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A plug-and-play data gathering system using ZigBee-based sensor network sensor network

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ABSTRACT

In order to quickly establish a data gathering system in a flexible manufacturing environment, this paper presents a ZigBee-based wireless sensor network combined with a data processing system. The proposed system includes a system simulator, instrument definition module and network monitor module. System functions include network parameter setting, real-time system status sensing and data collecting, intelligent event monitoring and warning, and ad hoc response mechanisms. The proposed system enables users to quickly plug-and-play any digital instrument in their production systems and automatically capturing production data. Production controller can adopt these data to make decisions in real-time.

1. Introduction

Global competition has forced many companies to alter their business practices [1,2]. To reduce inventories and improve their positions in the global supply chains, many manufacturers have been driven to shift their production strategies from build-to-forecast to build-to-order (BTO) or configuration-to-order (CTO) [3]. Manufacturers strive to be able to respond quickly as soon as possible to customer requirements. A flexible manufacturing system is usually adopted to fabricate products in small batches and to satisfy numerous specific orders. When a production line is reconfigured to fit new product processes, the installed data capturing system and/or status monitoring system must be synchronously modified in providing real-time data to shop-floor control. However, resetting cable-type devices and connecting to the existing network system, are difficult and expensive.

Wireless sensor networking is an emerging technology for the inexpensive, unattended monitoring of many industrial environments [4]. Their importance has been recognized by the recent delivery of the IEEE 802.15.4 standard for the physical and MAC layers and the forthcoming ZigBee standard for network and application layers [5]. Wireless sensors are equipped with a radio transceiver and a set of transducers through which they acquire information about the surrounding environment. When deployed in large quantities in a sensor field, these sensors can automatically organize themselves to communicate with each other by forming an ad hoc multi-hop network. A remote user can assign relative commands to the sensor network for data collection and processing and task transfer and can also later receive the messages sensed by the network [6].

To provide real-time data for production control, this study proposes a plug-and-play data capturing system based on a ZigBee-based sensor network. The proposed systems comprise an instrument definition module, system simulator and network monitor module. The system functions include network parameter setting, real-time production status sensing and data collecting, intelligent event tracing and warning, and ad hoc response mechanisms. A user can easily define the data transfer protocols of any digital instrument and then connect the defined instrument to the ZigBee sensor node. This study aims at establishing a wireless and portable data gathering environment.

The rest of this paper is organized as follows: Section 2 describes production control problems and ZigBee sensor network applications. Section 3 briefly describes the ZigBee communication protocol. The detailed specifications of the proposed model are then described in Section 4. Section 5 introduces the implementation of the proposed model. Discussions and conclusions are finally drawn in Section 6.

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2. Literature review

The core elements of the shop-floor control problem have been addressed extensively in recent decades. Melnyk and Ragate focused on the information system required to maintain and exchange information between the work order (WO) and the work center [7]. According to their results, an effective control mechanism must include order review and release, detailed scheduling, data collection and monitoring, emergency control and feedback and order disposition. Its main functions are to prioritize WO, transfer messages regarding work-in-process (WIP) and WO to the material requirement planning (MRP) layer, and supply real-time information concerning the work center to the capacity planning layer. The key control element was the order review and release function to adjust the schedules and routes of the work order [8,9].

Real-time information relating to the status of production lines includes information concerning resources, jobs and qualities. The information relating to the resources includes machines, WIPs, tools, labors, etc. The information relating to the jobs includes tracking data for each operation, data concerning successfully completed processes and information about schedule [10].

In practice, numerous variables need to be considered in making production decisions [11]. For example, a maintenance decision is based on variables including the availability of spare parts, maintenance personnel skills and experience, human resources and maintenance strategy [12–14]. However, these variables imply certainty and uncertainty conditions, particularly in a dynamically changing environment [15]. Thereby, quickly handling the production status and seamlessly providing the relative production information are the key factors to the production controllers for decision-making. Real-time information enables production controllers to improve the decisions of shop-floor control.

