A REAL TIME-BASED OPTIMIZED NODE LOCALIZATION TECHNIQUE FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

Industrial Internet of Things (IIoT) is playing a vital role in modern industries in terms of machine condition monitoring, early failure prediction, hazard gaseous monitoring, equipment and process monitoring etc. Sensor node location awareness is the prime requirement for any Wireless Sensor Networks (WSN) deployed in the industrial field. The wireless sensors installed in different area needs to be estimated first for further clustering and data transfer to the main control station. It’s an inimitable issue to recognize and maximize the coverage of the sensor nodes to ensure high quality of service (QoS). In this paper it has been attempted to find the position of the nodes by simulations and with experiment using Cat Swarm Optimization (CSO), a new swarm-based optimization algorithm inspired from the behaviour of cats. A small wireless sensor node group is developed to test the algorithm. The number of sensor nodes localized, and the localization accuracy has been the prime factor of consideration. It has been observed that utilizing CSO algorithm offers much better results than the other renowned swarm-based optimization algorithm Particle swarm optimization (PSO). The quick searching nature CSO algorithm helped to find the localization faster with best positioning accuracy and stability in wireless sensor network node localization.

Keywords: WSN, IIoT, localization, RSSI, CSO and PSO.


1. INTRODUCTION

Wireless Sensor Networks are distributed networks consist of sensor nodes which can senses the indented information for what it has been deployed for and update the data to the base station (BS) [1]. IIoT techniques are enabled in industries to increase the productivity and for better
maintenance. Are WSN technology emerged in all areas of applications including medical, military, process and offshore industries due to its easy implementation and maintenance. The major issues with WSN are the deployment of the nodes, location awareness and energy aware clustering. Traditionally location awareness in WSN is understood by equipping a global positioning system (GPS) with each sensor node; however, equipping a GPS in each deployed sensor node is not an economical solution. Therefore, an alternate solution needs to be found to address the localization issues, which comes out in the form of enabling the optimization algorithms for localization. The conventional optimization techniques are useful only for less number of nodes and requires more computational efforts with respect to the problem size. Hence an optimization method is required to overcome all these issues and currently researchers have developed lot more algorithms specifically based on the bio inspired techniques. The optimization based these algorithms are computationally efficient compared to the conventional analytical methods. In this paper we tried to make a real test bed to analyse and compare the performances of the proposed CSO based localization with other popular algorithm PSO. The features of these algorithms are discussed based on implementation, accurate solutions, computational efficiency and fast convergence.

This paper is organised as section 2: Literature review on different localization techniques and feasibilities. Section 3: Proposed localization techniques in WSN. Section 4: Problem statement and methodology. Section 4: the real time implementation of the sensor nodes for an indoor environment Section 6: Results and discussion on both simulated and experimental performance. Section 7: Conclusion and possible future scope.

2. LITERATURE REVIEW AND RESEARCH ISSUES

2.1. Traditional Approach
The existing localization techniques [2] for WSN give an insight of the strength of localization algorithms. WSN localization employs mainly two techniques [3]: namely, range based and range free. Range based is the popular scheme; in this mostly distance or angle measurement or the combination of distance and angle measurement is applied to localize the nodes. The Received Signal Strength Indicator (RSSI) is the famous method of measuring the sensor node position, which utilizes node distance calculation as emphasized in [4]. The other common methods are: Time of arrival (ToA), Angle-of-Arrival (AoA), Triangulation and Maximum Likelihood (ML) estimation. Time based methods, Time of Arrival (ToA) estimates the distance by the difference of propagation time between two nodes with known velocity of signal propagation. Angle-of-Arrival (AoA) also known as Direction of Arrival (DoA) techniques calculates the position by geometric coordinates with the angle from where signals are received. The ToA, and AoA methods are surpassing ahead RSSI as per accuracy is a matter of concern due to loss in radio signal amplitude by environmental factors particularly noise in distance measurement. Triangulation technique utilises the direction measurement of the node instead of the distance measured in AoA systems. The node positions are determined by laws of trigonometry by applying sin\(\theta\) and cosin\(\theta\). The Maximum Likelihood (ML) estimation resolves the position estimation of a node by minimizing the differences between the measured distances and estimated distances. The RSSI technique uses power received and attenuation of radio signal exponentially with the increase of distance. The distance in RSSI can be calculated by loss in power by comparing the theoretical model. The time of arrival and time difference of arrival methods are based on the propagation time between the transmitter and receiver.
2.2. Bio-Inspired Algorithm based Approach

