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Centralized approach for multi-node localization and identification

Ola A. Hasan
Electrical Engineering Department
University of Basrah
Basrah, Iraq
Loliastar91@gmail.com

Ramzy S. Ali
Electrical Engineering Department
University of Basrah
Basrah, Iraq
rsawaily@gmail.com

Abdulmuttalib T. Rashid
Electrical Engineering Department
University of Basrah
Basrah, Iraq
abdturky@gmail.com

Abstract: A new algorithm for the localization and identification of multi-node systems has been introduced in this paper; this algorithm is based on the idea of using a beacon provided with a distance sensor and IR sensor to calculate the location and to know the identity of each visible node during scanning. Furthermore, the beacon is fixed at middle of the frame bottom edge for a better vision of nodes. Any detected node will start to communicate with the neighboring nodes by using the IR sensors distributed on its perimeter; that information will be used later for the localization of invisible nodes. The performance of this algorithm is shown by the implementation of several simulations.

Index Terms— Beacon node, Identification, Localization, Multi-node.

I. Introduction

Wireless sensor networks have attracted a lot of attention due to their important role and increased utilization in many military and civilian domains [1-3]. Localization is one of the most important challenges in the development of wireless sensor networks [4-5], the reason for that is, collecting data without locations will make these data geographically meaningless [6-7].
Wireless sensor network consist of many sensor nodes that each contains sensors, battery, processor and other devices that may be needed [8]. Every node in wireless sensor network collects data and either forwards them to a central node to calculate their locations and this will be called a centralized architecture [9-10] or use these data to localize itself and then forward the data and this will be called a distributed architecture [11-12].
Localization can be relative, absolute or a combination of them [13-14] .Relative localization is usually based on the dead reckoning (that is, monitoring the wheel revolutions to find the distance from a known starting location). The unbounded accumulation of errors is the main disadvantage of this method and in the case of movement, relative localization is preferable. On the other hand, absolute localization depends on the satellite signals, beacons, landmarks or map matching to find the location of a node. GPS is one of the used methods as an example of the absolute localization but it can be used only outdoor and it is inaccurate for mobile nodes [15-16].
In this paper, we introduce a combination of both absolute and relative localization; the absolute localization is represented by the beacon which scans the environment looking for visible nodes. On the other hand, the relative localization is generated by visible nodes while exploring the environment in search of their neighbors. Also, in this paper we use the centralized architecture where all the information results from scanning the environment by both of the beacon and visible nodes is collected in the beacon to construct two tables which will be used later to localize the invisible nodes. The details of this algorithm will be discussed in section II and the related work in section III; section IV shows the simulation results of this algorithm. Finally the conclusion will be in section V.

II. Related Work

When we talk about obtaining location information, the first thing came into our mind is the global positioning system (GPS) proposed by B. Hofmann-Wellenhof [17]. But due to its high cost and in ability to work in indoor environment, a lot of algorithms concerns with localization according to the type of information used to localize nodes have been studied [9]. Many of those algorithms lay on the range-based schemes which use the ranged measurements strategies such as the received signal strength (RSS), angle of arrival (AOA), time of arrival (TOA) and time difference of arrival (TDOA) to compute either the distance or angle between two nodes [18]. As an example is the algorithm proposed by P. Bahl et al. [19] which is a method to convert the RSS to a distance and then uses the triangulation to calculate the node's position. Some other papers lay on the range free strategies such as: approximate point in triangle (APIT), DV-Hop and centroid. Those strategies take into account the connectivity among nodes to achieve localization [9]. For example, centroid algorithm proposed by N. Bulusu et al. [20] which uses a centroid formula to localize the nodes after receiving the locations of beacons. The range based algorithms are more accurate than the range free but the range free algorithms are less in the term of complicity and cost. Therefore, some researchers focused on proposing methods that combine the benefits of the range based and range free both and considered to be more accurate than the range free and less cost and complicity than the range based. An example for that is the algorithm proposed by A. T. Rashid et al. [21] where a beacon is provided with distance sensor to determine the locations of visible nodes and construct clusters; those clusters will be compared later with unit disk graph for each node which constructed by the connectivity among nodes to know the identity of them. In this paper we will propose an algorithm that is better than the algorithm proposed by A. T. Rashid et al. in the case of visibility, accuracy and computation complicity.

