Expert Systems With Applications 44 (2016) 344–353

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Micro genetic algorithm with spatial crossover and correction schemes for constrained three-dimensional reader network planning

Shin-Yeu Lin*, Hsing-Fang Tsai

Department of Electrical Engineering, Chang Gung University, 259 Wen-Hwa 1st Road, Kwei-Shan, Tao-Yuan 333, Taiwan, ROC

ARTICLE INFO

Keywords:
Radio frequency identification (RFID)
RFID reader network planning
Micro genetic algorithm
Spatial crossover
Correction scheme

ABSTRACT

Due to the fast growing electronic commerce, the constrained three-dimensional reader network planning (C3DRNP) of the radio frequency identification (RFID) system for large warehouses is a subject that is worthy of study. A micro genetic algorithm (mGA) with novel spatial crossover and correction schemes is proposed to cope with this C3DRNP problem. The proposed algorithm is computationally efficient, which allows a frequent replacement of the RFID readers in the network to account for the fast turnaround time of the stored objects in the warehouse, and guarantees 100% tag coverage to avoid missing the records of the objects.

The proposed algorithm is tested and compared with the existing methods such as the particle swarm optimization (PSO) method and the conventional GA (CGA) on solving several C3DRNP problems with various network sizes. The comparison results demonstrate the computational efficiency of the mGA and the effectiveness of the novel spatial crossover and correction schemes in searching the solution.

1. Introduction

In recent years, applications of *radio frequency identification* (RFID) technique strongly grow in various areas such as the warehouse (Bottani & Rizzi, 2008), asset tracking in healthcare systems (Oztekin, Pajouh, Delen, & Swim, 2010), hospitals (Yeh, Yeh, Chou, Chung, & He, 2012), supply chain management (Ko, Kwak, Cho, & Kim, 2011; Leung, Cheung, & Chu, 2014; Vlachos, 2014), reverse logistics system (Lee & Chan, 2009) and construction (Montaser & Moselhi, 2014), etc. In general, *tags* and *readers* are two major types of devices in the RFID system. Tag contains a unique identifier and information of the object. Reader will periodically read the information of the objects from the appended tags. The range for a reader to read tags is called the *interrogation zone*. Due to the limited interrogation zone, the deployment of minimum number of readers to cover all tags in the entire space is known as the *reader network planning* (RNP) problem. Most of the existing methods (Bacanin, Tuba, & Strumberger, 2015; Bhattacharya & Roy, 2010; Feng & Qi, 2013; Gong et al., 2012; Ma, Chen, Hu, & Zhu, 2014; Tsai & Lin, 2013) formulated the RNP problem as an *unconstrained combinatorial optimization* problem to find the optimal reader placement in a two-dimensional floor plan to achieve the following goals, maximizing tag coverage, minimizing reading interference, minimizing cost and others. To solve this two-dimensional RNP problem, Bhattacharya and Roy (2010) proposed a particle swarm optimization (PSO) method, Gong et al. (2012) proposed a PSO method with a tentative reader elimination operator to enhance the quality of the solution, Tsai and Lin (2013) proposed a genetic algorithm (GA), Feng and Qi proposed a combination of GA and PSO method, which divides the single population of the PSO into multi-swarm and use the genetic selection and mutation strategy to improve particle swarm dynamic rules, Ma et al. (2014) proposed a hierarchical artificial bee colony (ABC) algorithm and Bacanin et al. (2015) proposed an ABC algorithm hybridized with heuristic to estimate the initial number and locations of RFID readers.

Since most of the warehouses are of three dimensions with considerable height, a three-dimensional RNP (3DRNP) is more appropriate in practice. Furthermore, treating the tag coverage as a term to be maximized in the objective function cannot guarantee 100% tag coverage. Therefore, setting the 100% tag coverage as a hard constraint to guarantee the complete tag coverage, a constrained 3DRNP (C3DRNP) problem in a discrete working area, which partitions the storage room into a finite number of boxes to contain readers and tags (Bhattacharya & Roy, 2010; Guan, Liu, Yang, & Yu, 2006; Yang, Wu, Xia, & Qin, 2009), is considered in this paper. This problem is new in the RNP related literature.

The objective function of the considered C3DRNP problem is composed of two terms, which are cost and reading interference. Cost can be evaluated by the number of placed readers, such that the smaller the number of placed readers, the better the cost. Therefore, eliminating redundant readers is a core concern in many research works (Carbunar, Ramanathant, Koyuturk, Hoffmannt, & Grama, 2005; Gu, Gao, & Wang, 2014). Reading interference is closely related to the

---

* Corresponding author. Tel.: +886 3 2118800x3221; fax: +886 3 2118026.
E-mail addresses: shinylin@mail.cgu.edu.tw (S.-Y. Lin), m0021014@stmail.cgu.edu.tw (H.-F. Tsai).

http://dx.doi.org/10.1016/j.eswa.2015.08.046
0957-4174/© 2015 Elsevier Ltd. All rights reserved.

reader collision problem (Li, He, Li, & Huang, 2014; Li, Li, & He, 2014), which may occur when tags are located in the overlapping area of any two readers' interrogation zones, and both readers read tags simultaneously. To minimize the reading interference, one should minimize the number of tags located in the overlapping area of interrogation zones. Therefore, the considered C3DRNP problem is a type of *constrained resource allocation problems*, which is a *constrained combinational optimization problem* and is an *NP-hard optimization problem*.

