Part Data Integration in the Shop Floor Digital Twin: Mobile and Cloud Technologies to Enable a Manufacturing Execution System

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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.

Keywords
Manufacturing Execution System, Android, MTConnect, CNC, Digital Twin, Cyber Physical Systems, Industry 4.0

Nomenclature

MES	Manufacturing Execution System	XML	Extensible Markup Language
ERP	Enterprise Resource Planning	PLM	Product Lifecycle Management
SME	Small and Medium Enterprises	CC	Cloud Computing
CPS	Cyber Physical Systems	CM	Cloud Manufacturing
HTTP	Hypertext Transfer Protocol	REST	Representational State Transfer
IoT	Internet of Things	WIP	Work in Process
LAMP	Linux Apache MySQL PHP	GUI	Graphical User Interface
OEE	Overall Equipment Effectiveness	AMPF	Advanced Manufacturing Pilot Facility

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 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 include 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]). Figure 1 presents the transforming agents [3,14] that take part in the CPS of the proposed MES concept. The transforming

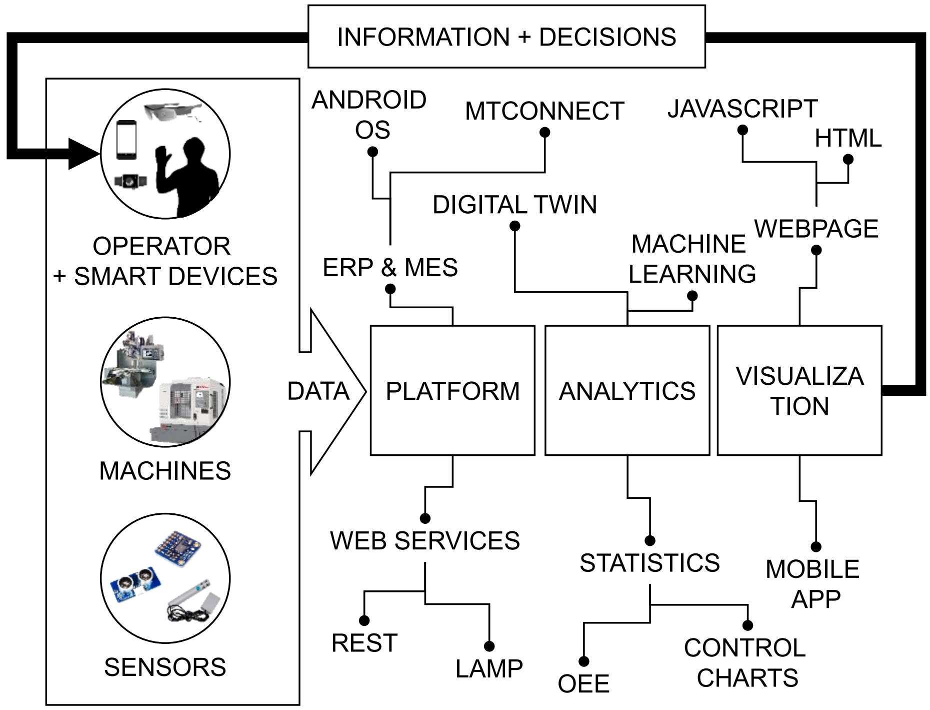


Figure 1. CPS transforming agents and related technologies

elements are the platform, the analytics and the visualizations, which transform the data into information. The Figure 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.

Figure 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.

2.3 Enterprise Resource Planning and Manufacturing Execution Systems

While the MTConnect capability of a machine can provide a wealth of valuable process information, some data are either not collected by the machine or not supported by the MTConnect standard [17]. MTConnect

