Modeling wireless sensor networks radio frequency signal loss in corn environment

He Pan[1] · Ying Shi[1] · Xin Wang[1] · Taihao Li[1]

Abstract In order to arrange cornfield wireless sensor network nodes rationally, fields of corn were studied in signal loss of 2.4GHZ wireless sensor radio frequency signal, and selecting 3 levels of planting density the field random test were carried out with the transmission distance and antenna height as influencing factors, and then curve fitting and analysis were made by MATLAB simulation. Research shows that different planting density has certain influence on signal attenuation degree, when planting density, intensive plants as well as plant's scattering, reflection and diffuse will be more serious, leading to the increase of slope signal attenuation; in RF signal propagation model, environmental impact factors and antenna height exist linear relationship, establishing the mathematical model, its correlation between theory value and measurement value is in 0.937 and 0.9888.

1 Introduction

Fast, effective and timely collection and processing agricultural information is the basic link and the most important foundation of fine agriculture and modern agriculture [11]. Wireless sensor networks (WSN) relies on self organization, low cost, low power consumption, intelligent and other characteristics, to provide a powerful means for the distributed monitoring of industrial, agricultural, military and natural environment [19]. Sensor nodes were deployed in surface or low altitude object Many WSN applications in order to achieve real-time monitoring physical signals in layout environment [16]. Due to the low power wireless sensor network nodes, it is very difficult to achieve high reliability in the large-scale network deployment. In agricultural applications, wireless sensor networks are used in the information collection of precision agriculture that is a hot research topic in the application of wireless

✉ Taihao Li
   thlee@jlau.edu.cn; lth@jlau.edu.cn

[1] Information Technology Teaching and Management Center, Jilin Agricultural University,
    Changchun 130118, China

sensor networks [1, 17]. For the agricultural applications, wireless sensor networks must be able to run in a variety of environments from bare land to the orchard and from the ground to the complex topography, and it also need to work in all weather conditions, all of this will affect the performance of the radio waves [3]. Even in the absence of complicated topography, the communication ability between two points is still faced with great challenges, the signal transmission between the transmitter and the receiver need to through the dense crop canopy, and it can not guarantee adequate clearance area, it will cause a radio signal reflection, scattering and absorption when the signal goes through the spread crop, so as to have great attenuation and differences when the receiver receives the RF signal strength and link quality [6]. Therefore, network nodes deployment must consider communication quality besides the spatial and temporal variability of the parameters. Wireless communication system performance is largely dependent on its working environment, so the energy and resource constrained WSN need a wireless channel surface model to describe the propagation characteristics accurately, so as to achieve low redundancy and high energy efficiency, and it is a good foundation for the QoS of network system. Under the premise of energy and resource constrained, we focus on upper layer routing and network as well as access protocol, involving the physical underlying, especially channel based research [4, 7, 10].

The agricultural environment is complex and changeable, and wireless signal transmission is affected by the terrain, vegetation density, plant height, wind, emission and receiving points, leading signal receiver's RF signal attenuation [8], all of that seriously affect the communication quality, which will bring difficult for the wireless sensor networks, It is one of the bottlenecks of wireless sensor networks in large-scale practical application.

The corn crops was selected as the research object in our paper, radio frequency signal loss test was carried out in 2.4GHz to determine the main factors of signal attenuation, and then establishing the relevant mathematical model can provide theoretical basis for the deployment of wireless sensor network nodes in corn field.

Large-scale agricultural field environment is complex and changeable where wireless signal propagation was affected by the common factors of terrain and landform, vegetation density, stem length, wind-forth and transmitter and receiver height, etc. [8]. The RF signal attenuation always exists and communication quality was seriously impacted, thus it is difficult to deploy wireless sensor nodes. In our research maize crops in northeast China was chosen to test radio frequency signal loss with 2.4GHz. Relevant mathematical model was established which provides theoretical basis for the deployment of wireless sensor network in corn field.