Localization system emphasized in [4] using PSO algorithm for unknown emitter nodes assumes that there are four anchor nodes with known locations and one or more unknown nodes; it uses RSSI to transmit RF signals that can be received by the four anchor nodes. The survey of localization systems for WSNs using bio inspired algorithms [6] reveals the strength and weakness of each algorithm. Review in [7] Analyses the node localization awareness by dividing into three distinct components: distance-angle estimation, position computation, and localization algorithm. Besides providing a research viewpoint and showed sub areas of the localization problem that need to be studied separately. The centralised localization techniques approach requires many beacons in order to localize all dumb nodes. In [8] a genetic algorithm (GA) based node localization algorithm determines locations of all non-beacon nodes by using an estimate of their distances from all one-hop neighbours. Similarly, a two-phase centralized localization technique [9] that uses a combination of GA and simulated annealing algorithm proposed to address the uncertainty issue. A case study on bio inspired algorithm [10] is dealt in and presented the convergence and localization error. The iterative methods by Bacterial foraging algorithm (BFA) in comparison with PSO is analysed in simulation. The position estimation and localization error is determined in [11] for Shuffled frog leaping algorithm and firefly algorithm in [12-13] in comparison with the well-known PSO.

3. PROPOSED LOCALIZATION METHOD IN WSN LOCALIZATION

This segment presents a localization method that combines the data from RSSI and initial deployment information. After the deployment, the sensor node locations are determined by RSSI value, and then the sensor nodes communicate with their adjacent nodes to exchange their radio signal strength. In this paper, to improve the localization accuracy, heuristic based localization algorithm is formulated that uses both the deployment measurements and the adjacent nodes RSSI-based distance estimation to construct the unknown node’s probability function of the correct position. The node placement pattern is as shown in Fig.1.

3.1. Cat Swarm Optimization Algorithm

Cat Swarm Optimization (CSO) is one of the new heuristic optimization algorithms based on swarm intelligence [14] based on the behaviour of the cat. It consists of two sub models representing the behaviour of cats namely “seeking mode” and “tracing mode”.

Seeking mode: Create copies of cats and if stores the present position of the cat. Calculate the fitness value for all the coordinate points by Eqn.5. Select the coordinate points and replace with best candidate points.

\[ P_i = \frac{(f_i - f_b)}{(f_{\text{max}} - f_{\text{max}})} \]  

where \( f_i \) is current fitness and \( f_b \) is best fitness. If the objective is to minimize the solution, then \( f_b = f_{\text{min}} \); otherwise \( f_b = f_{\text{max}} \).
Tracing mode: The cats in this sub model depict the pray tacking of cat’s behaviour. Update the velocities for each cat direction as per Eqn.7. Check the velocity for in range and if not, it has to be set equal to the maximum limit. Update the position of each cat according to Eqn. 8.

\[ v_{id} = v_{id} + r \cdot c \left(x_{best} - x_{id}\right) \]  
\[ x_{id} = x_{id} + v_{id} \]  

Where, \( x_{id} \): current position of the cat and \( x_{best} \): local best position of cat, \( v_{id} \): velocity of the cat in an \( M \)-dimensional solution space, \( r \): random number (0-1) and \( c \): acceleration constant (0.5 - 2)

In this study, the CSO proposed by Chu [17] for searching the sensor node positions is used for the global optimization. CSO has been used in various applications such as IIR filter design WSN clustering [18-19] etc. like other heuristic algorithms PSO used in [4]. The CSO is initialized with a population of random solutions, also called cats.

