International Journal of Electrical and Computer Engineering (IJECE)
Vol.2, No.5, October 2012, pp. 632~638
ISSN: 2088-8708

Model Study for Temperature Microchange by WSN Technology

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Article Info

Article history:

Received Jul 22, 2012
Revised Sep 15, 2012
Accepted Sep 27, 2012

Keyword:

Global change
Tmote Sky
Wireless sensor network
ZigBee

ABSTRACT

The forest temperature microchange becomes critically important due to the study of global change. In this paper we develop a model to study the microchange of forest temperature by the wireless sensor network (WSN) technology. The model is developed by a pairs of modified integral equations. The measurement system includes the temperature sensor, ZigBee and Tmote Sky wireless sensor network system. The measured time interval is 1 hour. From the measurement and model analysis, we found the temperature reaches maximum peak at different time due to the different dielectric constant of tree skin. The different dielectric constant of tree skin has different electromagnetic wave resistance and will cause the different scatter strength of electromagnetic wave. The scatter strength along the azimuth angle is complicated. After complicated calculation we compare the model prediction and the measurement and found the difference between them is less than 1 dB. In model development we also found the distribution of temperature microchange has an exponential function distribution. After comparisons of model prediction with the measured data the correlation coefficient between them is 0.935736. The excellent prediction reaches in this model study.

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1. INTRODUCTION

The temperature microchange of forest tree cannot be measured by the traditional thermometer and need to be studied by the wireless sensor network technology. The microchange of forest temperature is a critical factor to the growth and the type of tree, therefore the distribution and the forest temperature can affect the global temperature change. In general, forests are sensitive to the variability and change of climate. The Climatic factors influence forest health-temperature, rainfall, atmospheric levels of carbon dioxide, other greenhouse gases and extreme weather. Due to the vast potential of WSN technology to enable the applications to be able to connect the physical world successfully. The design and implementation of WSN technology has become a popular research in recent years, By connecting and networking large numbers of tiny sensor nodes, it is possible to obtain data about physical phenomena that was difficult or impossible to obtain in conventional ways. Potential applications for such large-scale wireless sensor networks exist in a variety of fields, including environmental monitoring [1-2], medical monitoring [3-4], and industrial machine monitoring.

The WSN technology is an emerging technology, which consists of large numbers of tiny sensing devices distributed over physical space. Each device is capable of limited computing, radio communication and sensing. In the past couple of years, wireless sensor networks have found a wide range of applications such as environmental monitoring. The WSN technology is used in agriculture to monitor and control the environments of the greenhouses and provide convenient services to users with hand-held devices such as PDA. The WSN technology is proved to be available and useful in automated agriculture field. For low power consumption, the sleep scheme is proposed to prolong the measured time period [5-6]. Precision agriculture needs the optimal treatment from the information of soil and crop statuses. The information can be delivered by WSN technology based on the development of “Smart Dust”. The “Smart Dust ” includes a sensor, a processor and a means of communication. Such wireless sensor systems can form a dense network to provide the continuous monitoring of relevant parameters in a dense agriculture grid [7-8]. All the update applications of WSN technology is available to monitor the environments of the greenhouses and the status of soil and crop. In this paper we apply the WSN technology to monitor the temperature of tree skin in the forest. The measured data of the temperature microchange of the tree skin is applied to predict the global temperature change.

Compared with the conventional techniques of temperature change detection, a wireless sensor network paradigm based on a ZigBee technique was proposed. The proposed technique is in real time, given the change rate of forest temperature. The architecture of a wireless sensor network for forest temperature microchange detection is described. The hardware circuitry of the network node is designed based on a Tmote Sky chip. The process of data transmission is discussed in detail. Environmental parameters such as temperature and humidity in the forest region can be monitored in real time. From the information collected by the system, the modeling for temperature microchange is studied by the mathematical second-order differential equation. In last section we study the difference of modeling prediction and the measured to evaluate the prediction of model. The analysis of characteristics and contributions could be useful for relevant research opportunities of new applications.

