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Homogeneous sensor deployment in WSN using PSO algorithm

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Abstract: In Wireless Sensor Networks (WSNs), sensors are randomly deployed in the sensor field which brings the coverage problem. Hence sensors need to be deployed in a position such that the sensing capability of the network is fully utilized to ensure high quality of service and thus reducing the complexity of problem. In this paper, Particle Swarm Optimization (PSO) was used to find the optimal positions of homogeneous sensor nodes to determine the best coverage. The results show that PSO is effective and robust to solve the coverage problem for sensor deployment also it produce more accurate results in terms of coverage and overlap percentage area than GA (Genetic Algorithm)within a relatively short execution process time.

Keywords: Node Deployment, Wireless Sensor Network, Particle Swarm Optimization, Genetic Algorithm, Homogeneous Nodes.

I. INTRODUCTION

A wireless Sensor Network (WSN) is a focused wireless network that composes of a number of sensor nodes deployed in a specified area for monitoring environment conditions such as temperature, air pressure, humidity, light, motion or vibration, and so on. The sensor nodes are usually involuntary to monitor or collect data from surrounding environment and pass the information to the base station for remote user access through various communication technologies [1]. The position of sensors affects coverage, communication cost, and resource management. This paper focuses on homogeneous sensor node deployment strategies that maximize the coverage for a given number of sensors [2].This paper is organized as follows: In section 2, Particle Swarm Optimization algorithm is introduced. In section 3, Genetic Algorithm basics are given. Section 4 presents the assumptions and models. In section 5, algorithm description is presented. In section 6, simulation and results and section 7 contains the conclusion.

II. PARTICLE SWARM OPTIMIZATION

Eberhart and Kennedy in 1995, established PSO algorithm to be widely used as a problem solving method in engineering and computer science [3]. PSO has been inspired by the foraging behavior of kinds like birds in nature [4].PSO maintains a set of particles, each one of them is comprised of two parts, position and velocity. The former represents the candidate or potential solution; the following important notes may be interested [5]:

- The swarm is defined as a set: $S=\{x_1, x_2, \ldots, x_m\}$ of m particles (candidate solutions).
- Let $X = \{x_i | i = 1,2, \ldots, m\}$ be the set of positions of the m particles. Where $x_i = \{x_{id} | d = 1,2, \ldots, n\}$ is the position of the i-thparticle.
- Let $V = \{v_i | i = 1,2, \ldots, m\}$ be the set of velocities associated with the m particles. Where $v_i = \{v_{id} | d = 1,2, \ldots, n\}$ is the velocity of the i-thparticle.
- The constant m is the number of particles and n is the dimensions of the problem at hand.

The classical inertia weighted PSO is characterized by the following two equations, velocity updating and position updating rules, respectively:

$$v_{id}(k+1) = \omega . v_{id}(k) + \varphi_1(P_{id} - x_i(k)) + \varphi_2(P_{gd} - x_i(k)) \quad \ldots (1)$$

$$x_{id}(k+1) = x_{id}(k) + v_{id}(k+1) \quad \ldots (2)$$

Where ω is referred to inertia weight, $\varphi_1 = U(0,c_1)$ and $\varphi_2 = U(0, c_2)$ are two uniform distributedrandom numbers in $(0, c_1)$ and $(0, c_2)$, respectively, $P_i = \{P_{id} \mid d = 1, 2, \ldots, n\}$, referred to personal best solution, is the best solution ever found by the i-th particle and $P_i \in \{P_i \mid i = 1, 2, \ldots, m\}$, may be denoted as P_{best} , $P_g = \{P_{gd} \mid d = 1, 2, \ldots, n\}$, called the global best, is the best solution ever found by whole population, may be denoted as G_{best} , the $P_i$and P_g represent the experiences (or memory) the whole population and individual ever encountered.

PSO algorithm starts by initial random placement of particles, in each iteration the particle will update its velocity and position and the solution will be evaluated by fitness function. If the current fitness is better than the fitness of P_{id} or P_{gd} the best value will be replace by current solution accordingly. This update process will continue until either maximum iteration or target solution is achieved [6].

