users provided an authentication token. It is a subscription service component and the security manager will create, monitor and evaluate the token. The authentication token is a time-based and auto-expiring component of the security service.

2.1.4. **Application layer** Application platforms can be web browsers, mobile applications that are available for download from the repository, built-in applications that allow customers to perform manufacturing operations across the Internet [10].

2.1.5. **The communication methods** The interaction of the layers is illustrated in figure 2. Cloud components are designed and implemented to provide web RESTful services in a GMC architecture. The architecture is considered from the bottom up. The physical resource layer interacts with the resource virtualization layer using two types of communication such as RESTful MTCOnnect and TCP/IP. Virtualization layer and the resources layer can interact in two ways: obtain and monitor information status about machine operation and send requests to the machine. Processing commands are transferred over TCP/IP. MTCOnnect is used to send data to the cloud and store data in XML format. The virtualized resource layer interacts with a cloud layer through RESTful web service. The customer layer interacts with the cloud layer components by making REST calls and receiving an HTTP response. The data is transmitted in XML format.

3. **Implementation of GMC**

This section discusses the implementation of four web services as follows: STEP-NC File Analyzer and Viewer, Converter STEP-NC, Tool Path Viewer.

3.1. **The STEP-NC file analyser**

The STEP-NC File Analyzer (SFA) is an accessory program that generates a spreadsheet or CSV files as shown in figure 3. The spreadsheet simplifies the test configuration information at the entity levels and attributes. A customer typically has a hierarchical display of high-level information in the STEP-NC file, where the user can navigate to the individual attributes of the parts. STEP-NC files are used to represent the geometry part, manufacturing information (PMI) and product, which are used for data exchange and interaction between CAX systems. STEP-NC files are also used for storing in a database. The software can also view STEP-NC boundary representation part geometry, tessellated part geometry, PMI for geometric dimensioning and tolerancing (GD&T), supplemental geometry, and finite element models. Other general-purpose STEP file viewers might not display PMI, tessellated
part geometry, and finite element models. However, those viewers are usually better at viewing b-rep geometry than the STEP-NC File Analyzer.

Figure 3. The STEP-NC file analyzer of GMC (left), Convertor STEP-NC (right).

3.2. Convertor STEP-NC
STEP-NC convertor is developed using JS, HTML, CSS, C#, EXPRESS, and SQL. It is a utility model of a convertor of the STEP-NC file to XML, to transfer data in XML format to the manufacturing or some part of STEP-NC in XML. This part of STEP-NC designates means by which schemas and data can be performed as an XML document. These schemas are defined by the EXPRESS language and data is carried out by EXPRESS schemas. Key entities which influence the tool path and CNC code would be identified and algorithms are generated considering the key entities as inputs and ‘jscad’ and ‘.nc’ files as outputs. Figure 3 shows few user interfaces of STEP-NC convertor.

3.3. Tool path viewer
There are two ways to implement the Tool Path Viewer, the first is the OpenJSCAD which offers full control over the modeling process allowing users to write scripts with object-oriented concepts. Another one is NC.js with SignalR, which offers real-time monitoring from manufacturing. The detailed description below.

3.3.1. OpenJSCAD
It is a web-based 3D viewer allows the use of JS concepts, libraries, CSG approach for CAD models and interactive parametric modeling with programming guide is identified to be suitable for Tool Path Viewer. Unlike many CAD applications, which offer interactive modeling, it offers full control over the modeling process allowing users to write scripts with object-oriented concepts. Initial testing of tool path templates with interactive parametric modeling is performed against various operations. These toolpath files subsequently refined to incorporate the influence of various other STEP-NC entities and shop floor practices. Algorithms are developed to render simulation for coordinate system, workpiece geometry, feature geometry, tool bit geometry, rapid path, machining path cycles, finishing tool path, return path to retract plane. Working with TPV as discussed in section explains the final output against each of the working steps from STEP-NC. Figure 4 shows the working interface of OJSCAD.

3.3.2. Three.js and SignalR
MTConnect, Three.js, and SignalR are three great tools to implement real-time manufacturing monitoring. Real-time web functionality is the facility to provide connected clients with the real-time content using server-side code. Figure 4 shows the real-time movements of the cutting tool and the workpiece.
Figure 4. Working interface of OJSCAD (left), Real-time manufacturing monitoring using TPV of GMC (right).

Three.js is the Web interface for the Digital Thread. This provides a rich REST API for process and models as well as a matching client that displays the 3D part models for the machining workpiece, tools, CNC, as well as removal simulation, PMI annotations, MTConnect positional data, QIF face status, and other aspects of a Digital Twin on the Digital Thread.

Three.js allows the creation of Graphical Processing Unit (GPU)-accelerated 3D animations using the JavaScript language as part of a GMC without relying on proprietary browser plugins. This is possible due to the advent of WebGL.

SignalR proactively chooses the best accessible transport and takes advantage of multiple transport types. It also takes into account the best available client and server transport. SignalR uses WebSocket, an HTML5 API that provides bi-directional interaction between the browser and the server.

4. Conclusion
The article has presented scalable service-oriented structure, virtualization techniques and methods of communication of the GMC. The international organization for standardization (ICO) has issued the relevant standard - ISO 10303, also called STEP. ISO 14649 Application Reference Model (ARM) to work with CNC is also called STEP-NC. ISO 14649 standard, replaces the use of G-code, facilitating the integration of CAD / CAPP / CAM and CNC systems and the development of MTConnect modules creating the opportunity to monitor the CNC machine in real-time. To enhance connectivity with NC, researchers began to work on various individual STEP-NC systems compliant in the categories of Adapter, Converter, Simulators and CNC controllers. There are very few developed platforms that combine multiple systems. The combination of STEP-NC and CMfg concepts offer a new breed of collaborative and distributable manufacturing solutions. As a fundamental element of the structure, a web server is developed, which link the manufacturer and the customer. It uses the RESTful Internet MTConnect Protocol to acquire the data status of machine tools and monitors their operations over the Internet. The data is exchanged in XML format without converting the STEP-NC file to G-code. Thus, it supports a TCP / IP based solution for the exchange of operational production services in the manufacturing cloud. Users can import and export STEP-NC files from the cloud data associated with their login data implements to work from anywhere. Users simulate the path of the tool in the Tool Path Viewer service. The implemented operational test bench demonstrates the ability to monitor processing activity and the execution of production operations and processes directly from the production cloud across the Internet.

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