Localization accuracy of farmland wireless sensor network localization algorithm based on received signal strength indicator

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ABSTRACT. *This paper attempts to improve the localization accuracy under the farmland environment. The accuracy of the localization algorithms based on received signal strength indicator (RSSI) hinges on the working environment. However, there are many disturbances during the wireless signal propagation in farmland wireless sensor network (WSN), such as fading, shielding, reflection and scattering. The impacts of these disturbances vary with the plant growth. Considering these, the author adopted an improved RSSI-based localization method, which divides the target area into multiple small triangles and let each node decides its local triangle. Then, a global path loss exponent was calculated for the entire localization area, and local exponents were also computed for each small triangle. Through example verification, the proposed algorithm was proved to have good localization accuracy and good adaptability to the time-varying environment in farmland. The research findings provide a reference for location estimation in large-scale farmland and real-time channel modeling.*

RÉSUMÉ. *Cet article tente d'améliorer la précision de la localisation dans l'environnement des terres agricoles. La précision des algorithmes de localisation basés sur l'indicateur d'intensité du signal reçu (RSSI) dépend de l'environnement de travail. Cependant, de nombreuses perturbations se produisent pendant la propagation du signal sans fil dans le réseau de capteurs sans fil (WSN) des terres agricoles, telles que le déclin, la blindage, la réflexion et la diffusion.Les impacts de ces perturbations varient avec la croissance de la plante. Compte tenu de ces éléments, l'auteur a adopté une méthode de localisation améliorée basée sur RSSI, qui divise la zone cible en plusieurs petits triangles et laisse chaque nœud décider de son triangle local.Ensuite, un exposant de perte de chemin global a été calculé pour l'ensemble de la zone de localisation et des exposants locaux ont également été calculés pour chaque petit triangle. Au moyen d'exemples de vérification, il a été prouvé que l'algorithme proposé avait une bonne précision de localisation et une bonne adaptabilité à l'environnement variable dans les terres agricoles.Les résultats de la recherche fournissent* *une référence pour l'estimation de la localisation dans les terres agricoles à grande échelle et la modélisation des canaux en temps réel.*

KEYWORDS: *farmland wireless sensor network (WSN), localization methods, received signal strength indicator (RSSI), range based localization, path loss exponent.*

MOTS-CLÉS: *réseau de capteurs sans fil pour les terres agricoles (WSN), méthodes de localisation, indicateur d'intensité du signal reçu (RSSI), localisation basée sur le champ, exposant de perte de chemin.*

DOI:10.3166/ISI.23.5.69-80 © 2018 Lavoisier

1. Introduction

Localization is one of the key technologies in sensor networks. The location information of the sensor nodes is urgently needed to fulfill typical applications like environmental monitoring, target tracking, battlefield surveillance, and forest fire prevention (Zhao *et al.*, 2013). For instance, the wireless sensor network (WSN) is often utilized to monitor a large area of farmland; In addition to the environmental data, the sensor nodes collect the location information, which helps to improve the effect of agricultural environment monitoring.

There are mainly two types of WSN localization methods: range-based algorithm (Ahmad *et al.*, 2015; Ma *et al.*, 2017) and range-free algorithm (Anand *et al.*, 2015; Zhang *et al.*, 2015). From the perspectives of time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA) and received signal strength indication (RSSI), the range-based algorithm calculates the location of unknown nodes on account of distance and angle between anchor nodes and the unknown node, and then identifies the location of the unknown node by triangulation, i.e. the trilateral maximum likelihood estimation (Shao *et al.*, 2014). Instead of the distance and angle between anchor nodes and the unknown node, the range-free algorithm relies on the connectivity information of the network and the proximity and distance (hops) between nodes. The most popular range-free approaches include DV–hop method, centroid method, convex programming method and the SPA algorithm (Liu *et al.*, 2016). In comparison, the range-based algorithm achieves better localization accuracy than the range-free algorithm.

