Sensor Node Position Estimation using Neural Network for Wireless Sensor Networks

Ajay Kumar, V. K. Jain, P. P. Bhattacharya

Abstract*: Applications such as smart home, environmental monitoring, smart traffic management etc. are made possible with the help of Wireless Sensor Networks and other recent technologies. Identification and communication setup is very important task, especially in Internet of Things or Internet of Everything, among the different sensor nodes in the network and other mobile devices. Designing a efficient, reliable, scalable and cost effective localization process is required for the effective communication. Range free node estimation technique named Centroid algorithm is used to obtain the estimated positions to improve the precision. Other neural network-based technique is also used to improve the location precision for the sensor nodes. The neural network-based methods like radial basis, feed forward and recurrent network has been used to improve the accuracy of node position. A comparison of all the techniques has been done and it has been discovered that the neural network-based processes are better and provides result with higher accuracy.

***Index Terms*: Centroid Algorithm, Internet of Things, Neural Network, Wireless Sensor Networks**

I. INTRODUCTION

Wireless sensor network (WSN) is the vital component of many recent advancements and technologies like Internet of Things (IoT). The sensor node consists of nodes in hundreds and thousands in numbers which can sense various parameters like temperature, sound etc and perform various required computations and also can set up communication with other sensors in the same network. Wireless network is setup in the interested area and the nodes are scattered randomly for number of applications such as distributed computing, fault detection and diagnosis, security and tactical surveillance, defence operations, etc. The nodes senses the required data and sends their gathered data to destination nodes through relay nodes, which is connected to central depository also called base station. The base station is connected to the outside world through wired or may be wireless network [1].

Information or data gathered is valueless or can not be utilized until the location of the node is known. That is why it is necessary to obtain the accurate position of the sensor nodes. Localization is used to obtain the actual position of the sensor node and hence the data sent by the respective nodes can be further utilized. Easiest way to obtain the position is to setup network manually which is practically not feasible in unreachable areas [2]. Other option is to ass global positioning system (GPS) to the every deployed sensor nodes but GPS requires Line of Sight(LoS) between sender and receiver and also setting up GPS is costly and may also effect the accuracy due to poor signal strength. Number of localization methods has been proposed to obtain the node position in wireless sensor network [3].

Anchor or Beacon nodes are used in the methods to localize a sensor node, who has their accurate position with the help of GPS or placing them at fixed or obtained coordinate position [4]. Depending upon the methods used the methods can be classified as range free and range based techniques [5].

Localization methods:

1. Range free methods: Centroid, APIT, DV Hop
2. Range based methods: ToA, TDoA, AoA, RSSI

Range-free algorithms uses the proximity sensing, radio communication or information related to node connectivity , to obtain the sensor node positions. Range free methods are CPE [6], centroid [7], APIT [8], and the distributed algorithm in [9]. Range-based algorithms assess the distance among the sensor nodes using extents such as time of arrival (ToA) [10], time difference of arrival (TDoA), Angle of arrival (AoA) [11], received signal strength (RSS) [12].

Neural Networks is equally an efficient option for localization. The biological neuron network is known as neural network. The term neural network is also referred as artificial neural networks in modern time, which consists of artificial neurons or nodes. Thus the term artificial neural network may refer to either biological neural networks or artificial neural networks. Weights are used to model the connections of the neurons. Excitory connection is with the positive weights and inhibitory connection is with negative weights.

For faster and accurate localization, implementation of neural network in WSN is a positive and promising approach[15]. In this paper various classes of neural networks are implemented and compared. Those are Radial basis, Feed Forward Networks and Recurrent Networks.

A centroid algorithm proposed by Bulusu et al. in [18], in which un-localized nodes uses beacon's position and locates themselves as the centroid of the polygon formed by the beacon's. An improved centroid method is proposed, which achieved significant enhancements, by J. Blumenthal and Yu Liu et al [19].

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II. PROPOSED METHODOLOGY

A. Centroid Algorithm Approach

Anchor nodes with known positions with the help of GPS are used to find the location of unknown nodes in centroid algorithm. This technique first checks for an unknown node (node whose location is to be found) to be in the communication range of the anchor node. Following actions are performed for the implementing the centroid algorithm:
All the nodes with known positions broadcast their location to all unlocalized sensor nodes available in their transmission range. The distance between the nodes can be measured to check whether a node is in transmission range or not, which can be measured using received signal strength (RSS). RSS value obtained is inversely proportional to distance (1).

