Research on coverage control algorithm based on wireless sensor network

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Abstract. Wireless sensor network has many sensor nodes with characteristics of limited cost, collecting data, good fault tolerance and storage. It has been used in environmental monitoring, health care, military and commercial. Coverage control is a significant issue that needs to be solved in wireless sensor networks. In order to solve the problem of overlapping coverage for environmental monitoring and improve coverage rate, an improved immune fuzzy genetic algorithm (IIFGA) based on cluster head selection is proposed. the mathematical model is systematically described. In the experiments, ant colony optimization (ACO) and simulated annealing (SA) are given to compare the performance of IIFGA. The experiments show the proposed coverage control algorithm has a higher convergence speed and improve the coverage rate.

1 Introduction

The wireless sensor network has been applied in many fields, which include forest fire monitoring, rainstorm monitoring, traffic monitoring, agricultural pest monitoring, etc ^[1]. After deployment of the sensor node, data redundancy is generated due to the high density of coverage. In order to improve the coverage rate, reasonable coverage control scheme needs to be optimized. Hence, this paper focuses on the above issues to carry out in-depth research, design energy-saving and efficient network coverage scheme, and ensure the monitoring application and work of sensor network ^[2].

However, the existing optimization algorithms generally consider the influence of coverage, energy cost and other factors on the optimal node set selection, but ignores the influence of overlapping coverage ^[3]. For the high-density deployment of wireless sensor networks, considering the problem of overlapping coverage, an improved immune fuzzy genetic algorithm (IIFGA) is proposed. The algorithm designs immune and fuzzy mechanisms to optimize the population, which can increase the diversity of population, improve the quality of the individuals and ensure the population quality. In addition, considering the overlapping coverage area, the obtained working node subset can effectively reduce the waste of redundant information and resource to fully sleep the redundant nodes

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under the condition of high coverage quality, and select as many disjoint working nodes as possible. On the basis of proposed algorithm, the disjoint working node set is selected. The algorithm can effectively realize the selection and rotation of the optimized working node set, better guarantee the network coverage rate.

In the simulation, ant colony optimization (ACO) and simulated annealing (SA) are given to compare the efficiency of IIFGA. Results show the proposed coverage control algorithm has a better performance and achieves high coverage rate.

2 Organization of the text

2.1 Research background and significance

With the development of wireless sensor networks, information acquisition, storage, data processing, transmission and utilization are gradually penetrating into various fields in the daily life. The Internet of things integrates various sensing devices, including sensor networks and Internet. The physical world and the logical world are linked by information interaction. that is to say, it completes the on-demand interaction between people and word to acquisitor information, storage data and transmission ^[4].

Through the cooperation among multiple types of integrated nodes, the network monitors, perceives and collects the user demand data in real time, and forwards the data to the user terminal, so as to realize the integration between the logical information world and the objective physical world, so as to realize the "ubiquitous computing model", and finally realize the connection of the computing world, the physical world and the ternary world of human society. Wireless sensor network involves many fields, such as computer, semiconductor, communication, network, optics, chemistry, microelectronics, etc. It develops towards the domains of land, sea, air, space and underground integrated sensor network. In addition to military and national defense applications, wireless sensor network has a very broad application prospect in industrial and agricultural control, digital buildings, urban management, environmental monitoring, biomedical, remote control of dangerous areas, emergency relief and other fields ^[5-7].

2.2 Development and research status of coverage control technology

The wireless sensor network receives the information collected by each node through the base station, and then forwards the data to the data processing center of the network for analysis and processing. The quality of data collection and collection depends on the coverage quality of the network. Therefore, in order to improve the effectiveness and accuracy of data collection, we must use different optimization strategies to allocate and integrate the whole network space. At present, the mainstream sensor optimization strategy has two major directions. The first objection is large-scale random deployment strategy; the other is a planned deployment strategy to achieve specific goals under the constraints of specific conditions. Wireless sensor networks often work in the complex outdoor environment, battlefield environment and many other uncertain environments, it is usually a large-scale random deployment of these wireless sensors. In essence, wireless sensor network coverage control is a constrained optimization problem. It aims to maximize the overall network life with the minimum number of working nodes and the maximum number of successfully monitored targets to ensure the sensor energy consumption of the whole network as much as possible. Different types of optimization strategies depend on different types of practical applications. How to carry out energy-saving and efficient coverage

control of sensor networks according to different application environments is a basic and urgent problem.

