Incorporating Social Sensors and CPS Nodes for Personalized Production under Social Manufacturing Environment

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Abstract

This work addresses the social sensors and the cyber-physical system (CPS) nodes, and incorporates them into the cyber-physical-social system (CPSS) platform to facilitate the personalized production under social manufacturing environment. Social sensors deal with the social data sensing in social interactions among customers, enterprises, and other stakeholders. CPS nodes deal with the industrial data gathering and distributed production self-control in enterprises. By incorporating social sensors and CPS nodes, CPSS platform bridges the gap between different stakeholders when facing the collaborative and personalized production. Customer requirements can be easily sensed by social sensors and further extracted via social big data analysis. The production state of orders can be achieved in real-time via CPS nodes and industrial big data fusing for both enterprises and customers. CPSS platform is firstly proposed to interconnect the cyber space, physical space, and social space among different stakeholders in personalized production to achieve flexibility, efficiency, and a win-win situation.

Keywords: Social sensors; CPS/CPSS; personalized production; social manufacturing

1. Introduction

Today’s manufacturing is facing the diversification and variability of customer requirements. Customers interact and collaborate with enterprises in the whole product lifecycle to get sense of participation and value embodiment. Thus, mass personalization becomes the solution [1], in which mass interaction and collaboration between customers and enterprises create a vision of social manufacturing where personalized products and services are provided by socialized producers or service providers such as SMEs, smart factories, and even individuals [2-5]. To this end, the cyber-physical-social interconnection among them becomes vital.

As we move into the world incorporating social networks and Internet of Things (IoT), the living and production have changed much. On one hand, as a kind of social sensors, smart terminals/mobile devices (e.g. smartphones, tablets, wearable terminals, etc) facilitate people’s daily activities and offer a fast way to communicate with others via online social networks. With the aid of mobile devices, objective data (e.g. positions, relations, etc) and subjective data (e.g. needs, feelings, intentions, and other human behaviors), can be achieved to analyze some social phenomena [6]. However, mobile devices should not only act as a vehicle to deliver information and communication applications in living, but also as a tool to activate the sophisticated multi-role interactions and collaborations in production. Based on the mobile devices and social networks, the cyber-social interconnection of different stakeholders in production is built.

On the other hand, cyber-physical system (CPS) in industry 4.0 has been leveraging the interconnectivity and management of physical assets (e.g. machines, tools, auxiliaries, etc) and information systems in smart factories [7,8]. CPS nodes, which represent the integration of equipment, physical sensors, actuators, and embedded systems, are the enhanced components of IoT in production. CPS nodes have self-aware and self-control capabilities and CPS nodes-driven production is self-organized, self-coordinated, and rapid-responsive with the application of cyber technologies in the physical space [9]. Smart workpieces are manufactured by various intelligent
equipment with seamless interoperations and plug-and-play configurations. By clouding the CPS nodes of different enterprises under certain authority and privacy, the cyber-physical interconnection and the production information sharing of different stakeholders is built.

In all, with the bridge of cyber technologies, the cyber-social and cyber-physical interconnections of different stakeholders in personalized production are merged into cyber-physical-social interconnection. Thus, cyber-physical-social system (CPSS) platform should be provided to enable it. CPSS is an extension of CPS that integrates the social space for social interactions among different stakeholders, which is essential to inter-enterprise service sharing. CPS/CPSS, IoT, and Cloud Manufacturing all involve a certain level of resource virtualization and emphasize the combinational applications of cyber technologies in the physical domain [10]. CPS/CPSS give rise to the IoT or Industrial Internet and endow them with new characteristics such as self-configuration, self-control, and social interaction. As to the relationship between CPSS and Cloud Manufacturing, CPSS can be viewed as an implementation form of Cloud Manufacturing which applies cyber technologies in inter-enterprise collaborative manufacturing systems and provides manufacturing services with the premise of cyber-physical-social interconnection and Internet of Services (IoS).