III. GENETIC ALGORITHM

GA was invented by John Holland in the 1960s and was developed by Holland and his students and colleagues at the University of Michigan in the 1960s and the 1970s. In contrast with evolution strategies and evolutionary programming, the original goal of Holland was not to design algorithms to solve specific problems, but rather to formally study the phenomenon of adaptation as it occurs in nature and to develop ways in which the mechanisms of natural adaptation might be imported into computer systems [7]. GAs begin with a population of string structures created at random. Thereafter, each string in the population is evaluated. The population is then operated by three main operators - selection, crossover and mutation to create a new population of points. The population is further evaluated and tested for termination. If the termination criteria are not met, the population is again operated by the above three operators and evaluated. This procedure is continued until the termination criteria are met. One cycle of these operators and the evaluation procedure is known as a generation in GA terminology [8].

IV. ASSUMPTIONS AND MODELS

Fine-tuned optimizations in the real world are designed by adjusting to various, small-scale non-idealities, such as irregular shape of test area, and obstacles. In order to simplify these problems, the proposed method assumes the following:

1. Sensors have an adjustable range; they can have different sensing ranges.
2. The binary sensing model is used when calculating the sensors' coverage and overlap areas.
3. No obstacles are present in the entire target area.
4. The test area for wireless sensor networks needs to cover a clear boundary. It will not be an infinite area. For simplicity, a square area is assigned to be the test area in this analysis and simulations.

A. Weighted Sum Model

Probably it is the most commonly used approach for an accurate evaluation of a multi-objective optimization problem, especially of a WSN. The evaluation is performed by adding all the objective functions together, after multiplying each one by an appropriate weight that represents its importance [9][10].

$$f_{wsm} = \sum_{j=1}^{n} a_j w_j \qquad \ldots(3)$$

B. Binary Sensing Model

If an event occurred within the sensing range of the node then it is detected by that node, otherwise it is not. This model eliminates the dependency of the environmental conditions and the emitted signal strength on the sensors detection ability. The area covered by a node is usually assumed to be circular with radius (R_s) that equals the sensing range of that node. The probability of a location $P(x_p, y_p)$ being covered by a sensor (x_i, y_i) is described by the following equation [11]:

$$p_s = \begin{cases} 1 & \sqrt{(x_i - x_p)^2 + (y_i - y_p)^2} \le R_{si} \\ 0 & \text{otherwise} \end{cases} \qquad \ldots(4)$$

C. Adjustable Range Sensors

Continuous range adjustable sensors are able to adjust their sensing range to any value as required by controlling their power [11].

V. ALGORITHM DESCRIPTION

Our algorithm suggests a deployment method for sensors with homogeneous sensing range using PSO algorithm to optimize the distribution angle and the sensing range parameters. Those parameters are used by the distribution process to determine the exact position of each sensor node on the target area.

A. Sensors Deployment

Distribution method for homogeneous nodes determines both position and number of sensor nodes used to cover the test area depending on the value of two parameters: the distribution angle and the sensing range.The distribution angle (θ_{Dist}) is the value of the angle formed between any two adjacent nodes with the center node. Its value determines the number of nodes used in each tier thus the distance between each two of its adjacent nodes. The sensing range is the value of the sensor nodes' radius. The deployment process can be divided into two processes:

i. Initialization Process

It is the first phase of the deployment process in which the parameters that will be used to find each sensor location are calculated using four parameters: distribution angle, sensing range, total number of available nodes, and the test area dimensions. The calculations of these parameters are described as follows:

1. The size of the area covered by the sensor (A_s) is found by:

$$A_s = r_s^2 * \pi \quad \dots (5)$$

Where (r_s) is the sensing range and $\pi = 3.14$.

2. The distance between each two tiers (Dist_t) is calculated using equation (6). Where (θ_1) represents the angle shown in figure (1) and is calculated using equation (7).

$$\mathrm{Dist}_t = 2 * r_s * \sin(\theta_1) \quad \dots (6)$$
$$\theta_1 = 90 - \theta_{\mathrm{Dist}} /2 \quad \dots (7)$$

3. The distance between two adjacent nodes in the same tier ($\mathrm{Dist}_{\mathrm{node}}$) is found from:

$$\mathrm{Dist}_{\mathrm{node}} = \mathrm{Dist}_t * \sin(\theta_{\mathrm{Dist}})/\sin(\theta_1) \quad \dots (8)$$

