IMPACT OF BORDER-DETERMINING ALGORITHM ON FUZZY LOGIC INFERENCE BASED LOCALIZATION SCHEMES IN WIRELESS SENSOR NETWORKS

Usman Hassan, Fahim Gohar Awan, Rizwan Khan, Suhail Aftab Qureshi, Asima Kiran
Faculty of Electrical Engineering, UET, Lahore, Pakistan

ABSTRACT - *Low-cost range-free solutions to localization problem in Wireless Sensor Networks are not as highly accurate as range-based solutions are. Border determining algorithm when combined with simple centroid scheme gives low location error than given by simple centroid scheme alone, when layout of nodes is rectangular or C-shaped. In this paper, we combine the Border Determining Algorithm UBA with Mamdani FLI and ANFIS trained Sugeno weighted FLI approaches and its effects are noted. It is observed that accuracy of Mamdani FLI scheme for localization is enhanced by combined approach while it has no effect on ANFIS trained Sugeno scheme.*

Index Terms — Wireless Sensor Networks, Node Localization, Border Node, Mamdani FLI Scheme, ANFIS Trained Sugeno FLI Scheme.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have found widespread applications over the past decade ranging from defense to commercial jargons [1,2,3]. Alongside other data, sensor nodes are often required to send their location coordinates to a processor node that may be local or remote. For that, a sensor node needs to determine its own location first. Two types of localization schemes namely range-based and range-free are in practice [4]. Both require a certain number of GPS receiver bearing location aware nodes called anchor nodes in the deployed region. Range-based methods demand highly accurate signal measurement and timing synchronization. Range-free methods are quite handy in situations where location accuracy requirements are not stringent [5,6,7].

In the local technique used in range-free localization schemes, a sensor node estimates its location coordinates based on position information of its neighboring anchor nodes received in the beacon signals sent by them [8]. Many of these schemes are based on weighted centroid scheme [9], [10] which was first suggested by Kim S. Y. and Kwon O. H. [11]. The challenge is to optimize the weights of anchor nodes. In [5], Ashok Kumar et al. proposed fuzzy logic interference (FLI) approaches i.e. Mamdani FLI approach, Adaptive-Network-Based Fuzzy Inference System (ANFIS) trained Sugeno weighted FLI approach and Mamdani-Sugeno combined FLI approach to compute the optimized edge weights of all neighboring anchor nodes of a sensor node. They observed that ANFIS trained Sugeno and Mamdani-Sugeno combined approaches give highly accurate positions of sensor nodes in comparison to Mamdani FLI approach which in turn outperforms the simple centroid scheme.

The Usman Border-Determining Localization Scheme [12] improved the accuracy of simple centroid scheme by eliminating the need to compute the average of either x or y coordinates of neighboring anchors if the sensor node is in close proximity of any of the physical borders of a rectangular or C-shaped pattern of node deployment. The estimate of that coordinate of sensor node's location takes the value of corresponding coordinate of the neighboring anchor node closest to the border it is near to. The closest neighboring anchor node is identified by Usman's Border Determining Algorithm (UBA).

In this study, we combine Usman's Border Determining Algorithm with Mamdani FLI and ANFIS trained Sugeno FLI schemes i.e. if a sensor node is found to be located very close to any of the borders (top, bottom, left or right), then one of its x and y coordinates (both in case of 'corner' nodes) is set equal to the corresponding coordinate of a suitable anchor node while the other coordinate is the weighted average of corresponding coordinates of all neighbors with weights optimized under either Mamdani or Sugeno approach. The two localization techniques are termed as UBA Incorporated Mamdani FLI and UBA Incorporated ANFIS trained Sugeno FLI respectively.

This paper is organized as follows. Section 2 presents a brief overview of Mamdani FLI and ANFIS trained Sugeno FLI approaches. Then it schematically describes generic UBA Incorporated FLI based localization technique. Section 3 discusses results obtained by simulating both UBA Incorporated schemes under test conditions of [12]. Conclusion is drawn in Section 4.

