

IMPLEMENTATION OF THE STEP-NC AND MTCONNECT STANDARDS FOR ADDITIVE MANUFACTURING

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Abstract. This paper describes a way to implement the STEP-NC and MTConnect standards for additive manufacturing processes. Generation, simulation, and validation of a STEP-NC program containing additive toolpaths are presented. The development of an MTConnect framework for remote monitoring of RepRap additive machines via the Internet is also detailed. Results from different experiments that were conducted demonstrate the feasibility of the proposed implementation approach.

Keywords: additive manufacturing, STEP-NC, ISO 10303-238, MTConnect, Interoperability

1. INTRODUCTION

In the last decade, the enormous advancements in information and communication technologies have drastically reshaped the manufacturing industry and initiated the fourth industrial revolution. According to (Liu & Xu, 2017), this new global industrial era leads to the need to develop the next generation of machine tools that are smarter, well connected, widely accessible, more adaptive and more autonomous, as a key element for consolidating smart manufacturing systems. Nonetheless, the lack of interoperability between CAD/CAM software and CNC systems still represents a severe limitation by the use of the old-fashioned programming language of ISO 6983/1980, so-called G-code (Xu & Newman, 2006). On the other hand, enabling ubiquitous Internet access to physical manufacturing equipment is also a subject to be solved as soon as possible (Lu & Xu, 2019). As part of international collaborations between industry and academic community, STEP-NC (STandard for the Exchange of Product model data – Numerical Control) and MTConnect emerge to overcome the interoperability problems of the CAx digital chain and enable connecting manufacturing equipment to the Internet.

Figure 1 illustrates the context of the research works being conducted in the LaDPRER (*Laboratório de Desenvolvimento de Produto e Engenharia Reversa*) laboratory, in University of Brasilia, around some of the challenges set by the Industry 4.0. Generally speaking, these works deal with the vertical integration of the information throughout the product life cycle by using STEP-NC and QIF (Quality Information Framework) standards. Likewise, they are focused on developing cyber-physical manufacturing systems based on MTConnect and OPC UA (Unified Architecture) technologies. All that involves advanced manufacturing processes (machining, additive, hybrid processes, incremental sheet forming), CMM inspection, industrial robotics, and information technologies. In such a context, this work proposes an approach for implementing STEP-NC and MTConnect standards for Additive Manufacturing (AM) processes by using 3D printers of the RepRap (short for Replicating Rapid Prototype) type.



Figure 1. Context of the research works being developed at LaDPRER laboratory.

2. MATERIALS AND METHODS

2.1 The STEP-NC standard

It developed by the International Standards Organization (ISO), first as ISO 14649 and now as ISO 10303-238, STEP-NC provides a high-level object-oriented data model that extends the data models of the STEP ISO 10303 standard to encompass NC process data. Demonstrations of the integration of the CAD/CAM/CNC chain provided by ISO 10303-238 were carried out in United States as part of the “Super Model” project between STEP Tools Inc. and a team of subcontractors including CAD and CAM software developers, machine tool producers, industrial leaders and research agencies (Hardwick et al., 2013). The STEP-NC models have been tested with implementations in milling and turning processes involving multi-axes machining functions. Recently, STEP Tools launched the project of a digital thread that fuses STEP-NC, MTConnect, and QIF metrology feedback. Regarding the additive processes, the development of STEP-NC is still in an incipient phase.

2.2 MTConnect

MTConnect has been developed by the Association for Manufacturing Technology (AMT) as an open source, royalty-free and read-only-safety communication standard that aims to increase the interoperability between shopfloor devices and software applications by making data reports through the Internet Protocol (Vijayaraghavan, Sobel, Fox, Dornfeld, & Warndorf, 2008). It founded upon the most prevalent technologies like XML (eXtensible Markup Language) and HTTP (HyperText Transfer Protocol). Its basic architecture consists, essentially, of an MTConnect Adapter and an MTConnect Agent. The adapter has the function of collecting data generated by a shopfloor device, converting it into a simple text-based dictionary (SHDR-Simple Hierarchical Data Representation, i.e., “Timestamp|name|value|name|value”), and delivering it to the Agent. The essence of MTConnect is the Agent, which is a program responsible for capturing data from the Adapter, formatting that data into an MTConnect XML stream and make it available for a web-client in the manufacturing cloud. In this work, MTConnect is used to connect additive manufacturing machines to the Internet in order to realize remote monitoring in the first instance.

