Hybrid approach for multi-node localization and Identification

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Abstract- **In this paper, a new approach for the positioning (localization) of multi-node systems is presented. Each node including the beacon node contains two types of sensors: one for the distance sensing and the other type is for communication. The main idea of our proposed approach is to use the control of beacon to construct a nodes' tree which is going to be used later by the nodes to know the paths in which the information will flow. During the tree construction the identities of nodes will be known. Every node except the beacon will use the information obtained from its previous neighbor in the tree to find its own location and orientation. Several simulations using visual basic 2012 are implemented to discern the performance of this algorithm.**

Index Terms—**Centralized, Distributed, Hybrid, Identification, Multi-node, Orientation, Positioning.**

I. INTRODUCTION

In general term, localization (positioning) can be defined as a mechanism for finding a spatial relationship for objects (humans or things) in some environment [1]. In wireless sensor network (WSN), localization is the process of determining the positions of sensor nodes [2]-[3]. The positioning property offers new opportunities in many fields such as: object tracking [4]-[5], monitoring [6], and all applications that require fast and optimal data routing as leading firefighters to an emergency place or military issues [7]-[8]. One of the most famous localization methods is the global positioning system (GPS) but this method cannot be used regularly due to some constraints such as their high cost, power consumption and large size [9]. Also, the GPS cannot be used for indoor environments and this fact caused to attract a growing attention to propose more algorithms that deal with the needs of indoor localization [10]. Localization can be classified to range based and range free algorithms where each of them has its own properties [11]. The range based algorithms depends on the distance or angle to estimate the locations of nodes by the use of the range techniques which are time of arrival (TOA), difference time of arrival (TDOA), received strength signal (RSS) and angle of arrival (AOA) [12]-[13]. In the case of range free, only the connectivity and hop counts will be used for nodes localization [14]-[15]. Range based algorithms provide more precise location estimation, cost, design complicity as compared with range free algorithms.

According to the architecture used for nodes' positioning, the localization can be divided into centralized and distributed [16]. In centralized architecture, every node sends its information to the beacon node that does all the computation while in distributed architecture each node does its own computation [17]-[18]. Usually, the centralized architectures are more accurate in the case of location estimation than the distributed ones which also have the problems of design complicity and require a lot of computations. On the other hand, centralized architectures suffer from the scalability issue where large scale network can cause congestion in the beacon node [19]-[20].

In this paper, we introduce a hybrid indoor approach that combines between the centralized and distributed architectures. The approach aims to make the beacon node constructing a nodes' tree with the help of connectivity among nodes and this represents the centralized part of the approach while the distributed part is exemplified when each node makes use of the flowing information through the tree to localize itself. The details of this approach will be discussed in section 2, section 3 displays the simulation results and the conclusion will be in section 4.

II. LOCALIZATION, IDENTIFICATION AND ORIENTATION ESTIMATION ALGORITHM

In this algorithm, all the nodes have the same structure that is shown in Fig. 1. where the center of every node is provided with a sensor for distance measurement fixed on a servo motor that rotates at 360^{o} .Also, every node has N of IR sensor pairs (transmitter and receiver) distributed evenly on its perimeter. One of these nodes has previous information about its location, orientation and the total number of nodes in the system this node is called the beacon node. The principle used to localize nodes in this algorithm depends on both centralized and distributed (hybrid) computation approaches. At first, a centralized calculation in the beacon node is used to identify and construct a tree structure for all the nodes and then, a distributed approach is achieved at each node with the help of the tree to calculate its location and orientation.

A. Tree Construction Algorithm

The purpose of this algorithm is to find suitable paths for the nodes that helping them to calculate their own locations and orientations. The nodes are communicating with each other using the IR sensor pairs as shown in Fig.2 and the steps used to construct the tree are as follow:

1. The process of the tree construction begins when the beacon node start to send its ID sequentially through the IR transmitter sensors. Any neighbor node that received the beacon ID will replay by sending its own ID as shown in Fig.3.

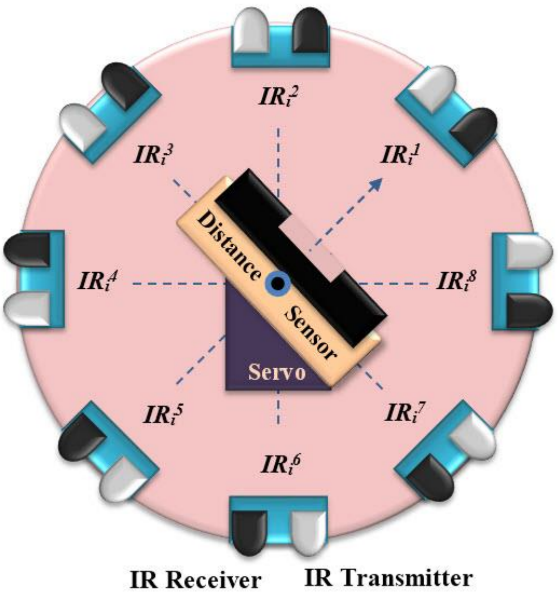


Fig.1. Schematic for node i with 8 IR sensor pairs and a distance sensor.

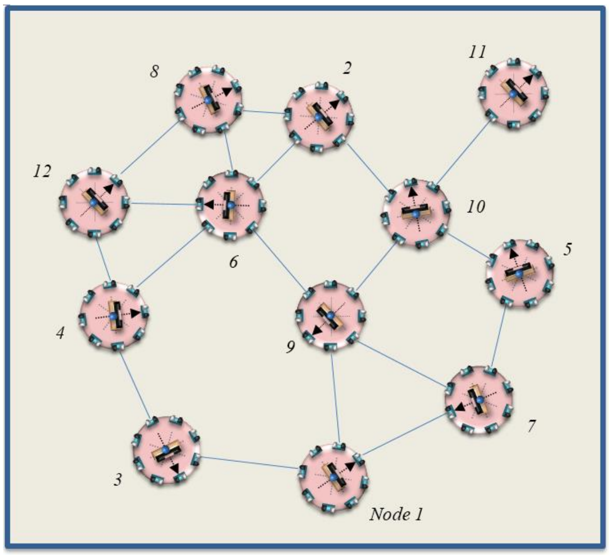


Fig.2. The connectivity structure of 12 nodes.

