2016 14th International Conference on Control, Automation, Robotics & Vision
Phuket, Thailand, 13-15th November 2016 (ICARCV 2016)

Fast Localization for Emergency Monitoring and Rescue in Disaster Scenarios Based on WSN

Mingxiao Lu*†, Xiaoguang Zhao*†, Yikun Huang*
*The State Key Lab of Management and Control for Complex System
Institute of Automation, Chinese Academy of Sciences, Beijing, China
†School of Computer and Control Engineering
University of Chinese Academy of Sciences, Beijing, China
Email: lumingxiao2014@ia.ac.cn, xiaoguang.zhao@ia.ac.cn

***Abstract*—Natural disasters, such as earthquake, typhoon and flood, have caused great loss of lives and property each year, which makes emergency monitoring and rescue an imperative problem to be addressed. In this paper, we designed a novel monitoring and rescue system based on wireless sensor network (WSN) for disaster scenarios, which combines environment monitoring, information transmission, and emergency localization. In our system, fast localization through WSN is a crucial technique for searching and rescuing. We proposed an improved weighted centroid algorithm with adaptive error correction to increase localization accuracy of sensor networks with sparse anchors. This method based on received signal strength indication (RSSI) is low cost, expandable, easy to implement, and suitable for disaster rescues.**

I. Introduction

Every year, numerous people lose their lives in the earthquake, typhoon, debris flow, and other natural disasters all over the world. Many tragedies occurred because of inefficient disaster report and rescue. On one hand, infrastructures including cell sites, signal towers, telecom bases would be damaged heavily after a disaster. On the other hand, the injured people might lose their mobility or even the ability to speak to send signal for help. Thus, localization and disaster rescue becomes a challenging problem under disaster scenarios. In this case, we can resort to wireless sensor network (WSN) to detect the injured, to recover basic communication, and to monitor other emergency [1].

Wireless Sensor Network is consisted of a large number of sensor nodes, which are equipped with microcontrollers, short-range wireless radios and various sensors [2]. With the development of the MEMS, integrated circuit and embedded technology, these nodes can be designed by inexpensive and energy-efficient hardware and applied to work in various fields, such as military, environmental monitoring et al. It is more appropriate and economic to deploy WSN than wired equipment, especially in wild fields or dangerous environments.

In this paper, we propose an emergency monitoring and rescue system based on WSN with applications in disaster scenarios. The system utility consists of two parts: monitoring the disaster situation and acquiring the location of emergency and the injured. In order to accommodate the ruined environment after disaster and satisfy the low cost and low power requirements for sustainable working, our localization method merges the advantages of range-based and range-free localization. We measure the RSSI to obtain distances between wireless nodes and according to these measures we propose an improved weighted centroid algorithm to get a more accurate position without further cost and energy consumption. The algorithm computing process has a relatively low complexity.

The subsequence of this paper is organized as follows. In section II, some related works of WSN-aid rescue systems and localization algorithms are shortly introduced. Section III describes the details of our new emergency monitoring and rescue system and presents a comprehensive analysis of the improved localization algorithm based on the weighted centroid localization. Experiment results and analysis are presented in Section IV. Section V concludes this paper and points out the future work.

II. Related Work

There are lots of projects dealing with disaster rescue and emergency response that use wireless sensor network technology [3]. In [4], H.F. Wu, L. Yang et al. utilized the WSN localization in maritime search and rescue, and proposed an improved micro-electromechanical system aided algorithm on the basis of triangle and centroid algorithm to locate and track the search targets in real time. In [5], S.S Yeh, C.C Hsu et al. applied the WSN technology to distribute rescue robots at disaster area. The robots can achieve remote monitoring and self-localization through WSN by integrating the characteristics of ZigBee and sensors of the robot. In [6], J.B Wang, Z.X Cheng et al. presented a new method to locate the 3D position of the survivors for searching after an earthquake based on WSN. The 3D localization with the depth information is calculated by an equilateral triangle device with a mobile beacon node.