III. LOCATION AND IDENTITY COMBINATION ALGORITHM

In this algorithm, the beacon which is located at middle of the frame bottom edge contains a distance sensor and IR sensor pair (transmitter and receiver) as shown in Fig. 1; those sensors are fixed on a servo motor which rotates at 180^0 . Also, there are n of IR sensors distributed evenly on the perimeter of every node in the system. The location and identity of each node are found according to the following subsections:

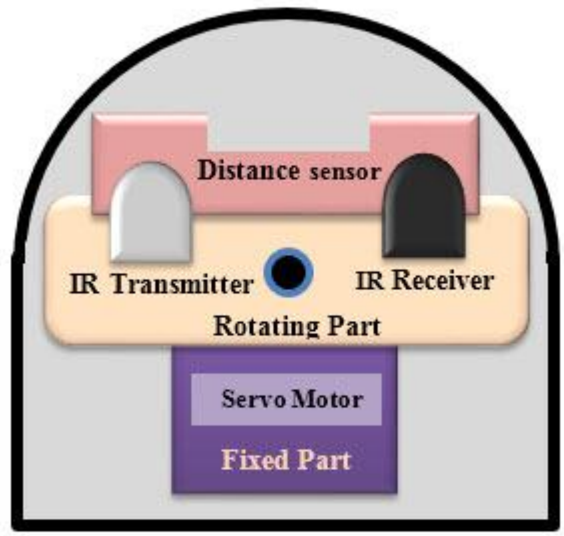

Fig.1, The construction of the Beacon node.

A. Localization of Visible Nodes: The beacon scans the environment at 180^0 searching for any node as shown in Fig.2, if the beacon detects a node, the coordinates of this node will be calculated as in the equation below:

$$x_i = x_b + d_b^i * \cos \alpha_b^i$$
$$y_i = y_b + d_b^i * \sin \alpha_b^i \qquad (1)$$

Where d_b^i and α_b^i are the distance and the detecting angle of node i respectively, (x_b, y_b) are the coordinates of the beacon and (x_i, y_i) are the coordinates of node i.

B. Identity of Visible Nodes: After detecting a node, the beacon uses the IR sensor pair to send an infrared signal to identify itself and waits for the node to reply with its identity number. Each node is provided with n of IR sensor pairs which numbered in sequentially form starting from the reference IR sensor as shown in Fig.3; the angle K between each two neighboring sensor pairs are equal and they are computed as in equation2:

$$K = 360 / n \qquad (2)$$

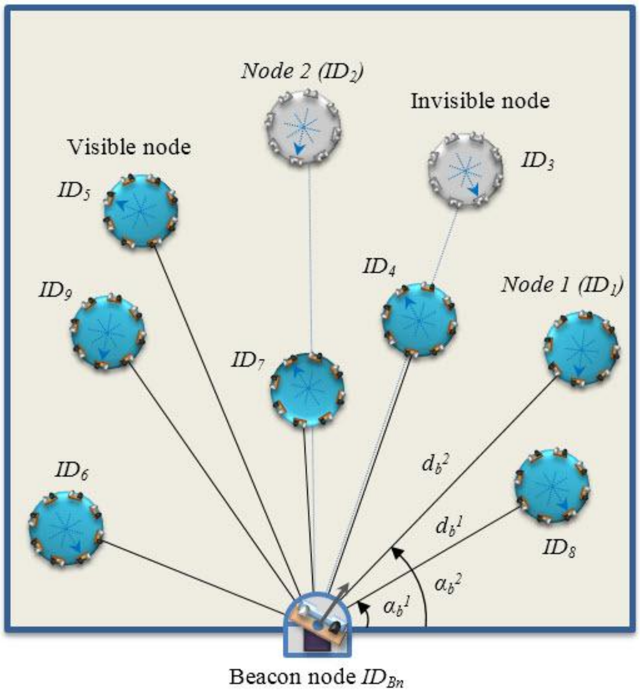

Fig.2, Scanning the environment with beacon node.

Each node in the environment sequentially activates their IR receiver sensor waiting for any signals come from the beacon. If any node detects a signal that represent the ID number of beacon then this node replays by sending its ID number through the transmitter sensor of the same IR sensor pair that has received the beacon signal.

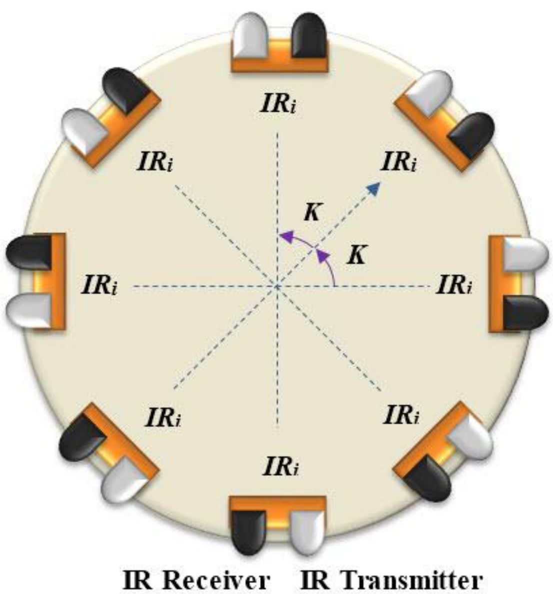

Fig.3. Schematic for node *i* with 8 IR sensor pairs (Transmitter and Receiver).

C. Construction of beacon visibility based table: After scanning the entire environment, the beacon starts to construct a table which contains the identity, detecting angle and the coordinates of each visible node. As an example the table's contents for visible nodes shown in Fig. 2 will look as shown in table 1.

