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Pseudorandom Tag Arrangement for RFID Based Mobile Robot Localization

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Abstract – This paper presents a pseudorandom tag arrangement for improved RFID based mobile robot localization. First, four repetitive tag arrangements, including square, parallelogram, tilted square, and equilateral triangle, are examined. For each tag arrangement, the difficulty in tag installation and the problem of tag invisibility are discussed. Then, taking into account both tag invisibility and tag installation, a pseudorandom tag arrangement is proposed, which is inspired from a Sudoku puzzle. It is shown that the proposed tag arrangement exhibits spatial randomness quite successively without increased difficulty in installation.

Key Words : Mobile robot, localization, RFID, tag arrangement, pseudorandom.

1. Introduction

There have been two different approaches to employ the RFID system for the localization of a mobile robot. It is common to both approaches that a set of tags storing the absolute positional information are deployed throughout a navigation environment. In one approach, either active or passive tags are installed along the wall and they are used as beacons or landmarks to guide the navigation of a mobile robot [1]-[3]. However, in the other approach, passive tags are installed on the floor and they are used to indicate the current position of a mobile robot [4]-[6]. This paper belongs to the latter approach.

As the density of tag distribution over the floor increases, the performance of RFID based mobile robot localization will improve. However, the increased tag distribution density may be accompanied by the economical problem of high tag installation cost and the technical problem of incorrect tag readings. The performance of RFID based mobile robot localization is also influenced by how a set of tags are arranged over the floor. There have been a variety of tag arrangements considered so far, but they can be categorized into three repetitive arrangements, including square, parallelogram, tilted square, and equilateral triangle [4]-[6].

In this paper, we present a pseudorandom RFID tag arrangement for improved performance of mobile robot localization.

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2. Repetitive Tag Arrangements

One important consideration in determining the tag arrangement should be how easily a set of tags can be installed over the floor. Practically, it is very difficult or almost impossible to attach many tags right on their precise locations one by one. To alleviate the difficulty in tag installation, two step procedure can be suggested. First, attach each group of tags on a square or rectangular tile in a designated pattern. Then, place the resulting tiles on the floor in a certain repetitive manner, for instance, side by side.

First, consider the case in which a group of four tags are placed on a square tile of side length of $2s(\geq 4r)$, where r is the radius of the circular tag sensing range. All four sensing ranges are restricted to lie within a square tile without any overlapping among them. In this paper, the number of tags sensed at one instant is assumed to be one or zero. Fig. 1 shows three typical tag patterns, including square, parallelogram, and tilted square.

Fig. 1a) shows the square pattern, where four tags are located at the centers of four quadrants of a square tile. Fig. 1b) shows the parallelogram pattern, which can be obtained from the square pattern shown in Fig. 1a) by shifting upper two tags to the right and lower two tags to the left, respectively. The degree of slanting, denoted by h, is the design parameter of the parallelogram pattern. Fig. 1c) shows the tilted square pattern, which can be obtained by rotating the square pattern shown in Fig. 1a). The angle of rotation, denoted by ϕ, is the design parameter of the tilted square pattern.

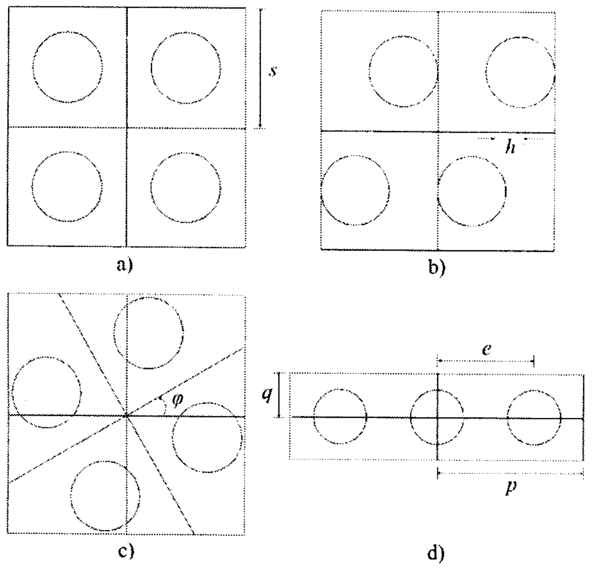


Fig. 1. Four tag patterns: a) square, b) parallelogram, c) tilted square, and d) line.

