Proceedings of KIIS Spring Conference 2008 Vol. 18, No. 1.

Application of Kalman Filter to Cricket based Indoor localization system

Cong-Yi Zhang* and Sung-Ho Kim*

* Dept. of Electronics and Information Engineering, Kunsan National University

Abstract

Kalman Filter is an efficient recursive filter that estimates the state of a dynamic system from a series of incomplete and noisy measurement. The filter is very powerful in the field of autonomous and assisted navigation. In this paper, we carry out comparative stduy to validate the performance of the application of Kalman Filter. We will build personal localization system based on Cricket mote, our system can present the real-time position of person when the man with PDA moves around. The proposed system is composed of cricket sensor networks, PDA and host computer. There is one listener attached to the PDA. The PDA will get the distance data from the listener synchronously. It will calculate the position of the person in the coordinate of the Cricket system with the trilateration method. Furthermore, it sends the real-time position information to the host computer by Bluetooth. The host computer will use Kalman Filter to process data and get the final estimated track of the person.

Key Words : Kalman Filter, Cricket, Bluetooth

1. Introduction

Kalman Filter has been around about 40 years, it has recently started popping up in a wide variety of the computer graphic application. Kalman Filter is an efficient recursive filter that estimates the state of a dynamic system from a series of incomplete and noisy measurements. In mathematical terms we would say that Kalman filter estimates the states of a linear system. It not only works well in practice, but it is theoretically attractive because it can be shown that of all possible filters, it is the one that minimizes the variance of the estimation error.

In this paper, we propose an indoor location system which is built by using wireless sensor network (WSN).Wireless sensor network is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions. In our system, the wireless sensor network is called Cricket system. Cricket node, is specified by the following features, user privacy, decentralized administration, network heterogeneity, cost. The Cricket nodes will measure the distances between the listener and beacons, using the method TDOA. At the same time, the listener can transmit the distance data to the connected PDA, The PDA synchronously processes the received data and calculates the real-time position of the person in the coordinate built by the Cricket nodes, then the position value will be sent to host computer by bluetooth. In the host computer, the track of the person will be show in the screen. As with any real system, these measurements include a component of error (or noise).We use the Kalman Filter to remove the noise of the signals and to provide the reliable estimate track of the person.

The pass few years have seen rapidly growing interest in location-aware applications [1] and in systems such as Active Badge [2],Active Bat[3] and Cricket[4], RADAR that provide location information in indoor environment. Our system is based on Cricket system. We use a PDA to make a track in the system , but in the future we can create many applications derived from our system.

In the next section, we will introduce the basic knowledge of Kalman Filter, it is the useful method to improve the accuracy of the tracking. In the section 3, we briefly review the pervious work. In the section 4, we present the results of the contrastive experiments, and there are some discussions about the experiment result.

2. Basic of Kalman Filter

Our localization system makes use of Kalman Filter scheme to estimate the real-time person's position. Kalman Filter is one of the most popular mathematical tools used for noisy sensor measurement by stochastic estimation. In real scene, the metrical distances are not always accurate, because the RF and ultrasonic signals may contain the noise such as sound reflection and interference. Kalman Filter is efficient to estimate system state from sequential noisy measurements by exploiting the dynamic of the person. We will give more particular descriptions on the work of Kalman.

Following are the Discrete Kalman Filter time update equations [11]:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_k \quad (1)$$

$$P_k^- = AP_{k-1}A^T + Q \quad (2)$$

$$z_k = Hx_k + v_k \quad (3)$$

Where x_k is the system state, $\hat{x}_k^-$ is a priori state estimate at step k , and $\hat{x}_k$ is the posterior state estimate at step k. P_k^- is a priori estimate error covariance and P_k is the Posteriori estimate errorcovariance. A is the state equation that describes the relation of the previous state and current estimated state. B relates the pervious distance difference u to the state x. In our application, the matrix A and B are I matrix; Q is the process noise covariance; z_k is the measurement value, v_k is the measurement noise and H is the measurement matrix, which is also equal to I matrix in this calculation.

The Discrete Kalman Filter measurement update equations:

$$K_k = P_k^- H^T(HP_k^- H^T + R)^{-1} \quad (4)$$

$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-) \quad (5)$$

$$P_k = (I - K_k H)P_k^- \quad (6)$$

The first task during the measurement update is to compute the Kalman gain, K_k. The next step is to actually measure the process to obtain z_k, and then to generate an a posteriori state estimate by incorporating the measurement z_k in the equation (5),the final step (6) is to obtain an a posteriori error covariance estimate. After each time and measurement update pair, the process is repeated with the previous a posteriori estimates used to project or predict the new a priori estimates. This recursive nature is one of the very appealing features of the Kalman filter.

In our system, $\hat{x}_k$ is a state vector maintained by the system at any discrete time instant t_n. In our application, the state vector includes two state variables, x value and y value of the moving person in the coordinate of our Cricket system.