2.2.1 Coverage model

In this section, suppose that there are X monitored targets and Y sensor nodes. The coverage relationship matrix A is demonstrated in (1):

$$\mathbf{A} = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,Y-1} & a_{1,Y} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,Y-1} & a_{2,Y} \\ \cdots & \cdots & a_{x,y} & \cdots & \cdots \\ a_{X-1,1} & a_{X-1,2} & \cdots & a_{X-1,Y-1} & a_{X-1,Y} \\ a_{X,1} & a_{X,2} & \cdots & a_{X,Y-1} & a_{X,Y} \end{bmatrix} (a_{x,y} \in \{0,1\})$$
(1)

where $a_{x,y} = 1$ and $a_{x,y} = 0$ indicates whether the x_{th} target within the range of the y_{th} node.

In (2), the monitoring relationship matrix B is demonstrated as following.

$$\mathbf{B} = \begin{bmatrix} b_{1,1} & b_{1,2} & \cdots & b_{1,Y-1} & b_{1,Y} \\ b_{2,1} & b_{2,2} & \cdots & b_{2,Y-1} & b_{2,Y} \\ \cdots & \cdots & b_{x,y} & \cdots & \cdots \\ b_{X-1,1} & b_{X-1,2} & \cdots & b_{X-1,Y-1} & b_{X-1,Y} \\ b_{X,1} & b_{X,2} & \cdots & b_{X,Y-1} & b_{X,Y} \end{bmatrix} (b_{x,y} \in \{0,1\})$$
(2)

where $b_{x,y} = 1$ and $b_{x,y} = 0$ indicates that whether the x_{th} target is monitored by the y_{th} node.

When V targets can be detected by every node within the coverage simultaneously, the constraint is shown in (3).

$$\sum_{x=1}^{X} b_{x,y} \le V(y=1,\cdots,Y)$$
(3)

The fitness function is shown in (4):

$$\max f(b_{1,1}, b_{1,2}, \dots, b_{X,Y}) = \sum_{x=1}^{X} c_x$$
(4)

where

$$c_{x} = \begin{cases} 1 & \sum_{y=1}^{Y} r_{x,y} \ge W \\ 0 & \sum_{y=1}^{Y} r_{i,y} < W \end{cases}$$
(5)

subjected to (3) and (6)

$$b_{x,y} < a_{x,y} \tag{6}$$

2.2.2 Performance evaluation

The application of coverage control algorithms is conducive to controlling the energy of sensor nodes, improving the quality of sensing service and prolonging the network lifetime, but on the other hand. It also brings related costs, such as information transmission, storage, calculation and management. Therefore, the performance evaluation standard of coverage control technology is very important for the availability and effectiveness analysis of coverage control algorithm. The following is a qualitative discussion of several commonly used evaluation criteria.

(1) Coverage.

The coverage degree of detection area or target point of network coverage is the first consideration to evaluate the quality of W basic n coverage control algorithm.

(2) Energy Efficiency.

Due to the limited energy resources, the large amount, the complex practical application environment and the battery replacement of wireless sensor nodes are not allowed in most cases. Therefore, decreasing the limited energy of each node and extending the network lifetime as much as possible has become an important performance standard. Target coverage rate is a major challenge in the network.

(3) Network Connectivity.

Wireless sensor network is data centric and cooperates with a large number of sensor nodes. It uses single hop or multi hop mode to transmit environmental information data to the terminal platform in time and effectively, so the algorithm must ensure the security and stability of the transmission channel. The improvement of the quality of service, such as sensing, monitoring and communication, and the effective guarantee of the completion of wireless multi hop communication are affected by the connection performance of the network.