2. RESEARCH METHOD

The aim of the paper is to apply the wireless sensor technologies and technology of wireless communications in the forest temperature measurement. The paper focuses on ZigBee based Wireless Sensor Networks. A general WSN protocol consists of the application layer, transport layer, network layer, data link layer, physical layer, power management plane, mobility management plane and the task management plane [9]. In the paper we applied the standard WSN with ZigBee technology operating in the Industrial Scientific and Medical (ISM) frequency band of 2.4 GHz. The ISM frequency band provides license free operations, huge spectrum allocation and worldwide compatibility. For monitoring the long distance data the WSN technology using Wi-Fi (IEEE 802.11) and PC-based systems is developed in Figure 1.

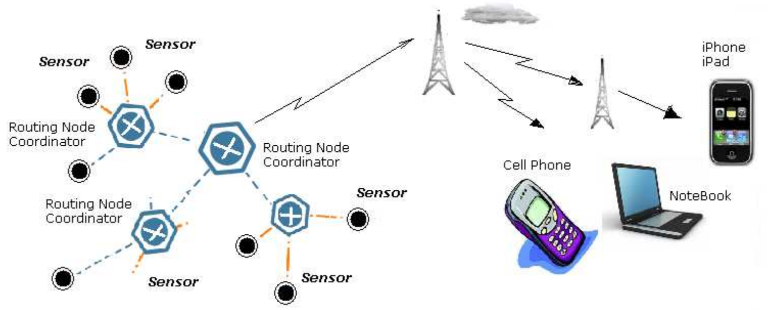

Figure 1. The layout structure of multi-hop in wireless sensor network technology system

In this study we install the ZigBee sensor node in the fir and gingko to collect the data by the wireless sensor network technology. The data retrieves and processed and transmitted for the real time monitoring. For avoiding the human interference the height of sensor node is installed in 3 meters far from the ground. Meantime we consider the sunlight will affect the data transmission situation the directions of sensor nodes faces the north direction. For the tree routing of ZigBee, when a nodes went to transmitting a packet that will follow the tree topology to the destination even if the destination is located nearby. The direction of ZigBee antenna is directional radiation pattern. All the nodes are distributed and installed along the zigzag path to enhance the successful transmission rate. The TmoteSky wireless sensor, product of Moteiv Corp., is developed by the TinyOS operation system platform. The operating voltage is in the range of 2.1V to 3.6V. The TmoteSky wireless system can transmit the power consumption status by wireless at a constant time period. The time interval can be adjusted as requirement. To save the consumption of power the transmission rate is set 5 minutes. The memory for the data storage is 1MB. The system is busy then the data to be transmitted will be stored in a short time. The ZigBee is a wireless network standard based on IEEE 802.15.4. It is a wireless sensor network technology that the main characteristics are low transmission range, usually less than 100 meters. The characteristics are low data rate, short distance, low price and low power consumption. Since the characteristics of ZigBee are low price, low complexity, and limited resources, it has limited capability of compute.

For the electromagnetic wave scattering from rough surface of tree in the forest, the scatter electric and magnetic fields are described and calculated based on a pair of integral equations. The governing equations for the tangential surface fields in medium 1 (incident plane) on a dielectric surface are [7].

$$\hat{n}\times\vec{E} = 2\hat{n}\times\vec{E}^{i} - \frac{2}{4\pi}\hat{n}\times\int \vec{E}''ds' \tag{1}$$

$$\hat{n}\times\vec{H} = 2\hat{n}\times\vec{H}^{i} + \frac{2}{4\pi}\hat{n}\times\int \vec{H}''ds' \tag{2}$$

In medium 2 (beneath the tree surface), we have

$$\begin{aligned} \hat{n}_t\times\vec{E}_t &= -\frac{2}{4\pi}\hat{n}_t\times\int \vec{E}_t''ds' \\ \hat{n}_t\times\vec{H}_t &= \frac{2}{4\pi}\hat{n}_t\times\int \vec{H}_t''ds' \end{aligned} \tag{3}$$

where

$$\vec{E}'' = jk\eta(\hat{n}'\times\vec{H}')G - (\hat{n}'\times\vec{E}')\times\nabla'G - (\hat{n}'\cdot\vec{E}')\nabla'G$$

$$\vec{H}'' = jk(\hat{n}'\times\vec{H}')G/\eta + (\hat{n}'\times\vec{H}')\times\nabla'G + (\hat{n}'\cdot\vec{H}')\nabla'G$$