3.2. Localization Model

In the proposed approach, the target nodes are determined by minimizing the objective function. The following approach is formulated for the localization of the scheme:

- For a simulated environment, initialize the \( M \) sensors nodes (target node) and \( N \) beacons randomly in a sensor field with a communication range of \( R \).
- The beacon nodes know their position coordinates.
- Calculate the real distance \( d_i \) ie the actual distance between the beacon and each deployed sensor nodes using Eqn.8.

\[ d_i = \sqrt{(x_i - x_m)^2 + (y_i - y_m)^2} \]  

- Assign measured distance ie the distance obtained by the beacons using ranging techniques. This is made by adding noise to the real distance \( \hat{d}_i = d_i + n_i \); where \( n_i \) is a random value is uniformly distributed in the range \( d_i \pm \frac{p_n}{100} \).
The target node is known as localizable node if there are at least three anchor nodes within the transmission range of the target node. The fundamental reason behind this requirement is that, the coordinates of the three anchor nodes A \((x_1, y_1)\), B \((x_2, y_2)\), and C \((x_3, y_3)\) and the distance between the target node \(d_i\) and three beacon nodes are known. Then, by using the trigonometric laws of sines or cosines, the coordinates of the target node are calculated. In this estimation method, the distance measurements of three or more anchor nodes are used to minimizing the error between actual distance and estimated distance. The method of calculation can be seen from Fig. 2.

![Figure 2 Trilateration Positioning Method](image)

For each localizable node, to determine the position of the target node. The nodes are initialized with the centroid of the anchor nodes that are within transmission range by:

\[
(x_c, y_c) = \left( \frac{1}{N} \sum_{i=1}^{N} x_i, \frac{1}{N} \sum_{i=1}^{N} y_i \right)
\]  

(9)

For each sensor that can be localized, the algorithm applied to minimize the objective function which represents the error function given by the Eqn.10.

\[
f(x, y) = \frac{1}{N} \sum_{i=1}^{N} (d_i - \hat{d}_i)^2
\]

(10)

Where \(d_i\) is the actual distance between un known and anchor nodes, \((x_i, y_i)\) is the corresponding beacon positions, \((x_m, y_m)\) is the position occupied by the particle and \(N\) is the number of beacons having transmission coverage over that sensor.

The algorithms return the closest values of the coordinates \((x_m, y_m)\) such that error is minimized. Then the algorithm is applied to the next sensor in range.

The localized sensors are removed from the sensor list and act as beacons in the next round of operation.

The localization error is computed after all the \(N_l\) nodes estimate their coordinates, it is the mean of squares of distances between actual node locations \((x_i, y_i)\) and the estimated node locations \((x_i', y_i')\), i.e., \(i = 1, 2, ..., N_l\) is determined by CSO and PSO. This is computed as given in eqn.11.

\[
E_l = \frac{1}{N_k} \sum_{i=1}^{N} ((x_i - x_i')^2 + (y_i - y_i')^2
\]

(11)

Fig 3. Represents the flow chart of CSO based iterative localization.
4. REAL TIME IMPLEMENTATION FOR INDOOR NODE LOCALIZATION

4.1. Preliminaries

In this experiment, a wireless sensor network positioning solution based on ZigBee technology is adopted. The CC1100 low power transceiver produced by Texas Instruments serves as the nodes of localization network. The CC110 transceiver with PIC16F87/88 can detect the RSSI values of the target nodes within the communication region. The experimental set up is illustrated in Fig.4. The target node in the centre is located based on the RSSI values received from its beacon nodes. The WSN is established by the gateway node. At first, all beacon nodes receive the signal of positioning information sent by the gateway node. The beacon nodes then transmit signals to the target node which in turn send these data to the gateway node. The gateway node takes out the RSSI values that are used for the position estimation using LabVIEW. The LabVIEW run the CSO/PSO positioning algorithm and provides the values of the nodes position of the target node as a coordinate.
4.2. Localization System Model

The experimental localization system model is shown as block diagram in Fig.4. It has the following important components, namely, the transceiver, RSSI to distance translator, CSO/PSO optimizer, memory unit and transmission scheduler. The beacon nodes deployed with known location; it starts to transmit its location to the target node. Then, the transmission scheduler will request the beacon nodes to send their beacon messages that include their estimated positions. Apart from that the RSSI to distance converter also measures the RSSI values of the received beacons and convert them to a distance. The CSO/PSO optimizer then finds out the sensor node’s estimated position using Eqn.4. A gateway node is used to receive the signals from the deployed sensor nodes and send it to the computer (BS) for calculation. Fig.5 represents the localization model.

