An ant colony based optimization for RFID reader deployment in theme parks under service level consideration

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Highlights

- The ACS-ILS algorithm is proposed to find the best locations of RFID readers for theme parks.
- The ACS-ILS algorithm provides a 39% improvement over the solution quality compared to the traditional ACS algorithm.
- A service level index, based on the quantity and type of readers, is developed to evaluate the deployment quality.
- Through the proposed index, theme park managers can decide whether reader settings are sufficiently met.

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Abstract

Radio Frequency Identification (RFID) tracking systems have been implemented in theme parks to help visitors find lost family or group members. When a visitor enters a park, he/she is assigned a wristband embedded with an active RFID tag. When the visitor passes through the coverage area of an RFID reader, the system can identify the visitor’s location. However, few studies have examined the optimal deployment of RFID readers or discussed how to best evaluate the deployment quality of the tracking system. To address this need, an Ant Colony System (ACS)-based reader deployment method is proposed. First, the grid size, the quantity of readers, maximum reading distance of the readers, and visiting frequency of each grid should be decided or derived. Next, the ACS with incremental location setting (ACS-ILS) algorithm is developed to determine the best reader locations to maximize visiting frequency coverage and minimize reader collision. A service level index is then defined and used to evaluate the service quality of the RFID tracking system. The experimental results show that the proposed ACS-based reader deployment method and service level index can help managers determine the near optimal quantity and locations of readers for the RFID tracking system.

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1. Introduction

Theme parks are aggregations of architecture, landscapes, rides, shows, food services, costumed personnel and retail shops (Pearce, 1988). Well-known examples include the Walt Disney World Resort (also known as Disney World), Disneyland, Universal Studios and Six Flags. Typically, modern theme parks are characterized by a large visiting area and large numbers of visitors (Bigné, Andreu, & Gnoth, 2005). For example, Disney World, the world’s most-visited entertainment resort, covers an area of 30,080 acres, which is almost twice the size of Manhattan. In 2005, the park was visited 42.8 times, an average of 117,260 visitors per day (Sterba, 2006). In such a large area and among such large crowds, finding lost family or group members becomes a great challenge for both visitors and park managers.

Traditionally, theme parks relied on broadcasting services to help groups find lost members. For example, when visitor A cannot find visitor B, visitor A goes to the information center (or the help desk) and requests broadcast assistance. The message is then broadcast through loudspeakers or electronic signboards. However, there is no guarantee that visitor B will receive the message. Although such broadcasting systems are relatively easy to
implement, the service is unreliable and provides mixed results. Recently, new people tracking mechanisms have been proposed using advanced locating technologies such as GPS (Global Positioning System), infrared detectors, ultrasonic waves, and Radio Frequency Identification (RFID). Among these technologies, RFID tracking systems are relatively light, small, and inexpensive, and provide relatively higher performance for location tracking (Aldebert, Dang, & Longhi, 2011). When a visitor enters a theme park, he/she is given a wristband embedded with an active RFID tag. RFID readers are deployed throughout the park and, when the visitor passes through the coverage area of a particular RFID reader, the visitor’s position is recorded (Tsai & Chung, 2012). Currently, RFID systems have been implemented to track visitors in theme parks such as Legoland (Billund, Demark), Steamboat Ski Resort (Colorado, USA), Wild Rivers Waterpark (California, USA), and Dolly’s Splash Country (Tennessee, USA) (Gilbert, 2004).

Although RFID tracking systems can immediately provide the visitor’s location, little discussion has been devoted to the appropriate deployment of active RFID readers in the park or the evaluation of the deployment quality of the tracking system. Lin, Lu, Kwan, and Shen (2010) proposed an RFID-based privacy-preserving children tracking (REACT) scheme to help locate missing children in large theme parks, but the study did not discuss deployment of RFID reader configurations. Related studies of Huang and Chang (2011), Laguna, Roa, Jimenez, and Seco Granja (2009), Li and Becerik-Gerber (2011), Luo, O’Brien, and Julien (2011), Ni, Liu, and Patil (2004), Zhou and Shi (2009) presented different methods to increase the positioning accuracy of RFID systems, but are not applicable to the context of theme parks. Tsai and Lo (2010) and Tsai, Liu, Chen, and Hsiao (2012) discussed the issue of using RFID information for personal route suggestion in indoor exhibitions but did not address the issue of optimal reader placement. The work in Lee, Fiedler, and Smith (2008), Oztekin et al. (2010a, 2010b) explored the deployment of RFID systems for hospital asset tracking and patient safety, while the work in Chen, Zhu, and Hu (2010), Chen, Zhu, Hu, and Ku (2011), Di Giampaolo, Forni, and Marrocco (2010), and Guan, Liu, Yang, and Yu (2006) explored different optimization methods for RFID system deployment problems. However, these studies focused mainly on the efficiency of optimization algorithms.

