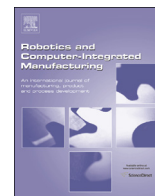




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The role of wearable devices in meeting the needs of cloud manufacturing: A case study

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ABSTRACT

Cloud manufacturing is a service-oriented, customer-centric and demand-driven process with well-established industrial automation. Even though, it does not necessarily mean the absence of human beings. Due to products and their corresponding manufacturing processes becoming increasingly complex, operators' daily working lives are also becoming more difficult. Enhanced human-machine interaction is one of the core areas for the success of the next generation of manufacturing. However, the current research only focuses on the automation and flexibility features of cloud manufacturing, the interaction between human and machine and the value co-creation among operators is missing. Therefore, a new method is needed for operators to support their work, with the objective of reducing the time and cost of machine control and maintenance. This paper describes a practical demonstration that uses the technologies of the Internet of things (IoT), wearable technologies, augmented reality, and cloud storage to support operators' activities and communication in discrete factories. This case study exhibits the capabilities and user experience of smart glasses in a cloud manufacturing environment, and shows that smart glasses help users stay productive and engaged.

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1. Introduction

After the epic changes of the world business caused by three industrial revolutions, we are in the midst of fourth industrial revolution, referred to Industry 4.0. It is a convergence of the physical world with the digital world, and it facilitates the vision of the smart factory [16] which enables centralized decision-making while requires distributed manufacturing equipment and resources [49]. The traditional manufacturing industry has been gradually superseded by a global chain of resources and various stakeholders. Therefore, a new dynamic and world-wide business model is needed.

Cloud manufacturing (CM) has emerged as a new solution to address all these challenges. It is a manufacturing version of cloud computing [32,49]. In this context, manufacturing resources and capabilities are virtualized and organized in a resource pool [24,32], therefore, all the partners in CM can perform real-time and collaborative manufacturing tasks [42].

The Internet of things (IoT) is a paradigm that takes advantage of sensor networks, also being known as "ubiquitous computing". The basic concept of IoT is the pervasive presence of objects, such as radio-frequency identification (RFID) tags, actuators,

mobile phones and sensors [9]. IoT and its relevant technologies rapidly gaining ground in CM with its position and status known in Industry 4.0 evolution. More "things", even people, need to be connected to the internet.

In this new stage of digital manufacturing, resources and services coordination and adoption in cloud infrastructure may only have to involve minimal human intervention [47,49]. Many e-services were developed to allow the control, operation, monitoring, and diagnosis become remotely [6,14]. However, CM covers the entire manufacturing lifecycle from pre-manufacturing (argumentation, design, production, and sale), manufacturing (product usage, management, and maintenance), and post-manufacturing (dismantling, scrap, and recycling) [24], some activities in the actual manufacturing processes require human involvement. Mostly, they comprise running and execution of sophisticated systems/machines, and also some after-sales services supporting the primary products (i.e. field services, maintenance, diagnosis, user assistance, and training, etc.) [8,32].

The interactions between humans and machines are emphasized in Cyber-physical systems (CPS) [33,48]. Mezgár [26] also pointed out the outstanding importance of collaboration and cooperation among users in networked enterprises. Human resource is considered as one type of manufacturing capability [49], and it includes employees, skills and knowledge required to complete a specific job. Unfortunately, the knowledge is rarely documented [44]. It always requires sophisticated training and advanced

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knowledge to participate and enable CM activities. Therefore, how to best support human activities becomes a central aspect of the modern working environment, and it opened up an enormous set of new research opportunities.

Even though, the integration of humans with software and hardware is one of the fundamental requirements to satisfy this new development in the industry [31]. In previous studies in CM area, human resources and management were rarely discussed. It is important to appreciate this consideration. Based on an analysis of previous studies, we noted some weaknesses of the current research in CM:

- Insufficient methods to support field services.
- Lack of collaboration among operators.
- Lack of communication between field services and the back office.
- Inefficiently knowledge management in the field.

The existence of wearable technology forms an integral part of the IoT. Based on Brauer and Barth's [5] study, they conclude that wearable technology can boost employees' productivity by 8.5% and life and job satisfaction by 3.5%. Although different kinds of wearable devices are available in the market, they are still in their infancy. In the manufacturing industry, wearable technology has the potential to be useful, but the question arises as to how we can use these devices in manufacturing and how these devices can improve manufacturing efficiency.