4. The number of nodes used in the first tier ($\mathrm{nodeNum}_{\mathrm{tier}}$) is found using:

$$\mathrm{nodeNum}_{\mathrm{tier}} = 360 / \theta_{\mathrm{Dist}} \quad \dots (9)$$

5. The number of tiers required to cover the test area ($\mathrm{tierNum}_{\mathrm{total}}$) is calculated by:

$$\mathrm{tierNum}_{\mathrm{total}} = \mathrm{floor}((\mathrm{size}/2) * \mathrm{Dist}_t)/\sin(45) \quad \dots (10)$$

Wherefloor$((\mathrm{size}/2) * \mathrm{Dist}_t)$: represents the number of the required tiers vertically andsize: is the width and height of the test area.

The final step in the initialization process is to set the position of the initial node in the center of the test area, which is used in the distribution process as a reference to calculate the position of the other nodes.

ii. Distribution Process

This is the second phase of the sensor distribution process that is responsible for calculating the position of each sensor node depending on the parameters supplied by the PSO or calculated by the initialization process.

This distribution is achieved by calculating the position of each node depending on the previous node's position starting from the initial node as follows:

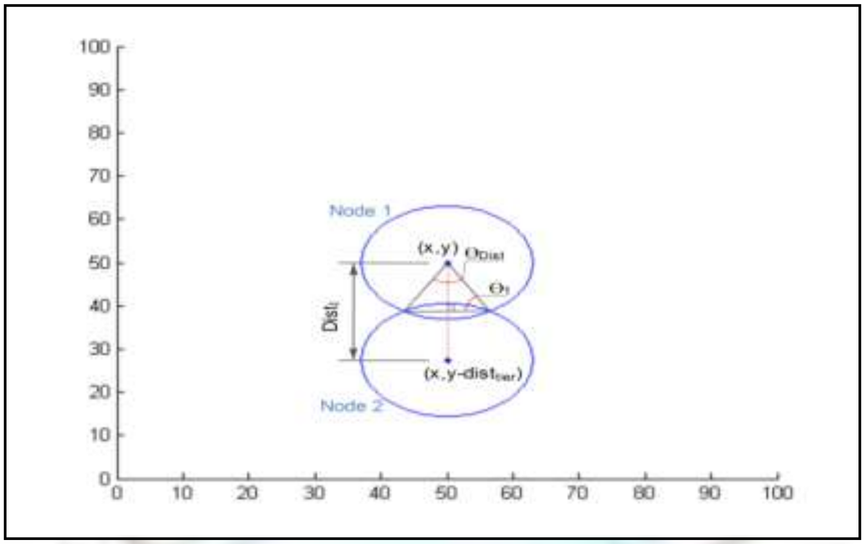

Figure 1. First node position calculation

1. Calculate the position of the first node in the next tier using ($\mathrm{Dist_t}$) value as shown in figure (1).
2. The position of the second node in the first tier (node 3) is set to $(x + t_x\,, y + t_y)$ where (x, y) is the position of (node 2), t_x and t_y represent the horizontal and vertical distances sequentially between the two nodes positions and are calculated using the following, see figure (2).
   $\theta_1 = (90 - (\theta_{dist}/2)) - (i * \theta_{Dist})$ … (11)
   $t_x = \mathrm{Dist_{node}} * \sin(\theta_1)$ … (12)
   $t_y = \mathrm{Dist_{node}} * \sin(90 - \theta_1)$ … (13)
   Where i : is a number between (0) and $(\mathrm{nodeNum_{tier}} - 1)$. This step is repeated for $(\mathrm{nodeNum_{tier}} - 1)$ times to complete the entire first tier nodes as shown in figure (3).
3. For all tiers except the first one, the values of t_x and t_y are used again to calculate the position of the next (tierNum) nodes, as shown in figure (4). The tierNum represents the number of the current tier, while the number of the first tier is 0.
4. Steps 2 and 3 are repeated until the tier is complete as shown in figure (5).
5. Whenever the node's position is located either outside the test area or too close to another node's position (less than r_s and $\mathrm{Dist_{node}}$), its position is used to calculate the next node's position then it is neglected.

The sensor distribution process is complete either when all the available sensor nodes are used or when the entire test area is covered.

