Range Free Localization of Wireless Sensor Networks Based on Sugeno Fuzzy Inference

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Abstract—**One of the challenges in wireless sensor networks is to determine the location of sensor nodes based on the known location of other nodes. This paper identifies an intelligent localization method, which is based on range free localization to estimate the location of the unknown nodes. In the proposed method, the anchor nodes are connected to the sensor nodes and then each sensor node receives a signal from the anchor node. The Received Signal Strength Indicator is then calculated by the node. The RSSIs are calculated based on the distance of the sensor node to each anchor node. The RSSIs are, then, fed to the Sugeno fuzzy inference system to calculate the weights to be used in the centroid relation. The centroid technique is proposed to estimate the location of the unknown sensor nodes. Both analytical and experimental results are discussed in this paper. The results show that with increasing the membership functions, the error decreases and that is because of the RSSI graph, which better fits the corresponding simulation result.**

Keywords-Range-free Localization; Received Signal Strength Indicator (RSSI); Centroid localization; Fuzzy Logic Systems; Wireless Sensor Networks.

I. INTRODUCTION

Wireless Sensor Networks consist of unique nodes, which are small, battery powered devices that can compute and communicate different signals in a target environment. The WSNs have many applications in building, air traffic control, manufacturing, automation, environment monitoring, other industrial and security applications [1].

The recent developments of micro electro mechanical systems (MEMS), communication technology and computing have motivated the use of massive distributed wireless sensor networks, which consist of hundreds or thousands of nodes. Thus every node is able to sense the environment, compute one or more tasks and communicate with central unit or other sensors [2].

Wireless Sensor Networks are particularly attractive in risky environments, specifically in a large deployment. In WSN applications, one of the important problems is the location of the unknown sensor nodes for the base service. The design of efficient localization algorithms depends on a successful localization technique to compute the correct sensor position in some coordinate system.

There are two kinds of nodes in WSNs, namely anchor nodes, and unknown sensor nodes. Some sensor nodes have pre-determined, known positions, which are called anchors or beacons. However, unknown sensor nodes don't have those specifications. One of the most significant problems in WSNs is the localization of these unidentified sensor nodes for the location based service and plays an important role in different applications scenarios in WSNs [3].

There are some works about localization in WSNs which can be divided into two classes: range based and range free schemes which are different in the information used for localization. The range based schemes require either node to node distance or the angles for estimating positions. They need more sophisticated hardware to estimate node range such as time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA) and received signal strength indicator (RSSI) [4].

On the other hand, the range free localization also has a drawback that it is not able to estimate the exact point to point distance. Nevertheless, the simplicity of the hardware made range free methods very appealing and advantageous for localization in wireless sensor networks. Although the results in range free schemes are not as precise as the range based, the low cost and simpler estimates are important reasons that the range free method has increased popularity in the recent years [5].

Fuzzy Logic (FL) is a multivalued logic which permits intermediate values to be defined between conventional evaluations such as yes or no, high or low, true or false, which has two different meanings. In the narrow sense fuzzy logic is a logic system of an extension of multivalued logic. FL has difference in both substance and concept of traditional multivalued systems in the narrow description. On the other hand, in a wide sense FL is synonymous with the theory of fuzzy sets that theory relates to classes of objects with limitations [6].

In this paper, the Sugeno fuzzy [10] inference is used for simulation to estimate the location of each sensor nodes.

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The reason for using Sugeno Fuzzy inference is the membership functions which are more suitable in order to model the RSSI graph. We increase the number of Fuzzy membership function in order to better fit the RSSI graph versus distance. In fact, all the RSSIs are fed to the fuzzy system to achieve the weights to be used in centroid relation in order to estimate the location of the sensor nodes.

The range free method has different techniques to estimate the position of sensor nodes in a specific region. In this paper Centroid localization based on RSSI has been utilized. RSSI is used in the estimation of the distance between each anchor and the sensor node.

