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Gravitational Search Algorithm for Node Localization in Wireless Sensor Network

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Abstract: The localization of Wireless Sensor Network (WSN) is an optimization problem of measurement based on different distance or path in essence. To improve the localization accuracy of WSN node, a novel algorithm named Gravitational Search Algorithm (GSA) for node localization in Wireless Sensor Network (WSN) is proposed. The algorithm uses the information received by the unknown nodes from the anchor nodes and searches the location of unknown nodes by means of the iterative method. Compared with its counterparts, the simulation results show that the proposed method could not only improve its localization accuracy but only effectively suppress the influence of range error on the localization error and then the localization accuracy of sensor nodes with range error and range-free error is greatly improved.

Key words: gravitational search algorithm, wireless sensor, node localization

INTRODUCTION

With the development of the electronic and communication technique, sensor technique has been improved greatly and WSN has become indispensable equipments during producing and testing of the electronics which has found widespread applications in industry, agriculture, national defend, transportation and so on. For all the applications in WSN, the position information of nodes is very essential to the monitoring activities of WSN, the acquired data from WSN would be nonsense and unusable without position information of nodes, every node must determine its position coordinate if the measured value would be obtained, so the self localization technology for sensor nodes has become a foundational base to many WSN applications. In the recent years, many location algorithms for WSN is proposed, the existing localization schemes can be classified as range-based schemes and range-free schemes. The first localization schemes share a common characteristic which we estimate the locations of sensor nodes with initially unknown positions depending on the location knowledge of relevant anchors. this sensor localization consists of two phases, the first phase is ranging phase, the algorithm determines the distance between the target nodes and the neighbor anchors; in the second phase, the position estimation of the target nodes is employed using the ranging information acquired (Gopakumar and Jacob, 2008). The distance between nodes can be obtained using Receive Signal Strength Indicator (RSSI) (Doherty *et al*., 2001), Time of Arrival (ToA) (Girod and Estrin, 2001), Time of Difference of Arrival (TDoA) (Savvides *et al*., 2001) or Angle of Arrival (AoA) (Niculescu and Nath, 2003a). Range-free localization schemes need the information about anchor nodes rather than any information of distance or angle between nodes which location accuracy is poor. The localization algorithms for range-based schemes may inevitably produce estimation errors owing to the imprecise range measurements (Zhao *et al*., 2007). So how to find an effective method for minimizing the error of the target nodes is a burning question.

In this study, a new optimization algorithm (Niculescu and Nath, 2008b) named Gravitational Optimization Algorithm is used which is inspired from one of the most restrictive law of gravity, the algorithm has a good optimization performance. So the novel Gravitational Search Algorithm based on the law of gravity and the notion of mass iterations is applied to node localization for WSN, the simulation results show that it has a rapid convergence speed and can effectively inhibit the influence of range error on the location error.

GRAVITATIONAL SEARCH ALGORITHM

GSA is a novel optimization algorithm which obeys the law of gravity and simulates Newton’s gravitational force behaviors which was introduced by (Rashedi *et al*., 2009). In the algorithm, agents are regarded as objects which performance is determined using their masses, all

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these objects attract each other by the gravity force and this force causes a global movement of all objects towards the objects with heavier masses. Hence, masses cooperate using a direct form of communication, through gravitational force. The heavy masses-which correspond to good solutions-move more slowly than lighter ones, this guarantees the exploitation step of the algorithm. In GSA, each mass has four specifications: position, inertial mass, active gravitational mass and passive gravitational mass. The position of the mass corresponds to a solution of the problem and its gravitational and inertial masses are determined using a fitness function.

Now, consider a system with N agents, the position of the ith agent is defined as follows:

$$X_i = (x^i_1, x^i_d, \ldots, x^n_i) \text{ for } i = 1, 2, \ldots, N \quad (1)$$

where, xd I presents the position of ith agent in the dth dimension.

In the time t a force acts on mass j from mass i. This force is given as follows:

$$F^d_{ij} = G(t)\frac{M_{pj}(t)\times M_{aj}(t)}{R_{ij}(t)+\varepsilon}(x^d_j(t)-x^d_i(t)) \quad (2)$$

where, M_{aj} is the active gravitational mass related to agent j, M_{pi} is the passive gravitational mass related to agent i, G(t) is gravitational constant at time t, å is a small constant and $R_{ij}(t)$ is the Euclidian distance between two agents i and j:

$$R_{ij}(t) = \|X_i(t), X_j(t)\|_2 \quad (3)$$

The total force acting on mass i in the dth dimension in time t is given as follows:

$$F^d_i(t) = \sum_{j\in Kbest, j\neq i}^{N} rand_j F^d_{ij} \quad (4)$$

where, $rand_j$ is a random number in the interval [0, 1], Kbest is the set of first K agents with the best fitness value and biggest mass. In term of the Newton's second law, the acceleration related to mass i in time t in the dth dimension is given as follows:

$$a^d_i = \frac{F^d_i(t)}{M_{ii}(t)} \quad (5)$$

where, M_{ii} is the inertial mass of ith mass. So, the next velocity of an agent is considered as a fraction of its current velocity added to its acceleration, its position and its velocity is calculated as follows:

$$v^d_i(t+1) = rand_i v^d_i(t)+a^d_i(t) \quad (6)$$

$$x^d_i(t+1) = x^d_i(t)+v^d_i(t+1) \quad (7)$$

The gravitational constant will take an initial value at the beginning and it will be reduced by time to control the search accuracy as follows:

$$G(t) = G_0 e^{-\alpha\frac{t}{T}} \quad (8)$$

where, T is the number of iteration, G_0 and á are given constant.

The gravitational mass and the inertial mass are updated by following equations:

$$M_{ai} = M_{pi} = M_{ii} = M_i,\ i = 1, 2, \ldots, N \quad (9)$$

$$m_i(t) = \frac{fit_i(t)-worst(t)}{best(t)-worst(t)} \quad (10)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \quad (11)$$

where, $fit_i(t)$ represent the fitness value of the agent i at time t and, worst(t) and best(t) are defined as follows for a minimization problem:

$$best(t) = \min_{j\in\{1,\cdots,N\}} fit_j(t) \quad (12)$$

$$worst(t) = \max_{j\in\{1,\cdots,N\}} fit_j(t) \quad (13)$$

NODE LOCALIZATION OF WSN BASED ON GSA

Fitness function for WSN: The fitness function is used to evaluate the optimal degree of each agent of a swarm; we select the individual extremum of each agent and the global optimum according to the fitness function value of every agent. For WSN, coordinate system is a two-dimensional space, let a total of M anchors (x_i, y_i), i = 1, 2,…, M to estimate N unknown nodes, let (x, y) be the coordinate of the unknown node and d_i be the distance between the unknown node and the ith anchor (Chen and Si, 2011):

$$(x-x_i)^2+(y-y_i)^2 = d^2_i \quad (14)$$

Due to the influences of many factors, ranging may cause error, so the fitness function is defined as:

$$F(x, y) = \sum_{i=1}^{M}(\sqrt{(x-x_i)^2+(y-y_i)^2}-d_i)^2 \quad (15)$$

The smaller the range error F(x,y) for WSN, the more accurate the localization result.

Node localization algorithm of WSN based on GSA: Based on the aforementioned analyses, a node localization algorithm of WSN based on GSA is proposed here and its procedure is described as follows:

Step 1: Search space is identified

Step 2: An population is initialized, velocity and position of each agent is initialized randomly, G_0, α, T are initialized and t = 1 is set, to get a better convergence speed, for each unknown node, the centroid of the anchor nodes within the transmission range of it is considered as a good initial point. The value of best(0) is initialized with the position of the centroid[1]:

$$(x, y) = \left(\frac{1}{n}\sum_{i=1}^{n} x_i, \frac{1}{n}\sum_{i=1}^{n} y_i\right) \tag{16}$$

where, (x_i, y_i) is the anchor node within the transmission range of a unknown node to estimated

Step 3: The fitness of each agent is evaluated using Eq. 15

Step 4: G(t), $m_i(t)$, M_i, best(t) and worst(t) and are updated using Eq. 8-13, respectively

Step 5: The total force in different directions is calculated using Eq. 2-4

Step 6: The acceleration of different directions is calculated using Eq. 5

Step 7: The velocity and the position of agents are updated suing Eq. 6-7

Step 8: If the stop criteria is reached then the iteration is terminated, otherwise return to step 3

EXPERIMENT RESULTS

We conduct simulations to evaluate the performance of the proposed GSA algorithm against that of PSO in this part. A sensor network with 5 anchors and 8 static unknown nodes is randomly deployed in 10×10 sequence area. For comparison, the GSA and the standard PSO are used in this study, the parameters for GSA are as follows: the population N is set to 50, the maximum iteration is set to 1000, the initial gravitational constant G_0 is set to 100 and α is set to 20. The PSO algorithm we used is the standard global version with inertia weight, the acceleration factors c1 and c2 are both 2.0, a decaying inertia weight w starting at 0.9 and ending at 0.4 is used, its population size is set to 50 and the maximum iteration is also set to 1000.

