Maximizing Read Accuracy by Using Genetic Algorithms to Locate RFID Reader Antennas at the Portals

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Abstract—**In the past, researchers solved the problem of choosing the optimum locations for reader antennas in a RFID equipped portal by using an exhaustion approach. However, the drawbacks of the exhaustion approach are that it requires take a long time and that the performance is not acceptable by users. This research uses the GA approach to find the optimum solutions for the portal reader antennas placement problem. Some experiments were performed to validate the performance of the GA approach. The results showed that 60% of the results of the GA approach were in the optimum solution set of the exhaustion approach, and that the execution time of the GA approach is only 30% of that needed by the exhaustion approach.**

Index Terms—**RFID, genetic algorithm, read accuracy**

I. INTRODUCTION

With advances in wireless communications, businesses now can use Radio Frequency Identification (RFID) systems to track the movement of objects in their supply chains. These RFID systems basically consist of two types of devices: the reader and the tags. The reader recognizes objects with passive tags that each has a unique ID and information. Passive tags are not equipped with batteries. Hence, a passive tag does not send its signal to the reader until it receives a signal with enough strength from the reader.

In the traditional approach, a business manually scans the barcode to collect the object's movement information through portals. By using the RFID technology, businesses advance the manual barcode scanning process to the automatic tag scanning process. Therefore, the business saves labor costs at portals. The simplest form of a RFID equipped portal is a wide doorway in which reader antennas were mounted at the portal perimeter. The design objective of RFID-equipped portals is maximizing read accuracy as objects with a tag move through these portals [1, 2]. However, many factors including limitations in the read range, tag locations, tag orientations, or interference cause missed reads and influence the read accuracy. Another difficulty is that, in practice, it is hard to fix the tag location and the tag orientation when the tag moves through the portal. In contrast, fixing the locations and orientations of the reader antennas that mount at the portals is more feasible than fixing that of the tags passing through the portals. Therefore, the placement of multiple antennas at the portals is critical to determining the read accuracy. This research calls the problem of locating RFID reader antennas to get the maximal read accuracy at the portals *the portal reader antennas placement problem*.

To find the optimal placement of reader antennas at the portal, Wang et al. [1] exhausted all possible placements of reader antennas at the portal. While the exhaustive approach finds the optimal placements, it may take unacceptable execution time. Wang et al. [2] further decreased the resolution of the solution space to reduce the time of the optimal placement finding. However, the execution time of the exhaustion approach take is still unacceptable by users. Genetic algorithm [7, 8] is one of the nature-inspired algorithmic techniques based on natural evolution and is widely used to solve optimization problems. The portal reader antennas placement problem can be modeled as an optimization problem too [2]. This research uses genetic algorithms to choose the optimum locations for reader antennas in a RFID equipped portal to reduce the execution time of the optimal placement finding.

To do the best effort on the related works survey of this research, this research did not find any publication on using genetic algorithms to solve the portal reader antennas placement problem. This research only found two close research works [3, 4] in which used genetic algorithms to solve the RFID network planning problem in the RFID systems. The RFID network planning problem is a multi-objective optimization problem in which reader antenna positions are selected to have a required coverage and the equipment cost is controlled within the limit [3]. Yang et al. [3] modeled the RFID network planning problem as a multi-objective optimization problem and mapped it into a genetic algorithm problem. This work further concluded that using the genetic algorithms to solve the RFID network planning problem is working and practical. Guan et al. [4] also used the genetic algorithms to solve the RFID network planning problem. Guan et al. proposed that the

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difference between the antenna positioning in traditional cellular networks and that in RFID networks is uplink signals, that is, signals from tag towards reader, and that must be considered in the RFID network planning. Therefore, planning the antenna position in RFID networks is more complex than that in traditional cellular networks. Guan et al. successfully used genetic algorithms to solve the RFID network planning problem.

The remainder of this paper is organized as follows. Section 2 gives the preliminaries of this paper. Section 3 defines the portal reader antennas placement problem. The genetic algorithm to solve the portal reader antennas placement problem is presented in Section 4. Section 5 reports the results of the performance study. Finally, Section 6 gives the conclusions.