2 Related work

With more and more extensive applications of WSN, the study of wireless channel transmission characteristics of different surface conditions has begun to be concerned by domestic and foreign scholars. Internationally, WSN radio signals have been studied from a variety of aspects. For the soldiers creeping ground communication needs situations, Foran et al. [5] measured and analyzed the propagation characteristics in 915 MHz radio signal when the antenna height was 3 cm,15 cm and 28 cm; for the battlefield sensor networks' communication requirements, Anderson et al. [2] respectively measured and analyzed narrowband and wideband characteristics of 300 MHz and 1900 MHz radio signal; Martinez [12] used experimental methods to study the path loss model of 868 MHz radio signal at three surface environment; Phaebua et al. [14] studied the 433 MHz wireless signals propagation characteristics under the

parking environment; Meng et al. [13] studied forest path loss model in the 2.15 m antenna height; Shen et al. [16] carried out measurement and analysis the 433 MHz radio signal propagation characteristics under the wild surface environment; Liu et al. [9] completed the winter wheat radio propagation performance test; Wen et al. [19] measured the 433 MHz signal propagation characteristics in orchard, selecting the antenna height is between 0.75 and 1.5 m; Wang et al. [18] carried out modeling for the surface wireless channel loss in grassland environment; Yue et al. [21] deployed star WSN sensor networks based on orange channel experimental studies.

According to the different geographical environment, the above research used different research methods to study on the loss of wireless sensor RF signal, it can be seen that different space, distance and environment needs to establish the different signals attenuation model under the same experimental conditions, but the impact of the current wireless sensor network RF signal attenuation has not been studied under the northeast corn field.

3 RF signal propagation characteristics

The path loss of the radio frequency signal attenuation in the crop area shows linear relationship with the logarithm distance. The wireless signal power loss uses the classical Shadowing model [15], it is

$$[p_r(d)]_{dbm} = [p_r(d_0)]_{dbm} - 10n\lg\left(\frac{d}{d_0}\right) + X_{dbm} \tag{1}$$

Among them, $p_r(d)$ is receiving signal power at the receiving end; is the received signal power in reference range d_0; X_{dbm} is Gauss random variables of the mean value 0; d shows transmitting and receiving unit distance; d_0 is reference range (taking near place 1 m); n is spreading factor, which is related to the environment.

Taking $d_0 = 1m$ and $X_{dbm} = 0$. According to the practical application, the relationship between the transmit power and the received power is obtained:

$$[RSSI]_{dbm} = A - 10n\lg d \tag{2}$$

Among them, A shows the received signal power when signal is transmitted 1 m away. The power loss formula (2) can be seen that determining the main factors of the signal loss are A and n, in which n is related to environmental impact factors, it affects the stability and reliability of wireless signal propagation [21].

4 Test design

4.1 Test factor

Northeast area is the China important commodity grain production base, in which the cultivated land is mainly distributed in the Songnen Plain, Sanjiang and Liaohe three. For a long time, the grain sown area of Northeast accounts for more than 80 % in the total area of arable land, food production accounted for about 15 % of the country's total grain output, which hold an unshakable position in Chinese grain security system [9]. Northeast is the main

maize producing areas in China, it is a year and a harvest system with cold temperate humid and semi humid climate, so it is basically in mid April to early May planting, until will be harvest in late September [22]. This experiment was carried out at the agricultural experiment base of Jilin University, the subjects were selected in the northeast region of corn, and the variety was 335, the growth of maize was divided into 12 stages. Big trumpet period of the maize is vegetative growth and reproductive growth, and then the eleventh leaves of the corn will be unfold, the upper few big leaf is prominent, about 60 % tassel has begun to floret differentiation. This plant has been formed, the height is about 1.5 m [20], it is a key period in field, so management, fertilization, irrigation and pest prevention need accurate field information. Therefore, this study selected large bell stage corn as the research object. Different planting density, scattering, diffusion and reflection of corn fields will affect wireless signal propagation mechanism, different density will lead to large differences in the corn spacing and the same distance will form different vegetation depth, they will cause different effects on the wireless signal [21]. This paper selects 4 levels of planting density including 3000, 4000, 5000 and 6000 plants /667 m^2. In this study, the specific values of the impact factors were shown in Table 1.