3. RESULTS

3.1 Application activities model

Application activities model to implement the STEP-NC and MTConnect standards for AM is described by using the IDEF0 (Integrated Definition Language 0) diagram shown in Figure 2. The model is comprised by five main activities: A1, slicing part model; A2, generating AM STEP-NC program; A3, simulation of AM toolpaths; A4, fabrication; and A5, remote monitoring. In A1, licensed AM CAM system (Netfabb) is used to slice the part 3D model either into an .xml or .cli file containing layer geometry data (thickness and contours), and (optionally) hatches data (toolpaths). This AM layer file (.xml or .cli) represents a data input for activity A2. This activity involves generation of the AM STEP-NC program by using an adapter software written in C# that reads the AM layer data and make a STEP-NC program file in Part-21 or Part-28 according to the ISO 10303-AP238. C# adapter uses the STEP-NC Machine stepnc.dll to create the STEP-NC data.

Then, the STEP-NC program containing toolpaths for AM is simulated in the STEP-NC Machine software (activity A3). Besides simulation integrating the kinematic model of different machines tool, the STEP-NC Machine software offers the possibility to append the generated NC program with workpiece geometry data and tool shape data. After verifying the toolpaths through simulation, the NC program is exported in G-code format of specific machine (Fanuc, Siemens) by employing post-processors in STEP-NC Machine. The CNC controllers of the AM machines understand the G-code program. However, this constitutes an indirect method of STEP-NC implementation where there is a loss of some information due to the post-processing. The G-code program is input to activity A4. In this activity, the part fabrication is carried out by using an AM machine based on fused filament deposition technology, equipped with an open architecture controller. Toolpath information contained in the G-code format file is interpreted by the controller to generate movements on the powered axes of the AM machine. The information about the amount of material to be deposited is computed by the firmware embedded in the controller. Outputs of activity A4 comprise the manufactured part and the machine operating data for remote monitoring.

Finally, activity A5 involves the real-time remote machine monitoring over the internet based on MTConnect protocol. A C++ MTConnect Adapter is responsible for recovering device raw data from AM machine and delivering it to the MTconnect Agent through an ethernet network via TCP/IP. Then, the Agent receives the data from the Adapter, accommodates them in an XML data streaming, and sends them as a response to a request originated from the web

application. In this way, the behavior of the AM machine during the manufacturing process of a part is remotely monitored in real time through the web application.