Localization is one of the most important issues of WSN applications. Generally, the main localization algorithms are classified into two classes depending on the information used to locate the unknown node: range-based and range-free [7]. In range-based techniques, such as TOA, TDOA and AOA, range finders are used to measure the absolute distances between anchor and unknown nodes, which complicate the design and increase the weight and expense of wireless nodes. RSSI (Received Signal Strength Indication) is an indication of the power level being received by the antenna which reflects the

978-1-5090-3549-6/16/$31.00 ©2016 IEEE

distance between sender and receiver [8]. RSSI can be used for both range-based and range-free localizations. It is easy to get and low-cost in application, so many schemes of RSSI-based localization have been proposed.

J. Blumenthal, R. Grossmann et al. in [9] have proposed the Weighted Centroid Localization (WCL), that uses a static degree-factor related to the distance and compute the position of a node by weighted averaging the locations of several neighbor anchors. In [7], G.A. Zodi, G.P. Hancke et.al have contributed two methods, Linear Weighting Centroid (LWC) and Neighbor Weighting Centroid (NWC), to enhance the weighted centroid localization algorithm while keeping computation simple. In [10], S. Ivanov and E. Nett have proposed a new localization-based method for the calibration of radio propagation models. The idea is to find the locations of the base stations and to use radio signal strength measurements from stations for adjusting the radio model parameters until the model better fits to the real environment. In [11], R.V. Kulkarni et al. have proposed a new bio-inspired node localization algorithm in WSN. In this method, ranging-based localization task is formulated as a multidimensional optimization problem and is addressed using particle swarm optimization (PSO) and bacterial foraging algorithm (BFA) to achieve a fast convergence to quality solutions.

III. Materials And Methods

The proposed emergency monitoring and rescue system is consisted of three layers, as Fig. 1 shows. Sensor nodes are the lowest layer of the system for monitoring the dangerous environment. The middle layer is made of anchor nodes, which are responsible for locating sensor nodes. The top layer is the base station which is connected to the control center directly. It manages the network and analyses the data collected from the environment. Referring to the information, the rescuers could be aware of the potential dangers while executing rescue mission effectively and thus reduce the property loss and casualty to minimum extent.

A. Wireless nodes

1) Sensor nodes: Sensor nodes are composed of wireless modules, data collection modules and sensor modules. The wireless module designed by our lab is controlled by Atmega128 microprocessor, which has advantages of low cost, high data throughput, low power consumption, and fast processing speed. The chip CC2420, a single-chip 2.4GHz IEEE 802.15.4 compliant RF transceiver designed for low-power and low-voltage wireless applications [12], is used for wireless transmission among sensor nodes. Fig. 2 shows the hardware components of a wireless node. In addition, the software system in Atmega128 is based on TinyOS [13], the operating system developed by UC Berkeley for embedded wireless sensor networks. The sensors mounted on these nodes are used to detect the light intensity, air temperature, air moisture, poisonous gas, abnormal sound, and so on. The sensor information is very important not only to monitor the occurrence of emergency events, but also to provide assistance for rescuers.

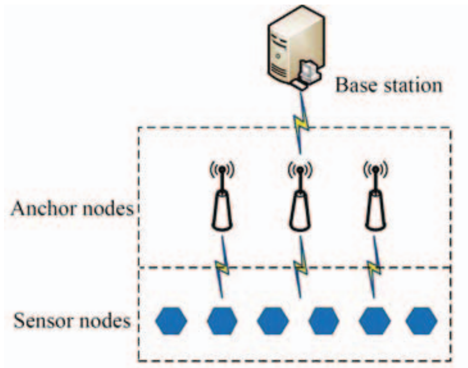

Fig. 1. The layout of the emergency monitoring and rescue system.