The fields in the lower medium can be written in terms of the fields in the upper medium by applying the boundary conditions on the continuity of the tangential fields as follows:

$$\begin{aligned} \vec{E}_t'' &= jk_t\eta_t(\hat{n}'\times\vec{H}_t')G_t - (\hat{n}_t'\times\vec{E}_t')\times\nabla'G_t - (\hat{n}_t'\cdot\vec{E}_t')\nabla'G_t \\ \vec{H}_t'' &= jk_t(\hat{n}_t'\times\vec{E}_t')G_t/\eta_t + (\hat{n}_t'\times\vec{H}_t')\times\nabla'G_t + (\hat{n}_t'\cdot\vec{H}_t')\nabla'G_t \end{aligned} \tag{4}$$

The *spectral* representation for the Green's function and its gradient are

$$\begin{aligned} G &= (-\frac{1}{2\pi})\int\frac{j}{q}\exp[ju(x-x')+iv(y-y')-jq|z-z'|]dudv \\ \nabla'G &= (-\frac{1}{2\pi})\int\frac{\vec{g}}{q}\exp[ju(x-x')+iv(y-y')-jq|z-z'|]dudv \end{aligned} \tag{5}$$

where $\mathrm{q} = \sqrt{\mathrm{k}^2 - \mathrm{u}^2 - \mathrm{v}^2}$ and $\vec{g} = \hat{x}u + \hat{y}v \pm \hat{z}q$.

The tangential surface field includes two components, the Kirchhoff component (scatter field) and its complementary component (rescatter field), and is described in Figure 2.

Two corresponding components for the scattered fields are [8]

$$E^{s}{}_{qp} = E^{k}{}_{qp} + E^{c}{}_{qp} \tag{6}$$

where *s* means the tangential surface field, *k* means the Kirchhoff field and *c* means the complimentary field in equation (6). In terms of the surface tangential field for the dielectric surfaces, the far-zone scattered fields can be derived. Consequently the average scattered power and the scattering coefficients can be found in terms of the far-zone scattered field.

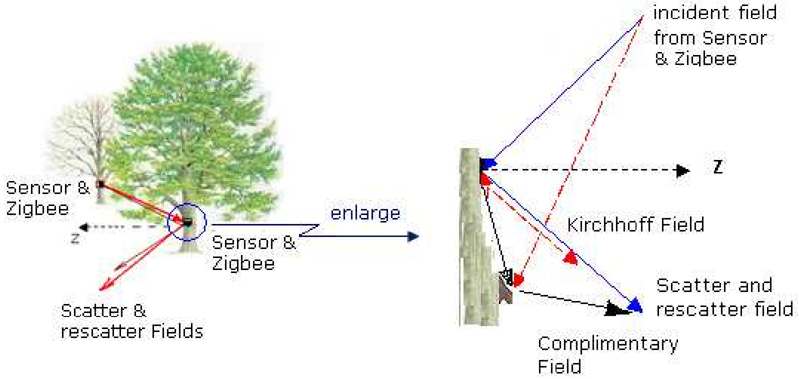

Figure 2. The scatter and rescatter fields from random rough surfaces of a tree

With the field expression the average scattered power is given by

$$\left\langle E_{qp}{}^{s} E_{qp}{}^{s*} \right\rangle = \left\langle E_{qp}{}^{k} E_{qp}{}^{k*} \right\rangle + 2\,\mathrm{Re}\left\langle E_{qp}{}^{c} E_{qp}{}^{k*} \right\rangle + \left\langle E_{qp}{}^{c} E_{qp}{}^{c*} \right\rangle \tag{7}$$

where *Re* is the real part operator and * is the symbol for complex conjugate. To obtain the coherent and incoherent power, we have to subtract the mean-squared power from the total power. That is,