II. MODELING OF UBA INCORPORATED FLI BASED SCHEMES

The basis of FLI based localization techniques is the weighted centroid formula [11] given as

$$(X_{est}, Y_{est}) = \left(\frac{w_1X_1 + \cdots + w_NX_N}{w_1 + w_2 + \cdots + w_N}, \frac{w_1Y_1 + \cdots + w_NY_N}{w_1 + w_2 + \cdots + w_N}\right). \quad (1)$$

where X_{est}, Y_{est} denote the estimate of the location of a sensor node, total number of its neighbors is N, (X_i, Y_i) denotes the position of any anchor node $(i = 1,2,3, \ldots, N)$ and w_i represents the i^{th} anchor node edge weight.

If w_i=1 for all i, (1) becomes simple centroid formula. Positions of anchor nodes become known to the sensor node through beacon signals.

The second vital information conveyed by each neighboring anchor node to the sensor node through beacon signals is received signal strength information (RSSI). RSSI of an anchor node serves as input to Mamdani and Sugeno-ANFIS schemes. RSSI on a scale of [1-100] is fed to input membership function shown in Figure 1 [5] and the firing degree of each weight (output) membership function shown in Figure 2 [5] is obtained as per Table 1 [12] and in case of Mamdani localization, crisp value of output weights is obtained by area bisector method as explained in [12]. In case of ANFIS trained Sugeno localization, the relationship between RSSI and edge weights is linear as shown in Figure

3 [5].

Table 1.
If-Then rule of Weight Function

RSSI	Weight membership functions/ Category
very low	very low/ 1
low	Low/ 2
medium	Medium/ 3
high	High/ 4
very high	very high/ 5