Out of the various range-based strategies, the RSSI method has been extensively applied in node localization, as it requires no additional hardware (Adewumi *et al.*, 2013). Nevertheless, the RSSI localization accuracy is prone to the influence of distance errors in the application environment, such as multipath, diffraction, obstacles, propagation loss of radio waves, and white noise of electronic devices (Yan *et al.*, 2015). If the RSSI method is applied to farmland environment monitoring, the complex environment may undermine the ranging and positioning accuracy (Vanheel *et al.*, 2015). For example, the different crops and growth conditions exert varied impacts on signal transmission, and agricultural production facilities form barriers in the signal propagation path.

In light of the above, this paper presents an environment adaption method to improve the RSSI ranging accuracy. Specifically, a reference node was set in addition to anchor nodes, and the localization area was separated into triangular areas by the connection lines between anchor nodes and the reference node. In each triangular area, the signal path loss exponent was corrected to enhance the accuracy of RSSI ranging and WSN positioning. These methods can effectively solve the space-time variation of channel environment caused by crop growth, and provide an effective positioning method in agricultural monitoring network.

The main contents of this paper are divided into four parts. Section 2 introduces the basic principle of RSSI positioning and discusses its channel influence; Section 3 introduces the calculation method of environmental attenuation factor in channel model; Section 4 introduces the positioning method combining global and local models. Section 5 carries out the algorithm through simulation experiments.

2. Network model and assumptions

2.1. RSSI ranging model

The following three models are often used to depict the signal path loss in the WSN: log-normal distribution model, free-space propagation model, and log-distance path loss model. Considering the path reflection, diffraction, obstructions and other factors, the log-normal distribution model is a popular tool for signal propagation distance. The mathematical statistical model is as follows (Blumrosen *et al.*, 2013; Chen *et al.*, 2015):

$$P_r(d) = P_r(d_0) - 10\eta \lg(\frac{d}{d_0}) + X \tag{1}$$

where d_0 is the reference distance (m); d is the distance between the receiver and the transmitter (m); $P_r(d_0)$ is the received power at the reference distance d_0 (dBm); $P_r(d)$ is the received power at the distance d (dBm); η is the path loss exponent; X is a log-normal random variable that reflects the variation in received power when the distance is constant (dBm).

In this research, the formula (1) was simplified by omitting the random variable X. Thus, the key to fix the model is to fix the value of the parameter η. Since η is closely related to the network environment, the RSSI ranging accuracy could be elevated by calculating η values according to the environment, laying a solid basis for better localization. In practice, the same η value is taken for the ranging of the entire localization area, ignoring the inconsistency between different directions caused by the complex environment (Ren *et al.*, 2014; Salari *et al.*, 2013).

2.2. Layout of anchor nodes and reference node

The anchor nodes were arranged on the edges of the localization area with equal distance (Lee *et al.*, 2012; Pandey and Varma, 2016). The layout was designed to simplify the arrangement and minimize the impact to agricultural production. The four edges were arranged with n, m, n and m anchor nodes, respectively. In total, the localization area had 2n+2m anchor nodes (Figurer 1). The anchor nodes were denoted as M_i (i=1,2...2n+2m).