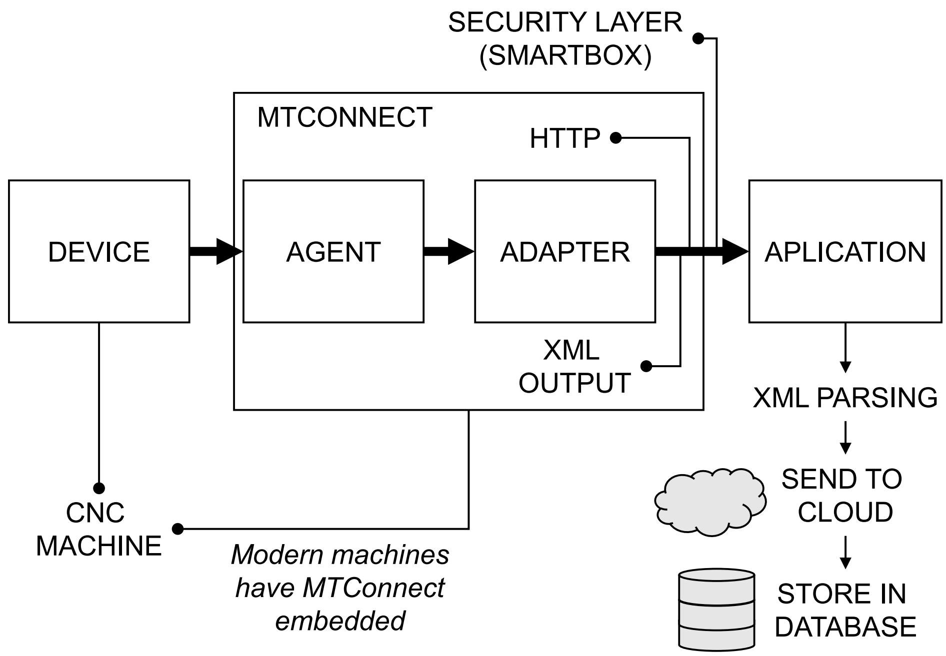


Figure 2. MTConnect signal flow from device to application

is being widely adopted in industry, but still contains areas of opportunity that are traditionally in the realm of product lifecycle management (PLM), ERP, and MES. For example, MTConnect data can be supplemented with part and tooling information by integrating them with data from a MES that tracks both tools used and parts produced by a machine. The combination of MES and MTConnect data can enable not only evaluation of machine efficiency, but can also provide a means to analyze the state of a part as it moves from raw material to final product.

A seamless integration among the levels of production hierarchy as defined by the standard ISA95 is necessary to formalize how MTConnect data is integrated into a CPS [18–20]. In the ISA95 standard, the MTConnect information would fit in the lower levels, while the ERP and other high-level management tools would fit in the upper levels. The MES can be considered a link between these two realms. However, problems identified in current MESs include: manual data entry by operators, lack of near-real time capability, and problems with interoperability and data sharing between different elements of the MES [21]. Additionally, most of the current MESs are designed for large enterprises that produce large quantities of a small number of parts, instead of customizable short-run products that are produced by many SMEs [22]. Researchers have identified a number of characteristics of a MES that would ensure its compatibility with Industry 4.0, including decentralization, mobility, connectivity, and cloud integration [23].

2.4 Web Applications and Smart Devices

Two of the technologies in daily use in the Internet age are mobile devices and applications hosted on the web. A web application allows the user to interact with a CPS without needing to install anything on their device. The application is hosted in the cloud, and is therefore accessible from any location using only a web browser. The web app is responsible for both data visualization and data management. A mobile device (tablet or smartphone), which is in the family of smart devices that also includes wearables (glasses and smartwatches), is one of the most ubiquitous consumer electronics in existence. Mobile devices offer a host of functionality to users, including sensors, connectivity, customizable graphical user interfaces (GUIs), and the ability to both access web apps and install mobile applications. A mobile app in the smart factory can be used as an input tool to replace paper forms and obsolete wired electronics (e.g., barcode readers).

Both mobile devices and web applications are used heavily in the realization of the CPS proposed in this work. The MES concept is deployed as an Android app and enables the interaction between the user and the CPS from any location without a personal computer. A web app that is hosted on a cloud platform is used to display plots and tables of the information being generated with the MES app. The specific tools used for the implementation of the web app are shown in Figure 1. The MES makes use of the connectivity, sensors, and GUI of the mobile device, in addition to other features such as user identification and indoor location. Other opportunities include the use of wearables, which are being explored in literature with industrial success in augmented reality applications [24].

2.5 Cloud Computing and Cloud Manufacturing

The use of Cloud Computing (CC) resources in the context of manufacturing is known as Cloud Manufacturing (CM); CM enables facilities to offload computational tasks needed in a manufacturing process to a remote and independently-managed computing platform. Globalization, one of the present challenges facing manufacturers, has increased the need for cloud manufacturing [25]; the benefits of CM include reduced costs and increased scalability of a manufacturing process by leveraging resources available in the cloud [26]. Additionally, CM enables a manufacturer to provide access to part and production data to any Internet-connected device; availability of data to a device anywhere in the world is one the main advantages of the cloud concept, and the global availability of data has been beneficial to the manufacturing industry [27]. The use of web applications and commonly used web protocols, such as REpresentational State Transfer (REST) throughout a manufacturing facility enables simple interfacing with cloud resources.

2.6 The Digital Twin Concept

Collection and aggregation of large amounts of product and process data enables the construction of digital models of components necessary to the manufacturing process. These models, known as Digital Twins (represented by the Analytics block in Figure 1), are updated in near-real time and can be used to view, analyze, and control the state of a part or process. The capability to implement Digital Twins is one of the benefits of data collection: large amounts of data enable the construction of simulations of different scenarios, which can be useful to make predictions about behaviors or failures, according to the latest data obtained from the physical twin [5,28].

The MES presented in this work is an enabler of a Shop Floor Digital Twin that represents parts, operators, capital equipment, and consumables. The Android-based MES, which is powered by mobile devices, web services, and cloud manufacturing, is an ideal platform for SME adoption of Industry 4.0; the MES captures part and tooling information using a mobile device and subsequently combines that information with MTConnect data provided by a machine tool using a cloud platform.