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II. CENTROID LOCALIZATION

In centroid algorithms, the locations of the unknown nodes are estimate from the coordinates of their neighboring reference nodes. In fact, centralized localization is mainly based on transferring of the inter node ranging and connectivity data to a powerful central base station. After that, the computed positions are transferred back to the respective nodes.

The main advantage of the centralized localization method is that it omits the problem of computation in every node. The centroid localization scheme is simple and easy to implement. A simple centroid localization algorithm is needed to calculate a node's location based on the positions of many reference nodes which is simple but the estimation error might be high because of the simplicity of the centroid formula. However, using appropriate weights for the reference nodes decreases the localization error [7].

A. *Fundamental Centroid*

The range free algorithm based on proximity uses the location of anchor nodes (reference nodes) (x_i, y_i) to estimate the nearest unknown node [7]. The task of the centroid algorithm is, to take several nodes around the unknown nodes as polygon vertices and the unknown node as the centroid of the polygon, which is indicated in Figure 1.

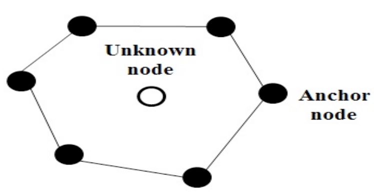

Figure 1. Centroid Localization Algorithm.

After receiving the message, the following relationship is used for estimating the coordinates of the unknown node:

$$(X_{est}, Y_{est}) = \left(\frac{X_1 + \ldots + X_N}{N}, \frac{Y_1 + \ldots + Y_N}{N}\right) \quad (1)$$

where (X_{est}, Y_{est}) indicates the estimated position of the sensor node and N is the number of the anchor nodes which is connected to the sensor node. This algorithm is simple but is not sufficient enough for estimating the unknown position. Therefore, the use of some weights on the reference nodes is required to solve this problem.

The method to improve the results of Eq. (1), where the anchor nodes are weighted in terms of their proximity to the sensor nodes, is given by this formula [8]:

$$(X_{est}, Y_{est}) = \left(\frac{x_1 w_1 + \ldots + x_n w_n}{\sum_{i=1}^{n} w_i}, \frac{y_1 w_1 + \ldots + y_n w_n}{\sum_{i=1}^{n} w_i}\right) \quad (2)$$

This method also has a weakness due to the choice of the weights $(w_1, w_2, \ldots, w_n)$ and the performance depends on the design of the weights.

Soft computing is an important tool to solve the problem of using low-cost, simple hardware and it is very appropriate for systems with uncertainties and nonlinearities. It is used to achieve tractability, robustness and low solution cost. Soft computing technique in fuzzy logic plays a crucial role in this paper [9].

III. LOCALIZATION USING FUZZY LOGIC

The fuzzy logic provides a distinct way to achieve control or classification in a system. This method is focused on what the system must do more than trying to model how it works and also it can concentrate on solving a problem more than the mathematical modeling of the system. The fuzzy logic is an area of research, which is fascinating and reaches a trade off between significance and exactness. Fuzzy logic is a reasonable way to map an input space to an output space where mapping is the starting point for everything [6].

One of the concepts in fuzzy logic is an if-then rule, which used in artificial intelligence that deals with fuzzy antecedents or consequents. Indeed, fuzzy logic solution is an interpretation of human thinking. On the other hand, FL can model nonlinear functions of optional complexity to a sufficient degree of exactness. Fuzzy logic is a simple way to model a multi input and multi output system [10].

IV. SIMULATION RESULTS

Estimating the location of each sensor node is done by the centroid method. Hence, the weights are the main variable in the centroid relation, which are the outputs of the fuzzy system in the simulation. In fact, the Sugeno fuzzy system receives RSSIs as inputs to map the outputs, which are weights of each anchor node to the sensor node.

A WSN consists of sets of anchor nodes and sensor nodes with anchor nodes are located at known positions as $[(X_1, Y_1), (X_2, Y_2), \ldots, (X_N, Y_N)]$ and transmit signal strengths containing their respective locations.

The anchor nodes in this implementation are located at (0,0), (10,0), (10,10) and (0,10), where the coordinates are in meters. Several sensor nodes are distributed randomly in the specific region and receive signal strengths from the anchor nodes to estimate their location. The main responsibility of the sensor node is to compute the RSSI information sent by the anchor nodes.