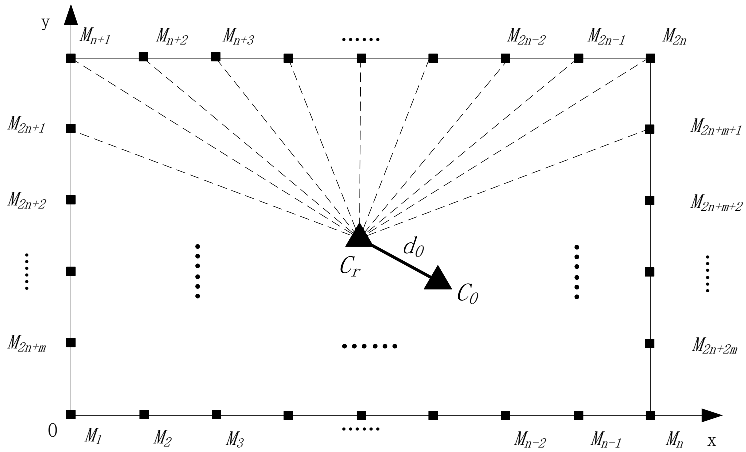


Figure 1. Layout of anchor nodes and the reference node

The reference node C_r was placed at the center of the rectangular localization area. The reference node was connected to each anchor node to obtain various signal paths: C_rM_i (i=1,2...2n+2m). These paths divided the entire localization area into a plurality of small triangular areas. The reference distance node C_0 was placed at 1m away from C_r.

3. EVALUATION OF PATH LOSS EXPONENT

3.1. Global path loss exponent

In order to calculate the path loss exponent with anchor nodes, Literature (Shang *et al.*, 2015) determines the distance between anchor nodes by node coordinates, measures the corresponding RSSI value, and obtains the path loss exponent of each anchor node through minimum mean-square error (MMSE) estimation. In the actual application scenario, many of the signal paths between anchor nodes are prone to the influence of the external environment, as the paths are situated on the edges of the localization area. In many scenarios, the localization area has clear inside and outside boundaries, e.g. production facilities or buildings, which has a great impact on signal propagation. Therefore, the path loss exponent calculated based on anchor nodes may cause ranging errors.

In this research, the author computed the global path loss exponent by the communication between the reference node and anchor nodes. The exponent is more reliable because the paths between these nodes are fully within the localization area, and immune from the impact of edge facilities or outside environment.

Ignore the random variable X in Formula (1),

$$P_r(d) = P_r(d_0) - 10\eta \lg(\frac{d}{d_0}) \tag{2}$$

The distance between the reference node C_0 and the reference distance node C_r was selected as the reference distance d_0, which was 1m according to Section 2. In light of the strength of the RSSI signal $P_r(d_0)$ received by C_0 from C_r, and the strength of the RSSI signal $P_r(d)$ received by C_0 from other anchor nodes, the path loss exponent η was calculated based on the MMSE estimation.

3.2. Local path loss exponent

In the localization area, the various small localization areas usually differ in path loss exponent, owing to the difference in crops and growth conditions. Therefore, the entire localization area was split into small areas. The ranging accuracy can be improved if the path loss exponents of the small areas are correctly identified. The local path loss exponent of each small area was calculated in the following steps:

First, the distance between the reference node and the nearest anchor node Md_0 was taken as the reference distance d_0; Second, the strength of the RSSI signal received by the reference node from Md_0 was measured as $P_r(d_0)$, and the strength of the RSSI signal received by the reference node from the anchor node to be corrected was measured as $P_r(d)$; Third, the distance between the reference node and the anchor node to be corrected was taken as the reference distance d, and η was calculated by Formula (2).

Each corrected path loss exponent η corresponds to an anchor node, and reflects the environment between the reference node and the corresponding anchor node. The local path loss exponent of each small triangular area equals the mean exponent of the two edges of the triangle, that is, the two connection lines between the reference node and the two anchor nodes.

4. LOCALIZATION BASED ON RSSI

4.1. Unknown node in triangular area

The distance between the unknown node N and the connection line between the reference node and the anchor node C_rM_i(i=1,2...2n+2m) helps to determine which of the triangular areas contains the unknown node. The connection line between the anchor node M(x_m, y_m) and the reference node Cr(x_r, y_r) is expressed as:

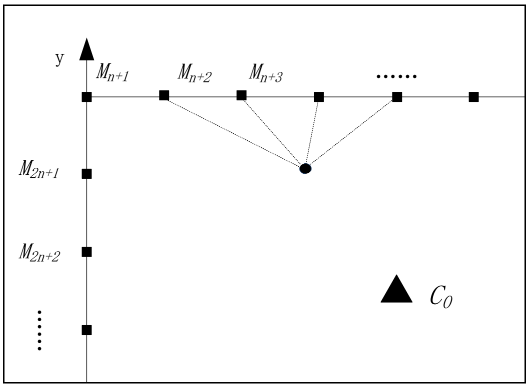
$$Ax + By + C = 0 \tag{3}$$

where

$$A = \frac{y_m - y_r}{x_m - x_r},\ B = -1,\ C = y_r - Ax_r.$$

Through the above process, the author obtained the coordinates N(x_i, y_i) of the unknown node. Hence, the distance from the unknown node to the straight line C_rM_i is:

$$d = \frac{|A(x_i - x_r) - y_i + y_r|}{\sqrt{A^2 + 1}} \tag{4}$$



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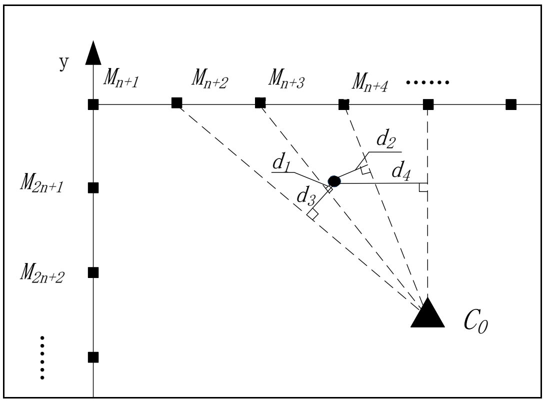

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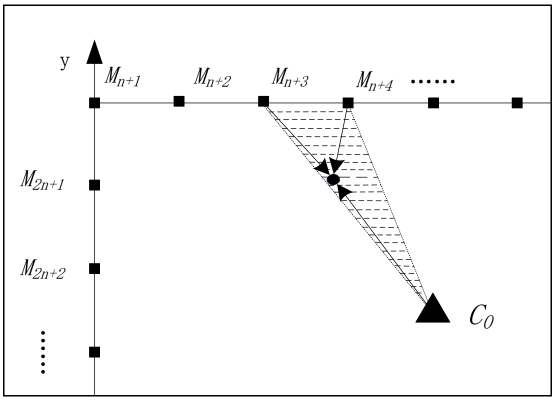


(c)

Figure 2. Determination of the triangle area of the unknown node

The four anchor nodes M_a, M_b, M_c and M_d closest to the unknown node were selected, and then the distance from the unknown node N to each connection line between the reference node and each of the anchor node was calculated, separately. Out of the four lines, the two lines closer to the unknown node were selected as the two edges of the triangle area, and the localization of the unknown node was corrected with C_r and the two anchor nodes in the two lines. The path loss exponent in the triangle area equals the mean exponent of the two lines.

4.2. Localization process

The process of proposed localization method is shown in Figure 3. It could be described as following:

(1) Calculate the global path loss exponent η_c.

(2) Calculate the local path loss exponent η_{Mi} (i=1,2,3...,2n+2m) of the connection line between the reference node and each anchor node, and calculate the local loss exponent of each triangle area.

(3) Calculate the distance between the unknown node N and each anchor node from which the unknown node receives signals, using the global path loss exponent, and obtain the coordinates $N(x_{i0}, y_{i0})$ by the maximum likelihood estimation method.

(4) Find the two anchor-reference node connection lines C_rM_{s1} and C_rM_{s2} closest to the unknown node N, and determine which triangular area contains the unknown node.

(5) Calculate the distance between the unknown node and anchor nodes M_{s1} and M_{s2}, as well as the reference node C_0; recalculate the coordinates $N(x_{i1}, y_{i1})$ by the

maximum likelihood estimation method.