3 The Shop Floor Digital Twin and MES Data Collection

An overview of the CPS envisioned in this work is presented in Figure 3. The bottom part of the figure presents the components of the physical factory: these components include both machinery and discrete sensing devices which transmit data to the cloud platform using MTConnect; and tooling, products, materials, and people, whose information is supplied directly to the cloud platform using the MES. Components related to the cloud are shown in the upper-right side of the Figure: these components include the information stored in the database, the web services used for management of that information, and the new information that is generated by both the MES and the MTConnect-compatible machines and devices. Each of these pieces is an integral part of the Shop Floor Digital Twin. Ultimately, the information provided by the Digital Twin can be made available for managers, providers, or clients, who take actions to affect the factory. The Figure 3 also indicates with arrows the main components of the federated MES which is composed by the mobile app, the web services and the database in which the data is being stored.

Each entity in Figure 3 is an object in the CPS: tools, materials, machines, products, and operators. Each object is defined by attributes and by their relation to other objects. Figure 4(a) is a graphical representation of the data structure in the MES. According to this figure, a product is defined by its attributes; such

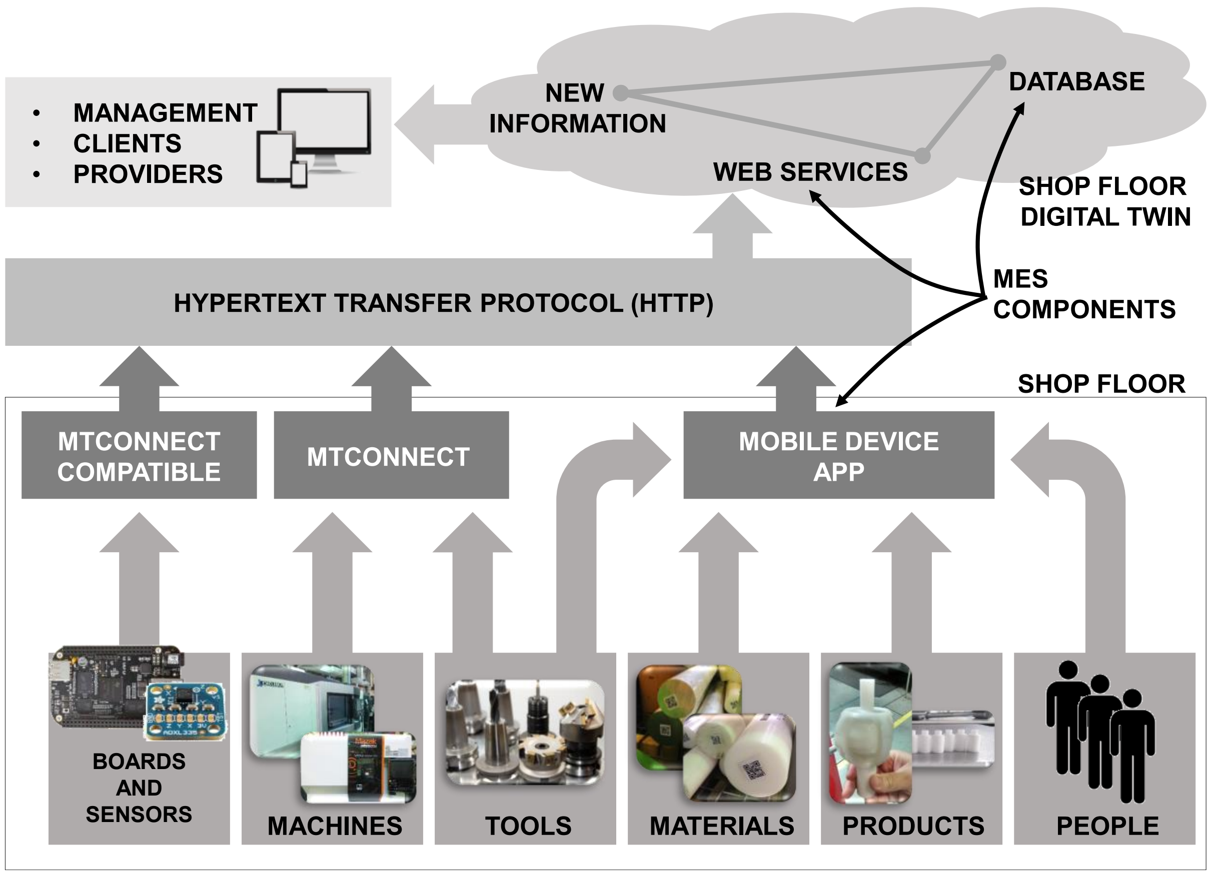


Figure 3. Overview of the shop floor Digital Twin

attributes include the operator that is responsible for the product, the material used to make the product, the machine in which the product is produced, the name of the product, and the picture of the product in the manufacturing stage (obtained using the mobile device), among several other definitions.

The MES was designed to identify the user in the main screen of the app, as shown at the bottom of Figure 4(b). The left side of the Figure 4(b) shows the menu of assets that can be created or modified by the operator. The camera of the smart device on which the app is installed can be used to scan barcodes of both materials and tooling, as shown in Figure 4(c). If information related to that barcode is found in the system, the operator does not have to specify another attribute related to the tool unless it must be modified (for example changing the tool number in the machine). If the barcode is not recognized in the system, the user can input information about the tool, such as its material, size, type, coating, etc. The same barcode procedure can be followed to register stock materials in the inventory. Although the current version of MTConnect does enable integration of cutting tools as assets [15], the MES is able to provide historical data collected from the operator on tool breakage and consumption that would be difficult to obtain from raw MTConnect data; this functionality is particularly useful for SMEs that specialize in small production runs, where cutting feeds and speeds are not necessarily optimized for tool life.