To deal with the cyber-physical-social interconnection in personalized production, this paper addresses the CPSS platform incorporating social sensors and CPS nodes. Social sensors, which act as the integration of smart terminals/mobile devices and mobile Apps, are proposed to collect and preprocess the data from social interactions. CPS nodes are proposed to collect and preprocess the industrial data from enterprises. The gathered data are fused into meaningful information, based on which customized production processes can be readily monitored, controlled and managed, and decisions can be made proactively during the interactions between enterprises and customers. Thus, market trends and customer’s real needs can be handled effectively, and customer loyalty can be improved.

2. The customers

We define the customers as a dynamic pool of individuals, organizations, and even enterprises with varying requirements and concerns of certain products or services. Customers build two kinds of social relationships with enterprise, i.e. follower-followee and demander-provider. The former indicates that customers (followers) concern about the news and updates of enterprises (followees), and interact with them to give advices to their products. While the latter indicates that customers (demanders) build product orders or business relationships with enterprises (providers). In this situation, customers not only follow the news and updates, but also collaborate with enterprises on their own product orders, such as co-create personalized parts, monitor order states of progress and quality, and so on. Different kinds of social relationships bring about different kinds of social context.

Mobile Apps, such as Facebook, Twitter, LinkedIn, QQ/WeChat, and other social media, has changed the way enterprises stay in touch with their customers, especially in the personalized production. Customers whether specialist or non-specialist can interact with enterprises to express their feelings and opinions, or co-create personalized products in social media. Technologies like instant messaging and live-streaming facilitate their efficient collaborations and help them get access to the in-situ data of production processes. During their interactions, social context, in form of plain text, picture, audio, or video, are captured to excavate customers’ real needs, which is helpful to improve customer’s satisfaction and explore the market trends.

3. Social sensors

Considering there are no direct sensing technologies to collect customers’ subjective data, the indirect approaches should be explored. Social sensors are developed to collect the invaluable customer requirements, social context, and some physical sensor data. Social sensors are hardware-software-integrated and are configured with unique resource identifiers (URIs) in Internet. The hardware performance depends on the smart terminals/mobile devices, while the software performance is determined by the mobile Apps functions.

3.1. Components

Social sensors play an important role in human-to-human and human-to-machine interaction. Social sensors make customers closer to enterprises, and their personalized requirements can be easily delivered to enterprises via social sensors. In analogy to the traditional physical sensors, a social sensor has four components, i.e. sensing unit, preprocessing unit, transferring unit, and assistant unit, as shown in Fig. 1.

**Sensing unit*** proactively crawls subjective social context from mobile Apps (e.g. social media) and perceives objective data from physical sensors (e.g. GPS, camera, etc) embedded in the mobile devices. Here, social media is embedded in the social sensors through software application program interfaces (API) to share much more social data.

**Preprocessing unit*** performs data checking of errors and duplications, and further normalizes the data in a standard and easy-transfer format. Duplicated data and the duplicated times are logged, which shows the importance degree of data. Then the social data is formatted in JSON for easy transferring. Besides, it borrows a cache from the smart terminals/mobile devices to cope with the intermittent connectivity. Thus, social sensors can synchronize the data whenever connectivity is available. Actually, preprocessing unit acts as the middleware to handle the collected data.

**Transferring unit*** transfers the formatted social data to the cloud database for further processing under certain data interfaces and network protocols such as HTTP, TCP/IP, or SOCKET.