Table 1.The beacon visibility based table

Node ID	***Detection angle***	***x***	***y***
ID_8	α_b^8	x_8	y_8
ID_1	α_b^1	x_1	y_1
ID_4	α_b^4	x_4	y_4
ID_7	α_b^7	x_7	y_7
ID_5	α_b^5	x_5	y_5
ID_9	α_b^9	x_9	y_9
ID_6	α_b^6	x_6	y_6

D. Construction of Neighboring Nodes Table: During the construction of the beacon visibility based table, there is also another table being constructed in the beacon which is called the neighboring nodes table ;this new table shows the neighboring nodes for each visible node and it will be used later to localize the invisible nodes. The following are the construction steps:

1. If the beacon detects an object, it will send its ID number (IDBn) and wait with a specific time to receive a reply .Otherwise the beacon will move to the next angle degree.

2. If the detected object is a node, then it will reply with its ID number first and start to scan searching for neighbors using its IR sensor pairs. The process of scanning is achieved by sequentially sending the ID number of the node from each IR sensor pair and waits for the ID number of the neighbor node. The IR sensor pair is marked by Null value if it does not have any replay. The beacon stays in a wait state until the reception of this node's

scanning data. Fig.4 is an example that shows step 1 and a part of step 2.

3. After the completion of step 2 a new raw is added to the neighboring nodes table contains the neighbor nodes to that detected node.

4. The beacon continues to repeat all the steps above until its rotation reaches 180°.

5. When the beacon completes its scanning the neighboring nodes table for visible nodes will be completed as showing in table 2.

Fig.5 shows the connectivity among the nodes in the environment witch their information is mentioned in table 2. The connectivity may be defined as the representation of nodes in a unit disk graph [21]. In unit disk graph we can use the absolute locations and orientation of some other nodes connected to the node which we want to estimate its location and orientation. The estimation accuracy increases as the connectivity of unit disk graph increases.

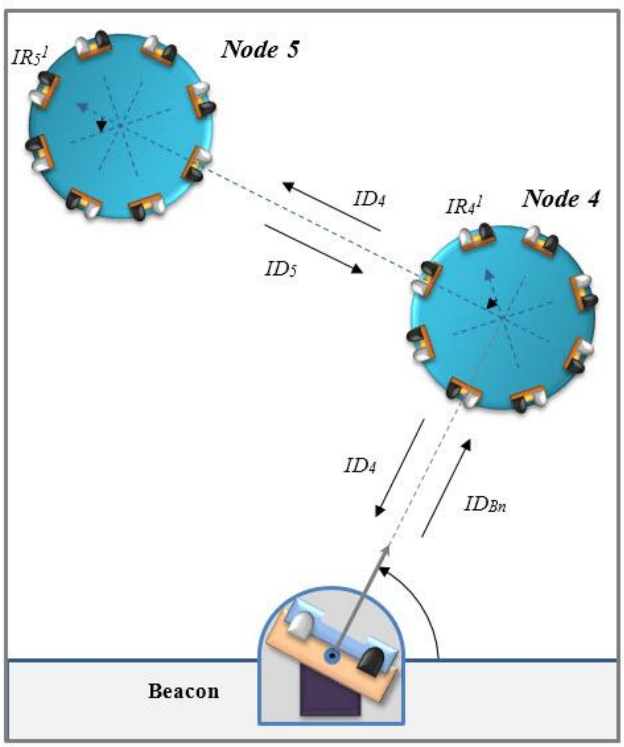

Fig.4. Schematic for single node with 8 IR Tr. And Rec. .

E. Localization of Invisible Nodes: The location of any invisible node in the system is found with the help of information obtained from two of its visible neighbors. This information includes locations of those two neighbors and the orientation of one of them. The process is achieved according to the following steps:

1. The beacon can conclude which nodes are invisible in table 1 and from table 2 the beacon can choose two of their visible neighbors which their coordinates are located in table 1. Fig. 6 shows node 2 which is invisible to the beacon and two of its visible neighbors which are node 4 and node 5.

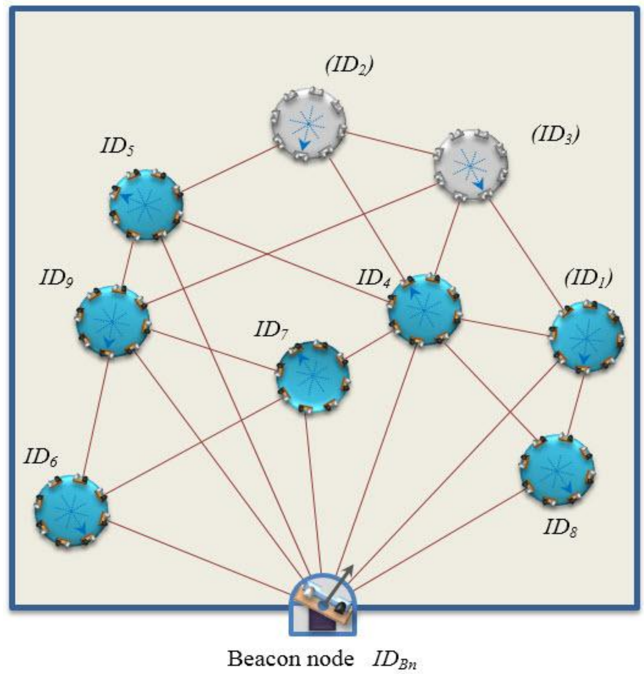

Fig.5. illustrates the connectivity among nodes in table 2.