The data obtained using the MES app is sent to the cloud and stored in a database, where it is merged with MTConnect data collected from the networked machine tools. When a new product is initialized using the MES, the app sends the information of the new product to the remote script using REST; the remote script queries the row ID of the MTConnect information database developed [16] and associates it with the information of the product just started. When the operator ends the product using the MES app, the remote server queries the row ID of the MTConnect information database and stores it as the final MTConnect data point of the product. Using the row IDs of the product at the start and end stages, all MTConnect information related to that product can be recovered from the MTConnect database.

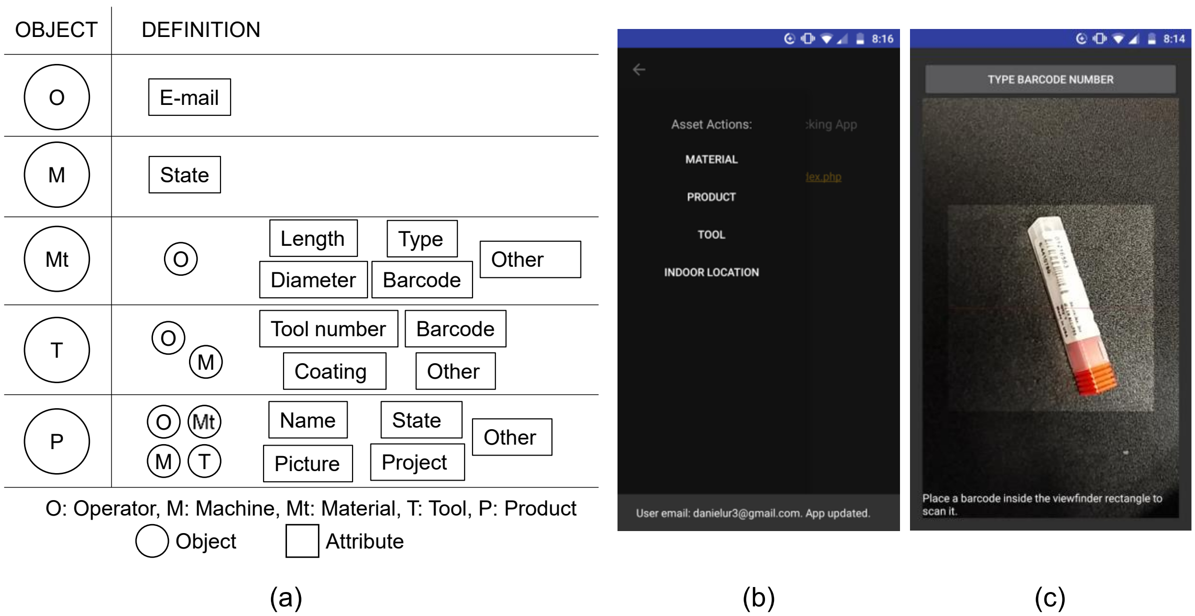


Figure 4. Data structure of the MES (a), the Asset Menu of the App (b), and the Barcode Scanner (c)

4 Case Study: MES and MTConnect Integration in a Manufacturing Facility

A case study was performed using the Android-based MES, in which part and tooling data were tracked with the MES while MTConnect data were collected from a group of machines making a variety of parts. The case study was performed over several months in the Advanced Manufacturing Pilot Facility (AMPF) at the Georgia Institute of Technology, which is a manufacturing research center with multiple CNC machine tools. The MES was used to log all material and cutting tool usage throughout the facility, which processed a wide variety of parts from different materials. A group of seven operators in the AMPF were asked to install the MES application on their personal Android devices and use it to register materials, tools, and products. Materials and cutting tools were ordered by shop management staff and provided to the operators upon receipt from the suppliers. The following Android devices were used: Samsung Galaxy S7, Asus Nexus 7, Moto G5 Plus, Samsung Galaxy S4, HTC One M8, HTC Nexus 9 and LG V20.

4.1 Facility-Wide Raw Material Tracking

During case study, all stock material that was added to inventory at the AMPF was registered using the MES and stored in the cloud database. An image of the web application that was developed to view material inventory is shown in Figure 5; this Figure shows both a bar plot that gives the remaining lengths of each available piece of material, and a pie chart that provides the distribution of the types of materials (e.g., aluminium, steel, etc) available in the facility. The pie chart, shown in the top right of the figure, can be accessed with a button in the UI of the application. The bottom right detail shows the length of each available piece of stock. The web app also provides access to a table with more details on each piece of material, such as supplier and bar diameter. The visualization updates each 500 ms to reflect any changes in material availability or procurement.