4.2 Experimental equipment and program

In this experiment, the experiment was carried out in agricultural ground of Jilin University and the variety is the first 335. The experimental field is flat, the temperature difference is less than 3°C, the humidity is less than 5 %, and there is no co frequency interference. In wireless sensor network, 10 sensor nodes of TI company were selected as the transmitters and worked in 2.4GHz, node receiving sensitivity is -110dBm, the nominal transmission distance is greater than 300 m in outdoor environment, and the nominal distance is greater than 50 m in indoor environment; The power of the received signal is represented by RSSI (radiosignal strength indicator), its unit is DBm; the RSSI value of the received signal is obtained by Xsniffer; the portable computer is used to connect the receiving nodes, so as to Xsniffer can obtain RSSI value and store the results; Vertical polarization omnidirectional antenna was chosen in our experiment, the transmitting node and the receiving node are the same level in the measurement process, and the antenna is kept in the same direction, preventing the loss of signal due to the polarity of the antenna.

The receiving node and transmitting node in the corn field are arranged (Fig. 1) in a fixed distance. The corn field nodes include 1 signal receiving nodes and 10 signal transmitting nodes. Both the receiving nodes and the transmitting nodes are placed in the adjustable height and movable bracket, and the antenna height is set to 1 m, 0.5 m, 2 m, 2.5 m and 3 m by adjusting the height of the bracket. The signal receiving node is placed on the edge of the corn field, first signal transmitting nodes and second signal transmitting nodes are respectively 10 m

Table 1 The influence of radio frequency signal factor in corn field

Communication distance/m	Density / plants / 667 m^2	Antenna height/m
0 ~ 160 (The interval is 10 or 2)	3000	1 ~ 3 (The interval is 0.5)
	4000	
	5000	
	6000	

(±0.1 m) and 20 m (±0.1 m) from the edge of corn, and the other transmitting nodes are placed one every 20 m (±0.1 m), the most transmitting node distant can receive 180 m, and the nearest transmitting node can receive 10 m. The communication code rate of transmitting nodes is 250 kb/s, the length of the data packet is 10Byte, and the data load is the launch node encoding information and the data sequence number. The packet loss rate of each node can be calculated by recording encoding information and data sequence number of each node.

5 Experimental analysis

Each launching point transmits 100 packets, they use MATLAB mean treatment, and then they use least squares curve fitting as the basic data model in formula (2). The four planting density relationship between wireless signal attenuation and distance were shown in Figs. 2, 3, 4 and 5.

5.1 The influence of different antenna height under the same planting density

Under the same planting density, the attenuation of the radio frequency signal and distance show a logarithmic relationship, signal will be gradually attenuation with the distance increasing, until the receiving frequency is −110dBm; with the increase of the antenna height, the signal transmission distance gradually increases; when the antenna height is the 1 m, RSSI attenuation will be the fastest, the transmission loss will be the largest and the transmission distance will be about 20–40 m; when the antenna height is the 3 m, RSSI attenuation will be the slowest, the transmission loss will be the smallest, and the transmission distance will be the farthest, which can be as long as 160 m. Therefore, considering the signal quality, engineering factors and cost, antenna height should be slightly higher than the big trumpet period of maize height (2.5 m or so). St this height, the transmission of the wireless signal is close to the line of sight.