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \quad (1)$$

where, P_r = received power,
P_t= transmitted power,
G_t = antenna gain (transmitter),
G_r = antenna gain (receiver),
λ = transmitter signal wavelength (meters).
d = separation between anchor and unknown node

- For a fixed time T from various anchor nodes, the nodes receive the signal and obtain location information.
- Compute the centroid (*Xest*, *Yest*) position from all of anchor nodes in the range by using the formula.

$$(X_{est}, Y_{est}) = \left(\frac{X_i + \ldots.. + X_n}{N}, \frac{Y_i + \ldots.. + Y_n}{N} \right) \quad (2)$$

where, (X_i, Y_i) & (X_n, Y_n) are anchor nodes coordinates, (X_{est}, Y_{est}) are the approximated position of the node, and N is the adjacent connected anchor nodes.
Each unknown node in the network can estimate its location by location information of anchor nodes and centroid of polygon formed with beacon nodes.

B. Neural Network Approach

Neural network based localization is the technique to obtain the accurate position of the sensor nodes. Neural network is the interconnection of sensor nodes with the activation function. Different activation function can be used to obtain various categories of the neural networks.

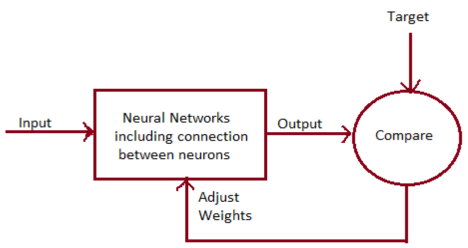

Fig. 1: Neural network architecture

Radial basis, feed forward and Recurrent neural network methods have been compared in this paper. The centroid algorithm is used as a reference for the performance verification of the implemented neural network.
The neural network is trained with the recorded values of positions of unknown node. Hidden layer transforms the input provided to the input layer which is further processed by the output layer to give the estimated positions of the nodes. Mean square error (mse) formula is used to measure the accuracy of the node positions.

$$mse = \frac{\sqrt{\sum_{i=1}^{n} [(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2]}}{R} \quad (3)$$

Where,

x_i and y_i = real node coordinates
$\hat{x}_i$ and $\hat{y}_i$ = estimated node coordinates
R = communication range
i = node index

The estimated position of node is obtained from neural network which is than used to obtain measure the mean square error. The process is repeated with updated weight and bias values to obtain the less mean square error than the centroid method.

III. RESULTS

A. Centroid Algorithm

For Centroid algorithm 100 anchor nodes have been considered and performance has been measured by considering 10 and 50 unknown nodes. The network area of 100x100 meters and communication range of 30 meters have been considered. The network parameters are shown in Table 1.

Table 1: Simulation parameters for Centroid Algorithm

Parameters	Values
Anchor nodes	100
Unknown nodes	10& 50
Range	30 m
Area	100*100 m

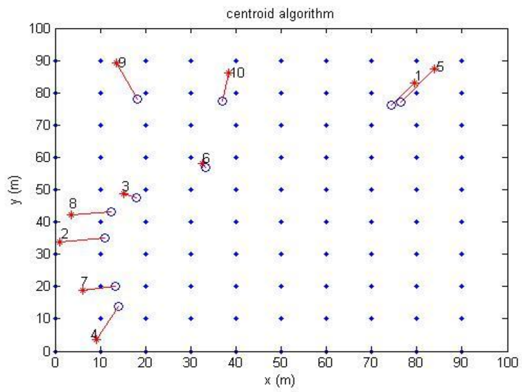

Fig. 2: Location estimation using centroid algorithm

In the above Fig. 2, the sensor nodes positions, actual positions of unknown nodes and positions of 10 sensor nodes approximated by centroid algorithms are represented by dots, stars and circles respectively.

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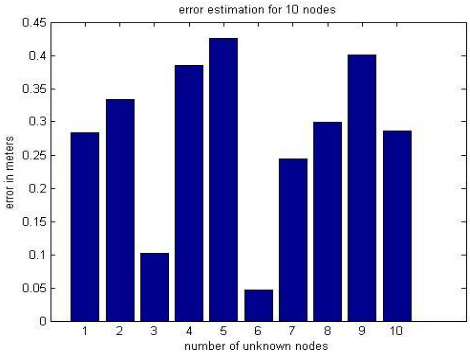

Fig. 3: Error distribution using centroid algorithm

In above Fig. 3, the approximated errors of individual 10 nodes are represented and it is clear that the node 5 is with maximum error and node 6 is with minimum error. The average errors of unknown nodes are approximately 0.2807 meters.