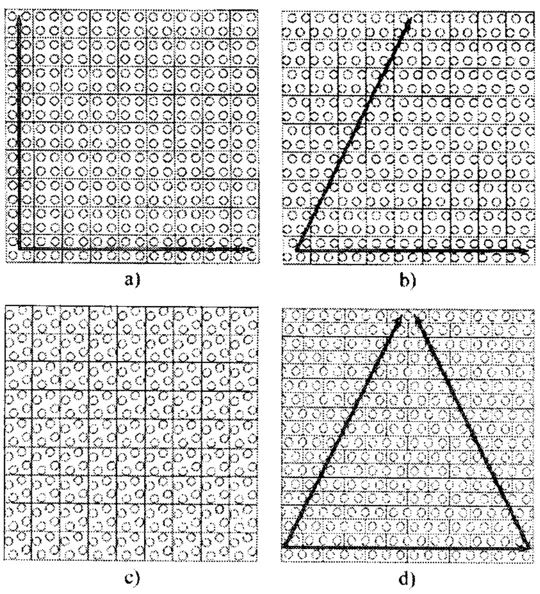


Fig. 2. Four repetitive tag arrangements: a) square, b) parallelogram, c) tilted square, and d) equilateral triangle.

Next, consider the case in which a group of three tags are placed in a line on a rectangular tile of side lengths of $2p = 3e(\geq 6r)$ and $2q = \frac{\sqrt{3}}{2}e(\geq 2r)$, where e is the tag spacing, that is, the distance between two adjacent tags. Note that the same restriction as above is imposed on the line pattern. Fig. 1d) shows the resulting line tag pattern.

Fig. 2 shows four different tag arrangements, each of which results from placing the corresponding tag pattern in a certain repetitive manner.

In RFID based mobile robot localization, it may happen that an antenna cannot have a chance to sense any tag during navigation, referred here to as the tag invisibility. If the tag invisibility persists for a long time, it may lead a mobile robot astray, resulting in the failure of RFID based localization. The tag invisibility should be one critical factor that needs to be taken into account in determining the tag arrangement. For a given tag distribution density, it will be desirable to make the tag visibility, which is the reverse of tag invisibility, evenly for all directions rather than being biased in some directions.

The square and the parallelogram tag arrangements, shown in Fig. 2a) and Fig. 2b), have been most widely used. In the case of square arrangement, tags cannot be sensed at all while a mobile robot moves along either horizontal or vertical directions. As the sensing radius is smaller compared to the tag spacing, the problem of tag invisibility becomes more serious. In the case of parallelogram arrangement, the problem of tag invisibility still exists along two but nonorthogonal directions, which results in a slightly better situation compared with the case of square arrangement. One the other hand, in the case of tilted square tag arrangement, shown in Fig. 2c), the situation gets better along both horizontal and vertical directions. Finally, in the case of equilateral triangular tag arrangement, shown in Fig. 2d), the problem of tag invisibility exists along three equiangular directions, however, the range of tag invisibility becomes smaller compared to the cases of both square and the parallelogram arrangements.

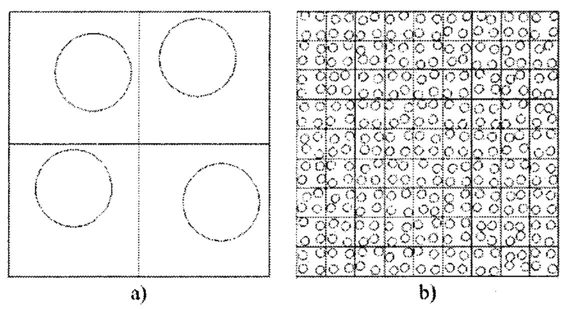


Fig. 3. Random tag arrangement: a) random pattern and b) random arrangement.