2) Anchor nodes: Fig. 3 is the structure of an anchor node. An anchor node is equipped with a GPS, a camera, a wireless module, a storage battery and a solar charging panel. An anchor node can get its actual position by the GPS and use it as a reference to locate other sensor nodes. The camera is used to collect environment images around the anchor. In addition, an anchor node is supported by a tripod which lifts the camera and antenna to a certain unblocked level. The wireless module using Zigbee protocol realizes the bidirectional data transmission among sensor nodes. Anchor nodes are not only responsible for localizing sensor nodes, but also for collecting and forwarding the information from sensor nodes to the base station as routing nodes in WSN.

B. An improved localization algorithm based on RSSI

RSSI is easy to get and low-cost in applications, so we choose the RSSI-based localization algorithm relying on the estimated distance between nodes, and as such, the design of nodes can be simplified as much as possible. In this paper a novel weighted centroid algorithm is proposed to improve the localization accuracy of sensor nodes while keeping computation simple.

1) Channel model and RSSI pre-processing: RSSI is the value that indicates the quantity of the electromagnetic energy in the current media. In order to estimate the distance between two devices by measuring the RSSI, we need to know the model of the transmission channel. The classical radio propagation model considering pass lost and shadow effect [14] is presented as follows:

$$P_i(dBm) = P_{Tx} + K - 10\eta \lg(\frac{d_i}{d_0}) + \psi_i \tag{1}$$

Where P_i is the receiving power of the node i placed at distance d_i from the transmitter, d_0 is a reference distance for the antenna far field, P_{Tx} is the nominal transmission power, K is a unit constant that depends on the environment and η is the pass loss exponent. The parameter ψ_i describes the fluctuation caused by shadow effect, which is generally assumed to be Gaussian with zero mean and variance σ^2.

In practice, the received RSSI values are not always stable because the propagation of the radio signal is interfered by a lot

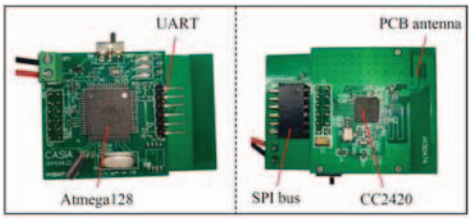

Fig. 2. Illustration of components of a sensor node.

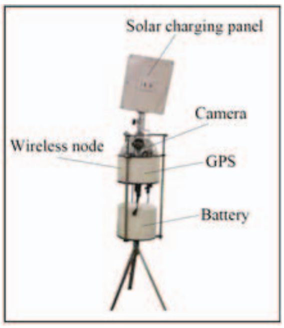

Fig. 3. Illustration of an anchor node.

of influencing effects such as multipath, scattering, obstacles, electromagnetic interference and so on. It is necessary to pre-process the RSSI values by a smooth filter before localization. As the best linear least square estimator, Kalman Filter [15] can weaken the measurement deviation of RSSI values caused by noise superposition. Thus, we utilize Kalman Filter to pre-process the RSSI values in this paper. The acquisition of RSSI value is assumed to be a discrete-time system without controlled variable by the following equations:

$$x_k = Ax_{k-1} + w_k \tag{2}$$

$$z_k = Hx_k + v_k \tag{3}$$

Where x_k is the RSSI value at time k, A is the system matrix, H is the observation matrix, z_k is the measurement of RSSI at time k, w_k and v_k are the process covariance and measurement covariance which are supposed to be independent of each other and to be white Gaussian noises with variance R and Q respectively. Then we can get the recursive Kalman filter equations consisting of two phases, a time update phase and a measurement update phase. The former is a prediction in time, as (4) and (5) shows. Where $x_{k|k-1}$ represents the prior estimation of RSSI value at time k, $x_{k|k}$ is the posterior estimation of RSSI value at time k, $P_{k|k-1}$ is the prior estimate error covariance of $x_{k|k-1}$, and $P_{k|k}$ is the posterior estimate error covariance of $x_{k|k}$. The latter is an update of the current time estimate based on a measurement that was just obtained, as (6), (7) and (8) shows. Where KG_k is the Kalman Gain used to minimize the posterior estimate error covariance.