II. PRELIMINARIES

In RFID systems, the power received by a RFID tag, P_T, from the reader antenna is determined by Friis' Equation [9], which is listed below.

$$P_T = P_R \frac{G_R(\theta_R, \phi_R) G_T(\theta_T, \phi_T) \lambda^2}{(4\pi r)^2} \left(1 - |\Gamma_R|^2\right)\left(1 - |\Gamma_T|^2\right) |\hat{p}_R \hat{p}_T|^2 \cdot \quad (1)$$

where P_R is reader transmitted power, $G_R(\theta_R, \phi_R)$ is the reader gain in which (θ_R, ϕ_R) are the azimuth and the tilt of the reader to define reader antenna orientation, $G_T(\theta_T, \phi_T)$ is the tag gain in which (θ_T, ϕ_T) are the azimuth and the tilt of the tag to define tag orientation, λ is the wavelength, r is the distance between the reader and the tag, Γ_R is the reader reflection coefficient, Γ_T is the tag reflection coefficient, $\hat{p}_R$ is the reader polarization vector, $\hat{p}_T$ is the tag polarization vector and $|\hat{p}_R \hat{p}_T|^2$ is the polarization loss factor (PLF).

While there are many different types of tag antennas and reader antennas in RFID systems, this research chooses a patch antenna with circular polarization for the readers and a half-wave dipole antenna for the passive tags, the same choice as [1, 2]. To specify both of the antenna' gains, the reader axis is defined as the line joining the centers of the tag antenna and the reader antenna [1, 2]. This research defines the z-axis as the direction of the tag's antenna, and then the spherical θ_T is defined as the angle between the reader axis and the antenna direction. Because the gain of a half-wave dipole antenna only depends on θ_T, the equation of the tag gain is given by [5]

$$G_T(\theta_T, \phi_T) = 1.641 \left[\frac{\cos\left(\frac{\pi}{2} \cos \theta_T\right)}{\sin \theta_T} \right]^2 . \quad (2)$$

The gain function of a patch antenna is given by [5]

$$G_R(\theta_R, \phi_R) = 3.136 \left[\sin \theta_R \frac{\sin\left(\frac{\pi}{2} \cos \theta_T\right)}{\cos \theta_T} \cos\left(\frac{\pi}{2} \sin \theta_T \sin \phi_T\right) \right]^2 .(3)$$

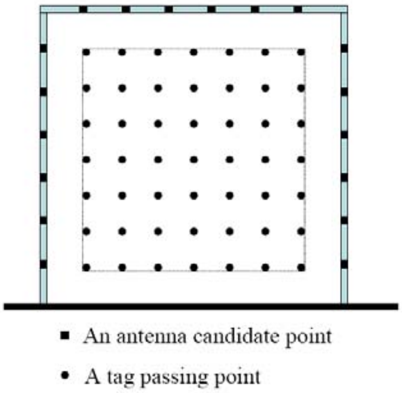

Figure 1. The working area of the portal reader antennas placement problem.

The gain of the patch antenna has a football shape. This research follows [1] and defines the direction of the patch antenna with maximum gain obtained the direction of the x-axis. According to [1], once the x-axis is defined, then ϕ_R is 0 and θ_R is $\pi/2$ – (angle between the reader axis and the x-axis).

III. THE PORTAL READER ANTENNAS PLACEMENT PROBLEM

In this section, this research gives a simple description of the portal reader antennas placement problem. Form a technical viewpoint, the readability of a passive tag relates to the amount of power it receives. The received power is a function, Friis' Equation, (1), of the distance from the reader antenna to the passive tag and the relative orientations of both the reader and the passive tag.

The working area of the portal reader antennas placement problem is shown in Fig. 1. In Fig. 1, the working area is a square area, discretized in some points. There are two kinds of points in the working area - the antenna candidate point and the tag passing point. The antenna candidate points are located at the left, top and right perimeters of the working area (portal) and are shown as solid square points in Fig. 1. Each antenna candidate point represents a location at which the reader antenna might be deployed. The tag passing points represent the locations at which tags may move through the portal. Therefore, the tag passing points are in the smaller square area of the working area, and are denoted by the solid rounded points in Fig. 1.