In this research paper, we investigate the application of wearable technology to visualize manufacturing information and to allow hands-free interactions in order to communicate with other users in CM networks. Due to almost no information concerning its successful application in industry [2], and also the lack of academic research on the strategic aspects of human resources management in CM, the case study method was chosen for this investigation. The company is a laser machine builder, and they sell machines to customer companies. They also provide a centralized helpdesk and remote assistance as well as training, etc. This paper will provide an example of the wearable technology, specifically refers to smart glasses, supporting CM.

Our proposed mechanism deals with the workers (i.e. maintenance technicians, machine operators and helpdesk units) in various locations, as the "things". All the workers can be connected in a virtual environment in the internet so that they can collaborate more effectively on troubleshooting issues. Smart glasses are adopted in this research to support the collaborative manufacturing training, maintenance and management of different participants and departments.

We found out that applying wearable technologies can increase the value of CM, avoid waste and increase sustainability, at the same time it can help to reduce risk and prevent human error on the shop floor. We will perform a pilot study to evaluate the use of wearable technologies (smart glasses) in improving the communication channel. This research outlines the following issues in a specific case company:

- Description of wearable devices and how they enhance workers' tasks in the factory.
- Definition of three distinct profiles of wearable devices users.
- Collecting data generated by wearable devices and the forming a human cloud.
- Processing a large dataset by using some form of cloud technology.

2. State-of-the-art review

2.1. Cloud manufacturing (CM)

Cloud computing and the IoT have moved from buzzwords to practical business principles recently. The idea of the "cloud" is progressively transforming the way that enterprises do business, especially IT-related businesses [35]. With the support of cloud computing and the IoT, CM has appeared as an innovative manufacturing paradigm. CM is a new, multidisciplinary domain that encompasses state-of-the-art technologies such as networked manufacturing, a manufacturing grid, virtual manufacturing and agile manufacturing [15,24,35,49]. It is a value creation manufacturing process across globally networked operations [35]. It involves global supply chain management, product service connection and the management of distributed manufacturing units [26].

Under the umbrella of CM, manufacturing resources and capabilities can be intelligently sensed and connected into the wider internet, and automatically managed and controlled using IoT technologies (e.g., RFID, wired and wireless sensor networks, and embedded systems) [37]. These resources and capabilities can be fully shared and circulated based on users' demands on a virtualization layer (Qanbari et al., 2014). Xu [49] uses two important concepts to describe CM: "integration of distributed resources" and "distribution of integrated resources". Providers publish their resources into this CM platform, and then the distributed resources are encapsulated into cloud services and managed in a centralized way. Consumers can use the cloud services according to their requirements. They can request services ranging from product design, manufacturing, testing, management and all other stages of the product lifecycle [49]. The problem is how the physical world and the internet world of ICT can connected without a gap.

Cyber-Physical Systems (CPS) was proposed a few years ago [34] to enable the interactions between computers and humans through many new formations by using today's computing and networking technologies [3,22]. Because the physical world is not entirely predictable, the CPS will not be operating in a controlled environment, and must be robust to unexpected conditions and adaptable to subsystem failures [22].

CM provides a cooperative work environment, not only for enterprises but also for individuals, enabling collaboration among the entire manufacturing ecosystem [53]. Although the concept of CM mirrors the definition of cloud computing, most of the resources in CM need to be operated manually by humans [13]. This manual operation is unlike the virtual resources in cloud computing. In addition to the performance of manufacturing equipment, human activities in providing field services also have a significant and direct impact on the quality of products. It is very difficult to maintain a high-performance operation because the system consists of a group of devices, such as robots, numerical control machines, sensors, and so on [29]. Similar findings are available in Ren et al.'s [35] research in which they classify cloud services into two types: OnCloud services, run entirely on a cloud platform, and OffCloud services, which need additional operation by an operator via a cloud platform. In order to improve the quality of manufacturing processes and products, the focus must move to improve the performance of people. As such, human activities and field services management must be considered as an important factor [7,13]. Ford et al. [10] suggest that enhanced human-machine interfaces and collaboration software are drivers of distributed manufacturing.

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