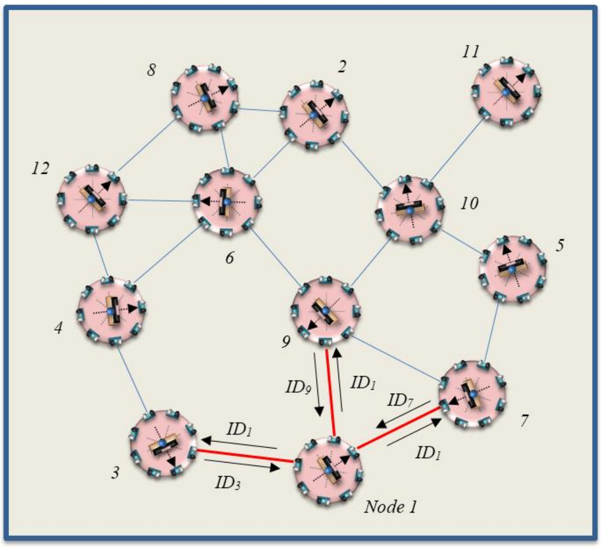


Fig.3. The first round to construct the tree of nodes.

2. Beacon node counts the number of replays to check if the tree is constructed. If the tree is not complete then the beacon start to activate each of its neighbors to construct a second hop in the tree as shown in Fig.4. In this round all the nodes that are neighbors to the beacon send their IDs to their neighbors. It is worth to mention that if any node which is a neighbor for more than one node has already received the ID of one of them then it will not replay to the query of others. As an example is node 9 which is a neighbor to the beacon and node 7 has received ID1 from the beacon in the first round then it will not reply to node 7 in the second round in spite of being a neighbor to node 7 as illustrated in Fig.4.
3. Again if the tree is not complete the beacon activates the neighbors of the beacon neighbors for sending their IDs just as in step 2, the beacon repeats this step until the last hop in the tree is reached which is shown in Fig.5.
4. Fig. 6 shows the final shape of the nodes' tree. The paths of this tree will be used to pass the information of each node to its next neighbor node in the tree.

B. Localization and Orientation Estimation Algorithm

In this algorithm a distributed approach is used to compute the location and orientation of each node in the environment. The distance from a node to its neighbour and also the orientation of the directional line between them are necessary to compute the location of next node in the tree. The distance is computed by rotating the distance sensor on that node to the direction of its neighbour. The direction of servo represents the orientation and the reading of distance sensor represents the distance between those two nodes. We are going to explain the process of computing the location and orientation of a node at the first and second hop. The nodes in other hops continue to use the same pattern of equations to find their own location and orientation.

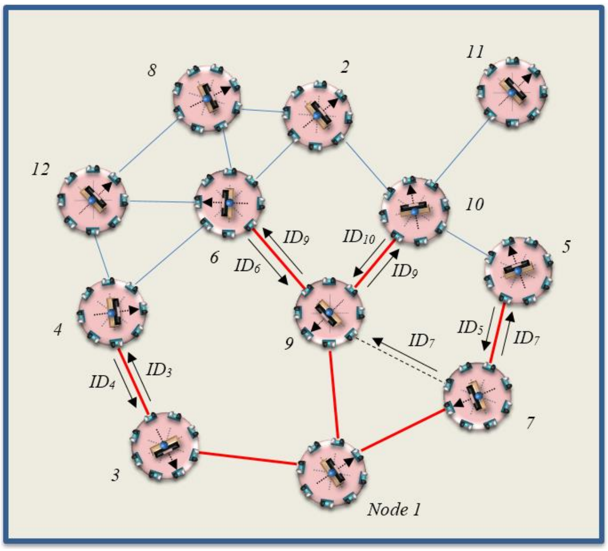


Fig.4. The second round to construct the tree of nodes.

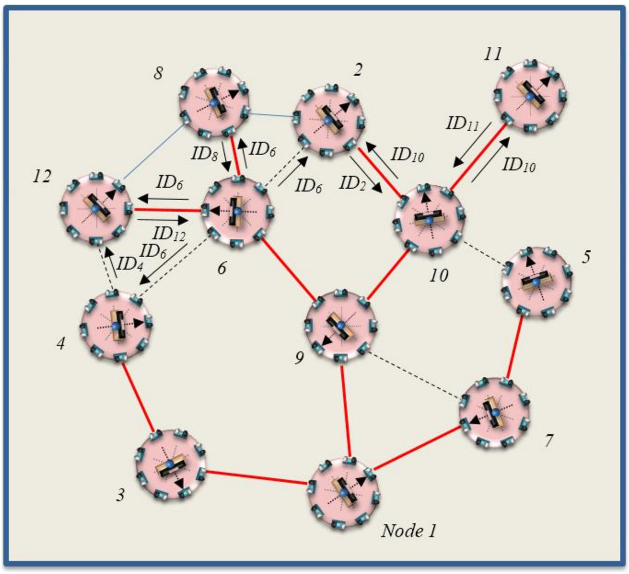


Fig.5. The third round to construct the tree of nodes.

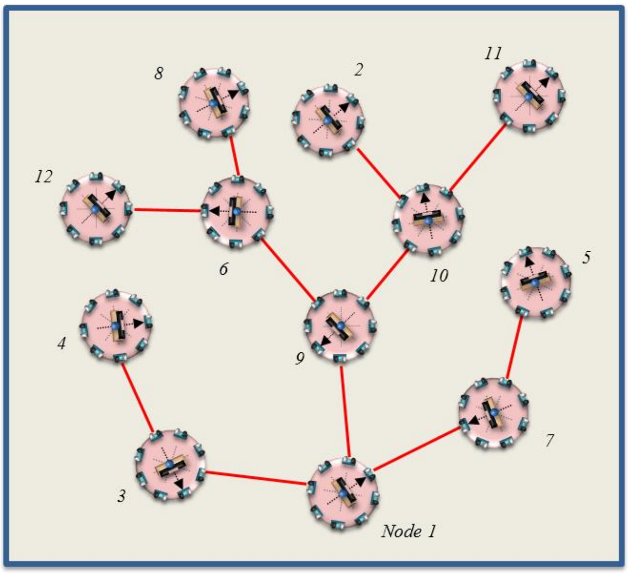


Fig.6. The tree structure of nodes.