To represent the equipped reader antenna state, both the location and the orientation of the reader antenna are required. For any reader antenna r, this research uses the coordinate (x_r, y_r, z_r) to represent the location of the reader antennas, and uses spherical coordinates, the azimuth θ_r and the tilt ϕ_r, to represent the orientation of the reader antenna. Similarly, to how it keeps the equipped reader antenna state, this research also keeps the location and the orientation of the tags when the tags pass through the portal. For any tag t, this research keeps the location, coordinate (x_t, y_t, z_t), of the tag, and the orientation, the azimuth θ_t and the tilt ϕ_t, of the tag.

The research defines the read accuracy of a tag passing point as the percentage of all possible orientations of the tag at the point for which it can be powered by one or more of the reader antennas that are equipped at antenna candidate points. This research further defines $100\alpha\%$ accuracy tag passing point as the read accuracy of the tag passing point is larger than $100\alpha\%$ where α is a number and its value is between 0 and 1. Then, the $100\alpha\%$ portal read accuracy is the percentage of the $100\alpha\%$ accuracy tag passing points at a portal. Following the above $100\alpha\%$ read accuracy of a RFID equipped portal definition, the portal reader antennas placement problem is to find a solution to maximize $100\alpha\%$ portal read accuracy and satisfy two constraints - the number of available reader antennas at the portal and the coverage of the area of all tag passing points.

This research uses vectors to organize the solution space of the portal reader antennas locating problem. Each of these vectors are $(5\times n)$-dimensional vectors where n is the number of available reader antennas. For example, this research creates and uses a 10-dimensional vector, $(x_1, y_1, z_1, \theta_1, \phi_1, x_2, y_2, z_2, \theta_2, \phi_2)$, to represent one solution for two reader antennas, antenna 1 and antenna 2, equipped at the portal.

IV. GENETIC ALGORITHM

In this section, this research describes using a genetic algorithm to solve the portal reader antennas placement problem, and introduces some basic elements for the genetic algorithm.

This research first encodes a solution of the portal reader antennas placement problem into an individual or a chromosome. All individuals are coded using a binary bit string.

```
Function Fitness(Solution){
  Set α_pointCount to 0;
  Set pointCount to 0;
  For each tag passing point do
    Set readableCount to 0;
    Set orientationCount to 0;
    For each tag orientation do
      Set tag_received_power to power(solution);
      If tag_received_power is larger than
          minimal_tag_activate_power
        Add 1 to readableCount;
      End if
      Add 1 to orientationCount;
    End for
    Set accuracy to readable count/orientation count;
    If accuracy is larger than $100\alpha\%$
      Add 1 to α_pointCount;
    End if
    Add 1 to pointCount;
  End for
  Return α_pointCount / pointCount;
}
```

Figure 2. Fitness function

The genetic algorithm starts with randomly generating 20 individuals (chromosomes) into the population. The genetic algorithm, then, calculates the fitness of each individual by using Function Fitness. Function Fitness is the function for evaluating the fitness of a solution, then, is shown in Fig. 2. The genetic algorithm retains the best two fitness chromosomes in the population to the next generation. The other chromosomes of the next generation are generated from the current generation by using the crossover or the mutation operation. At the time of generating the new offspring, the genetic algorithm first choose two chromosomes from the parent population by using "Roulette Wheel Selection." The two selected chromosomes, then, use single point crossover to perform crossover. After the genetic algorithm performs the crossover operation, the genetic algorithm stores the two new chromosomes in the population of the offspring. The genetic algorithm repeatedly performs the crossover operation until the genetic algorithm generates all chromosomes of the population of offspring from the population of the parent. The genetic algorithm performs the mutation operation after performing of the crossover operation. The genetic algorithm randomly selects the bits of the chromosomes to invert. After doing this, the population of the offspring is completed.

V. PERFORMANCE EVALUATION

In this section, this research evaluated the performance of the proposed genetic algorithm. This research compared two methods – the method using the genetic algorithm that was presented in Section 4 and the method exhausting all possible solutions to find the optimal solution. To shorten the names of the two methods, this research calls the method using the genetic algorithm *GA method* and the method exhausting all possible solutions *exhaustion method*.