5.2 The effects of different plant density

In different plant density, it is not hard to see that the signal transmission distance will change obviously under different density, when the antenna height is less than 2.5 m. 3000 plants/667 m^2 transmission distances are farthest, there are respectively 40 m, 40 m and 120 m; 6000 plants/667 m^2 transmission distances are nearest, there are respectively 20 m, 20 m and 40 m, indicating that the different planting density has a certain influence on the signal attenuation
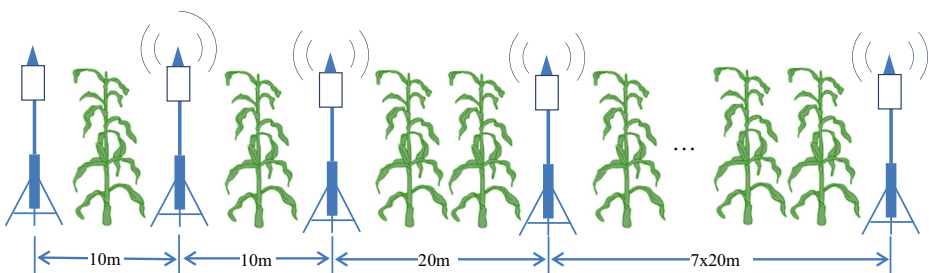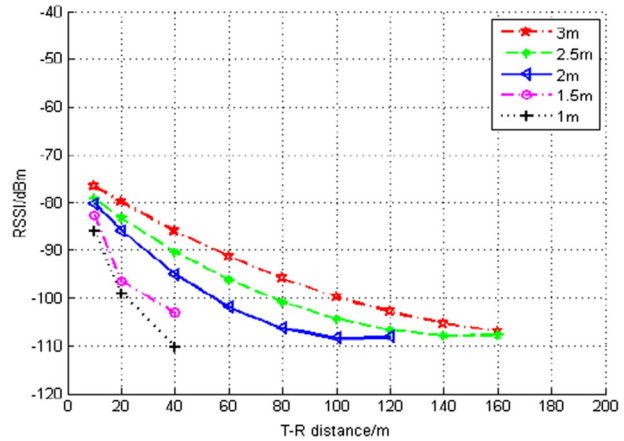

Fig. 1 The arrangement diagram of the receiving node and the transmitting node in the corn field

Fig. 2 Attenuation curves under 3000 plants/667 m²

degree; when planting density and plant intensive, plant scattering, reflection and diffuse will be more serious, resulting in increased signal attenuation slope.

5.3 Path loss prediction model

According to the formula 2, RSSI shows the received power, its value is equal to the received signal power A minus a 10nlog (d) when the signal propagation is 1 m away, in which the RSSI size depends on A and n. Regression analysis of the maize path loss was carried out in MATLAB for the big trumpet period under different planting density, we found that it follows the log path attenuation trend, the fitting parameters values were shown as Table 2.

R^2 is the correlation coefficient, it is the statistical analysis of the close correlation degree between the theoretical calculation and the measured values, in which close to 1 reflects the correlation degree between the data and theoretical model; if the value is close to 1, it shows that the relationship between the two is more closely related. The maximum value of R^2 is

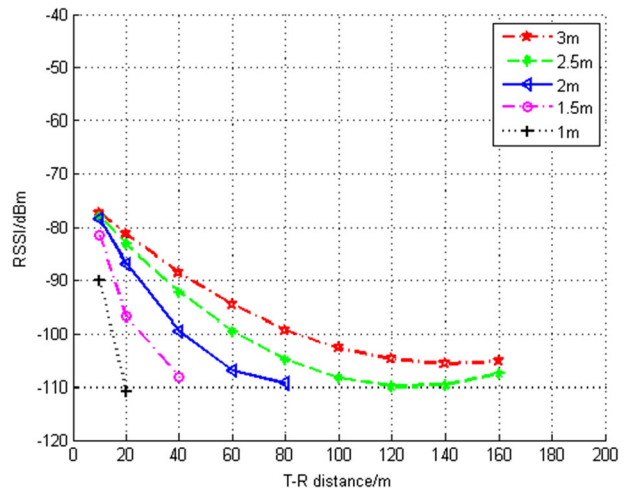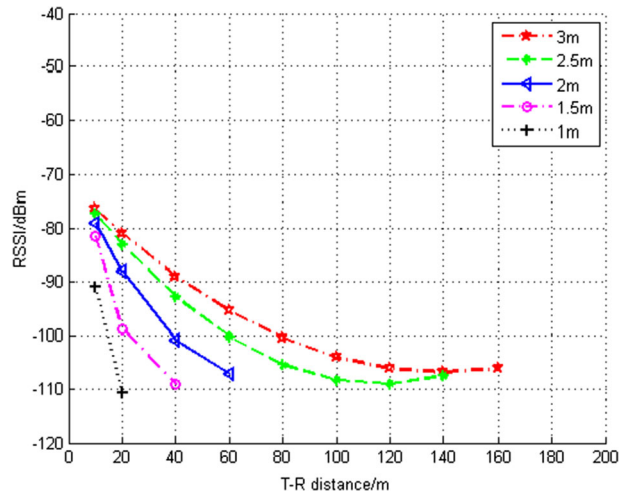**Fig. 3** Attenuation curves under 4000 plants/667 m²