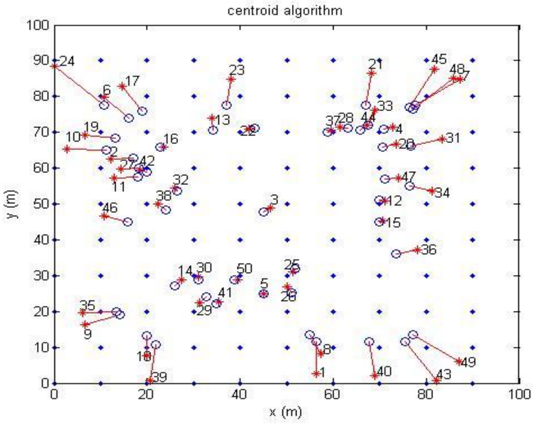

Fig. 4: Location estimation using centroid method

In the above Fig. 4, sensor nodes positions, actual positions of unknown nodes and positions of 50 nodes approximated by centroid algorithms are represented by dots, stars and circles respectively.

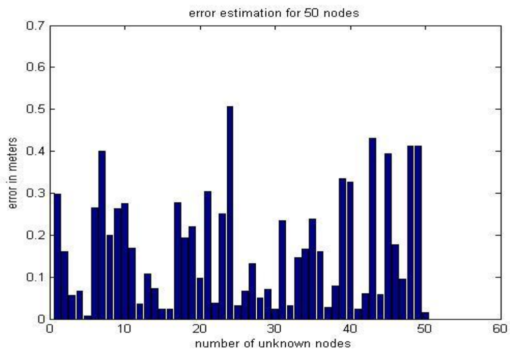

Fig. 5: Centroid method error distribution

In above Fig. 5, bars represent the approximated error of individual 50 nodes. In this Fig., node 24 is with maximum error due to maximum displacement from the real position and node 5 gives the minimum error. The average error is 0.1703meters.

B. 3.2. Neural network approach

Here, three different types of neural networks have been compared to obtain the higher accuracy of localization. These are Radial Basis Networks, Feed Forward Networks and Recurrent Networks. For performing these neural networks, we need to train the networks. Therefore, these networks can be trained by taking 50 epochs, 10 neurons, adaptive learning function, performance function and training function. These neural networks generated and trained with parameters as shown in the table below.

Table 2: Neural network simulation parameters

Parameters	**Values**
Number of neurons	10
Number of epochs	50

a. Feed Forward Networks

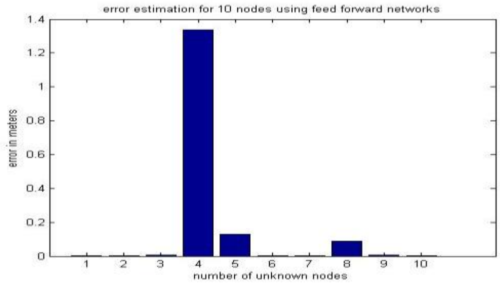

Fig. 6: Feed forward network error estimation

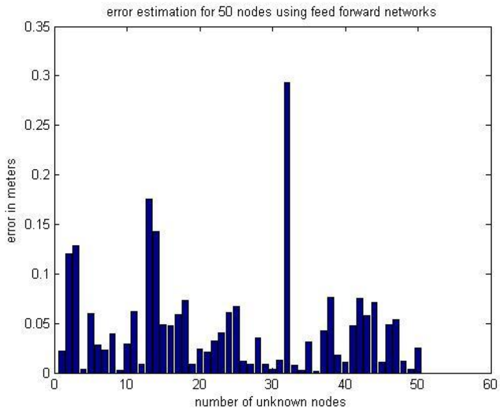

Fig. 7: Feed forward network (50 nodes) error estimation

Fig. 6 shows the obtained approximated error for ten unknown nodes with feed forward neural network approach [14]. In the Fig. 6 node four is with the maximum error, which shows maximum displacement from the actual position. Similarly, Fig.7 showing the same phenomenon for fifty unknown nodes and node 32 is with the maximum error. The obtained average estimated error for 10 nodes is 0.16 meter and for 50 nodes it is 0.05 meter.

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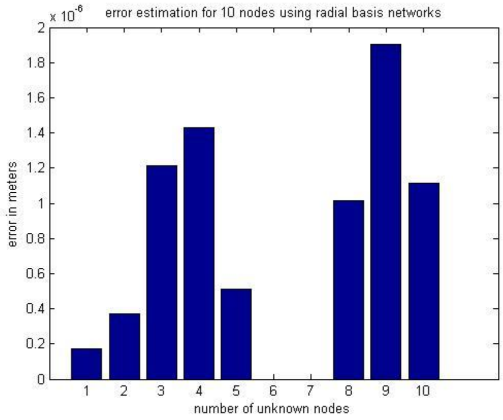
b. Radial Basis Networks



c.