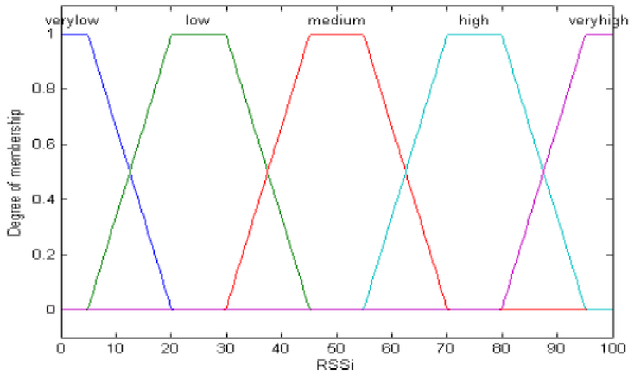

Fig 1. Mamdani fuzzy membership function of RSSI

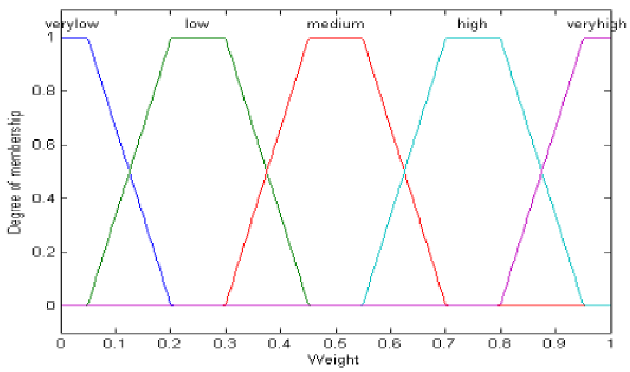

Fig 2. Mamdani fuzzy membership function of weight

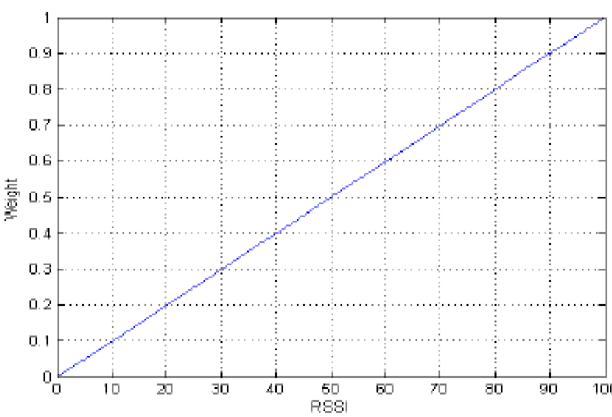

Fig 3. Relationship between RSSI and weight for ANFIS trained Sugeno

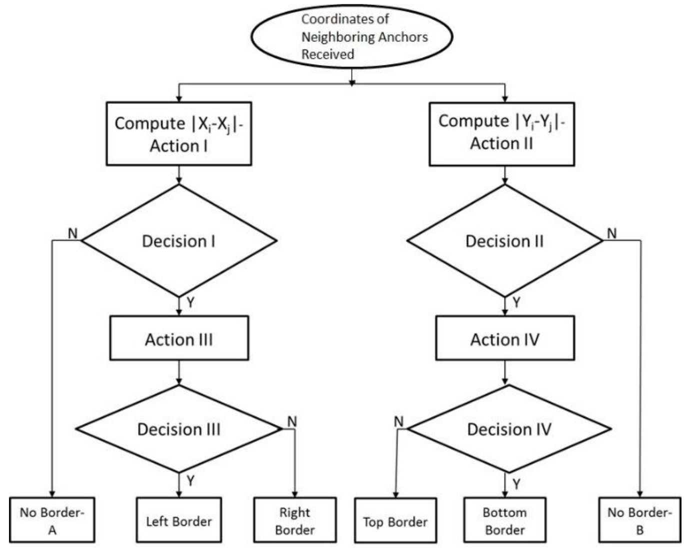

Fig 4. UBA Incorporated FLI Method.

The proposed UBA Incorporated FLI technique (steps are similar in Mamdani and ANFIS trained Sugeno methods) is elaborated through flowchart of Figure 4 as:

Action I: $i \in \{1,2,..,N\}$, $j \in \{1,2,..,N\} - i$
Action II: $i \in \{1,2,..,N\}$, $j \in \{1,2,..,N\} - i$
Decision I: $|X_i - X_j|$ < radio range for all i, j?
Decision II: $|Y_i - Y_j|$ < radio range for all i, j?
Action III: Arrange Xi; $X_1<X_2<\ldots<X_N$
Action IV: Arrange Yi; $Y_1<Y_2<\ldots<Y_N$
Decision III: $|X_1-X_2|==0$ && $|X_1-X_3|==0$?
Decision IV: $|Y_1-Y_2|==0$ && $|Y_1-Y_3|==0$?
A: No vertical border
B: No horizontal border

The essence of UBA Incorporated Mamdani and UBA Incorporated ANFIS-Sugeno techniques is as follows:

I) Each sensor node finds out using UBA if it is close enough to the left, top, right or bottom border of the region of deployment.

II) If sensor node is very near to left border, the estimate of its x-coordinate $X_{est} = X_1$, x-coordinate of the neighboring node closest to the left wall

If sensor node is very near to the right border, the estimate of its x-coordinate $X_{est} = X_N$, x-coordinate of the neighboring node closest to the right wall

If sensor node is very near to top border, the estimate of its y-coordinate $Y_{est} = Y_N$, y-coordinate of the neighboring node closest to the top wall

If sensor node is very near to bottom border, the estimate of its y-coordinate $Y_{est} = Y_1$, y-coordinate of the neighboring node closest to the bottom wall

III) Weights $w_1, w_2, \ldots, w_N$ are computed according to the FLI scheme (Mamdani or ANFIS trained Sugeno) being implemented. If X_{est} has not been set to any value in step II, and X_{est} is set as follows:

$$X_{est} = \frac{w_1 X_1 + \cdots + w_N X_N}{w_1 + w_2 + \cdots + w_N}. \quad (2)$$

If Y_{est} has not been set to any value in step II, and Y_{est} is set as follows:

$$Y_{est} = \frac{w_1 Y_1 + \cdots + w_N Y_N}{w_1 + w_2 + \cdots + w_N}. \quad (3)$$

III. SIMULATION RESULTS AND ANALYSIS

Performances of Mamdani localization scheme and ANFIS trained Sugeno localization scheme were tested under the similar simulation environment as in [12], with and without pre-identification of border nodes, to see in each of these two cases if pre-identification of border nodes brings improvement in localization accuracy or not. The simulation parameters are enlisted in Table 2.