Fig. 4 Attenuation curves under 4000 plants/667 m^2

0.9921, the lowest is 0.9385, which indicates that the experimental data has a high degree of correlation with the theoretical formula. From Table 2, it can be seen that under the same density, n shows the decrease trend with the increase of antenna height; if n is greater, it shows that the environment influence is also greater on the signal attenuation. It can be seen that the higher the antenna is, the smaller the environment impact is; the highest n is 1.720 in the 3000 plants/667 m^2 density, the lowest is 1.065; the highest n is 1.907 in the 4000plants/667 m^2 density, the lowest is 1.166; the highest n is 1.958in the 5000plants/667 m^2 density, the lowest is 1.191; the highest n is 1.988 in the 6000plants/667 m^2 density, the lowest is 1.253. Different planting density is in the same antenna height, n is different, n has an increasing trend with the increase of planting density, for that, the increase of planting density will lead to the increase of leaf reflectance, therefore n becomes big. From the Table 2, it can be seen that there is a linear relationship between n and antenna height under the different density. Curve fitting was carried out by MATLAB shown as Fig. 6.

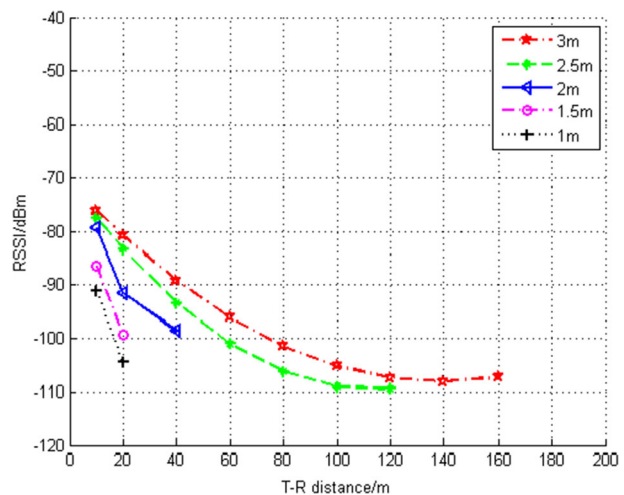**Fig. 5** Attenuation curves under 6000 plants/667 m^2

Table 2 The regression parameters of path loss model in different planting density

Density / plants / 667 m^2	Antenna height /m	A/dBm	n	R^2
3000	1	−42.1253	1.720	0.9921
	1.5	−43.8521	1.511	0.9793
	2	−42.2022	1.245	0.9866
	2.5	−43.2833	1.147	0.9798
	3	−45.9876	1.065	0.9866
4000	1	−42.1253	1.907	0.9422
	1.5	−43.8521	1.542	0.9385
	2	−42.2205	1.275	0.9690
	2.5	−48.2823	1.213	0.9575
	3	−45.9876	1.166	0.9442
5000	1	−44.1253	1.958	0.9823
	1.5	−44.8521	1.746	0.9705
	2	−43.8235	1.406	0.9793
	2.5	−44.4526	1.271	0.9614
	3	−44.4565	1.191	0.9886
6000	1	−43.6508	1.988	0.9875
	1.5	−44.4132	1.826	0.9842
	2	−44.3219	1.516	0.9563
	2.5	−45.8512	1.311	0.9792
	3	−46.1354	1.253	0.9786

A mathematical model between antenna height n and planting density is obtained by fitting the model:

$$3000 \quad \text{plants} \quad / \quad 667 \quad m^2$$
$$n = -0.6219\log(h) + 1.725 \tag{3}$$