3. Pseudorandom Tag Arrangement

To significantly reduce the tag invisibility in all directions, the random tag arrangement, as shown in Fig. 3, seems to be best. Note that each four tags are placed on a square tile under the same restriction imposed on three square tag patterns shown in Fig. 1. However, due to highly expected installation difficulty, it is hard to select the random tag arrangement in practice.

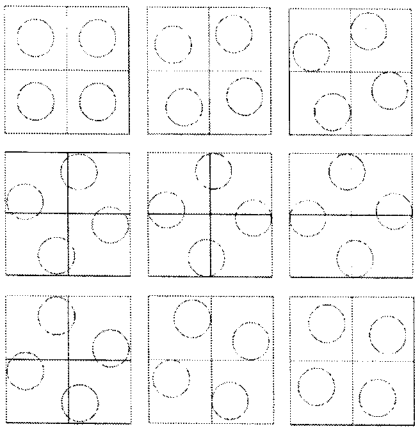
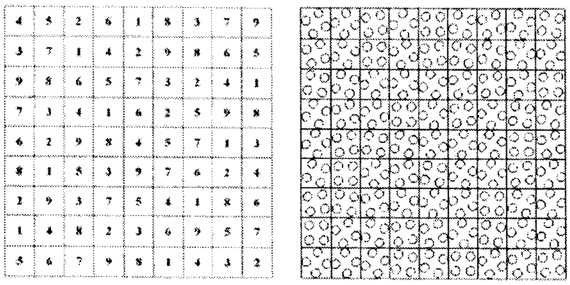


Fig. 4. The set of nine different tilted square patterns.



a) b)

Fig. 5. Pseudorandom tag arrangement: a) one solution to a Sudoku puzzle and b) the corresponding tag arrangement.

Taking into account both tag invisibility and installation difficulty, a pseudorandom tag arrangement is proposed using a set of different tilted squares that have different angles of rotation, shown in Fig. 1c). It is expected that the proposed pseudorandom tag arrangement exhibit randomness to some extent without increasing the difficulty in installation.

First, let us define a set of nine different tilted square tag patterns as follows. Since the rotation by $90°$ makes the resulting tilted pattern back to the original one, we propose to use the set of discrete angles of rotation, given by

$$\Phi_K = (K-1)\frac{\pi}{2}\frac{1}{9} = (K-1)\frac{\pi}{18}, \quad K=1,\cdots,9 \qquad (1)$$

where $K=1$ corresponds to the square pattern shown in Fig. 1a). Fig. 4 shows the set of nine different tilted square patterns, given by (1), from upper left to lower right. After making nine copies of each set of nine different tilted square tag patterns, we place them on the floor side by side, according to the number placement in a Sudoku puzzle. In a Sudoku puzzle, the numbers '1' through '9' should be placed in a 9×9 block so that no number appears more than once in any row, column, or subblock.

Fig. 5 shows one solution to a Sudoku puzzle and the corresponding tag arrangement. Compared to the random tag arrangement shown in Fig. 3d), it can be observed that the tag arrangement shown in Fig. 5b) exhibits randomness successively, which is called the pseudorandom tag arrangement.

4. Conclusion

This paper presented a pseudorandom RFID tag arrangement for improved performance of mobile robot localization. First, we examined four repetitive tag arrangements, including square, parallelogram, tilted square, and equilateral triangle, in terms of tag installation and tag invisibility. Then, taking into account both tag invisibility and tag installation, we proposed the pseudorandom tag arrangement, inspired from a Sudoku puzzle. Currently, a study is under way for the quantitative evaluation and optimal design of tag arrangements.

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