$$x_{k|k-1} = Ax_{k-1|k-1} \tag{4}$$

$$P_{k|k-1} = AP_{k-1|k-1}A^T + Q \tag{5}$$

$$KG_k = P_{k|k-1}H^T / (HP_{k|k-1}H^T + R) \tag{6}$$

$$x_{k|k} = x_{k|k-1} + KG_k(z_k - Hx_{k|k-1}) \tag{7}$$

$$P_{k|k} = (I - KG_kH)P_{k|k-1} \tag{8}$$

Above all, the optimal RSSI value $x_{k|k}$ of the current state can be acquired by combining the prediction and measurement. Then the distance $\hat{d_i}$ between sensor node and anchor node can be computed by formula (9).

$$\hat{d_i} = 10^{(P_{Tx}+K-P_i)/(10\eta)} \tag{9}$$

2) An improved weighted centroid localization with adaptive correction: Localization using weighted centroid is attractive and is commonly used in applications since it is simple and easy to implement. The Weighted Centroid Localization (WCL) proposed in [9] applied weights to attract the estimated position to the closest reference nodes provided with coarse distance measurements.

In this paper, we view a sensor network with n sensor nodes and m anchor nodes in the disaster ruins. The positions of the sensor nodes are unknown, whereas the positions of the anchor nodes are known. In the first phase, all anchor nodes broadcast their position (x_j, y_j) to all sensor nodes within their transmission range. Upon reception of k $(k \leq m)$ anchor positions, the coordinate $(\hat{x}_i, \hat{y}_i)$ of the sensor node is estimated according to the following formulas.

$$\hat{x}_i = \frac{\sum_{j=1}^{k} w_{ij} \times x_j}{\sum_{j=1}^{k} w_{ij}}, \quad \hat{y}_i = \frac{\sum_{j=1}^{k} w_{ij} \times y_j}{\sum_{j=1}^{k} w_{ij}} \tag{10}$$

The weight w_{ij} is a function depending on the distance and the characteristics of the sensor nodes' receivers. The nodes with shorter distances are more weighted than the ones with longer distances. In other words, the weight and the distance are inversely proportional. In [9], the weight is calculated by the following formula:

$$w_{ij} = 1/{d_{ij}}^g \tag{11}$$

Where d_{ij} is the estimated distance between sensor node i (position unknown and to be localized) and the anchor j at position (x_j, y_j). Empirical data shows that when transmission range is about 30m, the localization error is the smallest if g equals to 2. However, the WCL algorithm is not applicable for sensor networks with sparse anchors since the fewer the reference positions are, the greater the error is. As Fig. 4 shows, when the distance is longer than 10m, the slope of the weight $(g = 2)$ curve approximates to zero, which means the weights w_{ij} are almost equal. However, the number of anchor nodes is much less than the number of sensor nodes in our emergency monitoring and rescue system, so the distance d_{ij} is almost always longer than 10m. That is to say the weights $(g = 2)$ cannot distinguish the different distances well enough in this system.

To solve the problem above, we propose a new method named L-WCL to determine the weight given in (12). The resolution of weight in (12) is higher than the weight in (11) when the distance is greater than 10m, as Fig. 4 shows. That

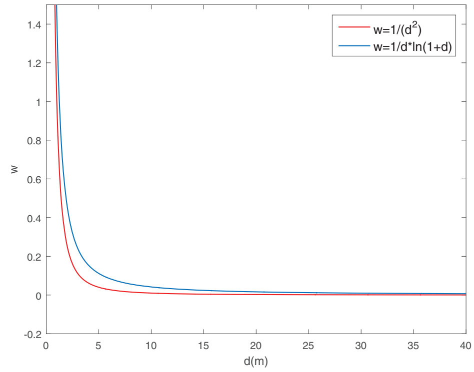

Fig. 4. The weight-distance curve.