In fact, several considerations should be taken into account when deploying RFID readers of the tracking system in theme parks. First, theme parks are largely divided between areas of public access (e.g., entrance, plazas, and pathways) and areas which are off-limits. Public access areas will obviously have a higher frequency of visitors passing through, and thus should be the focus of RFID reader deployment. Second, cost considerations require that RFID reader deployment be limited to the fewest units necessary while maintaining adequate service quality. However, previous studies have largely ignored cost considerations and have assumed that RFID readers can be installed without restriction, thus the tradeoff between service quality and implementation cost has not been considered (Dong & Siu, 2013). Third, the RFID reader deployment problem is actually an NP-hard problem (Oztekin et al. 2010b). Therefore, previous studies solved objective functions of the deployment problem using various heuristic optimization algorithms such as diversified local search method (Laguna et al. 2009), swarm particle swarm optimizer (Chen et al. 2011), and bacteria foraging optimization (Chen et al. 2010). These algorithms perform well when dealing with continuous optimization problems. However, in this study, reader deployment is a discrete optimization problem which cannot be efficiently solved using these algorithms.

This research develops an Ant Colony System (ACS)-based deployment method to determine the near optimal RFID reader positions for theme park environments. The method first determines grid size, quantity of readers, and maximum reading distance of the readers. The visiting frequency of each grid is then evaluated where the visiting frequency represents how often visitors pass through the grid during a fixed time. Next, the ACS algorithm with an incremental location setting strategy (ACS-ILS) algorithm is proposed to find the best locations of RFID readers to maximize coverage area while minimizing RFID reader collision. A set of experiments show that the ACS-ILS algorithm provides better solution quality than the traditional ACS algorithm since better initial locations for each ant are provided. A service level index is then defined and used to evaluate the service quality of the RFID tracking system. Through the proposed index, managers can decide whether current settings (i.e., grid size, quantity of readers, and maximum reading distance of the readers) are sufficiently met.

The remainder of this paper is organized as follows. Section 2 reviews the relevant research. Section 3 introduces the proposed reader deployment method for RFID tracking systems. Section 4 describes an implementation case to show the feasibility and performance of the proposed method. Section 5 presents conclusions and suggests directions for future work.

2. Literature review

Ni et al. (2004) presented an RFID location sensing prototype system, LANDMARC, for locating objects within buildings. The major advantage of LANDMARC is that it improves the overall accuracy of locating objects by using the concept of reference tags. Their research demonstrated that active RFID is a viable and cost-effective candidate mechanism for indoor location sensing. Guan et al. (2006) presented a genetic approach for network planning in RFID systems, using optimum selection factors including environment complexity, undesired mutual coverage, and unavoidable interference from multiple readers. Chow, Choy, Lee, and Lau (2006) developed an RFID-based Resource Management System (RFID-RMS) to help users to select the most suitable resource usage packages for handling warehouse operation orders. The system enhances the effectiveness in formulating resource usage package and managing resource operation by integrating the RFID, case-based reasoning (CBR) technologies and the programming model for forklift route optimization. Chang and Peng (2007) proposed an efficient sensor placement (ESP) approach for a sparse interested area. Their research considers the influence of data transmission with obstructions and sensing signals. Additionally, the issue of different radii for sensing and transmission is analyzed.

Hsiao and Huang (2008) proposed two practical considerations for beacon deployment in ultrasound-based indoor localization systems. To provide true coverage of the listeners, they proposed a water-drop shaped radio model for the beacon to replace the conventional spherical radio model. Chen et al. (2011) developed an optimization model for planning reader positions in RFID networks based on a novel Multi-swarm Particle Swarm Optimizer called PSO. The main idea behind PSO is to extend the single population PSO to the interacting multi-swarms model by constructing a hierarchical interaction topology and enhanced dynamical update equations. Their research considers some principal requirements such as tag coverage, economic efficiency, load balance, and interference between readers. Laguna et al. (2009) described the navigation of autonomous guided vehicles (AGVs) in industrial environments which often employs positioning systems based on landmarks or artificial beacons. In the proposed system, the position of an AGV navigating an indoor space is determined by calculating the distance between the object and nearby beacons, thus achieving the desired level of accuracy and optimizing reliability. A local search procedure coupled with a diversification
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