2. To compute the location of invisible node, the beacon must at first compute the orientation of one of its two visible neighbors that have been chosen. The orientation means the angle between X- axis and the direction of reference IR sensor pair.

3. From table 1 the beacon chooses the detecting angle α_b^5 of the visible node 5.

4. From Fig. 6, the orientation angle β_5 of node 5 is computed according to the following equations:

$$\phi_5^{14} = (4-1) * k \qquad (3)$$

Where ϕ_5^{14} is the angle between IR_5^1 and IR_5^4 sensors on node 5.

$$\sigma = 180 - \phi_5^{14} \quad (4)$$

$$\beta_5 = \sigma + \alpha_b^5 \quad (5)$$

5. The localization of invisible node 2 as in Fig.7 is achieved according to set of equations as follow:

$$L = ((y_5 - y_4)^2 + (x_5 - x_4)^2)^{1/2} \quad (6)$$

Where L is the distance between node 4 and node 5.

$$\phi_5^{56} = (6 - 5) * K \quad (7)$$

Where ϕ_5^{56} is the angle between IR_5^5 (the sensor which received the signal from node 4) and IR_5^6 (the sensor which received the signal from node 2) on node 5.

$$\phi_4^{12} = (2 - 1) * K \quad (8)$$

Where ϕ_4^{12} is the angle between IR_4^1 (the sensor which received the signal from node 2) and IR_4^2 (the sensor which received the signal from node 5) on node 4.

$$\phi_2^{82} = 180 - (\phi_5^{56} + \phi_4^{12}) \quad (9)$$

ϕ_2^{82} represents the angle between the IR sensors which received the signals from nodes 5 and 4.

By using the sin low:

$$L / \sin \phi_2^{82} = R / \sin \phi_4^{12} \quad (10)$$

Where R is the distance between node 5 and node 2.

$$\phi_5^{61} = (9 - 6) * K \quad (11)$$

ϕ_5^{61} is the angle between the orientation of node 5 and the distance between node 2 and node 5. The number 9 represents (8+1), where 8 is total number of IR sensor pairs on each node.

$$\theta = \beta_5 - \phi_5^{61} \quad (12)$$

The coordinates (x_2, y_2) of the invisible node 2 will be as below:

$$x_2 = x_5 + R * \cos \theta$$
$$y_2 = y_5 + R * \sin \theta \quad (13)$$

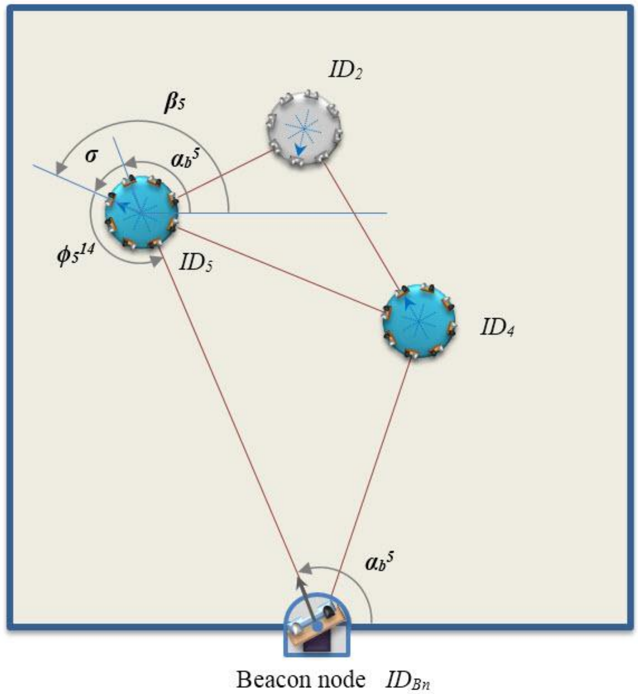

Fig.6, the orientation of node 5.