means the L-WCL is more suitable for large scale anchor networks than WCL.

$$w_{ij} = \frac{1}{d_{ij}\ln(1+d_{ij})} \tag{12}$$

However, the accuracy of RSSI-based distance measure tends to be affected by the environment in practice. For the nodes located in different positions in the network, the RSSI values received from other nodes might be the same while the corresponding distances are different actually due to the influence of environment. If we calculate the distances between nodes only using RSSI without correction methods, it may lead to a high localization error. In order to eliminate the error caused by environment and get a more accurate localization, we plan to introduce the influence of environment into the aforementioned algorithm. In other words, we adaptively correct the distance estimated through RSSI.

A calibration factor λ_{ij} is defined to correct the estimated distance using the following formula (13), where $\hat{d}_{ij}$ is the calculated distance between sensor node S_i and anchor node A_j by the formula (9), d_{ij} is the corrected distance [16].

$$d_{ij} = \lambda_{ij}\hat{d}_{ij} \tag{13}$$

If we consider the situation in Fig. 5, the sensor node S_i to be localized is located within the intersecting communication region of several anchor nodes. In the first stage, we set a distance threshold τ(m) based on the deployment of nodes. The anchor node, whose distance away from S_i is less than τ, is considered to be the reference node. The number of the reference nodes N is greater than or equal to zero. For all reference nodes, we calculate the error coefficient μ_{rj} using the following formula (14), where d_{rj} is the actual distance between reference node A_r and other anchor node A_j, $\hat{d}_{rj}$ is the calculated distance using formula (9). When the two nodes are relatively close, it can be considered that the distance measurement of the two nodes is affected by approximately the same environment. That means λ_{ij} is relevant to μ_{rj}, so we can consider the average of μ_{rj} as the calibration factor, as the formula (15) shows. Then more accurate distance d_{ij} in formula (13) is used in L-WCL-AC algorithm to compute the weight w_{ij} by the formula (16) associated with anchor A_j.

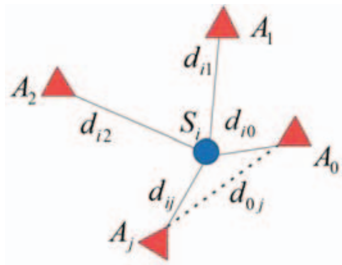

Fig. 5. The schematic of the L-WCL-AC.

$$\mu_{rj} = \begin{cases} 1 & j = r \\ d_{rj}/\hat{d}_{rj} & j \neq r \end{cases} \tag{14}$$

$$\lambda_{ij} = \begin{cases} 1 & N = 0 \\ \frac{1}{N}\sum_{r=1}^{N}\mu_{rj} & N > 0 \end{cases} \tag{15}$$

$$w_{ij} = \frac{1}{\lambda_{ij}\hat{d}_{ij}\ln(1+\lambda_{ij}\hat{d}_{ij})} \tag{16}$$

IV. Simulation And Analysis

In this section, we compare and evaluate the performance of WCL, L-WCL and L-WCL-AC algorithm based on the same simulation environment in MATLAB. Parameters are set as follows. We deploy 10 anchor nodes and 90 sensor nodes in a 100m*100m mission space. The anchor nodes are uniformly distributed in advance with known positions, while the sensor nodes are tossed at random. The path loss model parameters P_{Tx}, K and η have been estimated from the collected RSSI measurements according to a mean square error criterion in the actual experiments. The deterministic path loss model parameters are $P_{Tx}+K = -45.14$, $d_0 = 1m$, $\eta = -1.37$ and $\sigma^2 = 5$. The mean localization error of sensor nodes is computed using the following formula:

$$\varepsilon = \frac{1}{n}\sum_{i=1}^{n}\sqrt{(\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2} \tag{17}$$

Fig. 6 shows the position of the sensor nodes using WCL and L-WCL-AC respectively. The short lines in the plots indicate how the algorithm has moved a sensor node from its exact position to the estimated position represented with a cross in WCL or an asterisk in L-WCL-AC. The red triangles represent the exact positions of anchor nodes and the black circles represent the exact positions of sensor nodes.