4.2.1. Transceiver System

Each sensor node has a transceiver and a microcontroller system. The transceiver system is used to receive beacon packages from the adjacent sensor nodes, as well as to transmit its beacon packages. In this experiment, the hardware has been developed with CC1100 low power 1 GHz transceiver [15] and PIC16F87/88 microcontroller [16] processor for this experiment.

4.2.2. Transmission/Reception Schedule

In order to avoid data collision during transmission and reception, a transmission scheduler is developed for easiness, a simple polling process is adopted. After a sensor node has been deployed, it starts to poll its nearby sensor nodes to send its beacon packages. After the sensor has been successfully localized, the position of it will be changed.

4.2.3. RSSI to Distance calculation

- The CC1100 has an inbuilt RSSI which gives the value through the RSSI pin as analog output. The RSSI to distance calculation is computed by eqn.12

\[
\hat{d}_i = 10^{\frac{d_{0-RSSI}}{2n}}
\]

(12)

Where, \(\hat{d}_i\) is the distance; \(d_0\) is the received RSSI value for 1m distance and \(n\) is the path loss exponent. \(d_0\) and \(n\) are obtained before the system deployment. The LabVIEW converts the power levels in distances.

![Figure 4 Experimental set up](http://www.iaeme.com/IJEET/index.asp)
4.2.4. CSO Optimizer

The CSO optimizer is used to determine the sensor node’s estimated position, by combing the deployment and inter-node distances information using Eqn.10. The CSO algorithm searching for the sensor nodes position is utilized for the global optimization. The pseudo code for the CSO algorithm given in Table.1 is applied for the implementation. In each time step, the CSO optimizer changes the velocity that the cat moves towards its $p_{best}$ and $g_{best}$ with a random value of weight. In our study, each cat consists of two members, representing the X and Y coordinates of the sensor node.

All the three beacons BN1, BN2 and BN3 transmit the sensed temperature from the environment to the BS. The transmitted packets consist of the node ID, time, battery voltage, node RSS value etc. The information from sensor nodes to BS (computer) is received through serial port.

5. RESULTS AND ANALYSIS

5.1. Simulated Performance

Simulation of the WSN and its performance evaluation is done in LabVIEW with windows computer. For initial study 50 target nodes and 10 beacons are randomly deployed in a sensor field having dimensions of 100×100 square units. Each beacon has a transmission radius of $r = 25$ units. 30 trial experiments of localization are conducted for $P_n = 2$ and $P_n = 5$. For PSO the recommended settings are considered from [11] for faster convergence and adaptable weight and for CSO, [19-20] are considered as core reference for parameter settings. For PSO, initial values of $\omega = 0.7$ and $c_1 = c_2 = 1.5$ were recommended for faster convergence after experimental tests by [10]. For CSO simulation, initial values of $c = 1.5$ and $r = [0, 2]$ recommended for fast convergence. The detailed study on localization using all the three algorithms are made with five trial runs out of 50 experiments and the results are summarized in Table 2. The results of various trial runs are not same due to the stochastic nature of the algorithms; the average results of experiments conducted are summarized in Table.2. The performance in terms of number of nodes localized and localization error as shown in Table.2, the CSO values are less compared to PSO which is evident for better performance of CSO. Similarly, the computation time ($T_c$) required for CSO is notably less than the PSO. The position estimation with respect to beacon nodes and target nodes by the algorithms are shown in Fig. 6(a) and Fig. 6(b).