In the electronic commerce era, the objects in the warehouse have a fast turnaround time, which requires a frequent replacement of the readers in the network, and makes the computing time become a concern of the RNP problem. However, most of the existing PSO-type (Bhattacharya & Roy, 2010; Gong et al., 2012), GA-type (Tsai & Lin, 2013), combination of PSO and GA (Feng & Qi, 2013) and ABC-type (Bacanin et al., 2015; Ma et al., 2014) methods consume much computing time due to their large population size. To enhance the computing speed, we use a *micro genetic algorithm* (mGA) type method, which typically contains only five chromosomes in the population (Coello & Pulido, 1993). However, to compensate the degrading of exploration capability caused by the small population size, we propose a novel *spatial crossover scheme* to improve the exploration capability of the mGA. We also propose a novel *correction scheme* to convert an *infeasible* chromosome that is resulted from the evolution process of the mGA into a *feasible* one to guarantee the 100% tag coverage. Since the proposed correction scheme consists of a redundant reader elimination operator, the corrected feasible chromosome is a chromosome with smaller cost. Hence, the proposed correction scheme not only guarantees the complete tag coverage but also help reduce the cost. In the sequel, we will call the mGA with the proposed spatial crossover and correction schemes as the proposed mGA. The proposed mGA is novel owing to the novel spatial crossover and correction schemes, and its computational efficiency due to the utilization of mGA and the effective search for the solution of the C3DRNP due to the utilization of spatial crossover and correction schemes is the contribution of this paper.

We organized our paper in the following manner. Section 2 presents the formulation of the C3DRNP problem. Section 3 presents the proposed mGA and describes the spatial crossover and correction schemes in details. Section 4 presents the applications of the proposed mGA on several C3DRNP problems of various-size reader networks and compare the test results with those obtained by a PSO method and a conventional GA (CGA). Finally, we draw a conclusion in Section 5.

2. Formulation of constrained three-dimensional reader network planning problems

We assume that the 3D space for storing the objects with tags is a rectangular block. The fixed candidate reader positions (FCRPs) are distributed equally-spaced in this rectangular block, such that the union of interrogation zones of all FCRPs can cover the entire region.

We let n denote the index of a solution, t_N denote the total number of tags, t_C denote the total number of tags that are covered by all placed readers, r_N denote the total number of FCRPs, t_O denote the total number of tags lying in the overlapping areas of the interrogation zones of all placed readers and r_P denote the total number of placed readers. Then, the tag coverage ratio that is denoted by ρ can be defined as the number of tags covered by all placed readers divided by the total number of tags, such that $\rho = \frac{t_C}{t_N}$. Consequently, the 100% tag coverage hard constraint for solution n can be expressed as

$$\rho(n) = 1 \tag{1}$$

In general, GA is designed to maximize the *objective function* or the *fitness function*. To minimize the reading interference, we maximize the total number of tags *not* in the overlapping areas of the interrogation zones of all placed readers, which is defined by $e = (t_N - t_O)/t_N$, instead of minimizing $\frac{t_O}{t_N}$. To minimize the cost, we maximize $c = \frac{(r_N - r_P)}{r_N}$ instead of minimizing $\frac{r_P}{r_N}$. Combining the above two terms using suitable weighting coefficients, the fitness function for solution n that is denoted by $f(n)$ can be formulated as

$$f(n) = w_1 e(n) + w_2 c(n) \tag{2}$$

where w_1 and w_2 are weighting coefficients.

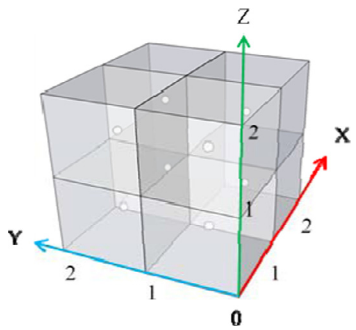

Fig. 1. Example rectangular block with FCRPs for storing objects with tags.

Based on the hard constraint and the fitness of a solution defined above, the C3DRNP problem can be stated in the following mathematical form:

$$\max_n f(n)$$
$$\text{subject to} \quad \rho(n) = 1 \tag{3}$$

Thus, the C3DRNP problem (3) is to find an optimal reader placement solution $n*$ that is with the largest fitness value among all placements that satisfy the 100% tag coverage hard constraint.

3. Proposed micro genetic algorithm for C3DRNP problems

3.1. Representation scheme

To present the proposed mGA, we need to define its representation scheme first. Fig. 1 presents an example rectangular block for storing all objects with tags. The hollow circle located at the center of each box represents a FCRP, which is identified by a three-dimensional coordinate (i, j, k). The length of a unit in any axis of the coordinate system is equivalent to a distance of $(2/\sqrt{3})R$, where R denote the radius of the interrogation zone of a reader, such that if a reader is placed at the center of a unit cube, the eight vertices of which will be on the boundary of the interrogation zone as presented in Fig. 2.

We use the variable $x(i, j, k)$ to indicate whether the FCRP located at (i, j, k) is selected for placing a reader or not, such that $x(i, j, k) = 1$ means the corresponding FCRP is selected and 0 otherwise. We let the length, width and height of the rectangular block be denoted by positive integers N_x, N_y and N_z, respectively. Then, the chromosome is represented by a string of binary codes starting from the left of the first row in Fig. 3 and continuing with the second row till the last. Notably, the position of each binary code in the string is related to a three-dimensional coordinate as indicated in Fig. 3. For example, the representation of the chromosome presented in Fig. 4 is {0,0,1,0,1,0,0,1} provided that the solid circle in Fig. 4 represents that the corresponding FCRP is selected for placing a reader.

3.2. Proposed mGA with spatial crossover and correction schemes

To deal with the hard constraint of 100% tag coverage, the proposed mGA includes a correction operation for converting the *infeasible* chromosomes that are resulted from the solution process into *feasible* ones. Since the typical population size in a CGA ranges from