Wireless sensor networks are an emerging low-cost technology for unattended monitoring of many industrial environments [16]. Their importance has been clearly demonstrated by the recent adoption of the IEEE 802.15.4 standard for the physical and MAC layers and the forthcoming ZigBee standard for the network and application layers [5]. When networked together over a wireless medium, these devices can combine their sensing functionality.

Diverse applications for sensor networks encompassing different fields have already emerged and include medicine, agriculture, environment, military, inventory monitoring, intrusion detection, motion tracking, machine malfunction, toys and many others. In medicine, sensor networks can be used to remotely and unobtrusively monitor physiological parameters such as heartbeat or blood pressure, which can be reported to a hospital immediately when they reach designated thresholds [17,18]. In agriculture, sensor networks can monitor climatic conditions in different zones of large cultivated areas and calculate different water or chemical needs. Pollution detection systems can also benefit from sensor networks. Sensors can monitor pollutants in a town or a river and identify the source of anomalous situations. Similar detection systems can be employed to monitor rain and water levels and prevent flooding, fire or other natural disasters [19]. Other possible applications include home/office automation, education, inventory monitoring, intrusion detection, motion tracking, and machine malfunctions [20–22].

3. Brief descriptions of ZigBee and related work

The ZigBee Alliance [23] is an association of companies working to develop standards for reliable, cost-effective, low-power wireless networking. ZigBee technology can be embedded in many products and in many consumer, commercial, industrial and government applications worldwide. ZigBee builds upon the IEEE 802.15.4 standard, which defines the physical and MAC layers for low cost, low rate personal area networks. ZigBee defines the network layer specifications for star, tree and peer-to-peer network topologies and provides a framework for application programming in the application layer.

The physical layer supports three frequency bands: a 2.4 GHz band (with 16 channels), a 915 MHz band (with 10 channels) and a 868 MHz band (1 channel), all of which use the Direct Sequence Spread Spectrum access mode. The 2.4 GHz band employs Offset Quadrature Phase Shift Keying for modulation while the 868/915 MHz bands rely on Binary Phase Shift Keying. Besides radio on/off operation, the physical layer supports functionalities for channel selection, link quality estimation, energy detection measurement and clear channel assessment.

ZigBee standardizes the higher layers of the protocol stack. The network layer controls the organization and routing over a multihop network (built on top of the IEEE 802.15.4 functionalities) while the application layer provides a framework for distributed application development and communication. The application layer is comprised the application object, the ZigBee device objects and the application sub layer. The ZigBee device object provides services that enable application objects to discover each other and to organize into a distributed application. The application sub layer enables the data and security services to interface with the application object and the ZigBee device object. Fig. 1 is an overview of the ZigBee protocol stack.

Based on the announcements of the organization of ZigBee alliance listed in Table 1, the ZigBee protocol and products possesses several benefits compared with other wireless technologies, especially in the working fields of short distance and low data rate [24]. ZigBee technology is well suited to a wide range of energy management and efficiency, industrial, medical, home automation applications. Essentially, applications that require interoperability and/or the RF performance characteristics of the IEEE 802.15.4 standard would benefit from a ZigBee solution.

4. System architecture

4.1. The Zigbee network

Fig. 2 depicts the monitoring networks established by a ZigBee network system. The networks include a master node connected with a server PC and a series of client nodes, which are classified into master, sensor, gatherer, actuator and, controller. The main functions of each element are described as follows.

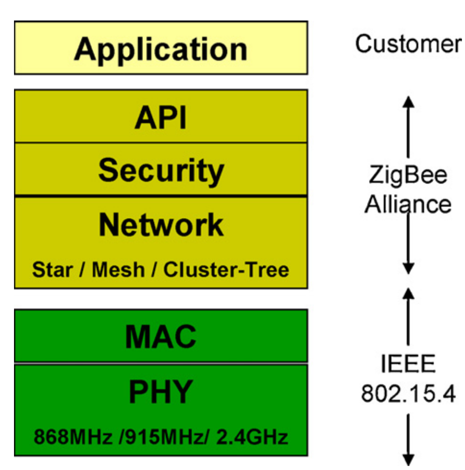

Fig. 1. The ZigBee network architecture.