Case of range-free error: In case of range-free error, Fig. 1 and 2 illustrate the distribution of localization nodes acquired using the GSA and PSO, each unknown node

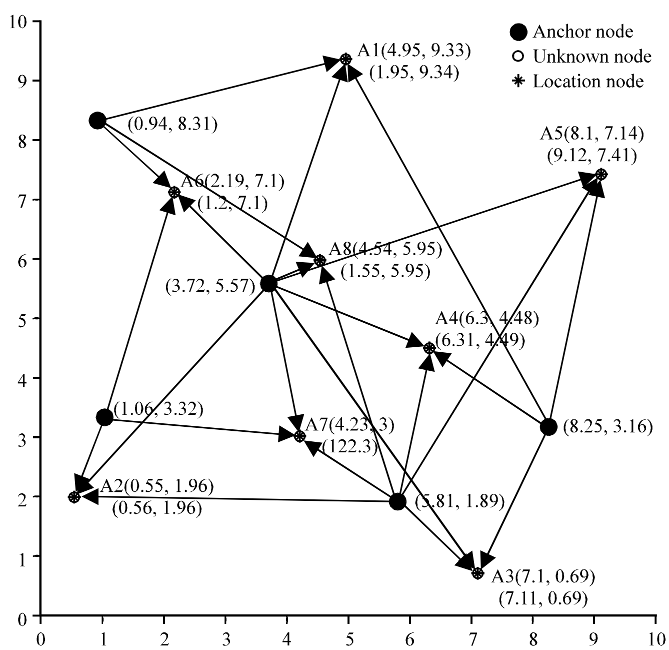

Fig. 1: Distribution of localization nodes for the GSA

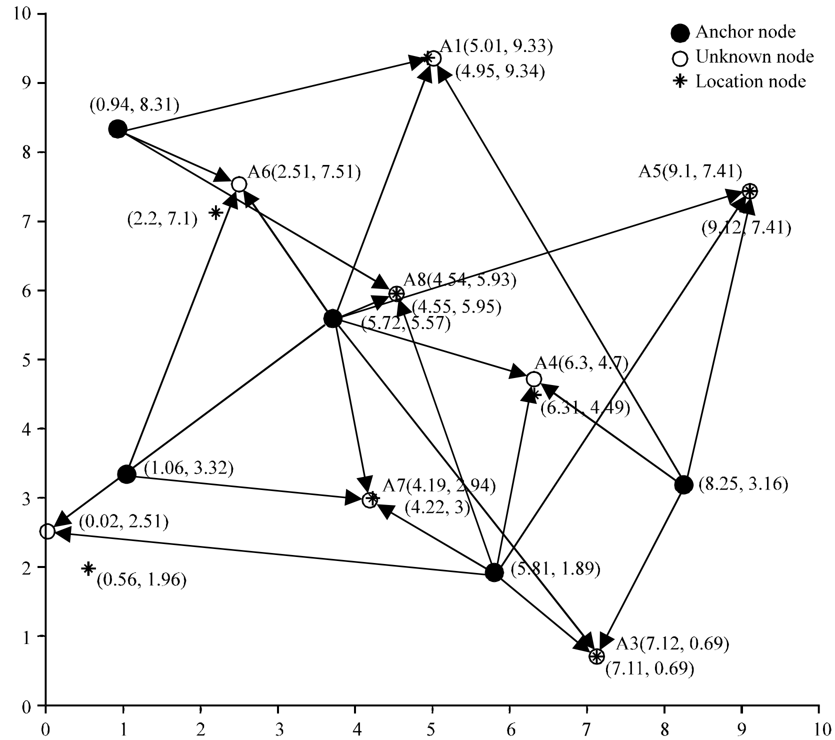

Fig. 2: Distribution of localization nodes for the GSA

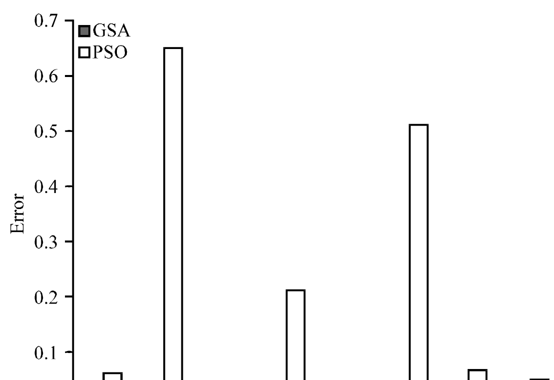

Fig. 3: Localization comparison between GSA and PSO

need to be determined using three nearest anchors from it, it can be seen that all unknown nodes are well localized for the GSA; for PSO, the localization accuracy of unknown nodes A1, A2, A3, A4, A5 and A6 is acceptable but the localization error of A7 and A8 is very low and the majority of unknown nodes have poor localization accuracy. Figure 3 shows the localization results of unknown nodes, from the comparison of the localization results of unknown nodes using the two methods, respectively, it is obvious that the localization accuracy differs greatly and the GSA can localize the unknown nodes more accurate than the PSO.