**Assistant unit*** provides the above three components with assistant services, e.g. power, screen, etc. It should be pointed out that the screen acts as the human-machine interface through which people can input their commands, feelings and other data, and display information from mobile Apps.
Based on the definition of social sensors, we can conclude that there are two ways to build social sensors: (1) design new specialized social sensors with the above function modules and components, and (2) transform the current devices into social sensors by adding new function modules and components. The first way is expensive while the second way is cost-effective and with high applicability, as the amount of mobile devices has been increasing exponentially in people’s life. Smart terminals/mobile devices with some certain installed Apps, which collect and handle the social data, can be viewed as social sensors. Under that, social sensors can facilitate the human-to-human interactions together with the human-to-machine interactions. Customers can interact with enterprises and other customers via social sensors to share ideas, feelings, advices, and other information. Besides, enterprises can monitor the state of machines, get real-time information from machines, and deliver commands to machines by using the mobile Apps installed in the smart terminals/mobile devices. Based on that, customers can further get access to their real-time order states under certain authority.

Note that a social sensor can collect various types of data. Nevertheless, considering the privacy and security, only a subset of data can be recorded, which depends on different levels of authorizations from customers. Before the mobile Apps in social sensors start working, they should apply for authorization from customers.

According to the relationship between the input and the output of social sensors, social sensors can be divided into eight kinds, as listed in Fig. 2. Each kind represents an application scene of social sensors. On the other hand, the social sensors are applied by customers, enterprise managers, and other stakeholders in personalized production. According to that, they can be classified into three kinds: (1) sense and handle the human-to-human interactions, (2) sense and handle the human-to-machine interactions, and (3) both of them. In some sense, social sensors bridge the gap between the physical space and the social space, with the aid of emerging cyber technologies.

3.2. Virtualization

Social sensors need to be virtualized and formalized as “virtual sensors” for connection, sharing, and management. Sensor Modeling Language (SensorML) is a standard XML encoding for sensors’ description and measurement processes, which can represent the metadata for any physical sensor [11]. We borrow the principles of SensorML to describe the metadata of social sensors, including the ID, name, location, etc. Descriptions of mobile Apps’ functions are encapsulated in the SensorML. Fig. 3 shows the description template of social sensors. Based on that, different social sensors from customers can be accessed by the enterprise.

4. CPS nodes

CPS is vital to realize dynamic production control and coordination. Lee et al. proposed a 5C architecture for implementing CPS from a systematic view [7]. However, personalized production has been driving the enterprise’s equipment to be separately accessible for customers, which means customers can know which machine tools are responsible for their product orders and how their current states are. Besides, they are able to select and organize the equipment from different enterprises, forming a virtual and collaborative group, to produce their personalized products. Thus, except for the CPS built at the systematic level, CPS nodes at the equipment level should be developed to collect
real-time data in field from each equipment in order to support collaborative production control. Of notable, each CPS node can be viewed as a small autonomous system, and the composite CPS at the systematic level can be viewed as the combination of a group of CPS nodes under the rules of interconnection and coordination. There are two ways for enterprises to develop CPS nodes: (1) transform the current equipment by adding physical sensors, actuators, network module, and other necessities on them; (2) apply newly born equipment that already has the CPS functions.

In this paper, we focus on the former way to generate CPS nodes. The components of CPS nodes and the virtualization of CPS nodes are described in the following section.

4.1. Components

CPS node is the basic production unit for personalized production and it consists of six main modules, i.e. equipment, sensors, actuators, human-machine interface (HMI), network, and functions & applications (see Fig. 4).

Equipment module is the base to build a CPS node. Different equipment has different manufacturing capability for part/component/product manufacturing.

Sensor module consists of different kinds of physical sensors, such as sensors for collecting ambient data (e.g. temperature, humidity, noise, live camera), sensors for collecting equipment’s running states (e.g. vibration, energy consumption, spindle speed, displacement deviation), and sensors for collecting WIP states (e.g. RFID reader, digital caliper, roughometer). All the sensors are seamlessly embedded in or bounded with the equipment.

Actuator module is responsible for the execution of commands and directives on the equipment. For example, PLC receives commands from the upper system and drives the motion of manipulators or machine tools. The embedded system integrates sensors, receives and preprocesses the sensor data, and further channels the data to the upper system.