Fig. 7 shows that the mean localization error of 20 iterations. From Table I we can conclude the average error of 20 experiment results. L-WCL-AC achieves an average error of 4.15m better than 5.66m average error achieved by L-WCL. Due to the calibration factor, the influence of the environment is greatly reduced. However, both algorithms achieve smaller localization error than the 7.32m obtained by WCL. Fig. 8 shows that the mean localization error decreases as the number of anchors increases. The L-WCL and L-WCL-AC algorithm

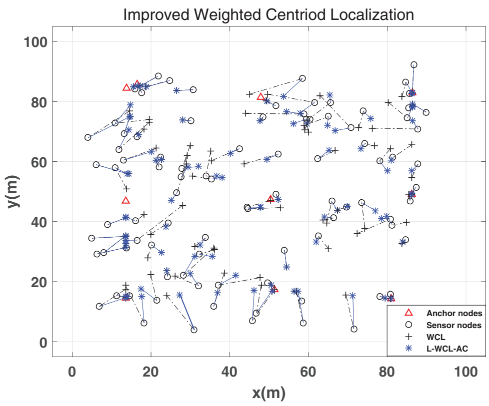

Fig. 6. Localization map using WCL and L-WCL-AC.

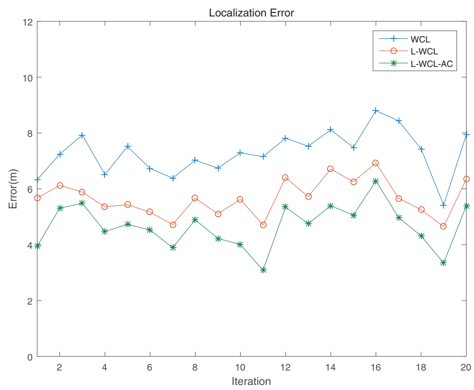

Fig. 7. Mean localization error of 20 iterations.

have achieved a smaller average error in general than the WCL algorithm. At present, we have not performed the real experiment to evaluate the proposed method, which will be one of our future work.

V. Conclusion

The paper has presented a new localization algorithm which is suitable for emergency monitoring and rescue in disaster scenarios based on WSN. The algorithm is mainly divided into three stages. In the first stage, the distance between two nodes is estimated roughly according to the RSSI value. In the second stage, the calibration factor is calculated to obtain more accurate distances. Finally, we calculate the weight of the L-WCL-AC depending on the above distances. Simulation results have shown that our algorithm is effective and greatly reduces the localization error. Compared to WCL, L-WCL-AC has higher accuracy and is more suitable for localization through the sensor network with sparse anchors. In the future work, the system will be deployed in several separated disaster areas to test its robustness and efficiency. Thus, we will concentrate on the problems such as power supply, network maintenance and the further improvement of localization accuracy.

TABLE I
Average Error of Three Localization Algorithms

Algorithm	WCL	L-WCL	L-WCL-AC
Average Error	7.32m	5.66m	4.15m

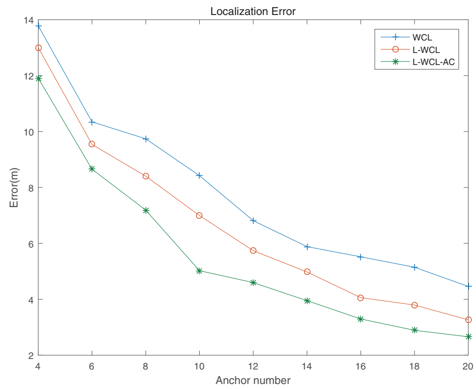

Fig. 8. Mean localization error versus number of anchor nodes.