Case of range error: The range error is inevitable in the actual applications which directly influences the accuracy of localization error (Zhou *et al*., 2010). For comparison, we calculate the localization error for both the GSA and least square method, respectively when the range error is 5, 10, 15, 20, 25, 30 and 35%. Figure 4 shows the localization result when the range error is 5% using the GSA and the least square method, the average localization error of the least square method is 4.29% and the average localization error of the GSA is only3.23%. Figure 5 shows the localization result when the range error is 10%, the average localization error of the least square method is 7.25% and that of the GSA is also 5.16 %. Figure 6 illustrates the change of average localization error with range error, for the two method, it can be seen that the average localization error increases gradually with the growth of the range error but the localization error of the GSA is smaller than that of the least square method which

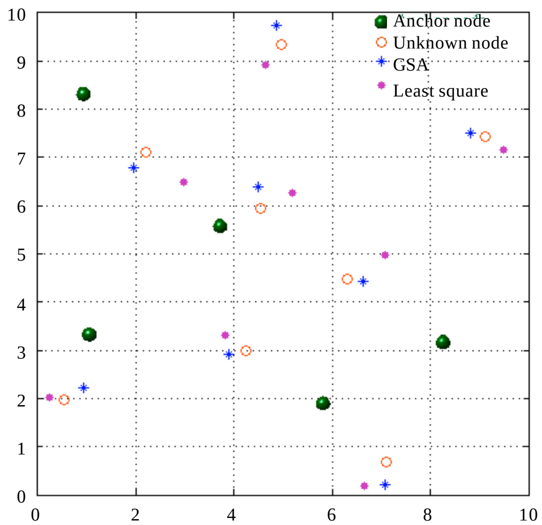

Fig. 4: Localization comparison when the range error is 5%

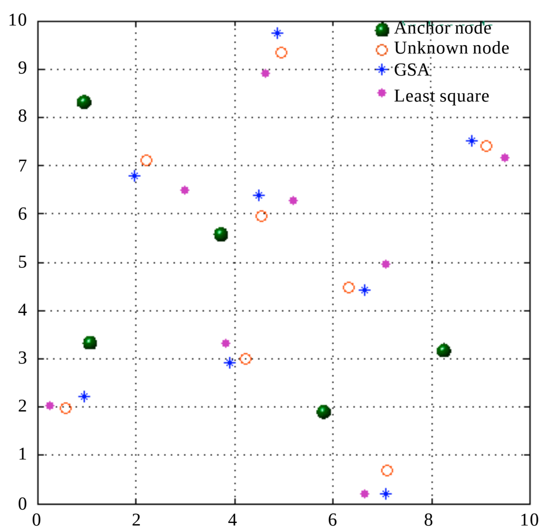

Fig. 5: Localization comparison when the range error is 10%

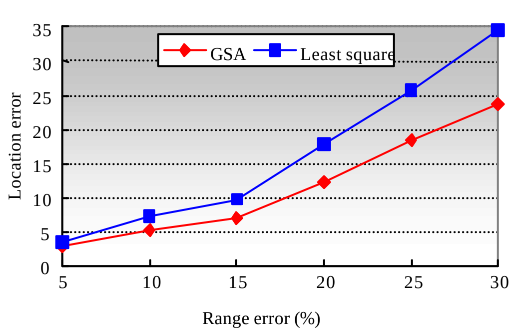

Fig. 6: Change of average localization error with range error

can achieve a better accuracy, moreover, the advantage of the GSA is more significant than its counterpart when the range error is relative big.

CONCLUSION

A novel algorithm named Gravitational Search Algorithm for nodes localization in Wireless Sensor Network is proposed, each of unknown node is determined by means of the iterative method. The simulation results show the GSA has a rapid convergence speed and can effectively improve localization accuracy of unknown nodes, especially in the case of the bigger range error, the GSA can achieve a better localization accuracy than the least square method. However, it needs a further improvement in the aspects of energy consumption of nodes and the stability of localization method.

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