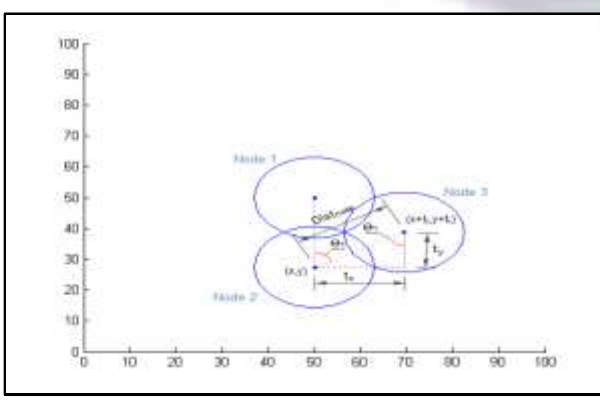

Figure 2. Position calculation for the tier's next node

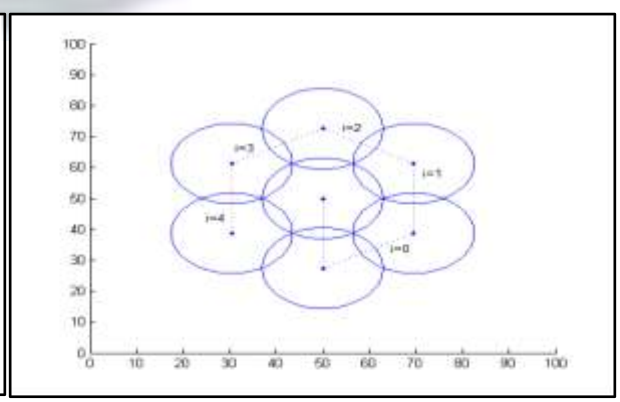

Figure 3. First tier nodes' distribution

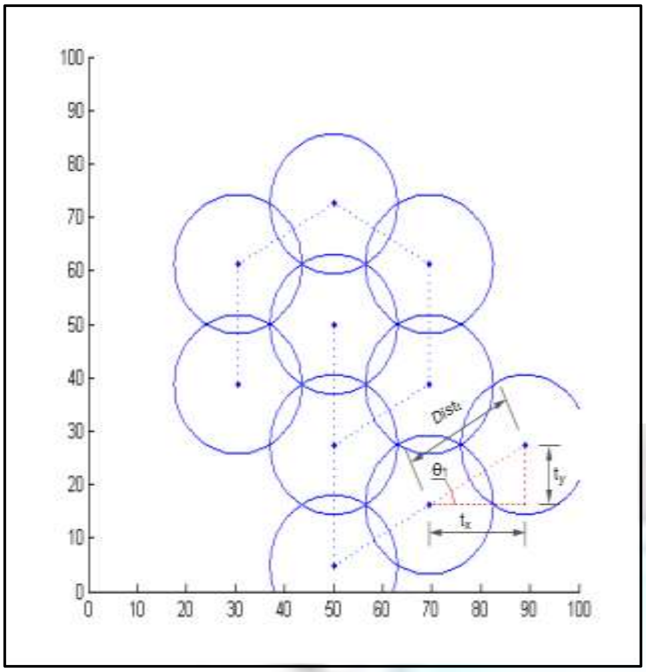

Figure 4. Calculate nodes' positions to complete a raw in the tier

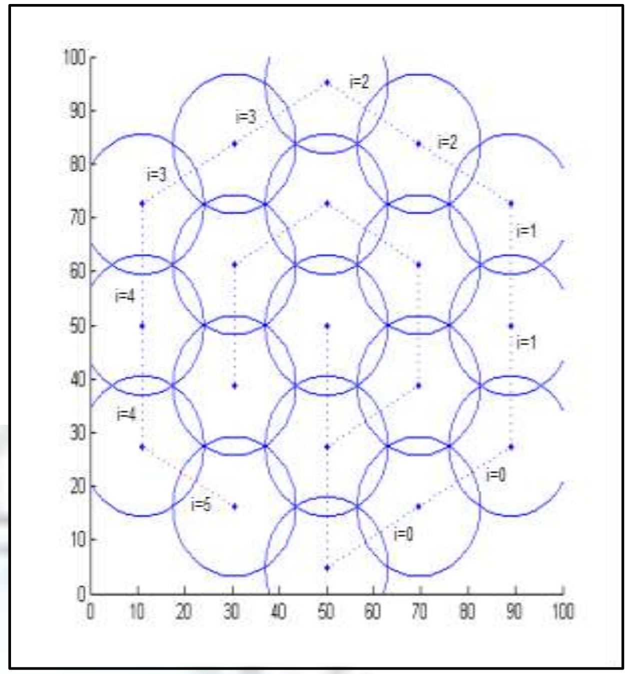

Figure 5. Second tier nodes' distribution

B. Fitness Evaluation

The sensor deployment fitness value is evaluated after each iteration. By using the weighted sum model, three fitness parameters(coverage, overlap and sensing range) were used to calculate the fitness value as shown in the equation (14).