The proposed algorithm is tested for various aspects for localization accuracy including the effect of additive Gaussian noise, beacon and target node densities, communication radius etc.
A Real Time-Based Optimized Node Localization Technique for Wireless Sensor Networks

**Effect of Gaussian Noise in localization accuracy:** When the of percentage of noise ($P_n$) in distance measurement is apparently seen that for all three algorithms the localization error decreases when the value of $P_n$ is reduce to 2 from 5. The results are shown in Table.3.

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Percentage Noise $Pn = 5$</th>
<th>Percentage Noise $Pn = 2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean $N_{NL}$</td>
<td>Mean $E_l$</td>
</tr>
<tr>
<td>PSO</td>
<td>5.7</td>
<td>0.58</td>
</tr>
<tr>
<td>CSO</td>
<td>4.5</td>
<td>0.32</td>
</tr>
</tbody>
</table>

- **Effect of transmission radius on localization accuracy:** The increase in transmission range in terms of communication radius of anchor nodes from $r=20$units through 40units shows an improving performance as this decreases the localization error. However, when the $r$ varied over 45units, it is observed that the distance error increases. Hence the percentage of localized nodes depends on the transmission range as shown in Fig. 8.

- **Effect of beacon node density on Localization accuracy:** With the increase in number of beacon node to localize the unknown nodes, it is evident that the number of node localized also increases; also it is necessary to have beacon $N \geq 3$ to locate the position of unknown nodes. The percentage of the localized nodes depends on the number of beacon nodes as shown in Fig.9. The performance of CSO overpowers the other algorithm.

### 5.2. Experimental Performance

The results of the experiments are designed to compare the proposed CSO algorithm with the RSSI based localization algorithm in terms of localization error. The test has been conducted at 30 different target node positions within the area ABCD. The beacon nodes are positioned at the four corners of the rectangle area as shown in Fig.11. The averaged RSS distances between beacon and target node in indoor environments is shown in Fig.12.
Here, it is observed that RSSI based distance measurement has more variation due to the impact of diminishing and shadowing. In indoor, there were more reflections due to the presence of walls and other metallic objects. Since each of the signals reflected, takes different path having different amplitude and phase. By applying the PSO and CSO algorithms it is able to reduce the mean position error considerably. The RSSI based method provides the distance estimation with an average error of 1.21m in indoor environment. The CSO algorithm is applied to minimize the localization error to 0.48m, whereas PSO offers 0.59m. Fig.14 depicts the position error computed by RSSI, PSO and CSO algorithms. It is observed that the heuristic algorithm CSO helps to reduce the localization error over PSO due to its better global searching efficiency. The Table 4 shows the mean and standard deviation value of position error computed by the algorithms.

### Table 3 Mean Localization Error

<table>
<thead>
<tr>
<th>Algorithm/ Method</th>
<th>Number of Nodes=30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>RSSI</td>
<td>1.21</td>
</tr>
<tr>
<td>PSO</td>
<td>0.59</td>
</tr>
<tr>
<td>CSO</td>
<td>0.47</td>
</tr>
</tbody>
</table>

### 6. CONCLUSIONS

Localization in WSN is an important performance issue as this plays a vital role in energy efficient cluster-based protocol. The main objective in this paper is to minimize the localization error using bio inspired algorithms.
In the experimental study, a low power transceiver with microcontroller has been used to realize two optimization techniques, namely, the PSO and the CSO for optimizing the node localization in a WSN. The RSSI is used to estimate the relative distance from the target node to the receiver node. However, it is found that the accuracy of this approach is not fair enough and gets affected by the indoor transmitting environment. The performance of the proposed techniques has been evaluated with experimental results. The results display that both PSO and CSO have better performance with improved accuracy than simple RSSI technique. However, the CSO is slightly edges over PSO and moreover requires less computation time due its global searching strategy. The simulated results display as an evidence that the CSO algorithm performs better than PSO in terms of number of nodes localization accuracy and computing time. It is also analysed the impact of other parameters such as additive Gaussian noise, beacon density, target node densities, and communication radius on localization accuracy.

Further, the scope of work is to apply the algorithms for the centralized energy aware clustering to minimize the energy utilization in WSN. In addition, the CSO can be collaborated with other optimization algorithm to further minimize the location estimation error.

REFERENCES