4.2 Facility-Wide Cutting Tool Tracking

In addition to tracking of materials, the MES was used to track cutting tool usage on each part. During the case study, cutting tools for all machines in the AMPF were registered and tracked by the MES. A total of 201 different cutting tools, complete with details (tool material, nose radius, etc.), were uploaded to the cloud over the course of the case study. The web app provides access to tables and plots to visualize the current state of the tools in the manufacturing facility. Figure 6 shows an image of the web app with the

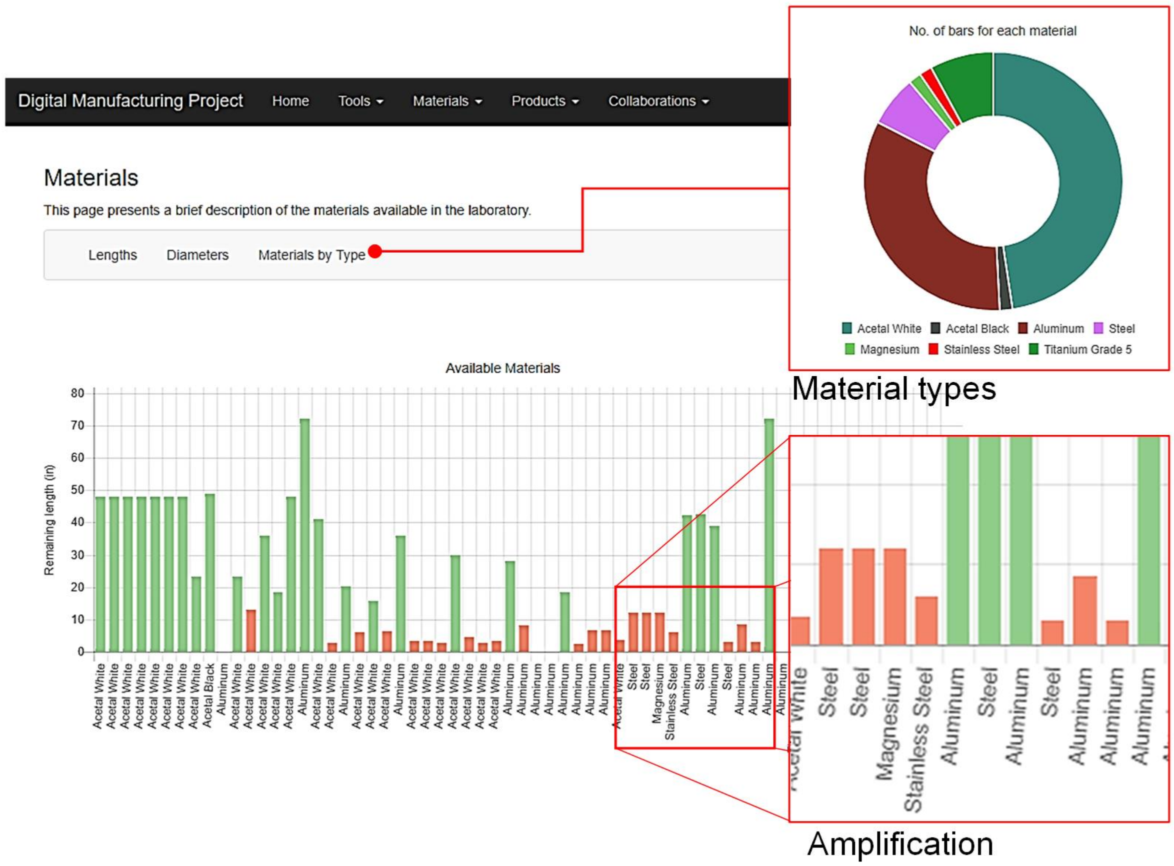


Figure 5. The UI of the web app showing the remaining lengths of the available materials.

table of the cutting tools. The table specifies the unique identification number assigned to each cutting tool upon receipt from the supplier, the machine in which the tool is installed, the tool number to which the tool is registered in the machine, and details on the geometry and material of the tool.

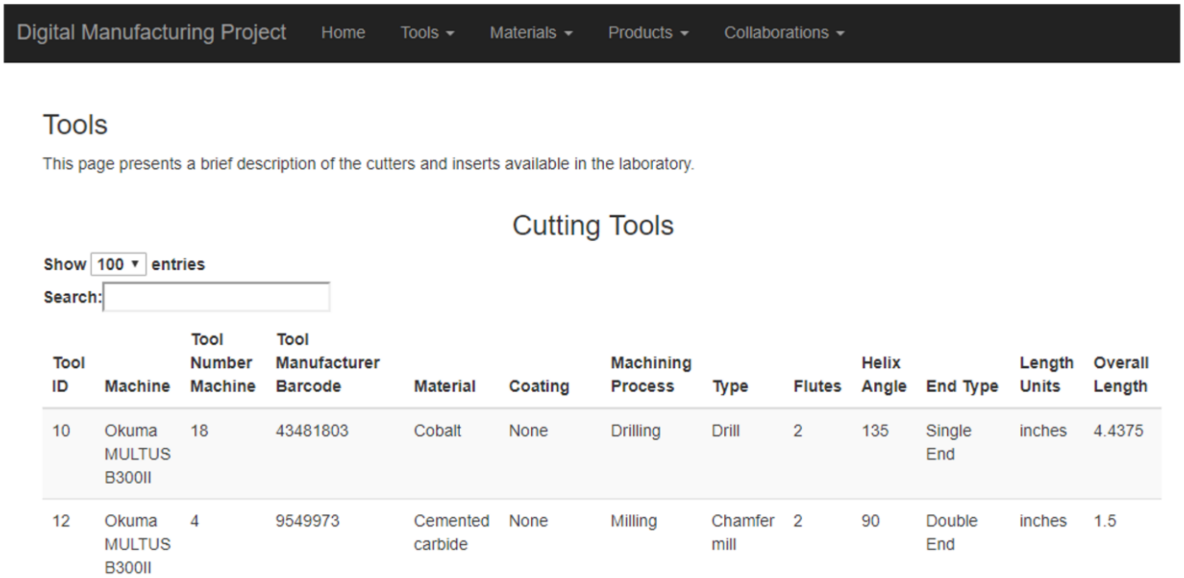
4.3 Facility-Wide Operator Activity Tracking