Fig. 6 The relationship between antenna height and pass-loss index
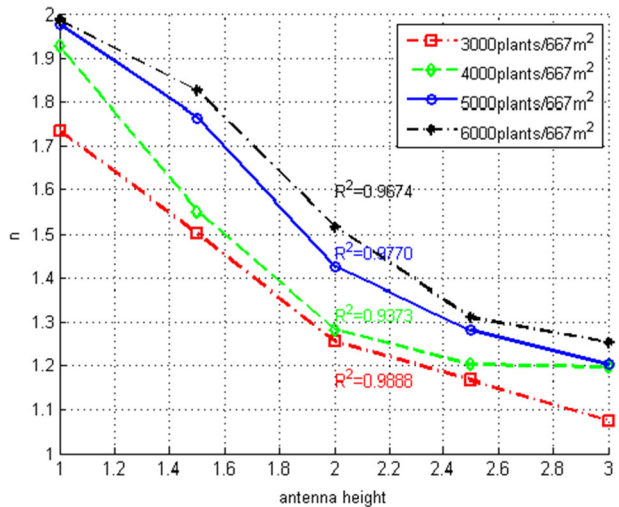
$$4000 \quad \text{plants} \quad 667 \quad \text{m}^2$$
$$n = -0.6931\log(h) + 1.852 \tag{4}$$

$$5000 \quad \text{plants} \quad / \quad 667 \quad \text{m}^2$$
$$n = -0.7435\log(h) + 1.977 \tag{5}$$

$$6000 \quad \text{plants} \quad / \quad 667 \quad \text{m}^2$$
$$n = -0.7263\log(h) + 2.031 \tag{5}$$

Among them, n is environmental impact factor; h is antenna height.

The three planting densities R^2 after fitting are respectively 0.984, 0.950, 0.976 and 0.967, and the experimental data of the correlation height and the theoretical deduction are related.

6 Conclusions

(1) In 2.4GHz, this paper study on the factors of the wireless sensor RF signal loss, and chooses the influencing factors of the transmission distance and antenna height, we focus on the radio frequency signal loss under different planting density (3000plants/667 m^2, 4000plants/667 m^2, 5000plants/667 m^2 and 6000plants/667 m^2), and the signal attenuation model of Northeast corn can be obtained by curve fitting in MATLAB.

(2) According to the analysis of the obtained model, it is found that the antenna height h and the influence factors n have linear relationship under different planting density, and then the mathematical model of the relationship between h and n can be obtained by the curve fitting.

(3) The further research direction is to in-depth study of the empirical value A and environmental factors n, and to improve the accuracy of the mathematical model.

References

1. Akyldiz IF, Su W, Sankarasubramaniam Y et al (2002) A survey on sensor networks [J]. IEEE Commun Mag 40(8):102–114
2. Anderson CR, Dietrich CD, Joshi GG (2005) Near-ground channel measurements over line-of-sight and forested paths. Microw Antennas Propag Iee Proc 152:589–596
3. Andrade-Sanchez P, Pierce FJ, Elliott TV (2007) Performance assessment of wireless sensor networks in agricultural settings[C]. 2007 ASABE Annual International Meeting
4. Darr MJ, Zhao L (2008) Modeling path loss in confined animal feeding operations[C]. 2008 ASABE Annual International Meeting
5. Foran RA, Welch TB, Walker MJ (1999) Verynear ground radio frequency propagation measurements and analysis for military applications [C]. Proceedings of IEEE Military Communications Conference. MILCOM, Atlantic City, USA, p 336–340
6. Hebel MA, Tate R, Watson DG (2007) Results of wireless sensor network transceiver testing for agricultural applications[C]. 2007 ASABE Annual International Meeting
7. Joshi GG, Dietrich CB, Anderson CR et al (2005) Near-ground channel measurements over line-of-sight and forested paths[J]. IEE Proc Microw Antennas Propag 152:589–596

8. Li SY, Gao HJ, Jiang JZ (2009) Impact of antenna height on propagation characteristics of 2. 4 GHz wireless channel in wheat fields [J]. Trans Chin Soc Agric Eng 25(Supp):184–189, **in Chinese**

9. Liu H, Wang MH, Meng ZJ et al (2010) Performance assessment of short-range radio propagation in crop fields[J]. J Jiangsu Univ 31(1):1–5, **in Chinese**

10. Lu Q, Luo WS, Hu B (2010) Multi-node cooperative JPEG 2000i mplementation based on neighbor clusters in wireless sensor networks [J]. Opt Precis Eng 18(1):240–247, **in Chinese**