B.1. First Hop Localization and Orientation Estimation

Beacon node rotates sequentially its distance sensor to the directions of each one of the IR sensors that received a signal from a neighbor node to compute the distance and orientation to them. Fig. 7 shows how we can compute the orientation (β_9) of node 9 and its coordinates (x_9, y_9) by using the distance between the beacon (node 1) and node 9 which is (r_1^9), the orientation (β_1) of node 1 and its coordinates (x_1, y_1) according to the following steps:

1. Each node including the beacon has N of IR sensor pairs with equal angles (K) between each successive pairs; K is calculated as in equation1:

$$K = 360 / N \tag{1}$$

2. The orientation α_1^9 of the directional line between node 1 and node 9 is computed as follows:

$$\phi_1^{12} = (1-2) * K \tag{2}$$

Where ϕ_1^{12} represents the angle between the orientation of node 1 and the IR sensors pair that received the ID of node 9.

$$\alpha_1^9 = \phi_1^{12} + \beta_1 \tag{3}$$

3. The orientation α_1^9 of the directional line between node 1 and node 9 and the coordinates (x_1, y_1) of node 1 will be sent to node9.

4. Node 9 computes its coordinates (x_9, y_9) using the following equations:

$$x_9 = x_1 + r_1^9 * \cos \alpha_1^9$$
$$y_9 = y_1 + r_1^9 * \sin \alpha_1^9 \tag{4}$$

5. The orientation (β_9) of node 9 is computed as follows:

$$\Phi_9^{12} = (2-1)*k \tag{5}$$

Where ϕ_9^{12} is the angle between IR_9^1 and IR_9^2 sensors on node 9.

$$\sigma_9 = 180 - \phi_9^{12} \tag{6}$$

$$\beta_9 = \sigma_9 + \alpha_1^9 \tag{7}$$

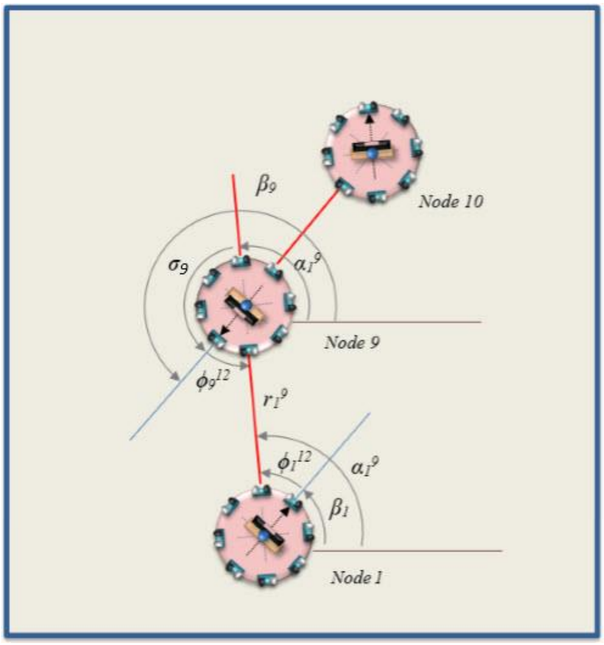


Fig.7. First hops localization approach.

B.2. Second Hop Localization and Orientation Estimation

Each neighbor node to the beacon rotates its distance sensor to the direction of each of its neighbors to compute the distance and orientation to this node. Fig. 8 shows how we can compute the orientation (β_{10}) of node 10 and its coordinates (x_{10}, y_{10}) by using the distance between the beacon (node 9) and node 10 which is (r_9^{10}), the orientation (β_9) of node 9 and its coordinates (x_9, y_9) according to the following steps:

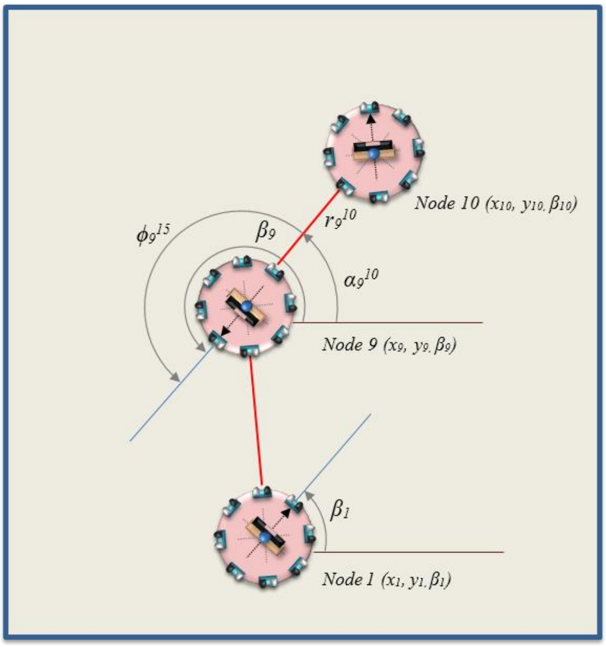


Fig.8. Second hops localization approach.

1. The orientation α_9^{10} of the directional line between node 9 and node 10 is computed as follows:

$$\phi_9^{15} = (5-1) * K \tag{8}$$

$$\alpha_9^{10} = \beta_9 - \phi_9^{15} \tag{9}$$

2. The orientation α_9^{10} of the directional line between node 9 and node 10 and the axis (x_9, y_9) of node 9 are sent to node 10.
3. Node 10 computes its coordinates (x_{10}, y_{10}) using the following equations:

$$\begin{aligned} x_{10} &= x_9 + r_9^{10} * \cos \alpha_9^{10} \\ y_{10} &= y_9 + r_9^{10} * \sin \alpha_9^{10} \end{aligned} \tag{10}$$

4. The orientation (β_{10}) of node 10 is computed as follows:

$$\phi_{10}^{14} = (4-1) * K \tag{11}$$

Where ϕ_{10}^{14} is the angle between IR_{10}^1 and IR_{10}^4 sensors on node 10.

$$\sigma_{10} = 180 - \phi_{10}^{14} \tag{12}$$

$$\beta_{10} = \sigma_{10} + \alpha_9^{10} \tag{13}$$

III. THE SIMULATION RESULTS

Hybrid approach for multi-node localization and identification was validated using simulation. It was carried out using visual basic 2012. Different network sizes have been used ranging from 5 to 100 nodes of 20 pixels and distributed arbitrarily on a square area of 250000 pixels (500*500). We have used some parameters to validate the performance of our approach which are:

1. Number of nodes in the system (N)
2. Infrared sensor range (R)
3. Number of hops (H)

Fig.9 shows the case of connectivity among nodes in environments of 20 and 30 nodes respectively and for different sensing ranges (100, 120 and 140). In fig. 9 (a) (b) and (c) when N=20, we will have a bad connectivity only when R=100 and the proposed approach will not perform properly while the other two figures (b) and (c) give us an acceptable connectivity for the approach to perform well. Fig. 9 (d) (e) and (f), all of the three cases of R show a very good connectivity among nodes when N=30.