Once each operator had installed the MES on their personal device, they were asked to set up a unique identifier to enable monitoring of their productive efficiency using the MES. The MES app allowed shop management staff to determine which operators were responsible for registering which materials and completing which parts. Table 1 shows the initials of the operators and how many entries each operator registered in four different possible activities in the manufacturing facility over the course of the study. These activities include starting of a new product, in which a raw piece of stock is placed in a machine and a cutting process is started; continuation or completion of work in process (WIP) in a machine; logging a new material into the MES; and logging a new tool into the MES.

4.4 Product Tracking: Manufacture of a Titanium Yo-Yo

While the case study was underway, a series of titanium yo-yos were manufactured for use in an undergraduate educational exercise at Georgia Tech [29–31]. The yo-yo was manufactured using an Okuma Multus B300II 5-axis millturn machine installed in the AMPF. This section presents MES and MTConnect data that were collected during the manufacture of a single titanium yo-yo half, although a number of both aluminum and titanium yo-yos were created during the course of the study.

To begin the process, the QR code of a titanium bar was scanned using the MES and the bar was placed in the chuck of the millturn machine. The operator selected that the bar was to be used to make a yo-yo half, and the MES automatically assigned Product 18 to the part, flagged the bar as WIP in the Multus, and logged the ID of the operator that registered the part. Data gathered from the MES indicated that the product


Digital Manufacturing Project Home Tools Materials Products Collaborations

Tools

This page presents a brief description of the cutters and inserts available in the laboratory.

Cutting Tools

Show 100 entries

Search:

Tool ID	Machine	Tool Number Machine	Tool Manufacturer Barcode	Material	Coating	Machining Process	Type	Flutes	Helix Angle	End Type	Length Units	Overall Length
10	Okuma MULTUS B300II	18	43481803	Cobalt	None	Drilling	Drill	2	135	Single End	inches	4.4375
12	Okuma MULTUS B300II	4	9549973	Cemented carbide	None	Milling	Chamfer mill	2	90	Double End	inches	1.5

Figure 6. Table displayed in the web app with detailed information about the tools in the inventory of the machining facility

went through a start-pause session (corresponding to the first setup), and then a resume-end session (corresponding to the second setup); these two steps can be explained by the fact that the part requires machining using two distinct fixtures. The operator documented pictures using the MES at the end of the first and second setups in the process, and the pictures were automatically uploaded and associated with Product 18. The pictures uploaded to the system are shown in Figure 7.

4.5 Cutting Tool Usage During Yo-Yo Manufacture

The cloud backend of the MES is responsible for registering the time at which a product goes through different stages of the manufacturing process. Each state change is logged with a timestamp for later analysis or correlation with other data sets. For the case of Product 18, the bar was registered in the machine tool (corresponding to the start of manufacture) at 3:44:26PM on 8/9/2017; the product was then paused (corresponding to removal from the first fixture) at 6:54:06 PM on 8/9/2017. Using these timestamps, the MTConnect data gathered from the machine can be associated with the product.

For the present case study, the distinct cutting tools used to manufacture the titanium yo-yo are as follows: two carbide turning inserts, one bull-nose endmill, one square-nose endmill, two cobalt drills, a carbide spotting drill, a carbide chamfer mill, a cobalt tap, and a cutoff tool. Figure 8 shows the tool changes necessary to machine all reachable features in the first setup in the manufacturing process for Product 18 according to MTConnect data provided by the machine. The Figure shows the tool numbers, as registered

Table 1. Activity of the operators registered by the app

Operator	Start a New Product	Pause, Resume or End a Product	Register a New Material	Register a New Tool
AG	5	15	4	21
AL	3	0	15	0
CG	1	0	5	0
JR	0	1	1	0
PU	0	0	36	123
RL	12	10	2	7
UC	0	0	0	47
Other	3	3	0	2

a. Product 18 after machining in first fixture

b. Product 18 after machining in second fixture

Figure 7. Pictures of Product 18 documented by the operator using the MES mobile app

to the machine itself, and the moments in which the tools were changed. The dashed lines on the left and right indicate the starting and pausing of Product 18. The tool numbers reported in the Figure represent the number of the tool within the machine's magazine; these numbers do not necessarily correspond to the unique identification number of the tool itself. By referencing the MES database for the tools installed in each machine, the machine's tool number can be converted to the unique ID of the tool that was assigned when it was registered in the MES. The information obtained in the app allows to know which tools of the inventory were used, since the app registered the machine and the corresponding tool number. In this case, the information of the provider, the type of tool (or insert), coating, and geometry are known for 7 out of the 9 tools used, since two were installed in the machine before the MES was implemented.