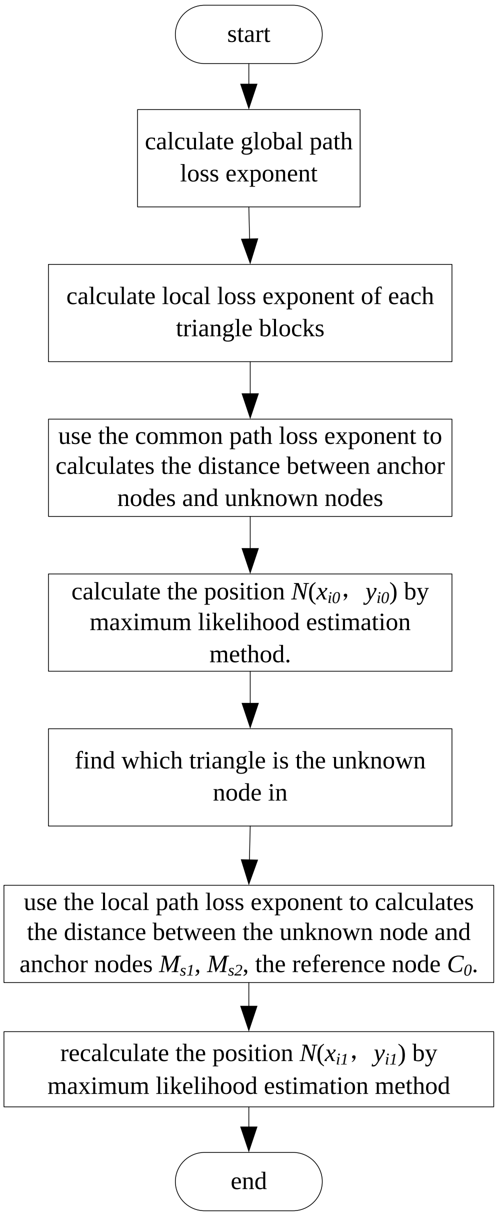


Figure 3. Localization process

5. Experiment and analysis

This section evaluates the performance of the proposed method. The localization areas were two pieces of 50m×100m farmland, denoted as F1 and F2, respectively. The two rectangle regions were planted with corn, wheat and vegetables. Different plants differ in height and density, creating different path loss exponents. Overall, F1 was a clear and open space, while F2 had a small section of wall or similar obstacles. The experiments were performed in the two fields separately.

A total of 30 anchor nodes were set along the edges of each area at an interval of 10m, the reference node was arranged at the center of each rectangle, and 20 unknown nodes were randomly distributed in each rectangular. All of the nodes were 1m in height. See Figure 4 for the layout of the nodes.

The result calculated by global path loss exponent was taken as the control group, and the result of each field calculated separately by the improved localization method was taken as the test group.