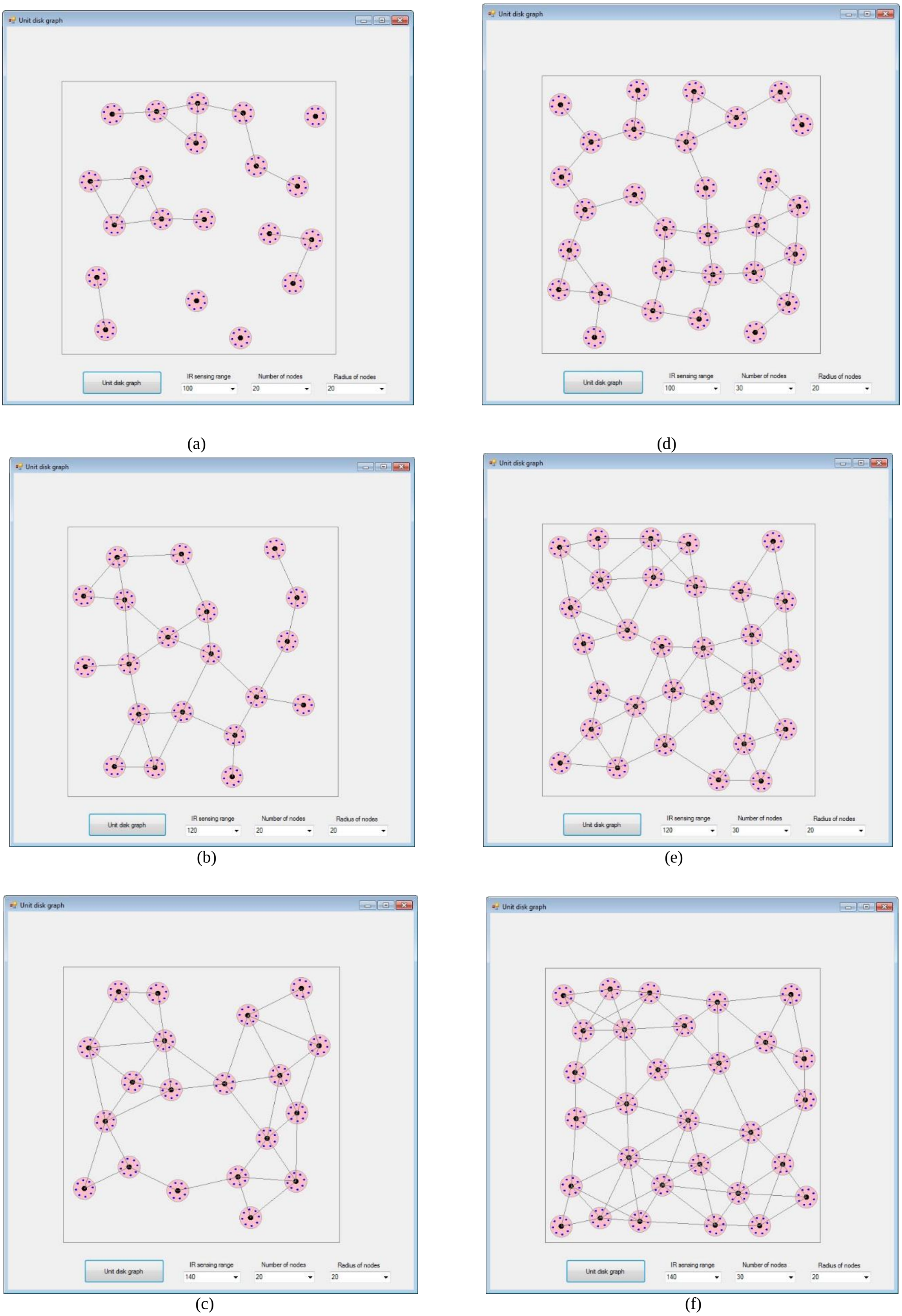
Fig.10. shows the relationship of the percentage of nodes connectivity with the network size (N) and the infrared sensor range (R). It is clear that increasing R and N or one of them will cause an increase in the connectivity percentage. We Also notice that the nodes connectivity reaches 100% starting from N=30 (when R=140), N=35 (when R=120) and N=50 (when N=140).

In Fig.11, Fig. 12 and Fig.13, the nodes opacity have been studied for the case of N=25 and R= 100, 120 and 140 pixels respectively. By the term of opacity we mean the nodes which are not reachable and we do not have any information to localize them. Fig.11 shows that 5 nodes are opacity when R=100 pixels while there is only one opacity node in Fig.12when R=120 pixels and no opacity is found when R=140 pixels in Fig.13.

Fig.14 illustrates the effects of N and R on the nodes opacity. The curve shows an inverse relationship between the percentage of nodes opacity and the number of nodes, the opacity percentage will decrease as the number of nodes are being increased. Also, any increase in R will decrease the opacity percentage. This ratio will shrink to 0% starting from N=25 (R=140), N=30 (R=120) and N=35 (R=100).

Two environments of 20 and 30 nodes are shown in Fig.15. Each environment experiences three values of R to show the result of changing R on the number of hops. For the same number of nodes (N=20) in Fig. 15 (a) (b) and (c), or (N=30) in Fig.15 (d) (e) and (f), changing R from 100 to 120 and then to 140 causes a noticeable decrease in the number of hops and also causes a great improvement to localize more nodes. Again, changing N from 20 to 30 while maintaining the value of R fixed (R=100 in Fig.15 (a) and (d), R=120 in Fig.15 (b) and (e), and R=140 in Fig.15 (c) and (f)) will increase the connectivity among nodes and this will also reflected positively on reducing the number of hops and nodes opacity.

