Journal of Manufacturing Systems xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Part data integration in the Shop Floor Digital Twin: Mobile and cloud technologies to enable a manufacturing execution system

Pedro Daniel Urbina Coronado*, Roby Lynn, Wafa Louhichi, Mahmoud Parto, Ethan Wescoat, Thomas Kurfess

George E. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, 30332, USA

ARTICLE INFO

Article history:
Received 30 November 2017
Received in revised form 12 January 2018
Accepted 2 February 2018
Available online xxx

Keywords:
Manufacturing execution system
Android
MTConnect
CNC
Digital Twin
Cyber Physical Systems
Industry 4.0

ABSTRACT

The availability of data from a manufacturing operation can be used to enable an increase in capability, adaptability, and awareness of the process. In current cyber-physical systems, data are collected from pieces of manufacturing equipment and used to drive useful change and affect production output. The data gathered typically describe the operating state of the equipment, such as a machine tool, and can be provided using standard protocols. One such protocol, known as MTConnect, is becoming increasingly popular to collect data from machine tools. Other useful data can be collected from production personnel using a Manufacturing Execution System (MES) to monitor process output, consumable usage, and operator productivity. However, MTConnect data and MES data usually reside in separate systems that may be proprietary and expensive. This paper describes the development and implementation of a new MES, powered by Android devices and cloud computing tools, that combines MTConnect data with production data collected from operators; the proposed MES is particularly suitable for small manufacturing enterprises, as it is low-cost and easily implementable. A case study using the MES to track a production run of titanium parts is presented, and data from the MES are correlated with MTConnect data from a machine tool. This work is integral to realizing a complete digital model of the shop floor, known as the Shop Floor Digital Twin, that can be used for production control and optimization.

1. Introduction

Modern manufacturing operations face numerous challenges, including ever-increasing demand, mass customization [1,2], predictive manufacturing systems [3], and production responsiveness [4]. The answer for these challenges resides in the availability of data, which is possible thanks to increasing digitization of the shop floor. Increasing digitalization has a positive impact in productivity: a physical manufacturing system can be represented in near real time in the digital world using feedback from sensors in the system to modify the digital model. This digital model enables offline simulation and analysis that can, in turn, be used to control the manufacturing process. The digital model of the system is referred to as a Digital Twin; these Digital Twins comprise the next wave in digitization of the shop floor [5].

Monitoring of production data is essential to high-level control of a manufacturing process. This is typically accomplished using a manufacturing execution system (MES) that records material input, consumable usage, and product flow. A MES can provide a manufacturer with long term data trends on production efficiency by considering raw material consumption and number of parts produced. However, a commercial MES, which is typically accompanied by an additional enterprise resource planning (ERP) system, can present a large expense to a manufacturer; this is particularly problematic for small manufacturing enterprises (SMEs) [6], whose ability to afford such systems may be limited. Deployment of MES and ERP systems may also require installation of dedicated hardware. Additionally, some current MES and ERP systems do not address the information needs of individual employees and may not integrate data analytics [7].

This work presents one approach to tackle these areas of opportunity: a MES built on free and open-source tools is proposed; the MES makes use of an application that is installed on an Android-based mobile device. The MES leverages web services to provide cloud accessibility, data backup, and computing capabilities. Finally, the proposed MES also integrates with data produced by computer numerical control (CNC) machine tools using the MTConnect standard. This system serves as an integral piece of the

* Corresponding author.
E-mail address: urbinacoronado@itesm.mx (P.D. Urbina Coronado).

https://doi.org/10.1016/j.jmsy.2018.02.002
0278-6125/

Nomenclature

MES	Manufacturing execution system
ERP	Enterprise resource planning
SME	Small and medium enterprises
CPS	Cyber Physical Systems
HTTP	Hypertext transfer protocol
IoT	Internet of Things
LAMP	Linux Apache MySQL PHP
OEE	Overall equipment effectiveness
XML	Extensible Markup Language
PLM	Product lifecycle management
CC	Cloud computing
CM	Cloud manufacturing
REST	Representational State Transfer
WIP	Work in process
GUI	Graphical user interface
AMPF	Advanced Manufacturing Pilot Facility

Shop Floor Digital Twin framework, as it enables collection of both part and process information that can augment MTConnect data collected from a piece of manufacturing equipment. The developed MES was tested in a small volume research manufacturing facility to evaluate its performance in a production environment. The features provided by the MES create low cost, expandable, universally available, near real time, and user-focused solution that adds additional value to machine-produced data. The contribution of this work is a Cyber Physical System (CPS) that is simple enough to move SMEs towards adoption of Industry 4.0, yet powerful enough to extract valuable information from the sensors and devices already in the factory. The final goal of this research is to provide a flexible and low cost starting point towards more complete realization of the smart factory paradigm.