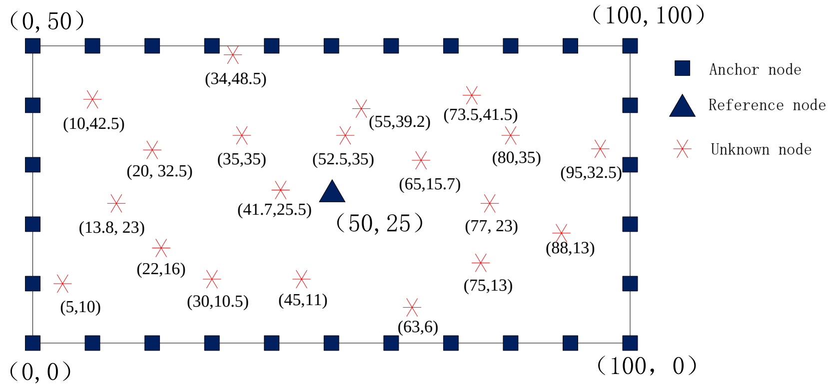


Figure 4. Experiment scene and node layout

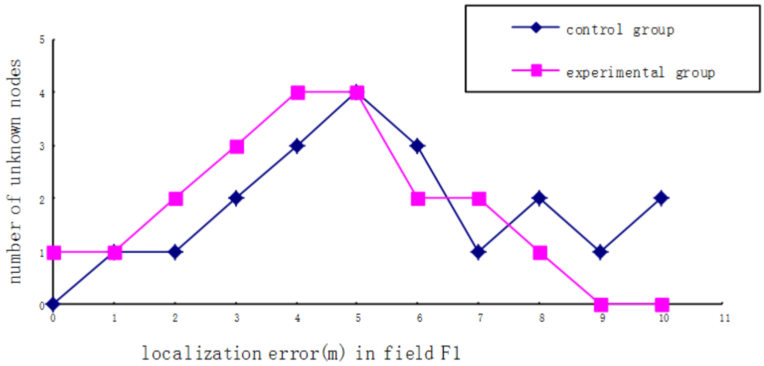
Table 1 and Table 2 list the localization errors of unknown nodes in fields F_1 and F_2, respectively.

Table 1. The Localization errors of unknown node in field F_1

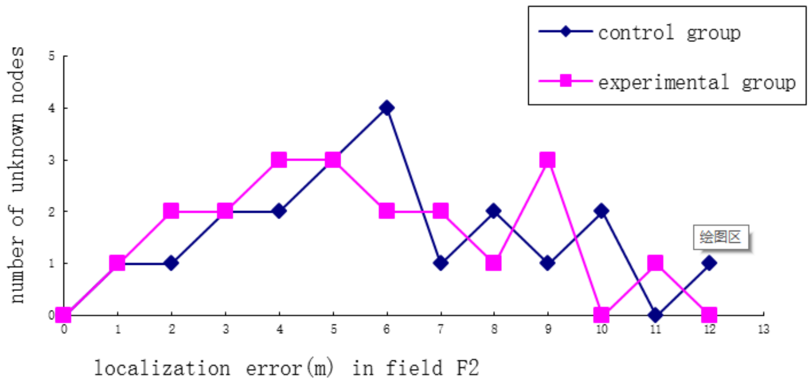
	result calculated by global path loss exponent	result calculated improved Localization Method
Maximum error/m	10.280	8.156
Minimum error/m	1.236	0.560
average error/m	6.248	4.366

Table 2. The Localization errors of unknown node in field F_2

	result calculated by global path loss exponent	result calculated improved Localization Method
Maximum error/m	12.396	11.015
Minimum error/m	1.653	1.357
average error/m	6.877	6.036



(a)



(b)

Figure 5. Error distribution chart

The error distribution is shown in Figure 5. The experiment results demonstrate that the improved WSN localization method performs well in F1, in which the difference is limited to crops. By contrast, the proposed method contributes to less obvious improvement of localization accuracy in F2, which contains point-like or linear obstacles.

6. Conclusions

(1) The entire localization area was divided into small triangle areas along the connection lines between the reference node in the center and the anchor nodes along the edges. The path loss exponent was calculated for each triangle to improve the adaptability to the environment.

(2) The location of the unknown node was fixed in two steps. First, the location of the unknown node was approximated by the global path loss exponent of the entire area; then, the location was corrected by the local path loss exponents of the corresponding small triangular areas. The two-step localization improves the ranging accuracy, and consequently the localization accuracy.

(3) The simulation results show that the proposed method has better performance in the area with massive environment differences (e.g. crops, growth conditions) than the area with point-like or linear obstacles (e.g. walls, agricultural production facilities).

Acknowledgment

This work was financially supported by Beijing Natural Science Foundation (4172024), Natural Science Foundation of China (61871041, 61571051) and Opening Foundation of Key Laboratory of Agricultural Internet of Things, Ministry of Agriculture (2017AIOT-08).

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