In order to evaluate the performance of GA method and exhaustion method, a portal with dimensions 3×3 m^2 had 15 antenna candidate points on three walls spaced at 0.5 meter intervals was set up. Each of 15 antenna candidate points had 3 orientations: 45, 0 and -45 degrees, respectively. The smaller area, called tag passing space, with dimensions 2×2 m^2 inside the center of the portal, was the possible area where the tag passing points are located. The resolution of the tag passing space was 0.1 meters and each tag antenna at any tag passing point had 8×8 (=64) possible orientations (both azimuths and tilts are between 0 and 360 degrees steps by 45 degrees).

The experiments equipped 2 reader antennas at the portal and set the portal read accuracy rate to 90%. The transmitted power of the reader antennas was 0.5 W. The passive tags operated at 915 MHz and their activation power was 50 W. Finally, the experiments set the crossover rate to 1.0, the mutation rate to 0.1 and the population size to 20 in the GA method. Both the GA method and the exhaustion method were implemented by using Matlab 7.0 [6] on a PC running Windows XP Professional. In the experiment using exhaustion method, the number of possible individuals was $15\times 3\times 15\times 3$ and

TABLE I. THE OPTIMAL SOLUTIONS

	Antenna 1					Antenna 2				
	locations			orientations		locations			orientations	
	x	*y*	*z*	*θ*	*ϕ*	*x*	*y*	*z*	*θ*	*ϕ*
1	2.5	3	1	90	-90	1	3	1.5	90	-45
2	1	3	1.5	90	-45	2.5	3	1	90	-90
3	3	1	1.5	270	0	0	2	1.5	90	0
4	0	2	1.5	90	0	3	1	1.5	270	0

equals 2025. To find which individual generated the optimal value of the 90% portal read accuracy, the experiment calculated the value of the 90% portal read accuracy for each individual. Therefore, the experiment needed 2025 calculations of 90% portal read accuracy. The results showed that four individuals reached the optimal value, that is, 0.8005, of the 90% portal read accuracy in the experiment. These four individuals were listed at Table I.

In the experiments of the GA method, the numbers of generations were varied as 10, 20, and 30. Because the population size was 20, 20 calculations of 90% portal read accuracy were needed for each generation in the GA method. Therefore, the numbers of calculation of 90% portal read accuracy were 200, 400 and 600 for the respective conditions of 10, 20, and 30 generations. Because the execution time of these experiments was directly proportioned to the numbers of calculating 90% portal read accuracy for each individual in the experiment, the ratio of the time to perform a 30-generation GA experiment to the time to perform an exhaustion experiment was 0.2963. In other words, the execution time of the 30-generatopn GA method was only 30% of that of the exhaustion method.

In the experiments of the GA method, the numbers of generations were varied as 10, 20, and 30. The experiments of each number of generations were performed 100 times. This research counted the number of the value of 90% portal read accuracy occurrences in 10-, 20-, and 30-generation experiments, respectively. The results are shown in Fig. 3. In Fig. 3, the optimal values of 90% portal read accuracy for each experiment are listed in the x-axis in descending order. The y-axis counts the number of times that the optimal values of 90% portal read accuracy occur in the experiments. The first result is that the counts of 0.8005, the optimal value of 90% portal read accuracy, were the largest regardless of whether the experiments were 10-, 20-, and 30-generation experiments. Second, the count of 90% portal read accuracy values that reached 0.8005 in the 30-generation experiment was 63, and was the largest among 10-, 20- and 30-generation experiments. This result showed that the GA methods with 30 generations had a ratio of 0.63 of finding the optimal result.

VI. CONCLUSION

In this paper, this research used GA method to solve the portal reader antennas placement problem. This research performed performance evaluation. The results showed that 63% results of the GA method were in the optimum solution set of the exhaustion method and the execution time of the GA method is only 30% of that needed as the exhaustion method.

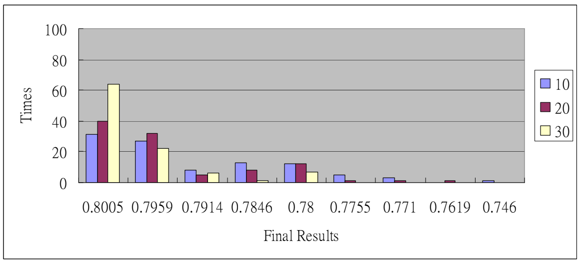

Figure 3. The results of the GA method at different generations.

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