The number of hops needed to reach to the furthest node in order to construct a complete tree is very critical parameter due to its effectiveness in obtaining a precise location estimation where increasing the number of hops has a negative effect on location estimation accuracy. From the curve in Fig.16, we notice that increasing N, R or both cause to lessen the maximum number of hops to reach the furthest node. It appears that when N=20, we need H=10 (when R=100), H=8 (when R=120) and H=7 (when R=140) to localize the utmost node. On the other hand, (when N=50) we only need to H=7 (when R=100), H=6 (when R=120) and H=5 (when R=140) to localize it.



(a)
IR sensing range: 100
Number of nodes: 20
Radius of nodes: 20

(d)
IR sensing range: 100
Number of nodes: 30
Radius of nodes: 20

(b)
IR sensing range: 120
Number of nodes: 20
Radius of nodes: 20

(e)
IR sensing range: 120
Number of nodes: 30
Radius of nodes: 20

(c)
IR sensing range: 140
Number of nodes: 20
Radius of nodes: 20

(f)
IR sensing range: 140
Number of nodes: 30
Radius of nodes: 20

Fig.9. Connectivity for 20 (a-c) and 30 (d-f) nodes with different R (100, 120 and 140).

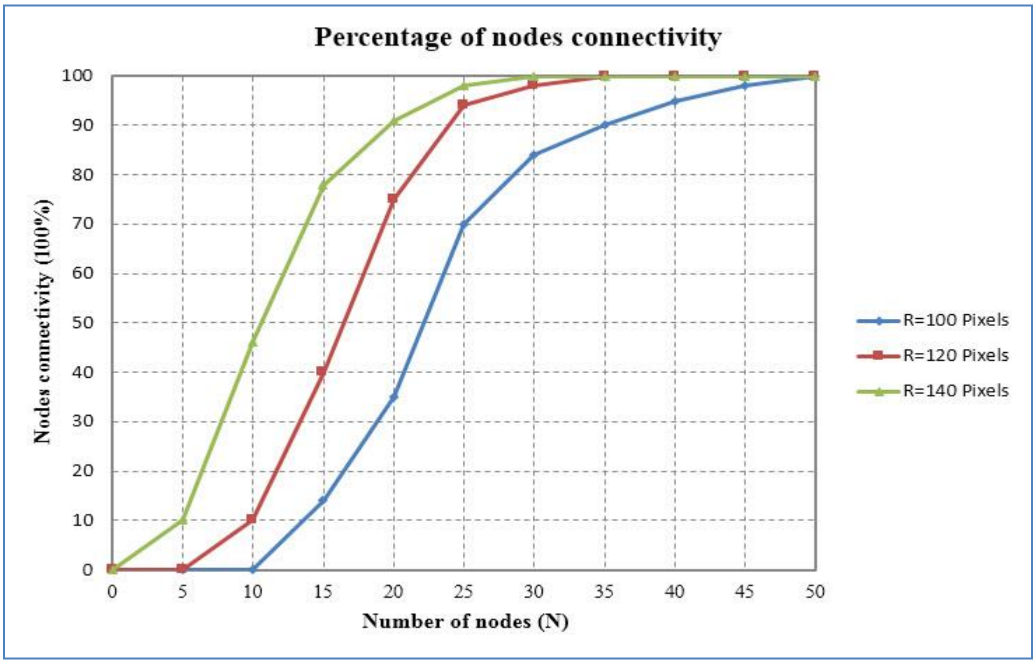
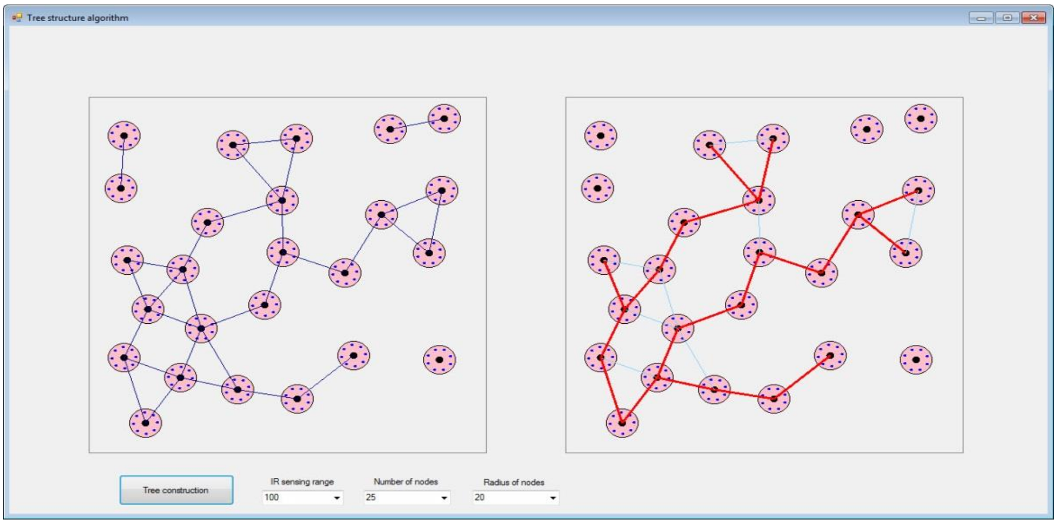
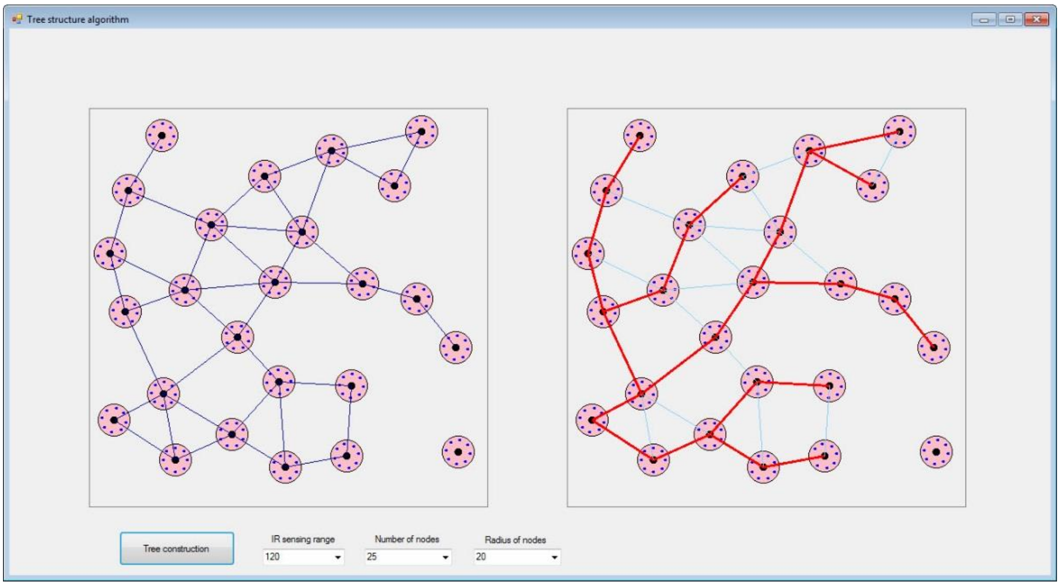


