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A RFID-enabled positioning system in automated guided vehicle for smart factories

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ABSTRACT

Smart factory, as one of key future for our industry, requires logistics automation within a manufacturing site such as a shop floor. Automated guided vehicle (AGV) systems may be one solution, whose accuracy will be influenced by some factors. This paper presents a radio frequency identification (RFID)-enabled positioning system in AGV for smart factory. Key impact factors on AGV's accuracy such as magnetic field in circular antenna, circular magnetic field, and circular contours stability are examined quantitatively. Based on the examinations, simulation studies and a testbed are carried out to evaluate the feasibility and practicality of the proposed approach. It is observed that large diameter antennas are used in driving zone and small diameter antennas are used in parking zone. This approach was compared with another method using passive RFID tags and it is superior to that method with greatly reduced tags' deployment. Observations and lessons from simulation and testbed studies could be used for guiding automatic logistics within a smart manufacturing shop floor.

1. Introduction

Automation in manufacturing is demanded continuously since it saves labors and materials to improve quality, accuracy, precision and efficiency [1]. Take a smart factory for example, some cutting-edge technologies such as cyber-physical systems (CPS) is employed to monitor physical processes through creating a virtual world so that manufacturing automation could be achieved by modularized and structured units [2]. Manufacturing systems using CPS technology play an important role in a smart factory. Within such systems, information from all related production activities will be closely synchronized and monitored between physical factory floor and cyber computational space [3]. One of key features of smart factory is the logistics automation which enables an efficient delivery of various components within the manufacturing sites such as workshops.

The logistics automation could be realized by automated guided vehicles (AGVs) which are able to move different materials like raw-materials, work-in-progress items, and finished products in a flexible manner without human interventions [4]. The high synchronization of manufacturing activities and logistics behaviors must be ensured so that the production could go smoothly. Therefore, positioning system for AGVs is crucial since determination of the location of an AGV will largely influence the entire manufacturing system. Machines and workers may spend extra waiting time for the arrival of materials if the AGVs' positioning system cannot work properly. Additionally, manufacturing performance heavily relies on the logistics efficiency and effectiveness within a smart factory where highly automated machines will be equipped. That brings great challenges for the positioning system in an AGV because its system layout and performance will greatly affected by manufacturing facilities and situations such as dynamic changes or emergency production orders [5]. Currently, fixed guidepaths with magnetic bands are widely used for positioning system due to its low cost [6]. However, this approach cannot fit the manufacturing flexibility since the facilities within a smart factory will be reconfigured and redesigned given different mass customize products. For example, the manufacturing machines may follow production line mode in peak-season and then follow another mode by grouping these machines with similar functionalities in off-season. Fixed guidepaths thus should be revised with more efforts in terms of labor and time cost.

As the development of Auto-ID technologies like radio frequency identification (RFID), the positioning systems for AGVs for

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smart factories could be improved. Some primary studies show the feasibility and practicality of using RFID for AGV's positioning in typical manufacturing factories. For example, RFID was used for positioning by placing readers and tags upon manufacturing environment so as to facilitate the automatic logistics through a cloud or remote controller [7]. Passive RFID is used in an indoor position tracking system based on a precise tracking algorithm [8]. However, there are some research questions needed to be addressed. Firstly, what is the key influence on positioning accuracy in a RFID-enabled AGV? Secondly, how to design and develop a RFID-enabled positioning system considering the key influences? Thirdly, how to evaluate the designed and developed system?

In order to answer this questions, this paper introduces a RFID-enabled positioning system for AGVs by making full use of the near-field coupling RFID to realize precise coverage positioning to support ultimate automatic logistics in a smart factory. To figure out the key influences, this paper analyzes the magnetic field in circular antenna, circular magnetic field, and circular contours stability. It is observed that a circular antenna in the YOZ plane will generate a distribution law of antenna radiation patterns. To design and develop a RFID-enabled positioning system, the key influences are considered. It is found that the positioning accuracy is largely influenced by the radius of the field contour circle. Thus, large diameter driving antenna coils are used for coarse positioning and small-diameter stopping antenna coils are used for precise positioning and posture correction. To test this system, this paper uses simulation study, laboratory testbed, and comparisons with another approach to verify the proposed system.