Table 2
Simulation Parameters

Parameter	Value
Sensing area	100 m^2
Number of sensor nodes	60, uniformly distributed
Number of anchor nodes	64, in a rectangular grid pattern
Radio range of each node	5m

Table 3
Average Location Error versus Radio Range

Scheme	Average Error
Mamdani FLI	0.65m
UBA Incorporated Mamdani	0.49m
ANFIS trained Sugeno	0.18m
UBA Incorporated ANFIS-Sugeno	0.21m

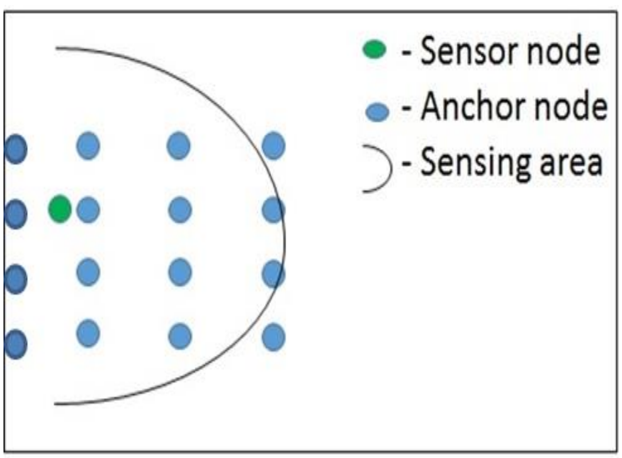

Fig 4. Sensor node is closer to the anchor node on its right but UBA declares it to be near to left Border.

The effect of pre-identification of border nodes by UBA on Mamdani FLI scheme can be seen by comparing Figure 5 and Figure 6 while impact of UBA on ANFIS-Sugeno scheme can be seen by examining Figure 7 and Figure 8. Table 3 lists the numerical values of average localization error in each scheme.

It is observed that UBA reduces the average location error of Mamdani FLI scheme by approximately 25% while it degrades the performance of ANFIS trained Sugeno scheme by 16.67%. The reason for this outcome is explained below.

Mamdani FLI scheme gives at least some weightage to the anchor nodes whose RSSI is low or very low; no matter how strong the RSSI from some other anchor nodes may be, 100% weightage is never given to any anchor node under Mamdani approach. Furthermore, Mamdani scheme gives equal weights to both x and y coordinates of a single anchor node. UBA guesses on the basis of collective evidence of all neighboring anchors if at least one of x and y coordinates of one neighbor can be given decisive preference over all other neighbors, thus improving the localization accuracy.

ANFIS trained Sugeno FLI method with nodes being fully trained is already an efficient scheme and UBA can erroneously declare some sensor nodes to be border nodes while they lie between the border and the anchor node(s) deployed nearest to that border as is illustrated in Figure 5. This increases the estimation error.

IV. CONCLUSION

In this paper we have investigated the impact of detection of border nodes prior to application of two range-free FLI localization schemes in rectangular or C-shaped Wireless Sensor Networks. The average location error has been reduced by 25% for Mamdani FLI scheme while the performance of ANFIS trained Sugeno scheme is degraded by 16.67%. It is concluded that detection of at least one coordinate of some nodes in proximity of any border and thus excluding the FLI method to determine that coordinate improves the accuracy in case of Mamdani approach having linear input and output membership functions; while border identification unnecessary pulls the estimate towards the border in case of already efficient ANFIS trained Sugeno approach.