The implementation is been done by Sugeno type fuzzy inference method. The Sugeno fuzzy inference is similar to the Mamdani method and the main difference between them is the membership functions where the output in the Sugeno method is constant or linear.

The input membership function of the Sugeno method is the RSS from the anchor nodes, which are decomposed into nine triangular membership function such as very very low (VVL), very low (VL), low (L), medium low (ML), medium (M), medium high (MH), high (H), very high (VH), very very high (VVH) that it shown in Figure 2. The input membership functions take value $[RSS_{min}, RSS_{max}]$, where RSS_{min} and RSS_{max} are the minimum and maximum RSS respectively, which are received by each sensor from each of the anchor node.

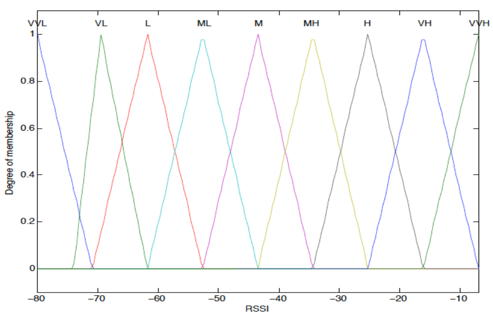

Figure 2. Input membership functions.

On the other hand, the output membership function of the Sugeno fuzzy inference is the weight of each anchor node for a given sensor node which takes a value $[0, w_{max}]$, where w_{max} is the weight with a maximum value of one. The output membership function distributes into nine linear functions such as VVL, VL, L, ML, M, MH, H, VH, VVH.

To find the range of output of each membership function, the logarithm of each RSSI at different distances should be mapped to linear variable between [0,1]. On the other hand, the RSSIs should be mapped among [0,1] in nine variable with weights.

The rules are considered for this Sugeno fuzzy method are in terms of the power of RSS. If the anchor node receives a high power from the sensor node, it indicates that the sensor node is near to the anchor node. On the other hand, if the senor node receives a low power, it shows that the sensor node is far from the anchor node. Table 1 shows the rules of Sugeno fuzzy system.

TABLE I. FUZZY LOGIC RULES

RULES	IF: RSSI IS	THEN: WEIGHT
RULE 1	V V LOW	V V LOW
RULE 2	V LOW	V LOW
RULE 3	LOW	LOW
RULE4	MEDIUM LOW	MEDIUM LOW
RULE 5	MEDIUM	MEDIUM
RULE 6	MEDIUM HIGH	MEDIUM HIGH
RULE 7	HIGH	HIGH
RULE 8	V HIGH	V HIGH
RULE 9	V V HIGH	V V HIGH

Figure 3 indicates the surface of the fuzzy system, which shows the weights corresponding to the RSSI values.

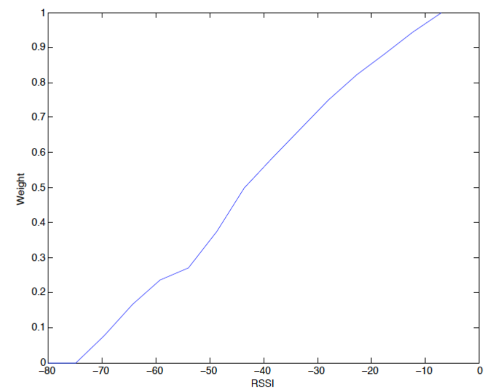

Figure 3. RSSI vs. Weight (Surface).

A. Calculating RSSI

The sensor nodes are distributed randomly in a square region with a side length of 10 metres. The first step is to estimate the RSSI by the following formula:

$$RSSI = -(10 n \log_{10}(d) + alpha) \quad (3)$$

where d is the distance of each sensor node to the anchor nodes, $n=3.25$ is path loss exponent, which may take different values because of ambient conditions may differ in different directions. Alpha is a constant and is the RSSI value of the sensor node that is located at 1-meter distance from the anchor node; so, in this paper, alpha is considered to be -40dBm for this implementation.