The remainder of this work is organized as follows: A brief review of the technologies enabling the smart factory is presented in Section 2; the vision for the Shop Floor Digital Twin implemented during this research is provided in Section 3; a case study of the application of the proposed MES is presented in Section 4; finally, discussion of the results, future direction of the research, and concluding remarks are provided in Sections 5 and 6, respectively.

2. Technologies enabling the smart factory

Several technologies contribute to what constitutes a smart factory. It is clear in the literature that CPS are at the heart of a smart factory [1,2,8,9], along with the Internet of Things (IoT) and the related tools that include cloud computing, web apps, mobile devices, sensors, and Digital Twins. This section aims to define and clarify the contribution of each into the proposed concept.

2.1. Cyber-physical systems

The technologies that enable the communications and interactions between machines, humans and other components of hardware and software are encompassed in the concept of CPS. The definition of CPS generally includes an integration or connection between physical and computational assets [8,10]. In literature, CPS have been investigated in topics ranging from cybersecurity [11] to its importance in building Industry 4.0 [10]. The architecture for building CPSs does not have a fixed design; rather, it can be viewed a composition of three levels (physical objects, models, and services [12]) to five levels (the 5C architecture [10]) or by layers (sensing, networking, service, and interface [13]). Fig. 1 presents the transforming agents [3,14] that take part in the CPS of

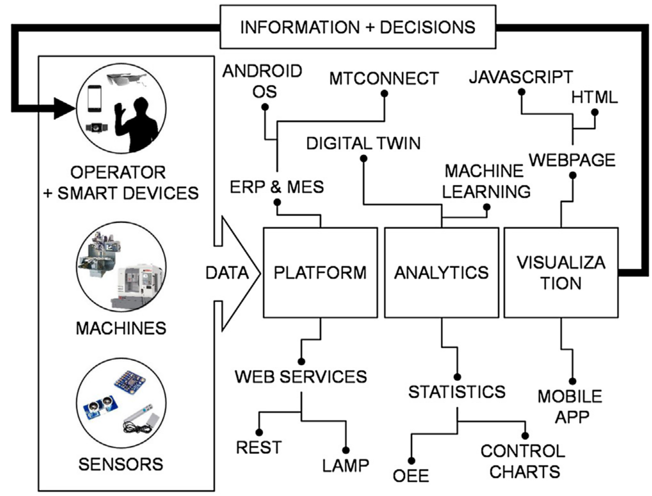

Fig. 1. CPS transforming agents and related technologies.

the proposed MES concept. The transforming elements are the platform, the analytics and the visualizations, which transform the data into information. The Fig. 1 indicates how the data produced by the operators, machines and other sensors is sent to the transforming agents, and the information produced and decisions from management are returned to the operators who control the machines. It is important to mention that some of the technologies shown in the figure are discussed in the rest of this section and some are part of the future work (e.g., machine learning).

2.2. MTConnect: a data transmission standard for manufacturing equipment

The MTConnect Standard is an open-source and royalty-free protocol that enables data transmission from manufacturing equipment; the standard is read-only, based on eXtensible Markup Language (XML), and allows communication from machine to machine and machine to operator. The two crucial elements in an MTConnect implementation are the adapter and the agent. The adapter functions as a data collection element that interfaces a physical sensor with a network connection; the agent is a data aggregator that collects readings from one or more adapters and stores them in a buffer. The agent also functions as a web server and provides an interface for applications to retrieve MTConnect data that is gathered from the adapter(s) [15]. The MTConnect standard itself defines the format and presentation of various data items that are relevant in a manufacturing process.

Fig. 2 shows the flow of data from a physical device to an external application. For this work, the devices are CNC machines, however, the concept is flexible to admit external sensors. Before the information arrives to the application, it goes through an extra layer of security provided by an IoT launch platform (Mazak Smartbox). The application, in this case a python script, performs the XML parsing and sends the data to the cloud. The data is stored in the remote server using a MySQL database [16]. MTConnect compatibility on a machine tool provides access to a wide range of variables including motor loads, axis positions, program name, and the emergency stop status. These data items can be used by a MES to determine the production state of a machine and to determine the overall productive efficiency of a process.

Please cite this article in press as: Urbina Coronado PD, et al. Part data integration in the Shop Floor Digital Twin: Mobile and cloud technologies to enable a manufacturing execution system. J Manuf Syst (2018), https://doi.org/10.1016/j.jmsy.2018.02.002