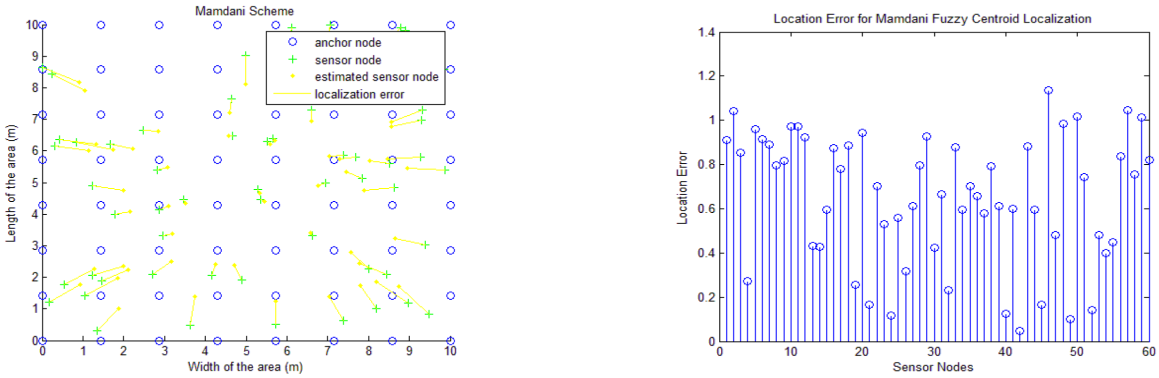

Fig 5. Location error in case of Mamdani FLI Scheme

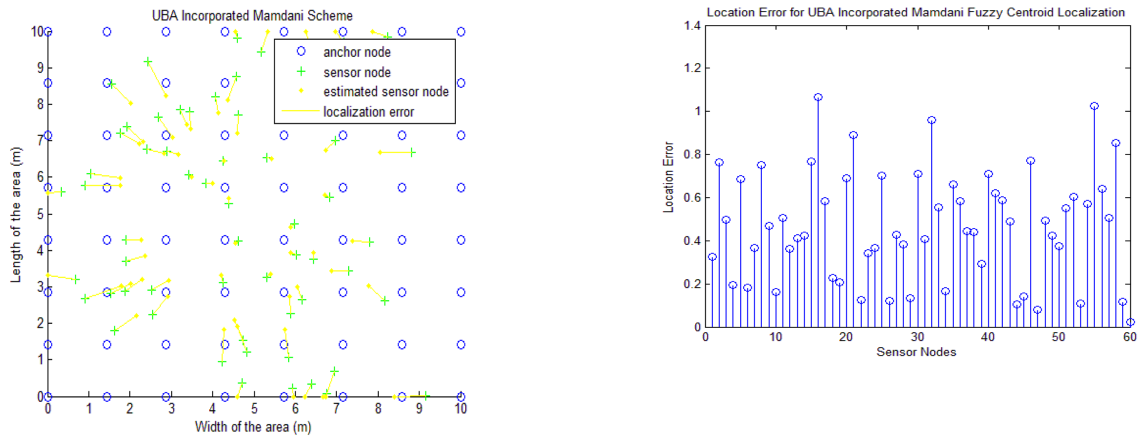

Fig 6. Location error in case of UBA Incorporated Mamdani FLI Scheme

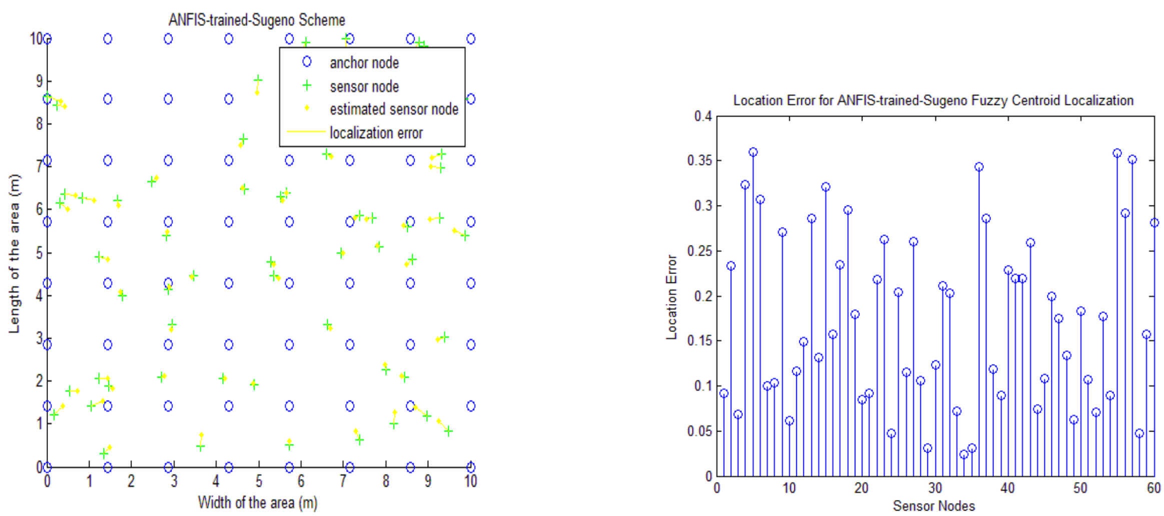

Fig 7. Location error in case of ANFIS-Trained-Sugeno FLI Scheme

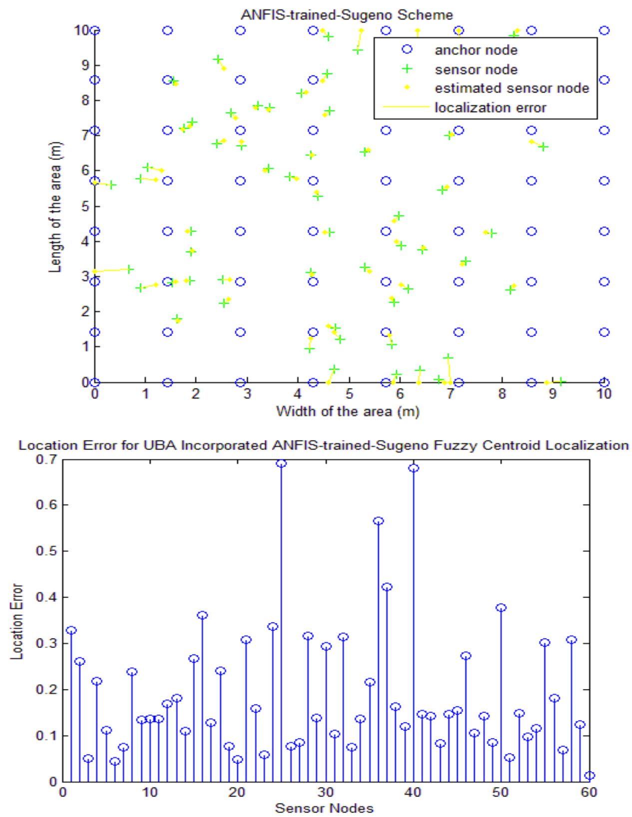

Fig 8. Location error in case of UBA Incorporated ANFIS-Trained-Sugeno FLI Scheme

REFERENCES

[1] G. Lukachan and M.A. Labrodor, "SELAR: Scalable Energy-Efficient Location Aided Routing Protocol for Wireless Sensor Networks," *Proceedings of LCN'04*, Tampa, FL, Nov. 16-18, 2004.

[2] D. Niculescu and B. Nath, "DV Based Positioning in Ad hoc Networks," *Journal of Telecommunication Systems*, Vol. 22, No. 1, January 2003, pp. 267-280.

[3] D. P. Qiao and G. K. H. Pang, "Evolutionary approach on connectivity-based sensor network localization", Applied Soft Computing, vol. 22, (2014), pp. 36-46.

[4] Li, Yingshu, and My T. Thai., "*Wireless sensor networks and applications*.", Springer Science & Business Media, 2008.

[5] A. Kumar, N. Chand, V. Kumar and V. Kumar, "Range Free Localization Schemes for Wireless Sensor Networks," *International Journal of Computer Networks & Communications*, Vol. 3, No. 6, November 2011, pp. 115-129.

[6] Kumar, Ashok, Vinay Kumar, and Vinod Kapoor, "Range free localization schemes for wireless sensor networks." In *the 10th WSEAS International Conference on Software Engineering, Cambridge, UK*, pp. 101-106. 2011.

