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Procedia CIRP 56 (2016) 354 – 359

www.elsevier.com/locate/procedia

9th International Conference on Digital Enterprise Technology - DET 2016 – "Intelligent Manufacturing in the Knowledge Economy Era

Using autonomous intelligence to build a smart shop floor

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Abstract

The vision of smart factory is based on the notion of Industry 4.0 that denotes technologies and concepts related to cyber-physical systems and the Internet of Things (IoT). In smart factories cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, cyber-physical systems communicate and cooperate with each other in real time. This paper presents a smart factory architecture based on communication and computing layers that embed scheduling mechanisms within a mechanical shop floor. Every physical entity in the shop floor is seen as an autonomous intelligent agent that performs tasks guided by dynamic scheduling functions. A test bed has been set up to show how physical entities can be cooperative and autonomous units that can automatize the shop floor operation processes. The results verify the feasibility and efficiency of proposed method.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production

Keywords: smart shop floor; agent; scheduling; cyber-physical systems; industry 4.0

1. Introduction

The vision of smart factory is based on the notion of Industry 4.0 that denotes technologies and concepts related to cyber-physical systems (CPS) and the Internet of Things (IoT). In smart factories CPSs monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, cyber-physical systems communicate and cooperate with each other and humans in real time.

In parallel, the advancement of IoT and CPS brings some challenges to manufacturing systems. Research on manufacturing systems is focused on production scheduling [1-3], production control [4, 5], production management [6], and other aspects of manufacturing industry. And manufacturing systems reveal increasing characteristics of discretization, intelligentization and autonomy. With complication of manufacturing systems, it becomes very difficult to realize these characteristics by traditional technologies. Therefore, how to realize these characteristics in manufacturing systems by using IoT and CPS is a crucial issue, which is the focus of this paper.

Currently, the research of IoT in manufacturing systems is mainly aimed at cloud manufacturing systems [7, 8]. This type of manufacturing model transforms traditional product oriented manufacturing to service oriented manufacturing. Research of CPS in manufacturing systems is primarily focused on the communication between physical entities [9]. It pays more attention to artificial intelligence, adaptivity, self-organization, self-regulation and other aspects of autonomic computing functions embedded in physical systems.

This paper presents a smart factory based on communication and computing layers that embed dynamic scheduling mechanisms within a mechanical shop floor. Every mechanical element in the shop floor is seen as an intelligent

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doi:10.1016/j.procir.2016.10.039

agent that performs tasks guided by dynamic scheduling functions. We embed computing power and optimization capabilities into each agent so that it can make decisions to agilely respond to frequent occurrence of unexpected disturbances at shop floor.

The remainder of the paper is organized as follows. Section 2 general describes the architecture of a smart shop floor. It defines three layers and uses information interaction between different levels to realize the dynamic scheduling and rescheduling of the smart shop floor. Section 3 presents communication protocols that act as cooperation and interaction rules through the architecture for automatically piloting the smart shop floor. Section 4 describes a pilot test bed for simulating the proposed smart shop floor. Section 5 concludes the paper.

2. Smart shop floor architecture

The idea beyond our smart shop floor is that CPSs monitor physical processes of shop floor, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, smart shop floor architecture (Figure 1) is built upon physical layer, communication layer and logical layer. The functions of different layers will be described in the following subsections.

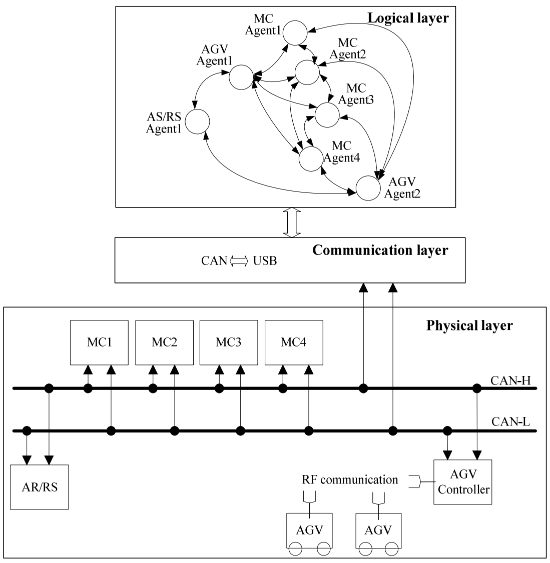

Fig. 1. Smart flow shop architecture.

2.1. Physical layer

Physical layer implements processing and transportation operations in shop floor, and it is composed of manufacturing cells (MCs), automated guided vehicles (AGVs), automated storage/retrieval system (AS/RS), radio frequency (RF) communication and controller area network (CAN) communication. The code developed at this layer is in charge of moving, controlling and monitoring the equipment through RF and CAN communications in the real world. And equipment sends and receives data at this level. The functions of each component are as follows:

- AS/RS handles storage and distribution operations of finished products and raw material.
- MC is composed of machine, robot and buffer. A machine provides several types of processing services; a robot conducts the role of shifting workpieces among machine, buffer, and AGVs; a buffer provides temporary storage service to workpieces.
- AGV deals with transportation operations between MCs and AS/RS.
- AGV controller dispatches AGVs by sending commands, receives feedback messages from AGVs simultaneously.
- RF is a wireless communication mechanism between AGV controller and AGVs.
- CAN is a wired communication mechanism between MCs, AS/RS and AGV controller.

2.2. Logical layer

Logical layer is the logical mapping of physical layer, composed of MC agents, AGV agents and AS/RS agent. In logical layer, every agent is an autonomous and cooperative unit, provided with strong computing power and embedded intelligent scheduling algorithms. Agents receive messages from entities (MCs and AGVs) in physical layer and cooperate with each other to generate the scheduling for the entities. The logical layer provides two types of scheduling services to physical layer: scheduling of operations on machines and scheduling of transportation by AGVs.

For the scheduling of operations on machines, different MC agents produce feasible and optimized plan by competing processing tasks with each other; during the scheduling of transportation tasks, MC agents and AS/RS agent compete AGVs for transporting workpieces, and AGV agents compete transportation tasks. By applying the two scheduling approaches, the logical layer is able to satisfy different scheduling demands of physical layer.

2.3. Communication layer

Communication layer establishes communication between physical layer and logical layer. It connects the two different ports: one port is used to receive and transmit messages in physical layer; another one is used for logical layer. It can transform messages from one layer to the other. It is composed of a set of standards for transforming a data value into zeros and ones that will be transmitted in a network. This layer concerns protocols and standards. In this architecture, a mutual conversion equipment between CAN and USB is used to connect physical layer and logical layer. On this basis, communication layer transforms messages which can be read at different layers. And this transformation implies as follows:

- Receive CAN messages from physical entities and build a message for logical layer that includes complementary information like a time stamp, parameters and other data required by agents.
- Deliver messages to logical layer (in time and order).