Fig.10. The percentage of nodes connectivity for different network sizes N and R= 100, 120 and 140 pixels.



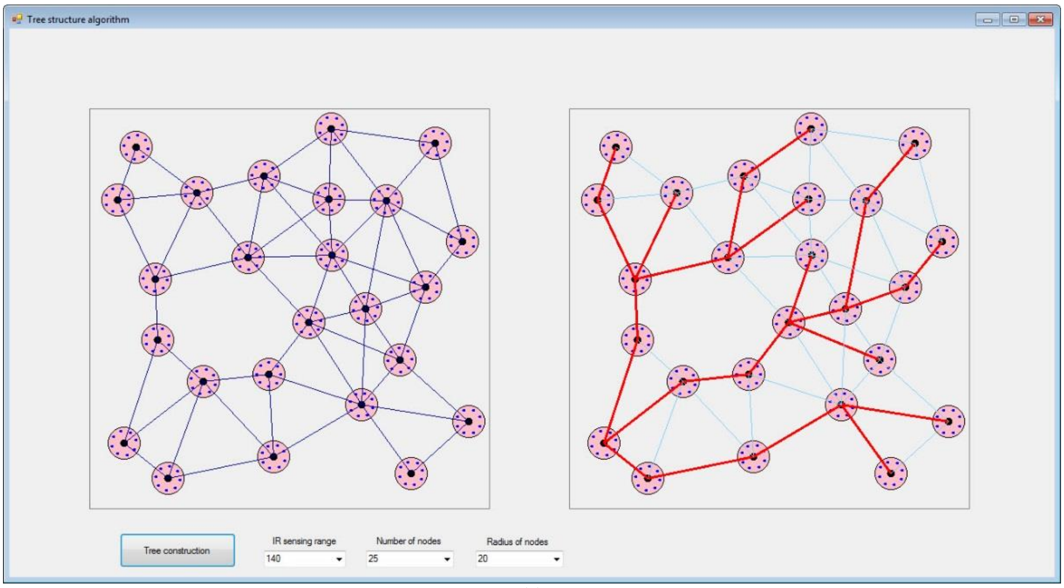
IR sensing range 100
Number of nodes 25
Radius of nodes 20

Fig.11 Opacity for an environment of 25 nodes and sensing range of R=100 pixels.



IR sensing range 120
Number of nodes 25
Radius of nodes 20

Fig.12 Opacity for an environment of 25 nodes and sensing range of R=120 pixels.



IR sensing range 140

Number of nodes 25

Radius of nodes 20

(c)

Fig.13 Opacity for an environment of 25 nodes and sensing range of R=140 pixels.