The rest of this paper is organized as follows. Section 2 gives a literature review about RFID technology, positioning in AGV system, and near field coupling (NFC) technology. Section 3 presents some basic definitions of NFC and analyzes three key impact factors. Section 4 reports on the design and development of a RFID-enabled positioning system. Section 5 demonstrates the simulation studies, a testbed, and a comparison study. Section 6 concludes this paper by giving our findings and future research directions.

2. Literature review

2.1. Cyber-physical systems (CPS)

CPS refers to a mechanism where physical and software components are significantly intertwined so that the physical objects could be well controlled or monitored in cyber space [3]. CPS-enabled manufacturing is able to convert typical resources such as workers, materials, and equipment into smarter objects which show great promise in smart factory in the future [9]. Thus, cyber-manufacturing based on CPS concept has been placed significant attention so as to ultimately realize high performance and reliable production.

CPS involves large number of transdisciplinary methodologies such as cybernetics theory, mechanical and mechatronics, design and process science, manufacturing systems, and computer science. One of the key technical method is embedded systems which enable a highly coordinated and combined relationship between physical objects and their computational elements or services [10]. A CPS-enabled system, unlike traditional embedded systems, is a networked interaction designed and developed with physical input and output as well as their cyber-twined services such as control algorithms and computational capacities. Thus, large number of sensors play important roles in CPS. For example, multiple sensory devices are widely used in CPS to achieve different purposes such as touch screens, light sensors, force sensors, etc. Typical CPS applications have been reported by making full use of sensor-based communication-enabled autonomous systems. Vast number of wireless sensor networks supervise the environmental aspects so that the information from the environment could be centrally controlled and managed for decision-makings [11].

2.2. RFID technology

RFID technology, as one of key elements in CPS, has been widely used due to its flexible operations and high accuracy [12]. RFID is able to track and trace objects by wireless radio waves [13]. Thus, it was used for tracking the key components in a production system so that the data captured could be used for supporting real-time scheduling [14]. With enormous data generated by RFID-enabled smart manufacturing objects, data mining approach was used to excavate valuable information and knowledge for supporting advanced production decision-makings. For example, standard operation times (SOTs) and dispatching rules were mined from large set of RFID production data to support real-time planning and scheduling in the shop floors [15,16].

Indoor localization is a particular application of RFID technology besides its tracking and tracing ability. Hasani et al. thus introduced a novel hybrid configuration for indoor positioning using passive RFID and wireless local area network (WLAN) [17]. The positioning system is based on a mobile device, a textile tag, and several RFID readers for locating various objects. For indoor locating persons, a foot-mounted inertial measuring units (IMU)-based position method was proposed from several active RFID tags placed at some locations in a building [18]. This paper integrates IMUs and RSS (Received Signal Strengths) with a loose Kalman filter to design a tight KF-based INS/RFID system. With different types of RFID frequency, large numbers of positioning system by assistance of RFID tags and readers have been studied, designed and developed [19].

2.3. Positioning in AGV system

Positioning plays a critical role in an AGV system. A recently proposed coil pad design named bipolar pad (BPP) was introduced with a 10-kHz 300-W distributed inductive power transfer (IPT) system for AGV applications [20]. A 3D finite element modeling tool is used to evaluate the distributed AGV positioning application. In an industrial guidance system, path tracking is significant. Villagra et al. introduced a control law which allows AGVs to operate tracking a predefined route with industrial grade of accuracy and reliability by integrating three control technologies: fuzzy, vector pursuit, and flatness-based control [21]. Automatic configuration of an initial position is one of the key research areas in AGV systems. Herrero et al. thus proposed an unconstrained optimization method coupled with probabilistic techniques to address the problem [22]. In order to achieve effective position tracking, Cho et al. used B-Spline surface equation based on passive UHF RFID to establish a wireless position tracking system for indoor applications [7].

2.4. Near field coupling (NFC) technology

NFC refers to an electromagnetic field around an object which carries reactive or Fresnel diffraction [23]. Wave interference is a basic manifestation of the superposition principle in many applications. Thus, [24] demonstrated that the near-field interference of a circularly polarized dipole resulted in a unidirectional excitation of guided electromagnetic modes in the near-field. Near-field analysis of Terahertz pulse generation from photo-excited charge density gradients was studied to show that the charge dynamics in the plane of the surface was able to radiate substantially stronger THz pulses than the charge dynamics in the direction normal to the surface [25].

Due to its advantages, NFC technology has been widely used. Hsu and Huang [26] reported a Koch-shaped log-periodic dipole array (LPDA) antenna for universal UHF RFID handheld reader. In this