$$\begin{aligned} &\left\langle E_{qp}{}^{s} E_{qp}{}^{s*} \right\rangle - \left\langle E_{qp}{}^{s} \right\rangle \left\langle E_{qp}{}^{s} \right\rangle^{*} \\ &= \left\langle E_{qp}{}^{k} E_{qp}{}^{k*} \right\rangle - \left\langle E_{qp}{}^{k} \right\rangle \left\langle E_{qp}{}^{k} \right\rangle^{*} + \left\langle E_{qp}{}^{c} E_{qp}{}^{c*} \right\rangle - \left\langle E_{qp}{}^{c} \right\rangle \left\langle E_{qp}{}^{c} \right\rangle^{*} \\ &+2\,\mathrm{Re}[\left\langle E_{qp}{}^{c} E_{qp}{}^{k*} \right\rangle - \left\langle E_{qp}{}^{c} \right\rangle \left\langle E_{qp}{}^{k} \right\rangle^{*}] \end{aligned} \tag{8}$$

To carry out the ensemble average operation we must make an assumption the surface with Gaussian height distribution in this research. After the operation of ensemble average and integrating, the incoherently scattered power can be obtained. The bistatic scattering coefficient is related to the average power expression as

$$\sigma_{qp}{}^{0} = (4\pi R^{2} P_{qp}) / (E_{0}{}^{2} A_{0}) \tag{9}$$

Where E_o is the incident field, R is the distance, P_{qp} represents the polarized and depolarized scatter power and A_o is the illuminated area of a tree.

3. RESULTS AND ANALYSIS

From the measured data the change rate of temperature is proportional to the time. During the time closing the noon the change of temperature is large each day. The data measured among 25 days. From Figure 3 we found the change rate of temperature is proportional to the second-order differentiation of the temperature measured. From the measured data the second differentiation of data collected seems proportional to the data measured, i.e. the general model for predicting the temperature microchange will be the format stated below to meet the real measured data.

$$T = k + k_1 e^{-(t-m)^2/k_2} \tag{10}$$

The correlation coefficient a concept from statistics is a measure of how well trends in the predicted values follow trends in past actual values. It is a measure of how well the predicted values from a forecast model "fit" with the real-life data. The correlation coefficient is a quantity that gives the quality of a least squares fitting to the original data. The square of the correlation coefficient r^2 is given by

$$r^2 = \frac{(\sum Tt - n\bar{T}\bar{t})^2}{(\sum T^2 - n\bar{T}^2)(\sum t^2 - n\bar{t}^2)} \tag{11}$$

Where T is the temperature data measured and t in the measured time interval. In statistics the coefficient of determination, r^2, is useful because it gives the proportion of the variance (fluctuation) of one variable that is predictable from the other variable. The coefficient of determination is a measure that allows us to determine how certain one can be in making predictions from a certain model/graph. In this paper we use the coefficient of determination to evaluate the model prediction. The coefficient of determination is the ratio of the explained variation to the total variation. The coefficient of determination is such that $0 \leq r^2 \leq 1$, and denotes the strength of the linear association between time range measured and temperature microchange. The coefficient of determination represents the percent of the data that is the closest to the line of best fit.