Human machine interface (HMI) acts as an intermediate between the physical objects (i.e. equipment, sensors, and actuators) and the operators. HMI has a middleware to communicate with the physical objects via communication interfaces such as RS232, CAN, and RJ45. The middleware deals with the processing of raw data from sensors. Besides, it has a panel screen to visualize the real-time data that indicates the current state of CPS node, together with the commands from upper systems. Besides, operators can input parameters or commands to exchange information with the physical objects. In some sense, HMI acts as another kind of social sensor which senses data from the human-to-machine interaction but not from the human-to-human interaction.

Network module adapts different network protocols to make the equipment networked, such as WiFi, ZigBee, Bluetooth, and industrial Ethernet. Besides, the network module provides an application interface to realize plug-and-play configuration for interoperability between equipment from different vendors. Thus, different equipment can coordinate with each other to make decisions. The network module of each CPS node enables them cloudized and accessible to customers.

Function & Application module includes some functional applications of a CPS node. It connects the physical space with the cyber space. Through data capturing, processing, and storing, CPS nodes can realize real-time monitoring, dynamic configuration, self-decision-making, rule-based operation, prognostics and health management (PHM), etc.

4.2. Virtualization

CPS nodes should be virtualized and formalized for sharing. Customers can get access to CPS nodes of different enterprises. XML is applied to formally describe the CPS nodes because of its characteristics of easy-to-use and lightweight. The XML file of CPS nodes includes five main sections: equipment, sensors, actuators, network, and other information. The corresponding formalization of CPS node is described as:  

\[
\text{CPS} = \text{Equipment, Sensors, Actuators, Network, OtherInfo}
\]

Each section is defined by specifying an optional list of configurable properties. Fig. 5 shows the equipment section of the XML file.
5. CPSS platform

The cyber-physical-social system (CPSS) platform incorporates social sensors and CPS nodes. It aggregates customers, enterprises, and other stakeholders to collaborate for personalized production. Here, social sensors connect customers with enterprises and their CPS nodes. Note that CPSS platform should be public, App-based, service-oriented, and should provide API to integrate social media and other Apps. In the following, we will describe the architecture and operating logic of the CPSS platform.

5.1. Architecture

Fig. 6 describes the architecture of CPSS platform. It can be seen that the architecture can be simply divided into three layers, i.e. physical layer, cyber layer, and social layer, which correspond to the physical space, cyber space, and social space. Each layer has multiple function modules.

- **Physical layer**

This layer includes social sensors, CPS nodes, and other physical objects. All of them operate their functionalities via RESTful API which represents and provides the Web services offered by the CPSS platform. Based on that, these physical objects are accessible to the outside world.

- **Cyber layer**

This layer connects the physical layer and the social layer. It provides servers for platform operating. Besides, this layer also provides various network access to customers and enterprise for interconnection and interoperation, based on which social and industrial big data can be collected. Then it provides cloud database for data storage and cloud computing for data processing. From the view of data processing, the computing predominantly includes six steps: data sourcing, collection, cleansing, integration, and querying.

- **Social layer**

Social layer integrates various social media via 3rd party API, which facilitates the interaction between customers and enterprises. Customers and enterprises can publish their posts separately in this layer. Instant messaging and live-streaming technologies facilitate the anytime and anywhere interactions.

With regard to the relationships among the three layers, it can be seen that customers at the social layer use social sensors (smart devices) at the physical layer to interact with enterprise or themselves. Social data are gathered and preprocessed by the social sensors and further channeled to the cloud. Also, enterprise at the social layer manages its CPS nodes to realize dynamic production orchestration, monitoring, and control. Industrial data are gathered and preprocessed by CPS nodes and further channeled to the cloud. Furthermore, at the cyber layer, social and industrial data in the cloud are fused into invaluable information and knowledge for the customers and enterprise.

5.2. Operating logic

For personalized production under social manufacturing environment, enterprise with its customers, followers, and even suppliers make up a social community in the CPSS platform to interact with each other. In the following section, we take the collaborative product development and production as an example to describe the operating logic in the CPSS platform.