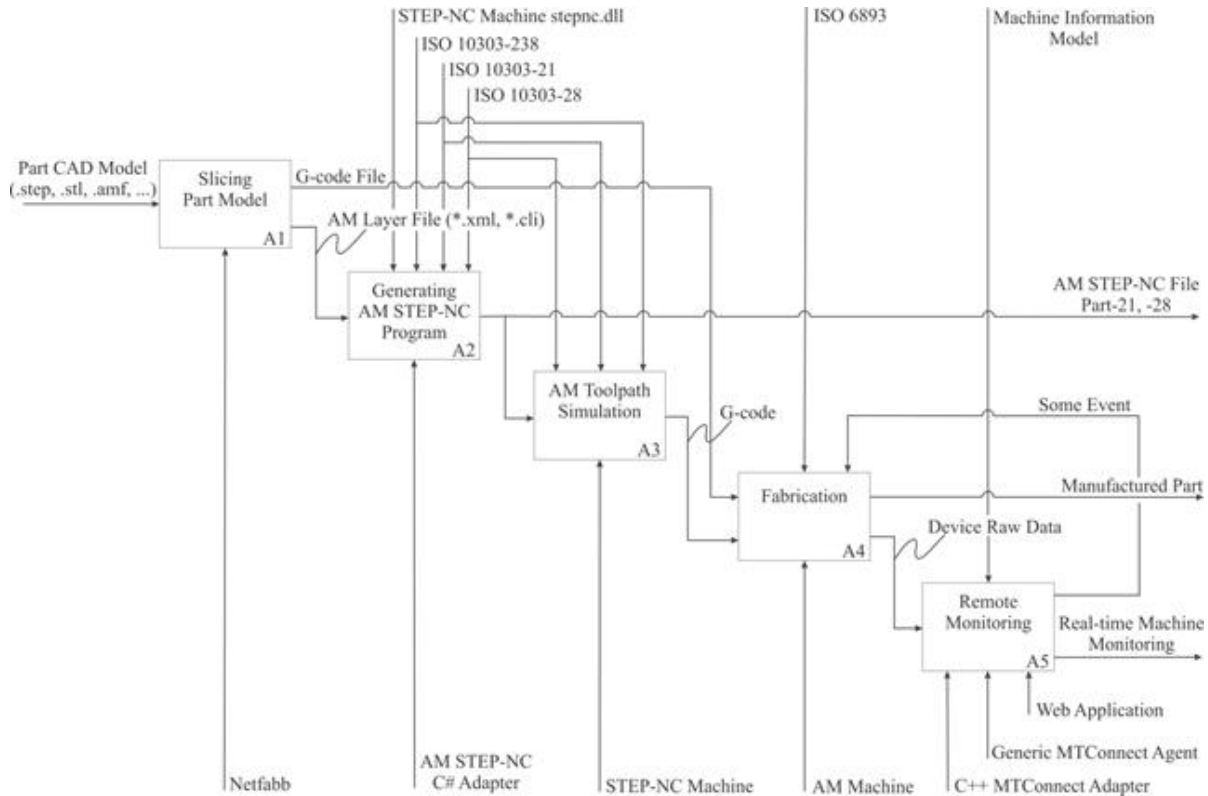


Figure 2. Application activities model of the proposed approach.

3.2 Implementing STEP-NC for AM

This section describes the proposed method for implementing STEP-NC for AM through a case study with a test-part to be manufactured. Firstly, slicing test-part is done in Netfabb software according to specified parameters such as where layer thickness, perimeters and infill pattern are defined. Then, the geometry data of each one layer is exported from Netfabb in an AM layer file in .xml or .cli (CLI-Common Layer Interface) format. In this AM layer file, the geometry of one layer is represented by its thickness, a set of contours (internal and external) and hatches. In turn, contours and hatches are defined polylines, which are made of a set of vertex points (x,y), connected contiguously in the listed order by straight line segments.

As the AM processes are based on deposition of material volumes (usually layers), each AM layer can be considered as the feature to be manufactured; that is, the additive feature. By using AM STEP-NC adapter developed in C#, additive feature information contained in the AM layer file is parsed to generate the NC program in AP238. Adapter uses classes and methods of the STEPNClib library of STEP-NC Machine. For instance, AptStepMaker is among the used class that contains functions in the form of APT (Automatically Programmed Tool) instructions, e.g., GOTO(...), FEEDRATE(...), RAPID(), etc. The source code of AM STEP-NC adapter is available in the URL: <https://github.com/StepNcLadprer/Additive-Manufacturing-STEP-NC.git>. A piece of the AM STEP-NC program generated for the test-part is shown on the right side of Figure 3. Simulation of the STEP-NC program was made in STEP-NC Machine. The group of all AM layers represents the Main Additive Workplan in the STEP-NC program. Each individual layer is mapped as an independent Additive Workplan. The perimeters (in the case of test-part there are three perimeters including those of internal and external contours) comprise the Additive Workingsteps. The hatches of the current layer also constitute Workingsteps. Simulation was enriched with the 3D model of the tool (print hotend) as shown on the lower right side of Figure 3. Finally, validation of this implementation approach was carried out by printing the test-part employing a 3D printer based on a linear Delta robot with open CNC controller.

3.3 Enabling AM with MTConnect

The development of the MTConnect framework for AM is composed of three phases illustrated in Figure 4. First phase involves the development of an MTConnect Adapter for additive machines of the RepRap type. That adapter is

comprised of a hardware piece and a software piece. Hardware piece is an ENC28J60 stand-alone Ethernet module compatible with Arduino controllers of RepRap machines. This module enables a communication channel based on TCP/IP, which is the most prevalent stream-based protocol for inter-process communication and is utilized by the MTConnect standard. On the other hand, software piece constitutes an adapter code component that has been included into the Sprinter firmware embedded in the Arduino controller to collect the raw machine data and send it via TCP/IP through the Ethernet module. Modified Sprinter firmware has been left in the URL: <https://github.com/StepNcLadprer/Sprinter-with-MTConnect-Adapter.git>. The adapter (hardware-software combo) allows extending the functionalities of RepRap machines to connect to the Internet.