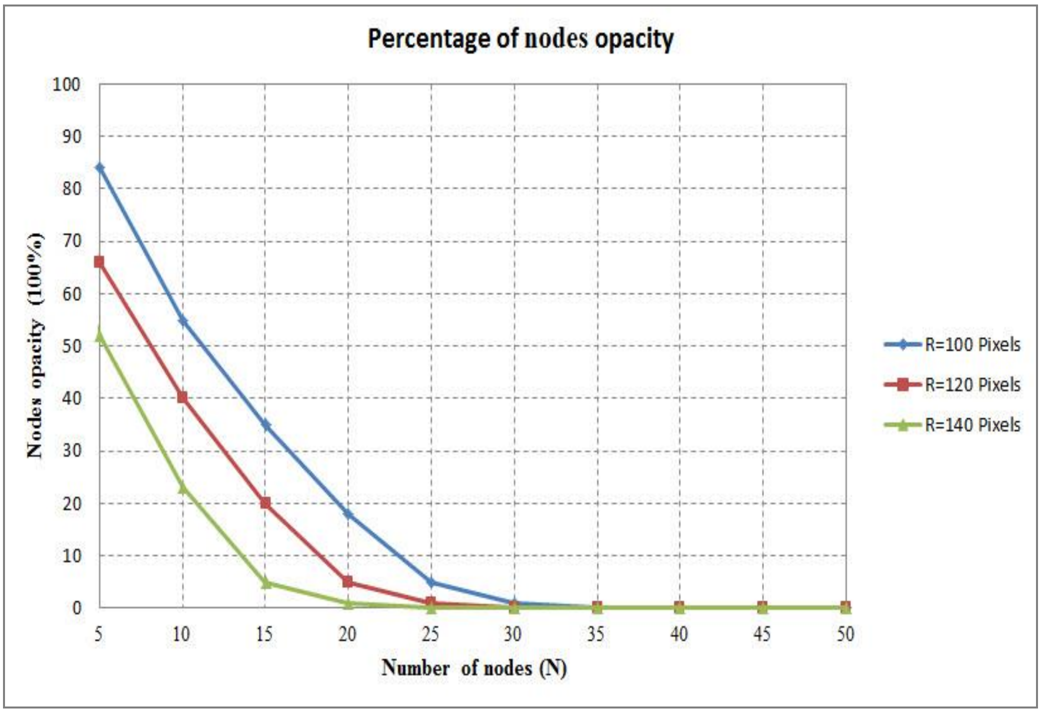
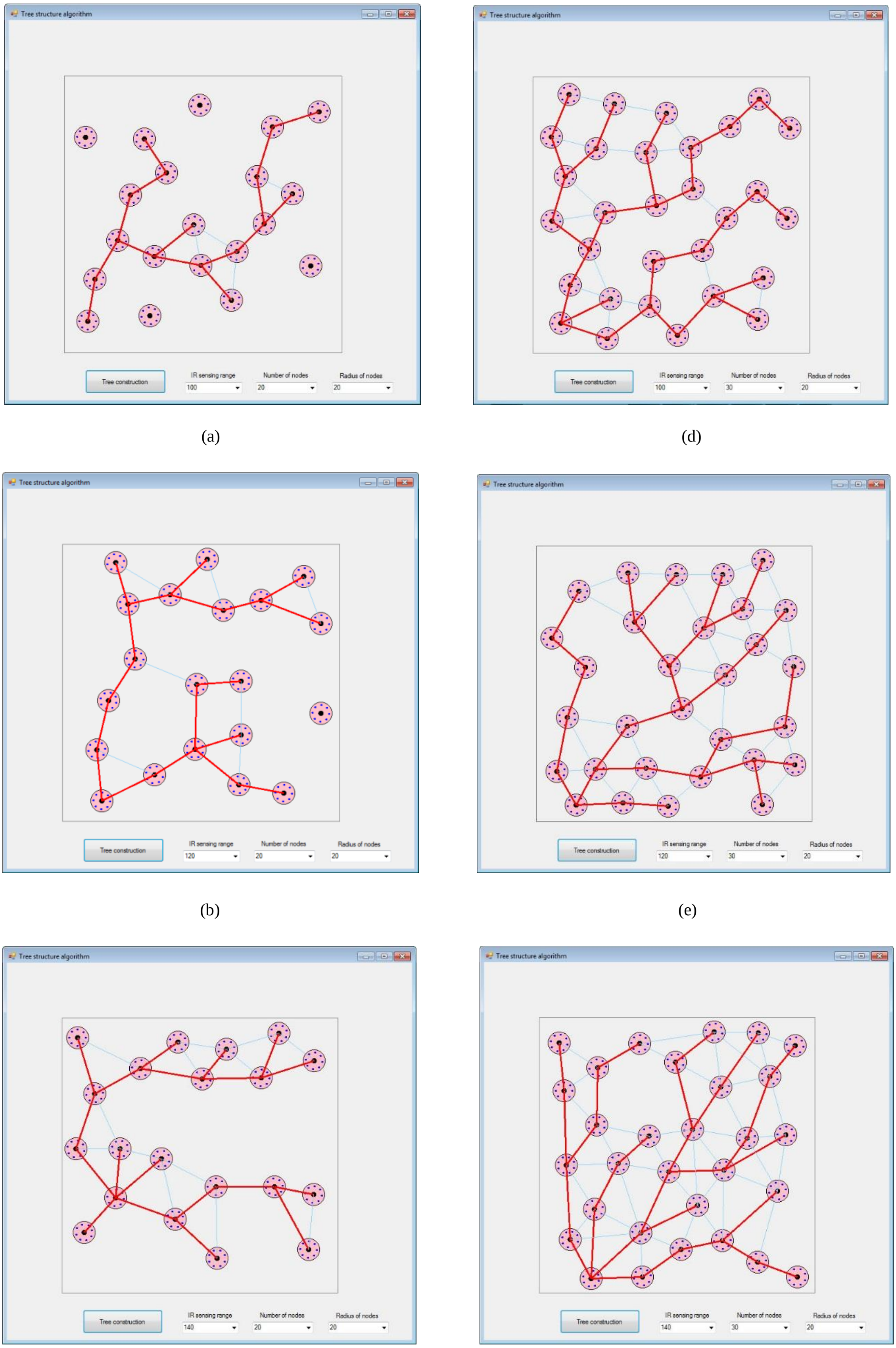


Fig. 14. The percentage of node opacity vs. N and for different values of R.



(a)

IR sensing range 100
Number of nodes 20
Radius of nodes 20

(d)

IR sensing range 100
Number of nodes 30
Radius of nodes 20

(b)

IR sensing range 120
Number of nodes 20
Radius of nodes 20

(e)

IR sensing range 120
Number of nodes 30
Radius of nodes 20

(c)

IR sensing range 140
Number of nodes 20
Radius of nodes 20

(f)

IR sensing range 140
Number of nodes 30
Radius of nodes 20

Fig.15. The effects of changing R and N on the number of hops with environments of 20 and 30 nodes.