- **First stage: product development**

Enterprise publishes a post in the social community saying it will develop a new product with some certain functionalities in the post. This event triggers reactions and discussions in the online social media. Its followers interact with enterprise to discuss the product functionalities and describe their concerns or opinions at times and locations. Meantime, the interaction events trigger the mobile Apps installed in the social sensors to crawl social contexts periodically and preprocess them into formatted social data. The physical sensors embedded in the social sensors perceive objective data such as GPS location. The physical sensors embedded in the social sensors perceive objective data such as GPS location. The physical sensors embedded in the social sensors perceive objective data such as GPS location. The physical sensors embedded in the social sensors perceive objective data such as GPS location.

- **Second stage: product manufacturing**

In this stage, product orders from different customers are planned and manufactured in the enterprise. Collaborations between customers and enterprise make the production dynamically improved and real-timely controlled.

From the view of enterprise, it manages its CPS nodes via social sensors, and real-time industrial data from these CPS nodes are preprocessed by the enterprise and further channeled to the cloud. Furthermore, at the cyber layer, social and industrial data in the cloud are fused into invaluable information and knowledge for the enterprise.

Based on the virtualization of CPS nodes, enterprise can dynamically release its equipment, and coordinate them to execute different tasks. Besides, customers can receive manufacturing service recommendation and monitor the state of their product orders based on Web services and protocols.
nodes are transferred to enterprise managers to make optimal production decisions. Meantime, enterprise broadcasts product updates periodically in the CPSS platform to its followers, and delivers the real-time information of each order (e.g. progress, state, quality, etc) to its customers. During which, customers interact with enterprise to discuss the production details, and dynamic requirements extracted from the discussions are handled by the enterprise. Based on the vast amount of historical data (both social and industrial), enterprise can make in-time adjustment of its production plans, which will relieve the bullwhip effect.

From the view of customers, they can track and trace the manufacturing processes of their own product orders, such as what is the current progress and quality, which operator and which CPS node is responsible for the current process, and so on. Besides, they may require participating in the manufacturing processes via mobile Apps in the CPSS platform. For example, they may require step-by-step observance of a manufacturing process lively, or they may want to discuss the production process routing with the enterprise based on the sharing of CAD/CAM model and the live-streaming of in-site machine tool’s state [12].

During the above two stages and the following product usage stage, customers can decide which context can be broadcasted and shared online by their friends in the CPSS platform, such as order state, manufacturing process video, and use experience, and that promotes the spreading of personalized products. What’s more, enterprise can get feedback from the social context among customers, which plays an important role in finding the extensional market requirements to launch new products.

6. Discussions
For personalized production, the amount of social and industrial data collected is dramatically growing bigger and bigger as the human-to-human, human-to-machine, and machine-to-machine interaction data becomes more prevalent. Thus, big data analytics should be exploited to seek the underlying value of the historical data and the real-time data streams, identify patterns and relationships among discrete production processes and inputs, and react in time to the disturbances and unexpected events. Based on that, the personalized production processes can be managed, and various varying factors in production can be optimized. Further work should be devoted to exploring big data approaches to implement the social and industrial big data analysis in detail. Considering the volume, variety, velocity, and value (4V) features of the intertwined social and industrial big data, some new computing technologies need to be considered, such as batch computing, stream computing, granular computing, ubiquitous computing, fog computing, and quantum computing.

7. Conclusions
We address social sensors and CPS nodes in this paper, and incorporating them in the CPSS platform to realize personalized production. The concepts, components, and virtualization of social sensors and CPS nodes are described step-by-step. Furthermore, the architecture and operating logic of CPSS platform are discussed. By incorporating social sensors and CPS nodes, CPSS platform will provide a deep dive into the mass personalized production, which is expected to suit for the future market-of-one mode.

However, some issues and challenges may hinder it from rapid development, such as the privacy and security of human information, cultural barriers in social interactions, and so on. Future work should be devoted to them.

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