4.6 Machine Position and Power Consumption During Yo-Yo Manufacture

Additional MTConnect data were correlated with the timestamps provided by the MES to evaluate spindle power consumption and axis position during the yo-yo production process. Figure 9 presents process data obtained from MTConnect related to Product 18. Figure 9a shows the positions of axes X, Y, and Z; Figure 9b shows the spindle speed; Figure 9c shows the spindle load; and Figure 9d shows the feedrate during the machining process. The dashed lines represent the start and end of the first part of Product 18. Some useful information can be garnered from these plots; for example, tool changes occur when the X axis moves to its home position (of 1120mm); additionally, the relatively light cutting parameters used for this process present a negligible load to the spindle. Finally, the period between 5:13:55PM and 6:11:13PM shows that the spindle is at zero speed, which suggests that the operator paused the machine in the middle of the process.

5 Discussion and Future Work

The results presented suggest that the use of the MES app have a positive impact on data collection in a production environment. In general, the results are a demonstration that a low-cost solution, which in this case is an Android mobile device and an accompanying app, can enable the creation of a Digital Twin with information on process output, operator productivity, and tooling usage. While the input process is not fully automated, it is a step in the direction of reducing operator input error; additionally, the MES provides both practicality by leveraging the camera, barcode reader, touch screen, and connectivity capabilities of a mobile device.

The simplicity of the MES also enables tracking and documentation of aspects of the products as they are being made. Photographs of products throughout stages of their production lifecycle, such as when they

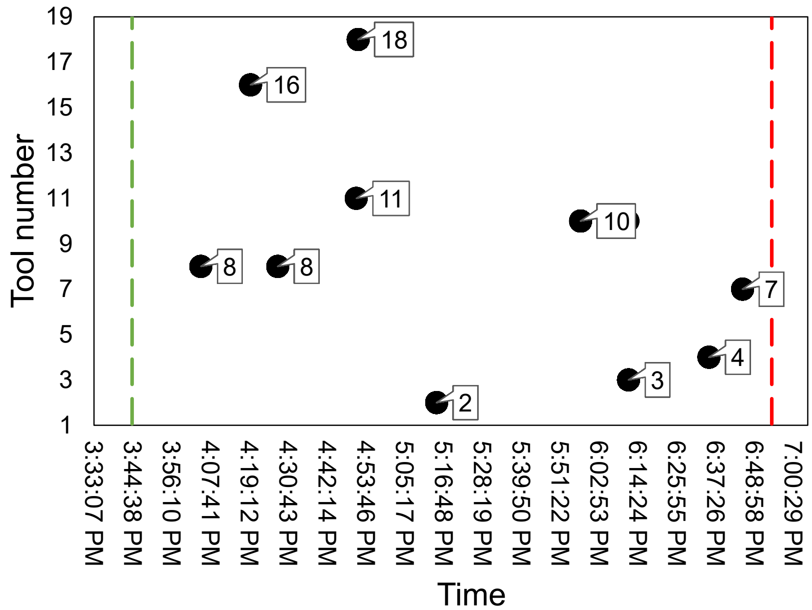


Figure 8. Tools used in the first fixture setup for Product 18

are transferred between fixtures, can be useful in quality control, vision system training using machine-learning techniques, metrology, or feature and defect detection. Although aspects of cloud storage space for a large number of photographs are out of the scope of this work, the web services used for this system allow for expandability in computing and storage capabilities; however, a high volume of pictures or data can become an issue in large-scale production environments.

The data collected by MTConnect can be linked with the data obtained by the mobile app to enable relation of important aspects of the operation to products, materials, tools, operators, and other physical assets. Not all these aspects are typically available to be obtained automatically by MTConnect or other technology. The combination of this information in the CPS unlocks future opportunities for analytics, the extraction of advanced information, and the construction of predictive models. With sufficient volume of data, the predictive models can be used to estimate process performance characteristics, such as tool wear, by relating process parameters with the material of the tool and the material of the part being machined. Additionally, the app also unlocks the possibility of operator performance tracking. As shown in Table 1, the app will register the activities of the operators and can be used as a tool to build a scoring system. Future work could include operator productivity measurement using the MES.

Future work includes the research into the creation of smart products by the increasing digitization of their lifecycle. The integration of design and analysis technologies (like CAD, CAM and CAE) with MES and ERP systems should provide major control in the role of products in the Industry 4.0. This seamless integration can be possible by using the cloud and web services, as well as decentralized computing.

6 Conclusions

This work described the development and implementation of a low-cost, MES that uses smart devices and cloud computing technologies to provide a connection with MTConnect data in a production environment.

A brief analysis of the technologies that comprises a smart factory was provided. A CPS was proposed that includes flexible, low cost, and highly available tools like mobile devices and web services. The concept of the Shop Floor Digital Twin produced by capturing data of the MES and the MTConnect enabled machines was presented.