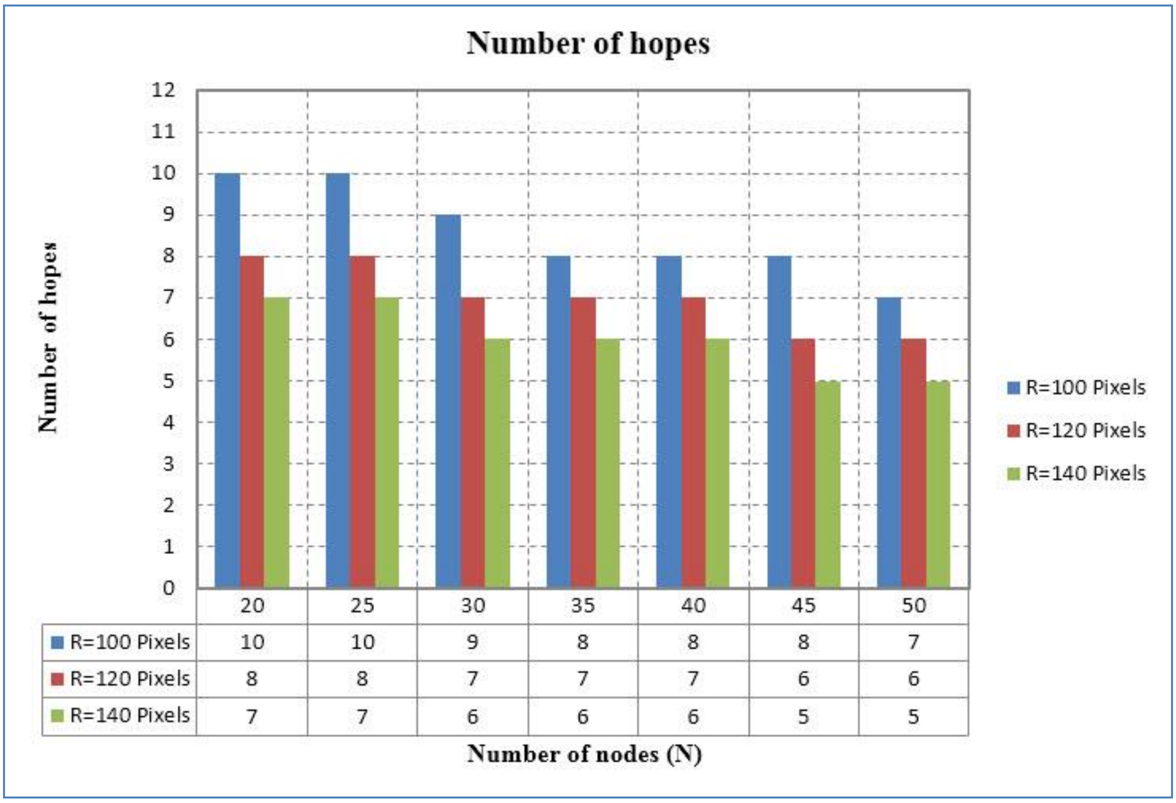


Fig.16. The maximum number of hops vs. N and with different values of R.

IV. Conclusions

In this paper, we have described a hybrid approach for multi-node localization and identification. This approach combines the properties of the distributed and centralized architectures both. It begins with the centralized phase to use the control of beacon node to construct a nodes' tree that shows the paths in which the information will follow. The tree construction gives an authentication to our approach since each node cannot communicates with other nodes except the ones mentioned in the tree map. The second phase of approach is the distributed one where each node calculates its own position and orientation. This phase characterized by using simple and easy computations and every node needs the information of only one previous neighbor to get acceptable location estimation. Also, the similarity of all nodes in shape gives us the flexibility of chosen any node to be the beacon and place it anywhere in the environment. From the simulation result, we found that our approach is scalable and we also found that increasing the sensing range of IR sensors and/or the number of nodes produces a complete tree with high connectivity and has no opacity which yields more accurate position estimation.

VI. REFERENCES

[1] S. Avinash, and J. Wu, "A survey on secure localization in wireless sensor networks," Encyclopedia of Wireless and Mobile communications,2007.

[2] C. P. Soumya, T. V. P. Sundararajan and N. Gowdhami, " Efficient Range based lgorithm for Localization in Pilgrim Tracking Scenario, " International Journal of Innovative Research in Computer and Communication Engineering, Vol. 2, Issue 4, p.p. 3743-3747, 2014.

[3] G. Han, J. Jiang, L. Shu , Y. Xu and F. Wang, "Localization Algorithms of Underwater Wireless Sensor Networks: A Survey," Sensors 2012, vol.12, 2026-206.

[4] Q. Tian , Z. Salcic , K. I-Kai Wang and Y. Pan, "A Hybrid Indoor Localization and Navigation System with Map Matching for Pedestrians Using Smartphones," Sensors, vol. 15, p.p. 30759-30783, 2015.

[5] H. Qu and S. B. Wicker, "A Combined Localization and Geographic Routing Algorithm for Rapidly-Deployed Wireless Sensor Networks," International Journal of Distributed Sensor Networks, vol. 4: p.p.43–62, 2008.

[6] D. Estrin, L. Girod, G. Pottie, and M. Srivastava, “Instrumenting the world with wireless sensor networks,” International Conference on Acoustics, Speech and Signal Processing, vol. 4, pp. 2033–2036, 2001.

[7] I. S. I. Abuhaiba and A. Y. Al-Sallut," Intelligent and Distributed Localization of Nodes in Wireless Sensor Networks," I.J. Wireless and Microwave Technologies, vol. 2,p.p. 22-36 , 2015.

[8] G. Giorgetti, S. K. S. Gupta and G. Manes, "Wireless Localization Using Self-Organizing Maps," ACM 978, 2007.

[9] N. B. Priyantha, H. Balakrishnan, E. Demaine, and S. Teller," AnchorFree Distributed Localization in Sensor Networks," Tech Report #892, 2003

[10] S. Biaz and Y. Ji, "Precise Distributed Localization Algorithms forWireless Networks," Technical Report CSSE05-02 , 2005.

[11] W. Katekaew, Ch. So-In, K. Rujirakul and B. Waikham, " H-FCD: Hybrid Fuzzy Centroid and DV-Hop Localization Algorithm in Wireless Sensor Networks," Fifth International Conference on Intelligent Systems, Modelling and Simulation, p.p. 551-555, 2014.

[12] Stefano, G.D. and A. Petricola, "A distributed AOA based localization algorithm for wireless sensornetworks," Journal of Computers, (3): 1, 2008.

[13] S. Capkun, M. Hamdi, and J. Hubaux, “GPS-free positioning in mobile ad-hoc networks,” Cluster Computing,2002.

[14] T. He, C. Huang, B. Blum, J. Stankovic and T Abdelzaher," Range-free Localization Schemes in Large Scale Sensor Networks," the Ninth Annual International Conference on Mobile Computing and Networking (MobiCom'03), pp.81--95, 2003.

[15] S.M Rakshit and S.G.Hate, " Range Free Localization using Expected Hop Progress in Wireless Sensor Network ," International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163Vol. 1, Issue 6, p.p. 172-179 2014.

[16] A. Karbasi, "From Centralized to Distributed Sensor Localization," MobiHoc Sˆ3’10, 2010.

[17] A. A Kannan, G. Mao and B. Vucetic, "Simulated Annealing based Wireless Sensor Network Localization," JOURNAL OF COMPUTERS, Vol. 1, No. 2, p.p. 15-22, 2006.
[18] Y. Ding, G. Han and X. Mu, "A Distributed Localization Algorithm for Wireless Sensor Network Based on the Two-Hop Connection Relationship," JOURNAL OF SOFTWARE, Vol. 7, No. 7, p.p. 1657-1663, 2012.
[19] C. Savarese, K. Langendoen, and J. Rabaey, "Robust positioning algorithms for distributed ad-hoc wireless sensor networks," USENIX technical annual conference, p.p. 317–328, 2002.
[20] S. Afzal, "A Review of Localization Techniques for Wireless Sensor Networks," J. Basic. Appl. Sci. Res., 2(8), p.p.7795-7801, 2012.