2.3 Coverage optimization based on improved immune fuzzy genetic algorithm

Energy is the most valuable resource for wireless sensor networks deployed randomly in dangerous environments. On the one hand, because the battery energy of sensor nodes is limited; on the other hand, because of the bad environment, it is not feasible to replace the batteries of nodes. Under the condition that the lifetime of a single node is limited, it is an important means to extend the network lifetime by using the redundancy of nodes. Due to the uneven density of network nodes, a certain area is often covered by multiple sensor nodes at the same time. This situation is called overlapping coverage, which will not only form a waste of network resources, but also lead to a lot of redundant information. Therefore, the factors that need to be considered in the selection of the optimal working node set are the

effective coverage of the working node set, the number of working nodes and the overlapping coverage of the node subset.

2.3.1 Genetic algorithm

In order to optimize and reproduce, population must fight with other species and environment. Excellent populations will survive due to the strong adaptability of genetic algorithm (GA). GA solves the practical application of genetic algorithm by simulating the process of mutation in the process of biological evolution. It is a global optimization search algorithm with the characteristics of highly parallel, random and adaptive characteristics. At the same time, it has strong resistance to change and global search ability and is easy to combine with other algorithms.

In this paper, The IIFGA first obtains the population of potential solutions to solve the problem, encodes the individuals in the population, and the potential solutions of the problem will be transformed into the individuals that can operate directly in the IIFGA. According to the fitness function, it is determined by the objective function. In the evolution process, the individuals in each generation of population should be evaluated. The core operations of IIFGA are carried out. The population obtains individuals with higher fitness through continuous evolution of IIFGA. In the process of continuous evolution, individuals in each generation of population are evaluated. The individuals in the population will eventually converge to an individual with the best fitness function after continuous evolution without IIFGA. This individual is the IIFGA optimal solution of the problem to be solved. The process of IIFGA to find the optimal solution is a random process, but it is not a complete random search IIFGA method in essence. It is a method that the fitness function of the current population guides the evolution process of the population, and then obtains the optimal population IIFGA.

2.3.2 The basic flow of IIFGA

The basic steps are given to initialize the population and create new chromosomes, which basically include selection, crossover, mutation and calculate fitness function until the maximum generation is reached, and the iteration is basically completed. The specific main processes are as follows:

(1) Chromosome Coding

Binary coding and floating-point coding are the most common coding methods. In the process of solving the problem, IIFGA does not directly operate on variables. The object of IIFGA is gene string. Therefore, it is necessary to transform the feasible solution of the problem into individuals in genetic operation and code individuals into binary gene.

(2) Population Initialization

The operation of IIFGA is based on the individuals in the population. After population coding, the initial population is generated.

(3) Fitness Calculation

Fitness represents the quality of each individual in the population, which is an important basis for guiding population evolution. No matter what method is used, individuals with high fitness value are more likely to be selected than those with low fitness value. In order to evaluate fitness, the number of successfully monitored targets can be calculated in (4). (4) Selection

Selection is used to select good solutions in the population. Excellent individuals are selected as the parent population according to the size of fitness value. The commonly used selection methods are random traversal selection and roulette selection, etc.

(5) Crossover

Cross operation will select two individuals from the population to exchange part of genes according to the cross strategy with a certain cross probability, so as to generate new individuals. Cross operation is an impact. The convergence speed of IIFGA is one of the main reasons. The selection of crossover operators has a direct impact on the search results of IIFGA.

(6) Mutation

Mutation operation is indispensable in the process of population evolution. It reflects the local search ability of IIFGA. It makes some genes in an individual be replaced by other genes according to a certain mutation probability (generally small), and gene mutation in basic IIFGA is its allele.

(7) Termination Conditions.

In the IIFGA, the condition of the end of the genetic operation cycle is generally evolutionary to the maximum iteration.

2.3.3 Characteristics of IIFGA

(1) IIFGA has self-organization. In the process of evolution, new fitness values of individuals will be constantly generated. IIFGA searches by self-organization according to these fitness values, and uses the survival principle of the fittest in the biological world. As the same as the biological world, individuals with large fitness values have a greater chance of survival and reproduction.