$$\text{fitness} = w_1 * (\text{coverage}) + w_2 * \text{overlap} + w_3 * \text{range} \quad \ldots (14)$$

The coverage and overlap values are calculated by dividing the target area into a matrix. The distances between each cell and all the nodes are calculated, and compared with the sensing ranges of those nodes. According to the binary sensing model, the cells located at distances less than or equal to the sensing range of a node is covered by that node.

VI. SIMULATION AND RESULT

The simulation of the suggested method was performed to solve the coverage problem for the homogeneous WSN first by using PSO algorithm (its parameters are shown in table 1), then by using GA (its parameters are shown in table 2). The number of sensors is set to 25, covering the area of 10000 m^2. Sensor nodes range can be adjusted to any value between 5-25mwhile the distribution angle value is between 0-180. The fitness weights percentage (w_1, w_2, w_3) used during the fitness calculation are 4:2:1respectively. The final sensors' deployment obtained from using the PSO is shown in figure (6).

Table 1: PSO Parameter Setting

Swarm Size	50
	2.8
	1.2
Max Iterations	200
Max inertia weight	0.8
Min inertia weight	0.4

Table 2: GA Parameter Setting

Max Iterations	100
Mutation probability	0.01
Population Size	50
Chromosome Size	16

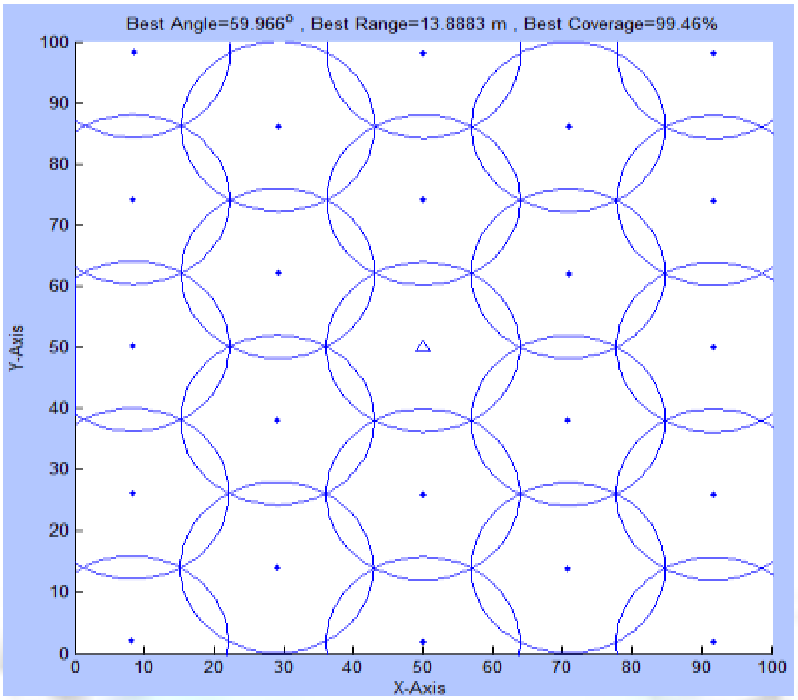

Figure 6. Sensors deployment using PSO

Figures (7) and (8) show the coverage and overlap results obtained from the simulation of suggested method using both algorithms. It can be seen that PSO algorithm produce a better coverage over the target area than when GA is used. While the overlap results show that PSO algorithm produce higher overlap than the GA. The final sensor deployment using PSO had (99.46%) coverage and (16.62%) overlap with distribution angle and sensing range of (59.966^o) and (13.8883)m after (47.2343) sec, while the deployment using the GA had (99.06%)coverage and (16.38%) overlap with distribution angle and sensing range of (59.3793^o) and (13.748)m after (86.8922) sec.