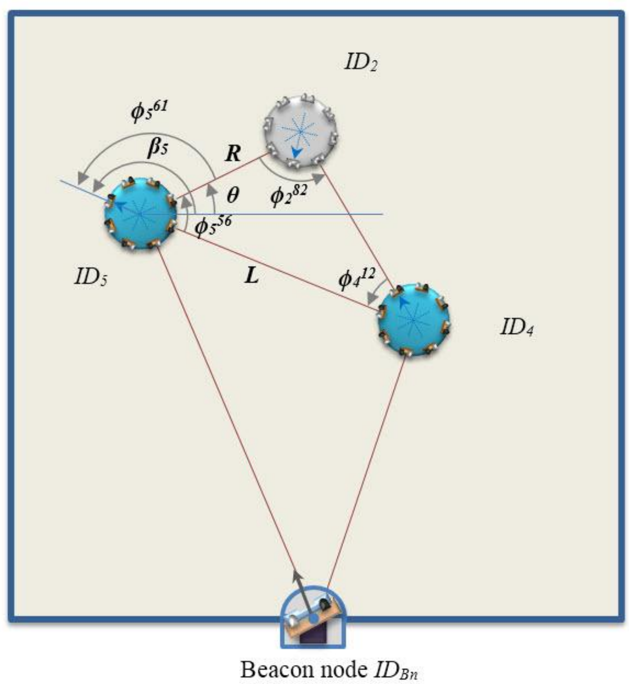

Fig.7. Localization of node 2.

Table 2. The neighboring nodes table

	IR^1	IR^2	IR^3	IR^4	IR^5	IR^6	IR^7	IR^8
ID_8	*Null*	*Null*	*Null*	ID_1	ID_4	*Null*	ID_{Bn}	*Null*
ID_1	ID_8	*Null*	*Null*	*Null*	*Null*	ID_3	ID_4	ID_{Bn}
ID_4	ID_2	ID_5	ID_7	ID_{Bn}	ID_8	ID_1	*Null*	ID_3
ID_7	*Null*	ID_9	ID_6	ID_{Bn}	*Null*	*Null*	ID_4	*Null*
ID_5	*Null*	*Null*	ID_9	ID_{Bn}	ID_4	ID_2	*Null*	*Null*
ID_9	ID_6	ID_{Bn}	ID_7	ID_3	ID_5	*Null*	*Null*	*Null*
ID_6	*Null*	ID_{Bn}	ID_7	ID_9	*Null*	*Null*	*Null*	*Null*

IV. THE SIMULATION RESULTS

Numerical simulations have been implemented by using visual basic 2012 programming language. It is repeated over 100 times on different sizes of networks ranging from 5 to 50 nodes and also repeated for three nodes' radiuses which are 10, 15 and 20 pixels. Nodes are distributed on an area of 500*500 pixels and each node has a unique ID number. The results of our algorithm are compared with the robotic cluster matching algorithm [21]; the robotic cluster matching algorithm uses a combination of absolute and relative sources for localization and orientation of multi-robot systems. The absolute information is obtained from the beacon which is a distance sensor located at the left bottom corner of the frame and rotates at 90°. The beacon scans the environment for visible robots that will be used to form clusters. On the other hand, the relative information is obtained from robots where every robot scans the environment looking for its neighbors to construct a unit disk graph. Finally, by the matching of clusters and the unit disk graph of each robot the visible robots will be localized. In our algorithm the beacon is provided with a distance and IR sensors; it is located at middle of the frame bottom edge and rotates at 180°. Fig.8, Fig. 9, and Fig. 10 study the effects of 10, 15 and 20 pixels node radius respectively on the visibility (the number of visible nodes) of 30 nodes environment, where the black nodes are visible to the beacon while the gray ones are not. It is obvious that the visibility decreases as the radius of nodes increases. The increasing in visibility means that the number of nodes which localized by the beacon increased and thus leads to an increase in number of nodes which have accurate locations.

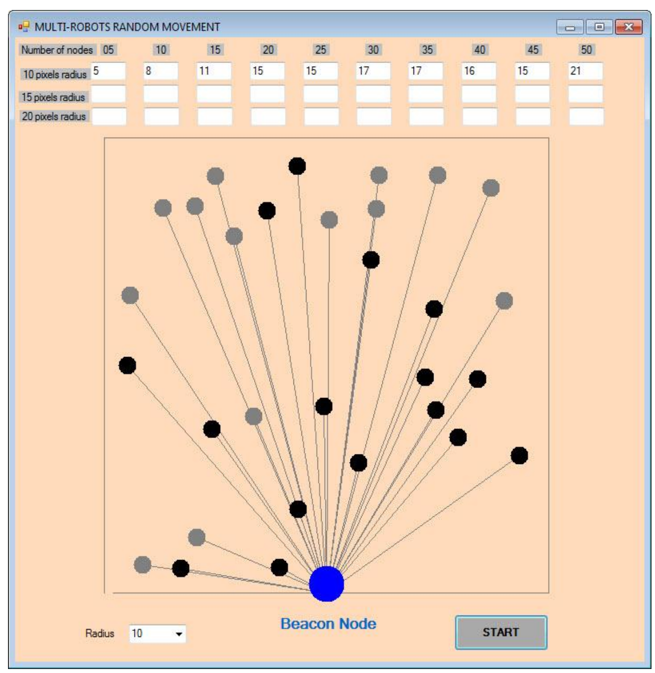

Fig. 8, Illustration the effects of nodes with 10 pixels radius on 30 nodes environment

Fig.11 shows a comparison between the visibility percentage of our algorithm and the robotic cluster matching algorithm with different number of nodes each of 10 pixels radius.