(2) IIFGA uses the characteristics of objective function to code, and the object of genetic operation is the individual after coding, not directly on the variable set.

(3) IIFGA determines the fitness function according to the objective function, and then evaluates the individual according to the value of the fitness function, without directly calculating the complex objective function. It is helpful for IIFGA to solve the optimization problem that the objective function cannot be derived or the derivation is complex.

(4) IIFGA has Characteristics of clonal immunity. IIFGA is a direct search method, which is a group operation. According to the parallel way, it can search the population with potential solutions to the problem, and can search multiple areas of the target space at the same time.

(5) IIFGA guides the change direction of individuals in the population according to the fuzzy operator.

2.3.4 Simulation and result analysis

In the simulation, Matlab r2014a is used to analyze the optimal node selection algorithm based on IIFGA.

The parameters of IIFGA are set as follows: chromosome number is 50, crossover rate is 0.85, mutation rate is 0.05, gap is 0.9, and number of iterations is 300.

The target area is a 200m × 200m rectangular area. The nodes in the area is 200. The coverage control model is used to simulate the coverage ability and wireless communication ability of sensor nodes. The sensing range is 30m.



Fig. 1. Comparison of three algorithms when the sensing range is 30m.

Fig.1 shows the coverage rate got by IIFGA, ACO and SA for 300 iterations when the sensing radius is 30m. We suppose that there are 200 targets and 200 sensor nodes. It can be seen that the proposed IIFGA found its optimal value of 0.98 after 300 iterations when the number of sensor nodes is 200. In comparison with the IIFGA, ACO and SA provide suboptimal results, and the values are equal to 0.89 and 0.73, respectively.

3 Summary

In this paper, an improved immune fuzzy genetic algorithm (IIFGA) based on the classic genetic algorithm is proposed. The coverage control model is built to calculate the coverage rate. In IIFGA, the immune and fuzzy mechanisms are designed to optimize the initial basic population of IIFGA, which can ensure the population quality. In addition, the working node subset obtained by considering the overlapping coverage area can effectively reduce the basic redundant information and the waste of resources. It can also obtain large number of successfully monitored nodes, high coverage rate and basic balance of energy consumption. The simulation results show that the coverage rate is improved efficiently optimized by IIFGA when compares with ACO and SA, so that the redundant nodes are fully dormant under the condition of high coverage quality.

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References

- R. Elhabyan, W. Shi, M. St-Hilaire. Coverage Protocols for Wireless Sensor Networks: Review and Future Directions. Journal of Communications and Networks, 21 (2019) 45-60.
- A. Adulyasas, Z. Sun, N. Wang. Connected Coverage Optimization for Sensor Scheduling in Wireless Sensor Networks. IEEE Sensors Journal, 15 (2015) 3877-3892.
- 3. C. Yang, K.W. Chin. On Complete Target Coverage in Wireless Sensor Networks With Random Recharging Rates. IEEE Wireless Communications Letters, 4 (2015) 50-53.

- 4. X.Y. Zhang, J. Zhang, Y. J. Gong, et al. Kuhn–Munkres Parallel Genetic Algorithm for the Set Cover Problem and Its Application to Large-Scale Wireless Sensor Networks. IEEE Transactions on Evolutionary Computation, 20 (2016) 695-710.
- Y. Yoon, Y. H. Kim. An Efficient Genetic Algorithm for Maximum Coverage Deployment in Wireless Sensor Networks. IEEE Transactions on Cybernetics, 43 (2013) 1473-1483.
- 6. Deif D, Gadallah Y. An Ant Colony Optimization Approach for the Deployment of Reliable Wireless Sensor Networks. IEEE Access, 5 (2017) 10744 10756.
- Zhang K, Zhang W, Jia H, et al. Genetic simulated annealing based coverage-enhancing algorithm for deployment of directional Doppler sensors system. International Workshop on Microwave & Millimeter Wave Circuits & System Technology. IEEE, 2012.