B. Using Localization Algorithm

The centroid method is the scenario considered in this paper. Therefore, for estimating the coordinates of the sensor nodes, the centroid formula given in Eq. (2) is used, where N is the number of connected adjacent reference nodes.

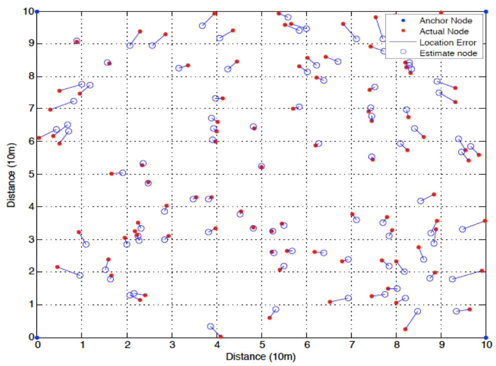

Figure 4. Simulation result of localization by Sugeno fuzzy method.

As seen in Figure 4, the region is 10 square meters, where the anchor nodes are located at (0,0), (10,0), (10,10) and (0,10). 100 sensor nodes are randomly deployed in the region. Each sensor node receives four different RSSI from each of the four anchor nodes, therefore, RSSIs reflect the distance of the sensor node to each of the anchor nodes. After estimating the RSSIs, each sensor node has four weights that are estimated by Sugeno fuzzy system.

The solid red dots shown in Figure 4 are the exact locations of the randomly deployed sensor nodes and the empty circles shown as connected to the solid circles are the estimated locations of the sensor nodes. The length of the line between them is the error of location.

C. *Performance Evaluation*

The location error between actual and estimated nodes is calculate by the following relation:

$$\text{Location error} = \sqrt{(x_{est} - x_{a})^2 + (y_{est} - y_{a})^2} \quad (4)$$

In order to estimate the position errors for all the estimated and actual nodes, the following relation is used

$$\text{Average Location Error} = \frac{\sum \sqrt{(x_{est} - x_{a})^2 + (y_{est} - y_{a})^2}}{N} \quad (5)$$

where N is the total number of sensor nodes.

After estimating the location of the sensor nodes in the simulation, Additive White Gaussian Noise (AWGN) is added to the RSSI with Signal to Noise Ratio (SNR) equal to 10. Figure 5 indicates the result simulation of localization with AWGN.

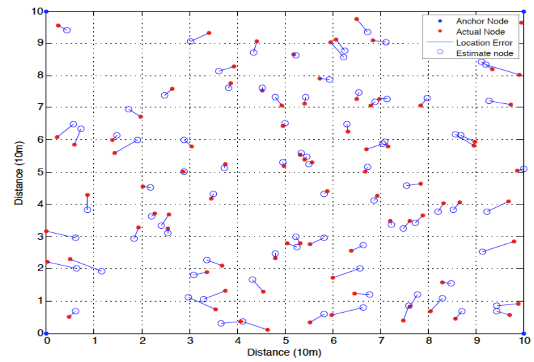

Figure 5. The location of sensors with AWGN.

Table 2 indicates minimum, maximum and average error locations of sensor nodes in both centroid method and fuzzy are shown. Hence, the result of centroid method error location comparing to the fuzzy is very high. For fuzzy, the result error location for both with and without AWGN also shown. The result of average errors in both areas are close to each other. According to this table and comparing the minimum and maximum of both results of error location in the areas, we see that this implementation has the highest accuracy in different environments.

TABLE II. THE COMPARISON RESULTS

	Min Error Location	Max Error Location	Average Error Location
Centroid Method without Fuzzy	0.10	4.35	2.95
Fuzzy	0.005	0.70	0.26
Fuzzy + AWGN	0.01	0.79	0.30

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V. EXPERIMENTAL RESULTS

The experiment is done in a square region with 10 meters side length. The RSSIs taken from each node in this experiment have slightly different values compared to the RSSIs obtained in the simulation. Figure 8 shows the result of RSSIs for both simulation and experiment. The solid line in this figure indicates the result of RSSI simulated in Matlab^{TM} and the other line is the result of RSSI taken from the experiment (Figure 6).

