International Journal of Advanced Smart Convergence Vol.3 No.2 14-17 (2014)
DOI 10.7236/IJASC2014.3.2.4

IJASC 14-2-4

Time of Arrival range Based Wireless Sensor Localization in Precision Agriculture

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Abstract

Precision agriculture relies on information technology, whose precondition is providing real-time and accurate information. It depends on various kinds of advanced sensors, such as environmental temperature and humidity, wind speed, light intensity, and other types of sensors. Currently, it is a hot topic how to collect accurate information, the main raw data for agricultural experts, monitored by these sensors timely. Most existing work in WSNs addresses their fundamental challenges, including power supply, limited memory, processing power and communication bandwidth and focuses entirely on their operating system and networking protocol design and implementation. However, it is not easy to find the self-localization capability of wireless sensor networks. Because of constraints on the cost and size of sensors, energy consumption, implementation environment and the deployment of sensors, most sensors do not know their locations. This paper provides maximum likelihood estimators for sensor location estimation when observations are time-of arrival (TOA) range measurement.

Keywords: *wireless sensor network, precision agriculture, general packet radio service, time of arrival range*

1. Introduction

Precision agriculture (PA) relies on information technology, whose precondition is providing real-time and accurate information. It depends on various kinds of advanced sensors, such as environmental temperature and humidity, wind speed, light intensity, and other types of sensors. Currently, it is a hot topic how to collect accurate information, the main raw data for agricultural experts, monitored by these sensors timely. In recent years, many researches have been carried out on remote monitoring in agriculture, forestry and animal husbandry via wireless communication, such as wireless public network [6]. Currently, most of the monitoring systems for Precision Agriculture adopt GPRS network, of which cost of design and maintenance is higher, to transmit data. Compared with others, wireless sensor network (WSN) is characterized with precision, low cost and real-time quality, Low-Power, large capacity and wide coverage region [5][7]. Sensor networks vary significantly from traditional cellular networks and WLAN, in that sensor nodes are assumed to be small, inexpensive, and deployed in large quantity. These features of sensor networks present unique challenges and opportunities for WSN localization. Patwari et al. described some general signal processing tools that are useful in cooperative WSN localization algorithms with a focus on computing the Rao-Cramer bounds for localization using a variety of different types of measurements [1]. This paper focuses on time-difference-of-arrival (TOA) measurements in view of PA WSNs.

2. Localization Measurement in GPRS Network

Currently, in most of the monitoring systems for Precision Agriculture, GPRS network is used to transmit

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data. In this network, a monitoring point must use a GPRS module. Thus, its cost of design and maintenance is very high in large system. To reduce the cost, WSNs are used to design the monitoring system for Precision agriculture, in which GPRS module is only used to design the sink node that transmits data to information center. In most monitoring systems of precision agriculture, monitoring areas are close to one another. So sensor nodes, including light intensity, temperature and humidity, can be set in the same radiation area of one sink node [3][4]. Meanwhile, power of sink node is unlimited. Therefore, this WSN adopts the star topology.

Distance related measurements include propagation time based measurements, i.e., one-way propagation time measurements, roundtrip propagation time measurements and time-difference-of-arrival (TDOA) measurements, and RSS measurements. One-way propagation time and roundtrip propagation time measurements are also generally known as time-of-arrival (TOA) measurements. One-way propagation time measurements measure the difference between the sending time of a signal at the transmitter and the receiving time of the signal at the receiver. It requires the local time at the transmitter and the local time at the receiver to be accurately synchronized. This requirement may add to the cost of sensors by demanding a highly accurate clock and/or increase the complexity of the sensor network by demanding a sophisticated synchronization mechanism. Roundtrip propagation time measurements measure the difference between the time when a signal is sent by a sensor and the time when the signal returned by a second sensor is received at the original sensor. Since the same clock is used to compute the roundtrip propagation time, there is no synchronization problem. The major error source in roundtrip propagation time measurements is the delay required for handling the signal in the second sensor. This internal delay is either known via a priori calibration, or measured and sent to the first sensor to be subtracted. A detailed discussion on circuitry design for roundtrip propagation time measurements can be found in [14]. Time delay measurement is a relatively mature field. The most widely used method for obtaining time delay measurement is the generalized cross-correlation method [2].