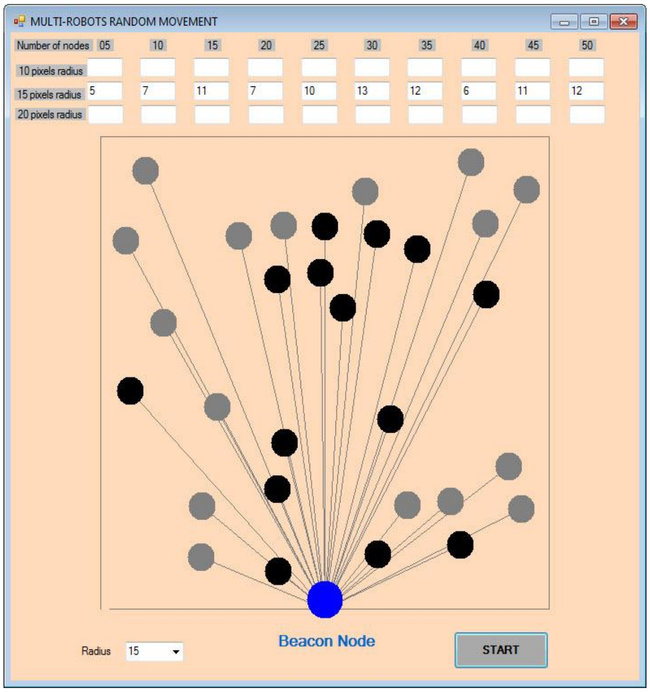

Fig. 9, Illustration the effects of nodes with 15 pixels radius on 30 nodes environment

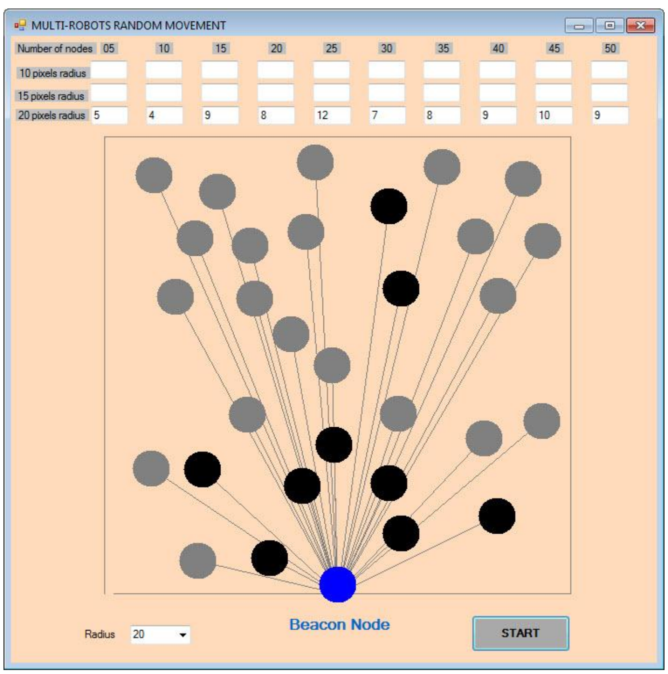

Fig. 10, Illustration the effects of nodes with 20 pixels radius on 30 nodes environment

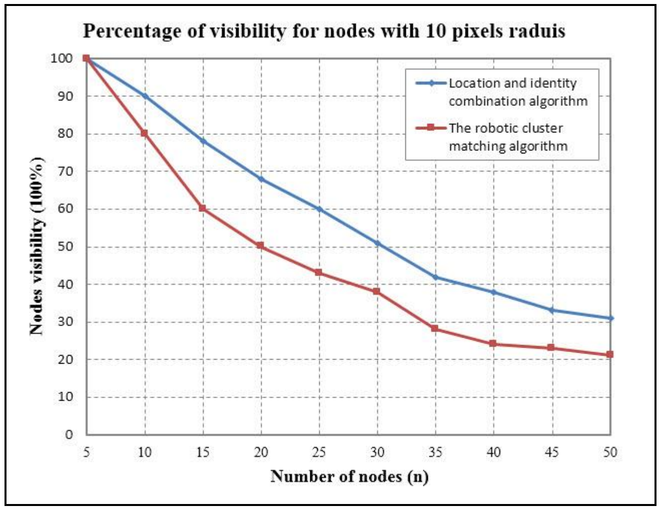

Fig. 11, the visibility comparison between the location and identity combination algorithm and the robotic cluster matching algorithm with nodes has 10 pixels radius.

Fig.12 and Fig. 13 show the same comparison but with 15 and 20 pixels nodes radius respectively. From these figures we notice that the visibility percentage of both algorithms decrease as the radius and the number of nodes increase but with all radiuses and with all number of nodes our algorithm shows a better performance than the robotic cluster matching algorithm.