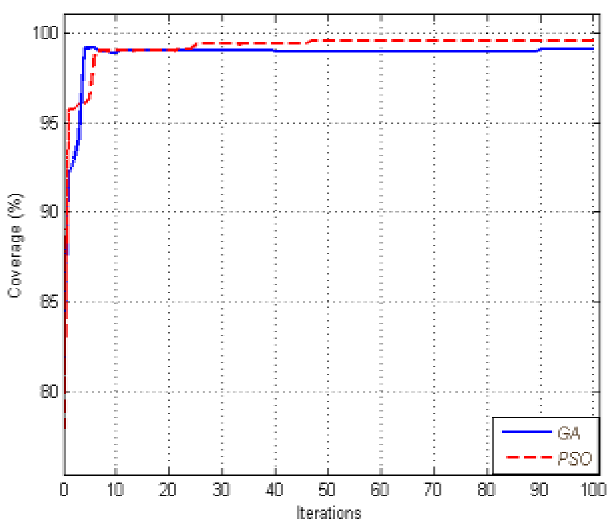

Figure 7. Coverage vs. Iterations

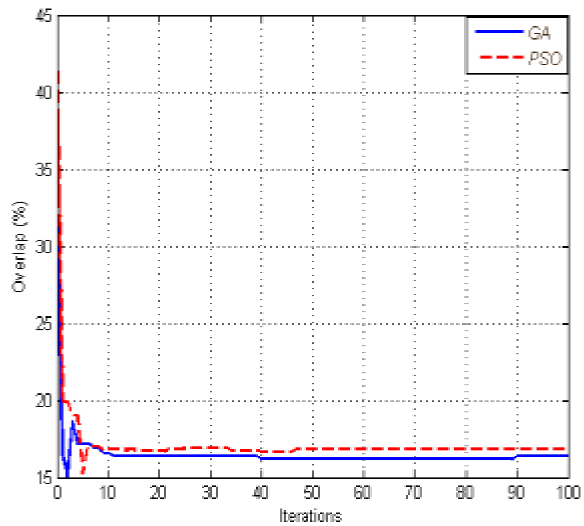

Figure 8. Overlap vs. Iterations

For accurate comparison between the two algorithms, multiple tests were performed using different numbers of nodes and weights. The results shown in table (3) and table (4) below contain the average of 10 tests for each scenario.

Table 3. Multi-Dimensional Optimization Results Using PSO

Weights	Node no.	Range (m)	Angle (degree)	Coverage %	Overlap %	Fitness	Time (sec)
4:1:2	10/9	21.9120	87.7564	97.9	29.06	0.875623	21.09173
4:1:2	25/23	13.8468	59.8093	99.51	16.76	0.756959	46.98003
4:1:2	40/40	10.3286	60.5184	97.67	18.06	0.729034	56.02653
4:2:1	10/7	24.9994	59.6794	95.41	13.02	0.778973	18.6277
4:2:1	25/23	13.9149	59.9536	99.57	16.8	0.70141	47.1959
4:2:1	40/39	10.9914	59.9999	99.07	18.75	0.693172	73.4912

Table 4. Multi-Dimensional Optimization Results Using GA

Weights	Node no.	Range (m)	Angle (degree)	Coverage %	Overlap %	Fitness	Time (sec)
4:1:2	10/9	21.8491	88.05033	97.86	29.47	0.875738	24.92849
4:1:2	25/23	13.7963	59.91943	99.27	16.8	0.757183	67.48293
4:1:2	40/40	10.2212	64.19593	97.20	18.73	0.734797	66.644
4:2:1	10/7	23.6378	62.22383	94.15	13.10	0.779642	20.2055
4:2:1	25/23	15.0208	54.764	97.50	19.03	0.727626	48.3388
4:2:1	40/39	10.5147	59.6182	97.67	17.61	0.695544	95.7755

VII. CONCLUSION

PSO algorithm has the ability to achieve optimal solution of coverage problem in homogeneous WSNs. The simulation results obtained from PSO algorithm indicate that it can provide a coverage that may exceed 97% and in a relatively short execution time. When comparing PSO results with results obtained from GA it is clear that PSO is more robust and accurate than GA and the execution time for GA (in all cases) is more than the execution time of PSO algorithm.

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