3. TOA based localization

Given the TOA measurement Δt_{ij} and the coordinates of receivers i and j, the TOA between a pair of receivers defines one branch of a hyperbola whose foci are at the locations of receivers i and j and on which the transmitter r_t must lie. Measurements from a minimum of three receivers are required to uniquely determine the location of the transmitter. In a system of N receivers, there are N - 1 linearly independent TOA equations, which can be written compactly as

$$\begin{bmatrix} \|r_1 - r_t\| - \|r_N - r_t\| \\ \vdots \\ \|r_{N-1} - r_t\| - \|r_n - r_t\| \end{bmatrix} = \begin{bmatrix} c\Delta t_{1N} \\ \vdots \\ c\Delta t_{(N-1)N} \end{bmatrix} \tag{1}$$

In practice, Δt_{ij} is not available; instead we have the noisy TOA measurement Δt_{ij}^* given by $\Delta t_{ij}^* = \Delta t_{ij} + \eta_{ij}$. Here η_{ij} denotes an additive noise, which is usually assumed to be an independent zero-mean Gaussian distributed random variable. The above TOA system is a nonlinear equation that is difficult to solve, especially when the receivers are arranged in an arbitrary fashion. Moreover, in the presence of noise, it may not have a solution.

A noisy TOA measurement can be written as

$$\frac{1}{c}\begin{bmatrix} \|r_1 - r_t\| - \|r_N - r_t\| \\ \vdots \\ \|r_{N-1} - r_t\| - \|r_n - r_t\| \end{bmatrix} + \begin{bmatrix} \varepsilon_{1N} \\ \vdots \\ \varepsilon_{(N-1)N} \end{bmatrix} = \begin{bmatrix} \Delta t_{1N}^* \\ \vdots \\ \Delta t_{(N-1)N}^* \end{bmatrix} \tag{2}$$

Denote by b the TOA measurement vector in the above equation. Denote by $f(r)$ the first left hand side vector in the above equation and denote by S the covariance matrix of the TOA measurement errors. The ML estimator minimizes the following quadratic function: $Q(r) = [b - f(r)]^T S^{-1}[b - f(r)]$. Here $f(r)$ is a nonlinear vector function. In order to obtain a reasonably simple estimator, $f(r)$ can be linearized using Taylor series around a reference point r_0, i.e., $f(r) \approx f(r_0) + f^*(r_0)(r - r_0)$. Here $f^*(r_0)$ is a (N - 1) by 2 matrix of partial derivative of *f* with respect to *r* evaluated at r_0.

4. Simulation results

To provide an easy means for M2M radio channel measurement and location estimation testing, we developed and fabricated at laboratory a test bed of 12 prototype peer-to-peer wireless sensor devices. The devices have FSK transceivers with a 50-kHz data rate which operate in the 900–928 MHz band at one of eight center frequencies separated by 4 MHz, which is approximately the coherence bandwidth of the channel. The sensor nodes are randomly placed in the given space then connecting each two nodes if the distance between them less than or equal to the communication radius. The received power was -37.4663 at the reference distance of 1m, in dBm. Figure 1 denotes a contour plot of time delay between sensors, in seconds. The elements of time delay are the average of 10 measured time delays, 5 with the transmitter at *i* and receiver at j, and 5 with the transmitter at j and receiver at *i*. The mean time delay error is 1.0884e-008.

If we want the original TOA measurements we should add it back in to each element. The estimated path loss exponent is 2.3022, and speed of propagation (speed of light) is 299792458 m/s. In 10 individual trials, the RMS location errors range from 1.2 to 1.9 m. If all device ranges are used together, the RMS error is 1.7 m. This error does not reduce significantly when the duration of time-averaging is increased. Much of the error is due to device #20, which has an error of 4.1 m.

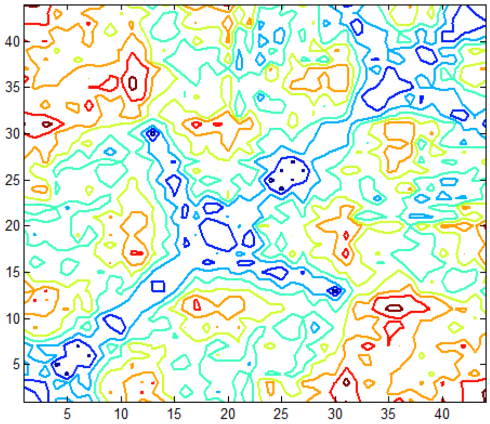

Figure 1. Contour plot of time delay between sensors

5. Conclusion

This paper has provided the measurement techniques in WSN localization and the corresponding localization algorithms for precision agriculture monitoring. These localization algorithms can be divided into one-hop localization algorithms and multi-hop localization algorithms. The results should help researchers determine if the accuracy possible from the location estimation can meet their application requirements. Sensor location estimation with approximately 1.5m RMS error has been demonstrated using TOA measurements. However, despite the reputation of RSS as a coarse means to estimate range, it can nevertheless achieve an accuracy of about 1.2~1.9 m RMS in a test bed experiment.

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