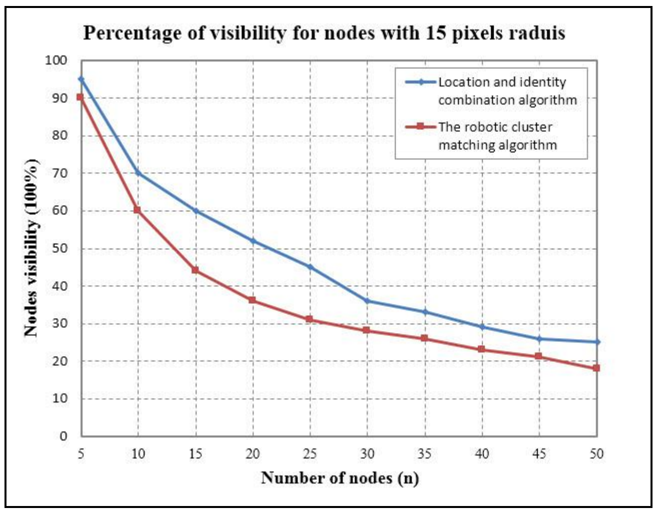

Fig. 12, the visibility comparison between the location and identity combination algorithm and the robotic cluster matching algorithm with nodes has 15 pixels radius.

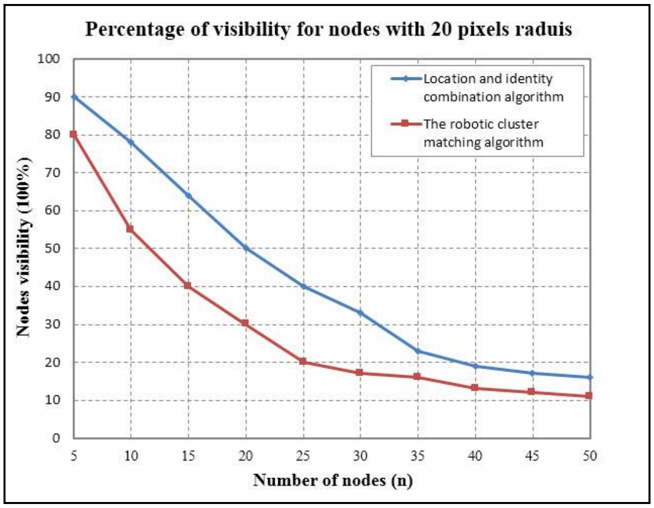

Fig. 13, the visibility comparison between the location and identity combination algorithm and the robotic cluster matching algorithm with nodes has 20 pixels radius.

In Fig. 14, Fig. 15 and Fig. 16 the effects of the beacon rotating angle and the offset between the beacon and visible nodes on the localization accuracy have been studied. Fig.14 shows an environment of 30 nodes each of 15 pixels radius nodes and a beacon with 1 degree rotation angle. Fig.15 and Fig. 16 show the same environments but with 2 and 3 degrees rotation angle respectively.

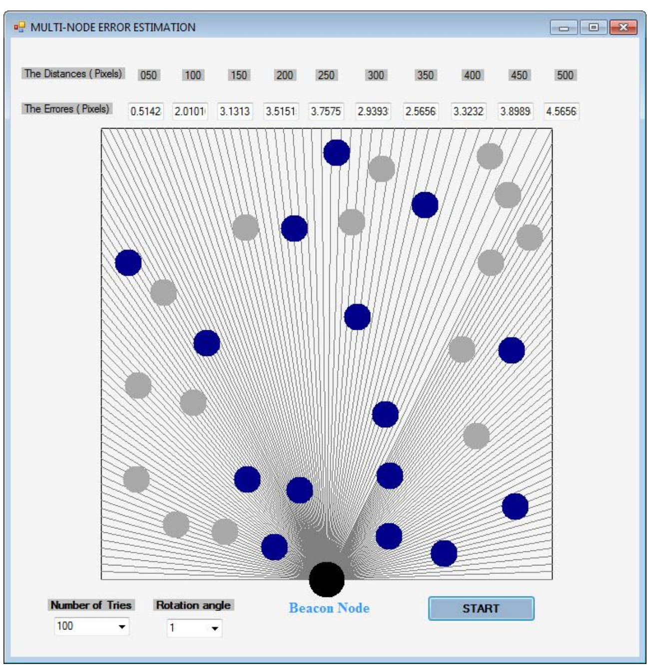

Fig.14. Median error in location estimation for nodes with 15 pixels radius and beacon with 1 degree rotation angle.