[7] Khadim, Rania, Mohammed Erritali, and Abdelhakim Maaden, "Range-Free Localization Schemes for Wireless Sensor Networks." *Indonesian Journal of Electrical Engineering and Computer Science* 16, no. 2 (2015): 323-332.

[8] L. Q. Gui, V. Thierry and A. Wei, "Improvement of range-free localization technology by a novel DV-hop protocol in wireless sensor networks", Ad Hoc Networks, vol. 8, (2014), pp. 1-19.

[9] D. S. Han, W. Yang, Y. Liu and Y. Liu and Y. Zhang, "A Weighted Centroid Localization Algorithm Based on Received Signal Strength indicator for Underground Coal Mine", Journal of China Coal Society, vol. 3, no. 38, (2013), pp. 522-528.

[10] So-In, Chakchai, Songyut Permpol, and Kanokmon Rujirakul, "Soft computing-based localizations in wireless sensor networks." *Pervasive and Mobile Computing* 29 (2016): 17-37.

[11] Kim S. Y. and Kwon O. H., "Location Estimation Based on Edge Weights in Wireless Sensor Networks," *The Journal of Korean Institute of Communications and Information Sciences*, Vol. 30, No. 10A, pp. 938-948, 2005.

[12] Hassan, U.; Awan, F.G.; Kiran, A., "Design and Analysis of a Border-Determining Range Free Localization Scheme Based on Fuzzy Logic Inference System for Wireless Sensor Networks," *Science International Journal* **(**CODEN: SINTE 8**)**, vol. 28, issue 1, pp. 105-109, February 2016.