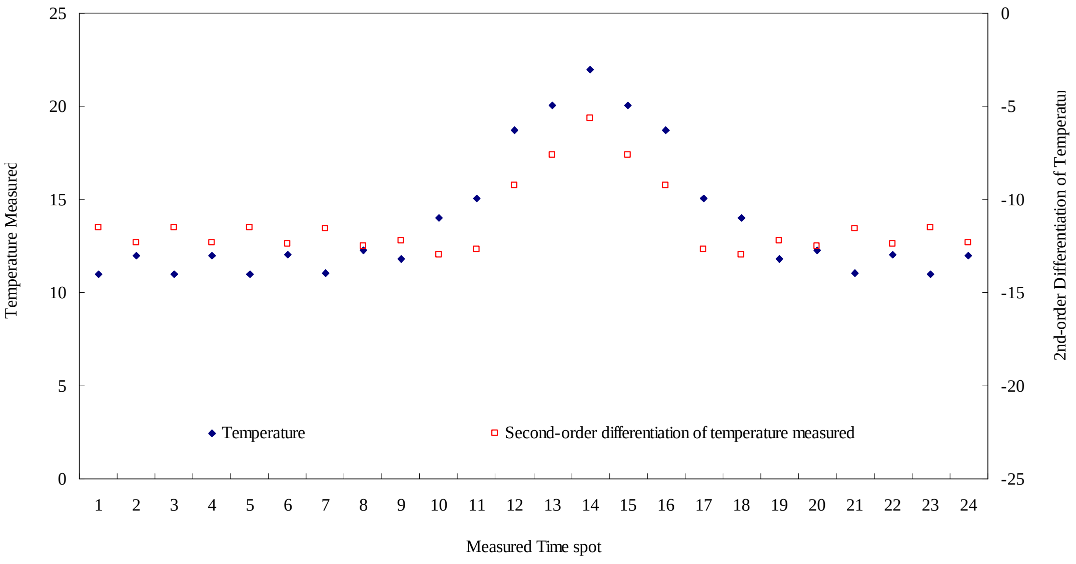

Figure 3. The comparisons of temperature measured with their second-order differential value

The coefficient of determination r^2 is to measure how well the least squares equation. r^2 is used to measure the relative sizes of SST and SSE. Essentially, r^2 tells us how much better we can do in predicting y by using the model and computing model prediction than by just using the mean value as a predictor. The higher the r^2, the more useful the model is. The r^2 takes on values between 0 and 1. The smaller SSE, the more reliable the predictions obtained from the model. The coefficient of determination is computed as:

$$r^2 = 1 - (SSE / SST) \tag{12}$$

Where SSE measures the deviations of observations from their predicted values:

$$SSE = \sum (y_i - \hat{y}_i)^2 \tag{13}$$

SST measures the deviations of the observations from their mean:

$$SST = \sum (y_i - \bar{y})^2 \tag{14}$$

The $\bar{y}$ means the mean value of the measured data of temperature microchange, y_i means the temperature measured and $\hat{y}$ means the model prediction. In the study we compare the temperature data measured for ginkgo tree with the model prediction of temperature and found the model prediction is very good. From the model simulation and the comparisons of the measured temperature with respect to the time interval of 25 days in Figure 3, we found the mean value of temperature is 13.83. The predicted exponential equation (10) with k_1=10, k_2=50 and modified by constant k=3. From equation (12), (13) and (14) we found the related correlation is 0.935736 after calculation. From the strong correlation coefficient of 0.935736, the model prediction is excellent.

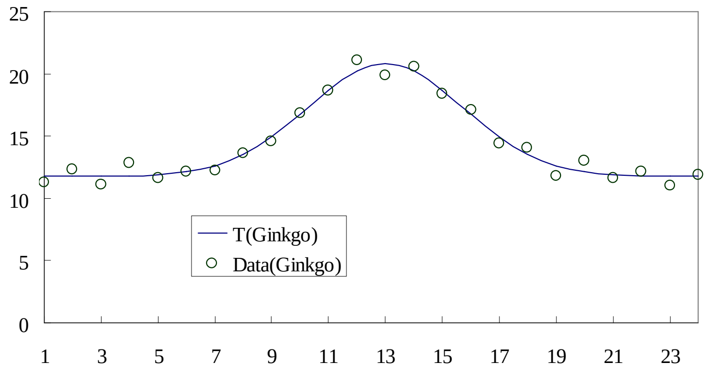

Figure 4. The comparisons of model prediction with measured temperature for ginkgo tree

4. CONCLUSION

The scatter strength of electromagnetic wave from the tree skin in forest is fluctuated with the dielectric constant of tree skin in forest, and the dielectric constant of tree skin in forest is affected by the temperature of environment. To study the temperature change by the wireless sensor network technology we developed a model to predict the scatter strength from rough dielectric tree skin surface and compare the prediction pattern with the measured data in forest. The measurement system includes the temperature sensor, ZigBee and Tmote Sky wireless sensor network for ginkgo tree. After comparing we found the difference between them is less than 1 dB. The correlation coefficient between model prediction and measurement is 0.935736 and show the excellent prediction in this model study. In the near future, the advances of micro-fabrication technology makes the cost of manufacturing sensor nodes to drop continuously. The increasing applications of wireless sensor networks are expected in the future. In the future the sensor node with stable low power communication scheme will be developed and applied in the applications of WSN technology.

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