Acknowledgment

The authors would like to thank for the financial support to our research from the National Natural Science Foundation of China (No. 61271432 & No. 61333016) and the science and technology project of State Grid (the Research of Multimedia and Streaming Media Based on Machine Learning).

References

[1] D. Paudel, J. Sae, and J. Lempiainen, "Applicability of macro sensor network in disaster scenarios," *4th International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace and Electronic Systems*, pp. 1–5, 2014.

[2] I. F. Akyildiz, T. Melodia, and K. R. Chowdury, "Wireless multimedia sensor networks: A survey," *IEEE Wireless Communications*, vol. 14, pp. 32–39, 2007.

[3] I. Benkhelifa, N. Nouali-Taboudjemat, and S. Moussaoui, "Disaster management projects using wireless sensor networks: An overview," *28th International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, pp. 605–610, 2014.

[4] H. F. Wu, L. Yang, L. Liu, M. Xu, and X. P. Guan, "Real-time localization algorithm for maritime search and rescue wireless sensor network," *International Journal of Distributed Sensor Networks*, pp. 1–6, 2013.

[5] S. S. Yeh, C. C. Hsu, T. C. Shih, J. P. Hsiao, and P. L. Hsu, "Remote control realization of distributed rescue robots via the wireless network," *SICE Annual Conference*, pp. 2928–2932, 2008.

[6] J. B. Wang, Z. X. Cheng, L. Jing, and Y. Taishi, "Design of a 3d localization method for searching survivors after an earthquake based on wsn," *2011 3rd International Conference on Awareness Science and Technology*, pp. 221–226, 2011.

[7] G. A. L. Zodi, G. P. Hancke, G. P. Hancke, and A. B. Bagula, “Enhanced centroid localization of wireless sensor nodes using linear and neighbor weighting mechanisms,” *proceedings of the 9th International Conference on Ubiquitous Information Management and Communication*, pp. 43–50, 2015.

[8] P. Bahl and V. N. Padmanabhan, “Radar: an in-building rf-based user location and tracking system,” *Proceedings IEEE INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, vol. 2, pp. 775–784, 2000.

[9] J. Blumenthal, R. Grossmann, F. Golatowski, and D. Timmermann, “Weighted centroid localization in zigbee-based sensor networks,” *IEEE International Symposium on Intelligent Signal Processing (WISP)*, pp. 1–6, 2007.

[10] S. Ivanov and E. Nett, “Localization-based radio model calibration for fault-tolerant wireless mesh networks,” *IEEE Transactions on Industrial Informatics*, pp. 246–253, 2013.

[11] R. V. Kulkarni, G. K. Venayagamoorthy, and M. X. Cheng, “Bio-inspired node localization in wireless sensor networks,” *2009 IEEE International Conference on Systems, Man and Cybernetics*, pp. 205–210, 2009.

[12] N. Pereira, B. Andersson, and E. Tovar, “Widom: A dominance protocol for wireless medium access,” *IEEE Transactions on Industrial Informatics*, vol. 3, pp. 120–130, 2007.

[13] P. A. Levis, “Tinyos: An open operating system for wireless sensor networks (invited seminar),” *7th International Conference on Mobile Data Management (MDM’06)*, pp. 63–63, 2006.

[14] A. Goldsmith, “Wireless communications,” *Cambridge university Press*, 2005.

[15] V. Venugopal and S. Ramakrishnan, “Received signal strength index estimation using kalman filter for fuzzy based transmission power control in wireless sensor networks,” *International Conference on Control, Instrumentation, Communication and Computational Technologies*, pp. 81–86, 2014.

[16] D. Y. Zou, H. Lv, D. L. Zheng, and T. F. Han, “The research of grid-based distribution weighted centroid localization algorithm,” *Jouranl of Zhongyuan University of Technology*, vol. 25, pp. 47–51, 2014.