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The optimal k-covering tag deployment for RFID-based localization ☆

Wei-Shinn Ku [a], Kazuya Sakai [a], Min-Te Sun [b,*]

[a] Department of CSSE, Auburn University, Auburn, AL 36849, USA
[b] Department of CSIE, National Central University, Taoyuan 320, Taiwan

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ABSTRACT

Radio Frequency Identification (RFID) technologies are applied in many fields for a variety of applications today. Recently, new solutions are proposed to deploy RF tags on the ground instead of attaching them to objects for RFID-based monitoring and localization. However, the optimal tag deployment strategy is yet to be addressed. In this paper, we identify the optimal deployment patterns that guarantee k-covering (i.e., at least k RFID tags are accessible anywhere in the deployment region), where $k \leqslant 3$. In addition, we analyze the achievable minimum upper bound and the average of localization error when the optimal deployment patterns are applied. The numerical results show that our optimal deployment patterns significantly reduce the required number of tags for k-covering compared with the square pattern which is commonly used in RFID-based monitoring and localization systems. The comparison between simulation and analytical results shows that our analytical models provide very accurate estimations of localization error.

1. Introduction

Radio Frequency Identification (RFID) is an electronic tagging technology that allows objects to be automatically identified at a distance using an electromagnetic challenge-and-response exchange of data (Want, 2004). By attaching Radio Frequency (RF) tags to objects, RFID technologies enable various applications such as supply chain management (Santos and Smith, 2008), transportation payment, warehouse operations (Chow et al., 2006), library management (Boss, 2003), indoor location sensing (Liu et al., 2007), and so on.

Recently, new types of RFID-based applications such as activity monitoring and localization have been proposed. In these applications, RF tags are deployed in a region instead of attaching them to objects. For example, in Liu et al. (2007), a few RF readers continuously monitor signal strength of deployed RF tag arrays for identifying frequent trajectories of moving objects. This system can be employed to replace expensive camera-based activity monitoring techniques. Similarly, in (Mitchell et al., 2009; Munishwar et al., 2009b), an iRobot Create (iRobotCreate, 2009) is equipped with RF readers and passive RF tags are deployed in a testbed field. By reading tag identification information, the robot can locate its current position. It has been shown that the RFID-based solution is capable of providing more accurate localization than sensor-based localization mechanisms. Although these systems support practical applications, they did not consider how to optimize the tag deployment so that the number of required RF tags can be minimized. Currently, the square pattern is commonly used to deploy RF tags for RFID-based localization and monitoring. While the square pattern is an intuitive way to deploy tags, it is not the optimal deployment pattern. Even though the unit price of RF tags is relatively cheap, the cost of a vast amount of tags is still significant. In addition, the relationship between localization error and tag deployment pattern has never been studied.

In this research, we investigate the optimal k-covering tag deployment patterns, which are defined as the deployment patterns that result in the least number of RF tags to cover a region with a given minimal number of tags k that a reader can access anywhere in the region. The contributions of this research are as follows:

- We identify the optimal k-covering tag deployment patterns for $k \in \{1,2,3\}$. When $k=1$, the deployment problem is essentially identical to the minimum cover set problem (Kershner, 1939). It is known that the equilateral triangle pattern with edge length $\sqrt{3}r$ is optimal, where r is the readable range of a tag. For $k=2$ and 3, we prove the hexagon pattern with edge length r and the diamond pattern with edge length r are optimal, respectively.
- We analyze the achievable minimum upper bound of localization error when our optimal k-covering tag deployment patterns are applied. The localization error is upper bounded by r when $k=1$, by $(\sqrt{3}/2)r$ when $k=2$, and by $(1/2)r$ when $k=3$.

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* Corresponding author.
E-mail address: msun@csie.ncu.edu.tw (M.-T. Sun).

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