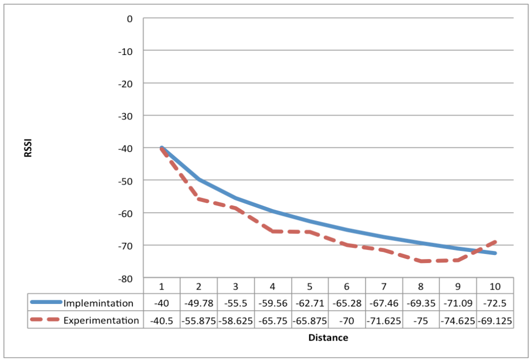

Figure 6. RSSIs in Simulation and Experimentation.

In the experiment, some nodes are located randomly in the region in order to obtain their RSSI from the anchor nodes. Each RSSI is then fed to the fuzzy system to get the corresponding weights.

This experiment is repeated 6 times for 6 different positions of the sensor nodes. Figure 11 shows the position of one of the random nodes located at (1,1).

Figure 7. Sensor node in position (1,1).

As can be seen from Figure 7, the sensor node is closer to the first anchor (0,0), so it receives the highest RSSI in comparison with the other anchor nodes. The centroid relation for the sensor nodes is given in Table 3.

As can be seen from Table 3, the node at (1,1) receives the highest RSSI from the anchor node at (0,0), which is the nearest anchor node. On the other hand, that node receives the minimum RSSI from the anchor node at (10,10) so it is located at the farthest distance from that anchor node. The difference between the measured and simulated results is very low.

TABLE III. THE RESULTS OF THE EXPERIMENT. THE POWER VALUES ARE IN dbm AND THE LOCATION IN meters.

(X_a,Y_a)	RSSI from (0,0)	RSSI from (0,10)	RSSI from (10,0)	RSSI from (10,10)	(X_{est},Y_{est})	Error Location
(1,1)	-41	-71.5	-68.5	-75.5	(1.37,0.74)	0.45
(4,3)	-57	-69	-63	-68	(4.67,2.98)	0.67
(2,7)	-67	-65	-75	-70	(2.10,6.56)	0.44
(5,5)	-69	-71	-70	-68	(5.52,4.98)	0.52
(7.5,7.3)	-75	-68	-67	-55	(7.89,7.54)	0.46
(9,5)	-73	-74	-64	-65	(9.21,4.34)	0.69

Table 4 represents the comparison results of error location in both implementation and experimentation.

TABLE IV: COMPARISON RESULTS OF ERROR LOCATION

	Average Error in Simulation	Average Error in Experiment
S. Yun, J. Lee, W. Chung, E. Kim, S. Kim (2009)	0.78	0.80
V. Kumar, A. Kumar, S. Soni (2011)	0.59	0.94
Proposed Method in this Paper	0.26	0.53

It can be seen that, the result of error location obtained in this paper by Sugeno fuzzy is less than the other existing methods. This is due to the enhancement in the input membership functions in the Sugeno fuzzy system which has been increased in order to better mapping between input and output.

VI. CONCLUSION

The node localization is a big challenge in wireless sensor networks. The range free localization method is very simple and does not require a complicated hardware. The range free method has different techniques to estimate the position of a sensor node in a specific region. In this paper Centroid localization has been used. The estimation of each sensor node's location has been implemented by RSSI. The Sugeno fuzzy inference is used to simulate for estimating the location of each sensor node. The RSSIs are fed to the fuzzy system to compute the weights to be used in the centroid relation in order to estimate the location of the sensor nodes. The weights are the main parameter in the centroid relation, which are the outputs of the fuzzy system. The Sugeno fuzzy system receives RSSIs as inputs to map to the outputs, which are the weights of each anchor node with respect to the sensor node. The simulated results are checked with an experimental setup. The experiment is repeated 6 times for 6 different sensor nodes in the region. The agreement between the simulated and measured results is very good.

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