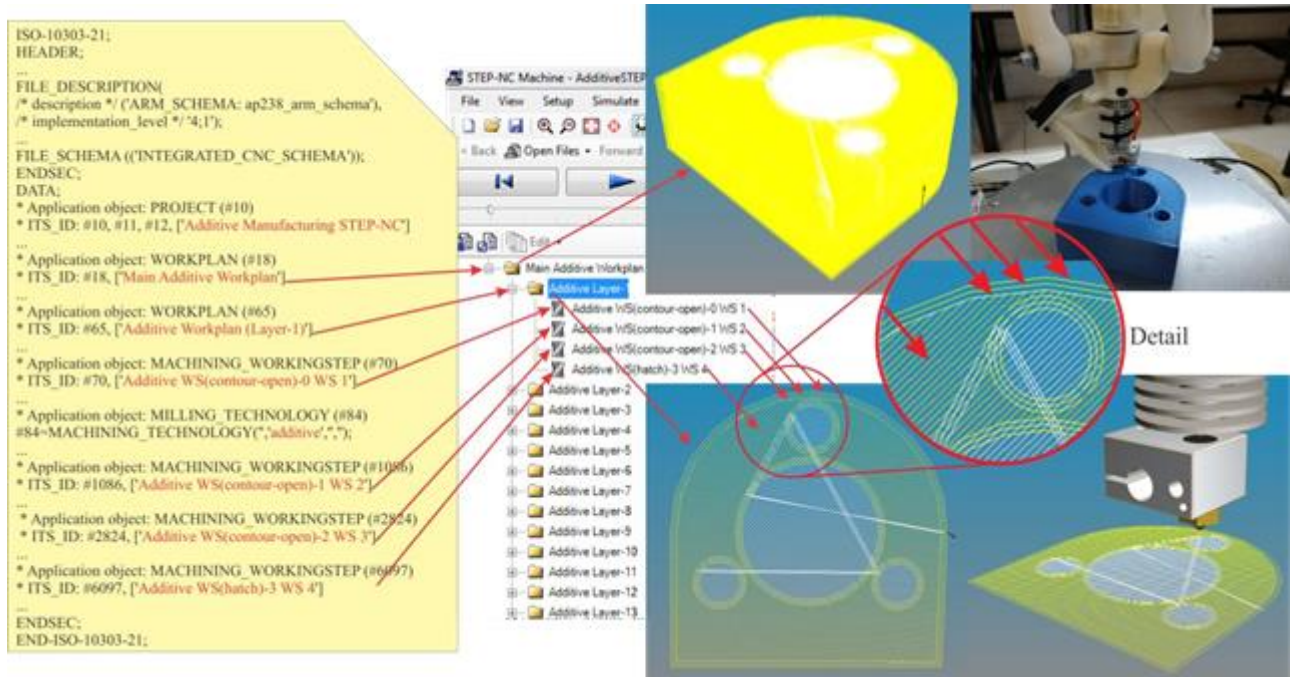


Figure 3. Simulation and validation of the additive STEP-NC program in the STEP-NC Machine software.

The second phase constitutes the building the machine information model using unified terminology provided by MTConnect, which is a fundamental step in the correct implementation of the standard. Figure 4 shows a simplified diagram of the hierarchy of the information model defined in this work to represent RepRap machines. That model contains structural elements and data items regarding to machine data of interest for monitoring such as X-Y-Z positions, material extrusion, heated temperature, extruder temperature, layer being printed, and build progress.