An Android OS application was developed to interact with a machine operator and collect data on part production, material inventory, and tooling supply. The app connected with a cloud database that stored

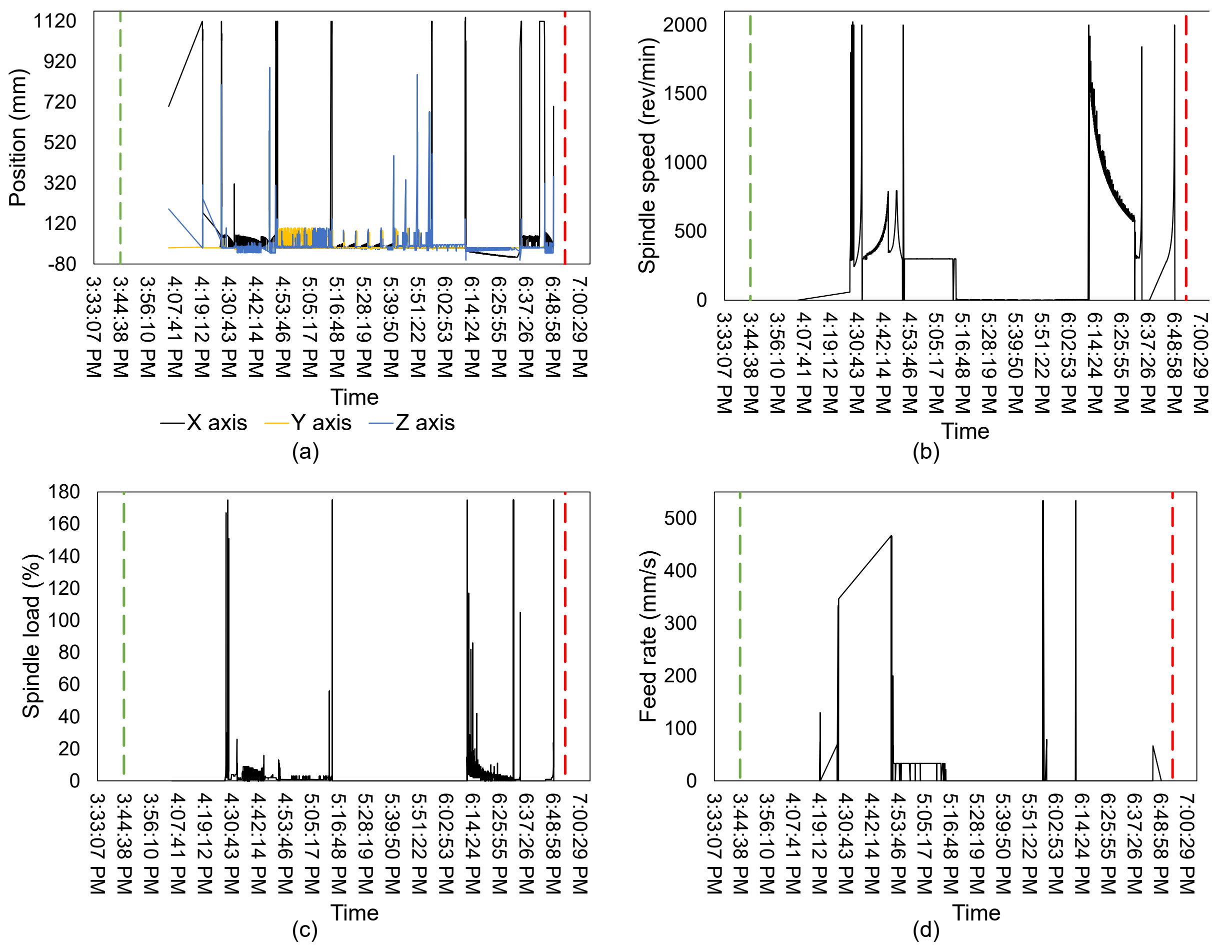


Figure 9. MTConnect data correlated with MES data for Product 18 using timestamps

historical data and was used to provide visualizations of shop floor status using a web application. The information was available for any device connected to the internet and was updated in near real time with new information.

As mentioned before, the app, cloud database, and web application formed a MES that was capable of integration with an additional database of MTConnect data from networked machine tools. A case study on the manufacture of titanium yo-yos was presented to validate the MES, and data collected both from MTConnect and the MES was presented. The next conclusions can be extracted from the exercise:

1. The MES app resulted in a powerful tool to eliminate paper forms, typing errors (in the functions in which the barcode reader was available), and update the information wirelessly in the moment it was generated.
2. The information generated by the MES expanded the information that was collected using MTConnect. This allowed the correlation with direct input from the operators about assets not tracked by MTConnect (materials, products, operators, and some information about tools), which allowed documentation and analysis of the MTConnect data in reference with the specific product.
3. The sensors available in the mobile device enable the documentation of pictures in several moments during the manufacturing process of the product. Other mobile device's capabilities like Bluetooth connectivity has potential to provide indoor location.

This work presented a potential alternative for SME to evolve into the Industry 4.0 age.

Acknowledgments

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