Fig. 8: Radial basis network (10 nodes) Error estimation

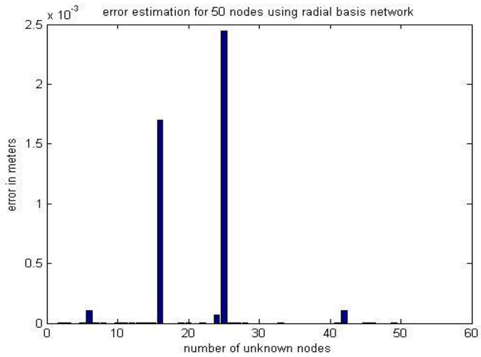


Fig. 9: Radial basis network (50 nodes) Error estimation

The above Fig 8 represents the error estimated practically for a network with ten unknown nodes using radial basis network [13] in which node 9 is with the error which is maximum. Similarly, Fig.9 represents the error experimentally obtained for a network with fifty unknown nodes, in this node 25 is with the maximum error. The obtained average approximated error for ten nodes is 7.73e-07 meters and for 50 nodes it is 8.87e-05 meters.

d. Recurrent Networks

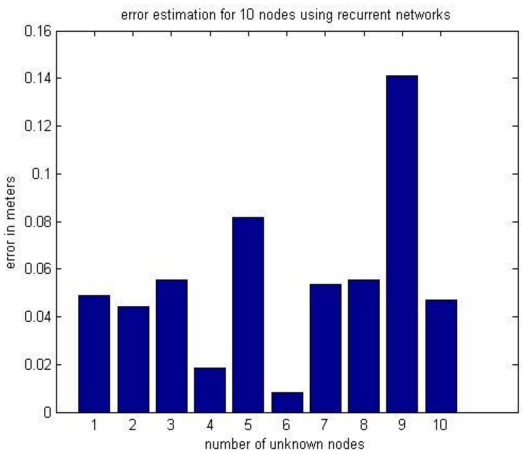


Fig. 10: Recurrent Network (10 nodes) error estimation

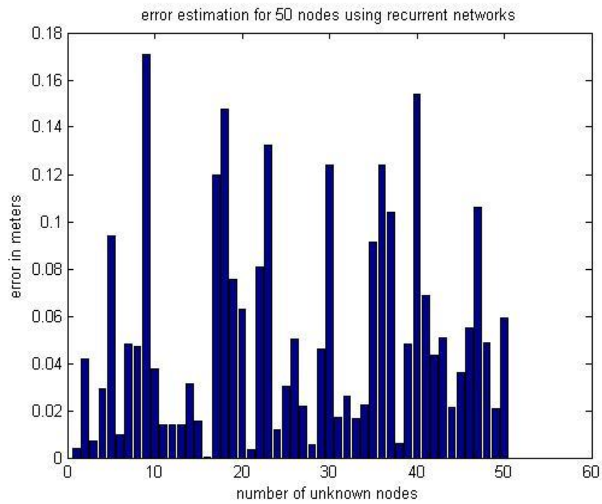


Fig. 11: Recurrent Network (50 nodes) error estimation

The above Fig 10 represents the error estimated through experiment for a network with 10 unknown nodes using recurrent network [20]. In Fig. 10 and Fig. 11 node 9 is with the maximum error. The calculated average approximated error for ten unknown nodes is 0.06 meter and for fifty unknown it is 0.05 meter.

Table 3: Performance Comparison (10 unknown nodes)

Method/Network	**Error**
Centroid	0.22
Feed	0.16
Radial Basis	7.73e-07
Recurrent	0.06

Table 4: Performance Comparison (50 unknown nodes)

ork	**Error**
Centroid	0.17
Feed Forward	0.05
Radial Basis	8.87e-05
Recurrent	0.05

The above Table 3 and Table 4 shows the result of performances compared on the basis of the results obtained through experiments. For evaluating and comparing the performances of various processes, average localization error is used. The results clearly show that the radial basis neural network gives the better performance. Hence the same can be used for localizing the sensor nodes with higher accuracy.

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IV. CONCLUSION

In this paper, various classes of neural network have been implemented and compared under common parameters with centroid algorithm for error approximation and neural network based approach promises better result and improved accuracy than centroid algorithm. Among the various classes of neural networks radial basis method performs more efficiently than all erstwhile approaches as shown in Table 4. Therefore approach using neural network can be preferred to achieve better accuracy of localization, as localization is a very vital part to obtain the valuable information from the different parts of the wireless networks which can be further utilized for various applications.

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