11. Luo XW, Zang Y, Zhou ZY (2000) Research progress in farming information acquisition technique for precision agriculture [J]. Trans Chin Soc Agric Eng 22(1):167–173 (**in Chinese**)

12. Martinez SA, Molina GPJM, Egea L et al (2005) An accurate radio channel model for wireless sensor networks simulation [J]. J Commun Netw 7(4):1–6

13. Meng YS, Lee YH, Ng BC (2009) Empirical near ground path loss modeling in a forest at VHF and UHF bands[J]. IEEE Trans Antennas Propag 57(5):1461–1468

14. Phaebua K, Phongcharoenpanich C, Torrungrueng D et al (2008) Short-distance and near-ground signal measurements in a car park of wireless sensor network system at 433MHz [C]. Proceedings of 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, Krabi, Thailand: ECTI-CON, p 241–244

15. Roos T, Ki PM, Tirri H (2002) A statistical modeling approach to location estimation[C]// IEEE Transactions on Mobile Computing, p 59–69

16. Shen J, Yao DY, Huang HQ et al (2008) Measurement and analysis of radio channel model fornear-ground wireless sensor network [J]. Opt Precis Eng 16(1):141–149, **in Chinese**

17. Sikka P, Corke P, Valencia P et al (2006) Wireless ad hoc sensor and actuator networks on the farm[C]//IEEE the Fifth International Conference on Information Processing in Sensor Networks. ACM, New York, pp 492–499

18. Wang DH, Song LL, Kong XS et al (2012) Path loss modeling for near-ground wireless channel in grassland environment [J]. Opt Precis Eng 20(6):1406–1413 (**in Chinese**)

19. Wen T, Hong ST, Li Z et al (2010) Test of wireless sensor network radio frequency signal propagation based on different node deployments in citrus orchards [J]. Trans CSAE 26(6):211–215, **in Chinese**

20. Yuan ZQ, Zhang JY (2007) Effect of water stress on growth of maize in the bel-mouthed period. Agricultural Research in the Arid Areas [J]. 25(4):235–242

21. Yue XJ et al (2013) WSN layout experiment based on radio frequency propagation tests in citrus orchard[J]. Trans Chin Soc Agric Eng 44(5):213–218, **in Chinese**

22. Zhao WY, Liu X (2013) Discussion on the direction of maize breeding in northeast china [J]. China Seed Ind 06:12–14

He Pan is an associate professor of Jilin Agricultural University and deputy director of Information Technology Teaching and Management Center. He received Marster's degree in Information Science and Engineering Institute from Jilin Agricultural University in 2010. He won the best Graduation Thesis Award Graduation which is about the computer network security. His research interests in recent years include agricultural engineering and Communication and Information System, most of his recent papers were about application of wireless sensor networks in agricultural engineering.
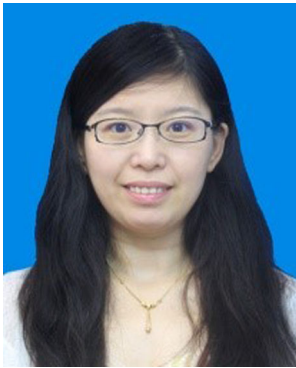
Ying Shi is an associate professor of Jilin Agricultural University, she received her Master degree in Information Science and Engineering Institute from Changchun University of Science and Technology. She joined the staff of Information Technology Teaching and Management Center of Jilin Agricultural University in 2000. She has been engaged in the study of digital agriculture for fifty years, and her research interests in recent years include agricultural engineering in addition.

Xin Wang is an associate professor of Jilin Agricultural University, she received her Master degree in Computer Science & Engineering from ChangChun University Of Technology in 2005. She joined the staff of Information Technology Teaching and Management Center of Jilin Agricultural University in 2006. Her research interests include communication and Information system.

Taihao Li is a professor of Jilin Agricultural University and director of Information Technology Teaching and Management Center, he received Bachelor degree in Physics from Yanbian University in 1985. More than 20 papers of his were published, most of them were about computer network and agricultural engineering. He has recently published his third book with the Jilin University Press. He is a council member of Jilin province information industry association.