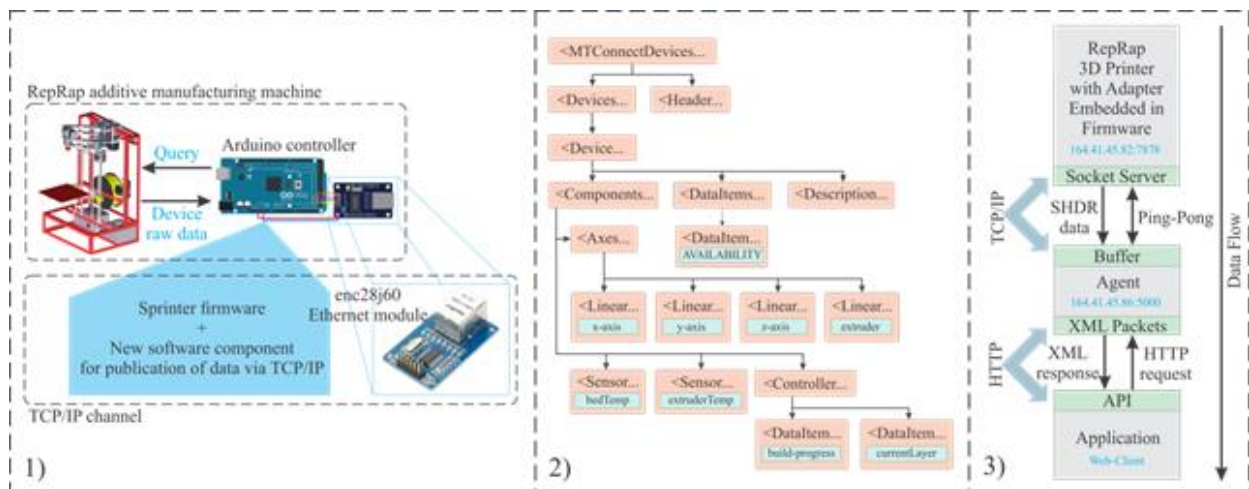


Figure 4. Phases of the development of the MTConnect framework for AM.

In the third phase, all MTConnect framework elements are properly linked to allow the flow of machine data to the web. The software component embedded in the machine's controller collects the data and sends it as text in SHDR

format directly to the Agent by socket server through the 7878 port. Then, the Agent stores the received data in buffer. Thus, when the web-client makes a request by the 5000 port, the Agent organizes a XML data stream following the information model defined before, and passes the data to the web-client depending on the type of request (“probe”, “current” or “sample”). This MTConnect framework is an affordable and efficient way to enable RepRap additive machines to post data over the Internet. To evaluate the system’s efficacy in the data access and real-time monitoring over the Internet was developed a web-client application programmed by using JavaScript language. A snapshot of the GUI (Graphical User Inter-face) of the web-client is presented in Figure 5 with monitoring data retrieved from the machine in operation.

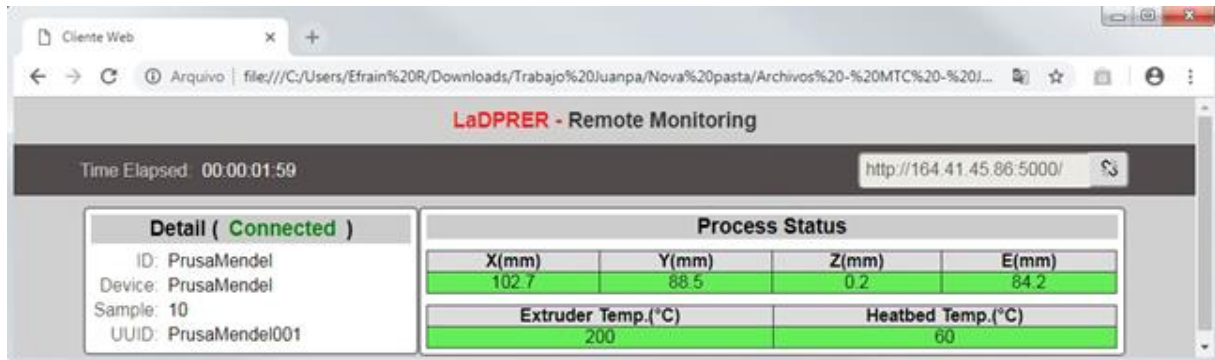


Figure 5. Machine monitoring through the developed web-client.

4. CONCLUSION AND FUTURE WORK

In this paper, we reported the development of an approach for implementing the STEP-NC and MTConnect standards for additive manufacturing. An additive STEP-NC program was created according to ISO 10303- AP238 standard, also simulated and validated through a study case. Model-based manufacturing technology of STEP-NC is promising to support a full vertical integration of CNC machines with the rest of the phases of the product life cycle. On the other hand, implementation of the MTConnect protocol for remote monitoring of additive machines over the Internet was presented. The developed MTConnect framework extends the functionalities of RepRap machines to connect to the Internet in cloud manufacturing environments. In future works, we intend to develop an extension of the data model of ISO 10303-238 to support more process information of additive manufacturing. Also, it is intended to enable the system with remote control operations over the Internet by employing OPC-UA technology.

5. ACKNOWLEDGEMENTS

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