Computers and Electrical Engineering 000 (2017) 1–10

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

Cloud robotics in Smart Manufacturing Environments: Challenges and countermeasures☆

Hehua Yan[a], Qingsong Hua[b], Yingying Wang[a,*], Wenguo Wei[c], Muhammad Imran[d]

[a] Guangdong Mechanical & Electrical College, China
[b] School of Mechanical and Electrical Engineering, Qingdao University, China
[c] Guangdong Polytechnic Normal University, China
[d] College of Computer and Information Sciences, King Saud University, Saudi Arabia

ARTICLE INFO

Article history:
Received 24 October 2016
Revised 18 May 2017
Accepted 19 May 2017
Available online xxx

Keywords:
Cloud robotics
Smart manufacturing
Simultaneous localization and mapping
Cloud computing

ABSTRACT

In Smart Manufacturing Environments (SME), the use of cloud robotics is based on the integration of cloud computing and industrial robots, which provides a new technological approach to task execution and resource sharing compared to traditional industrial robots. However, research on cloud robotics in SME still faces some challenges. First, highly flexible load scheduling mechanisms are immature. Second, traditional optimization mechanisms for the network service quality do not meet the requirements of smart manufacturing due to time variability and service quality dynamics. And, finally, existing learning algorithms used without cloud-assisted resources cause great resource wasting. Accordingly, this paper explores main technologies related to cloud robotics in SME. The research contents include self-adaptive adjustment mechanisms for the service quality of a cloud robot network, computing load allocation mechanisms for cloud robotics, and group learning based on a cloud platform. The results presented in this paper are helpful to understand the internal mechanisms of perception and interaction, intelligent scheduling and control of cloud robot systems oriented to smart manufacturing, and the design of a cloud architecture oriented to group learning.

1. Introduction

Recently, Cyber-Physical Systems have received more attention and promoted the rapid development of smart manufacturing, intelligent transportation, smart grids, and other related areas [1,2]. Nowadays, robotic arms and Automatic Guided Vehicles (AGV) are widely used in various fields, such as automobile, electronics, and home appliance manufacturing, wherein they are applied for grinding, welding, loading and unloading, and material handling. In Smart Manufacturing Environments (SME), industrial robots have become indispensable executive devices due to their standardization and flexibility, which play an important role in the realization of intelligent manufacturing.

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. J. Wan.

* Corresponding author.
E-mail addresses: hehua_yan@126.com (H. Yan), qihu@qdu.edu.cn (Q. Hua), wyybaby@163.com (Y. Wang), 447402586@qq.com (W. Wei), dr.m.imran@ieee.org (M. Imran).

http://dx.doi.org/10.1016/j.compeleceng.2017.05.024
0045-7906/

However, due to hardware resource constraints, industrial robots face enormous computational and storage issues in some applications, such as map reconstruction, navigation, and positioning. During the execution of complex tasks, even using fully optimized algorithms, industrial robots still have the problem of insufficient computational resources [3].

- Limited calculation and storage resources
  Robot computational resources include on-board computers or embedded computing units, memory, and hard drives. In a multi-robot system, although a robot can assign computational tasks to other robots in the network, the resource limitations of a single robot largely influence the efficiency and capability of the whole robot system during the execution of complicated tasks.

- Constraints of information and learning capacity
  The information carried by a single robot is limited by its information processing capacity, storage space size, type and number of sensors. On the other hand, a multi-robot cooperative system provides global cooperation through coordinated information exchange, but its information processing is often limited by the number of robots in the network topology. In a static environment, a multi-robot system might achieve better performance as time elapses. However, if the working environment changes, even partially, the robots have to restart the learning process.

- Limits of communication capacity
  Common protocols of robot inter-communication, representing Machine-to-Machine (M2M) communication, include proactive routing and ad-hoc routing. Proactive routing is characterized by periodic packet switching, which often challenges the endurance of the robot. Ad-hoc routing provides a dynamic routing topology before data packets reach specified nodes, which might cause severe delays. Actually, in SME, the load balance of the network bandwidth is a huge challenge for robot communication in the inter-network multi-task robot system.

In recent years, due to the rapid development of big data [4,5], cloud computing [6], and wireless communication technologies [7], the combination of cloud computing and industrial robots opened a new way for robot task execution and resource sharing, which has become a new hotspot in robotics research. Cloud robotics is a field of research that attempts to invoke cloud technologies, such as cloud computing, cloud storage, and other Internet technologies centred on the benefits of converged infrastructure and shared services for robotics. The introduction of clouds has completely changed the original topology and interaction mechanisms, while the introduction of the interactions between robots and clouds has greatly improved the flexibility and extensibility of task scheduling. When a robot's computational resources or storage are not suitable for local execution, the robot can upload the task to the cloud through the provided interface in order to overcome the resource constraints. At the same time, due to the massive storage resources of the cloud, theoretically, the information learning capacity is no longer a limit. By interacting with the cloud, the robot nodes can download information, effectively overcoming the robot's information and learning limitations. The strong computational power of the cloud server can compensate for the limited computational power of the robot system.

However, the research on cloud robotics is still in its initial stage, so cloud robot applications face some technical and theoretical difficulties as follows.

- Due to different tasks' complexity and different application scenarios, there is no general scheduling mechanism for robot tasks execution. In addition, due to dynamic network features and differences in real-time requirements of tasks, the choice of a scheduling mechanism greatly affects the quality of task execution.
- In SME, robot groups with different tasks have large differences in their work environments, communication signal strengths, network robustness, signal-to-noise ratio, and other characteristics. Therefore, communication often has time-varying characteristics. For a collaborative work of robot groups, as well as for collaboration between robots and other intelligent devices and/or products, the dynamic optimization of the network service quality is important for successful task completion.
- A cloud platform is responsible for cloud data uploading and storing. In intelligent manufacturing, cloud components and communication mechanisms among components, the cloud and bottom communication interfaces, often vary depending on different work scenarios and task requirements. The establishment of a general and compatible cloud architecture is vital for cloud robot systems, and is a research hotspot and challenge.

In summary, the contributions of this paper include three aspects: 1) the current status of cloud robotics and typical applications are reviewed; 2) the problems and challenges of cloud robotics in SME are discussed; and 3) the countermeasures for improving cloud robotics in SME are provided.

The remainder of this paper is structured as follows. In Section 2, the research on cloud robotics and typical applications are reviewed. The problems and challenges of cloud robotics in SME are discussed in Section 3. In Section 4, counter measures to improve cloud robotics are provided. Finally, Section 5 presents the conclusions.