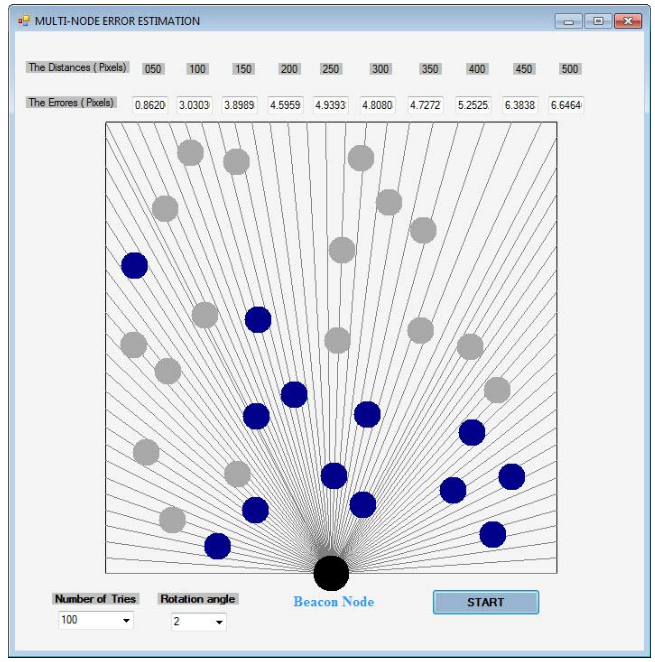

Fig.15. Median error in location estimation for nodes with 15 pixels radius and beacon with 2 degree rotation angle.

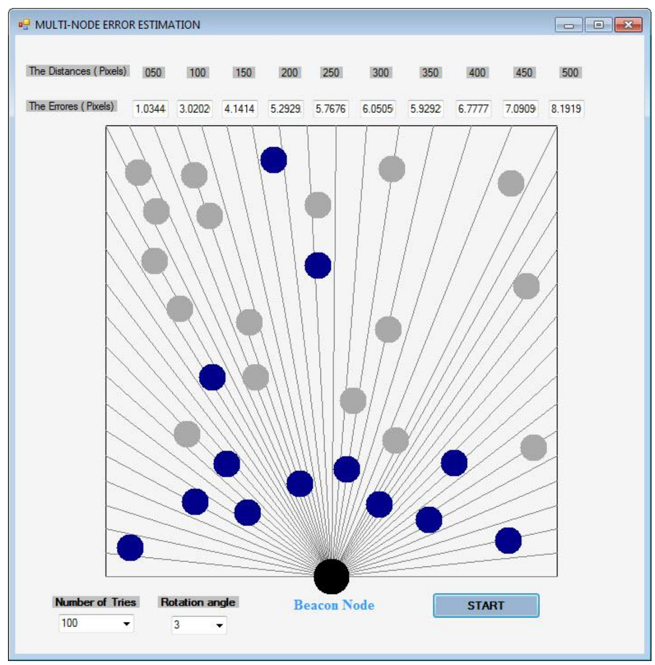

Fig.16. Median error in location estimation for nodes with 15 pixels radius and beacon with 3 degree rotation angle.

Fig.17 shows that by increasing the beacon rotation angle, the error in location estimation will also increase and thus will reduce the accuracy. It is worth to mention here, that increasing the offset between the beacon and visible nodes will also cause an increasing in the error average.

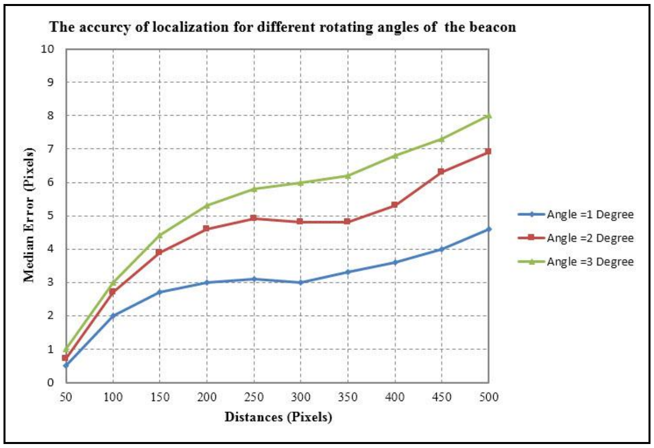

Fig. 17, the accuracy of localization for different rotating angles.

V. CONCLUSIONS

In this paper, an algorithm for multi-node localization system has been introduced; it uses the idea of centralized architecture where all the locations computation is done in a centralized station which is the beacon. In this algorithm, the beacon also serves as a source of absolute information during the environment scanning in search of visible nodes. The source of relative information is represented by the nodes where each node scans the environment to find its neighbors.

The position of beacon in our algorithm at middle of the frame bottom edge has highlighted the important role of this position on the nodes visibility average. So, as compared with the robotic cluster matching algorithm, our algorithm shows an increase in the visibility average meaning that more accuracy in location estimation will be obtained. Also, our proposed algorithm shows a better performance than the robotic cluster matching algorithm in addressing the nodes under the effects of different parameters such as the rotating angle of beacon, nodes radius and the size of network.

The proposed algorithm in this paper deals with nodes only. So, as an improvement we suggest to add a separate section for the orientation calculation to involve even the robots. Another suggestion is to add a beacon at middle of the frame upper edge to have more visibility average.

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