3. Related Work

Traditional location systems such as RADAR, GPS, etc., these provide location information for outdoor navigation are characterized by reference points deployed at known positions. The reference points, in the form of RF ground stations, satellite etc., constitute expensive infrastructure. And technologies like GPS are quite ineffective indoors because walls in buildings block the signals transmissions, and the accuracy of a GPS tracking system is inadequate for indoor application. By comparison, indoor location system requires a smaller coverage area compared to a typical outdoor system, needs cheaper infrastructure, and should be easy to deploy. There are several indoor positioning systems have been available today, and the accuracy of these systems is higher than the outdoor systems within a confined space. The most economical solution is to use the signal strength of wireless transmissions. RADAR [5], proposed by Microsoft Research, uses many wireless network nodes to cover an indoor environment, and builds a database to record signal strengths at different locations in an offline process. The location of a moving object is then estimated by looking up its measured signal strengths in the database. This approach requires only a RF transceiver, but has limited accuracy, some other localization and tracking systems, such as AT&T's Active Bat [6], Olivetti Research's Active Badge Location System [7], and Ubisense [8], are either expensive, or have low accuracy. An attractive indoor localization system is Cricket system, due to its relatively low cost and high accuracy in certain deployment configurations.

The Cricket system offers the following advantages:

1) Good scalability. The RF and US channel use is independent of the number of listening devices in any region; when host devices actively transmit, high density deployments are harder to achieve.

2) Ease of deployment. Cricket beacons are easy to deploy; they do not require any infrastructure connecting them back to a base station, and can be placed with few constraints inside rooms, open areas and corridors.

3) User privacy. Cricket's architecture allows a host device to infer its location without the infrastructure or any other entity learning that information. While Cricket by itself cannot guarantee user privacy, it makes centralized tracking of users hard. [9]

The location accuracy requirements of our system are reliable coverage and accuracy within 5 centimeters. Compare with the other systems, Cricket system uses the measurement technology called Time Difference of Arrival (TDOA), which can be implemented by ultrasonic pulse. This measurement technology offers high accuracy at a few centimeters. Thus, it is the suitable localization system for our system. Actually C Active Bat and Cricket systems are two successful products of similar type, but Active Bat system is an active mobile architecture, and Cricket system is a passive mobile architecture. Qualitatively, the passive mobile architecture scales better than the active mobile architecture as the density of devices increases, because the wireless (RF and ultrasonic) channel use is independent of the number of mobile devices. Unlike the passive mobile architecture, the active mobile architecture requires a network infrastructure to connect the deployed receivers to the central database. In addition, the active mobile architecture also allows users to be tracked more easily by the infrastructure, raising privacy concerns. In contrast, the passive mobile architecture allows a mobile device to estimate its location and control which other entities get that information. So for our project, we use Cricket system.

4. Configuration of the proposed Cricket based personal location system

The entire system framework is shown below:

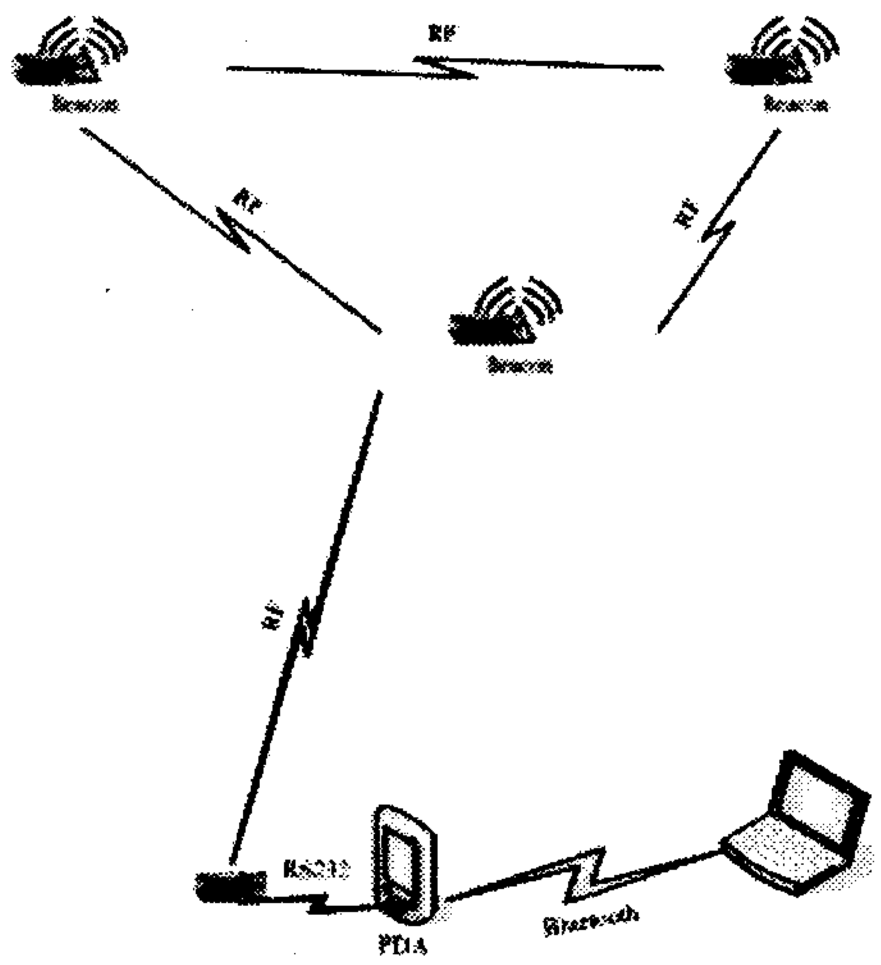


Fig. 1. The system framework

4.1 The sensor network

The Cricket node module was developed via joint design collaboration between Crossbow Technology and MIT, manufactured by Crossbow. In our system, we use the Cricket Mote MCS410CA. It is a location aware version of the popular MICA2 low-power Processor/Radio module [10].The Cricket Motes are equipped with an on-board ultrasonic transmitter and an ultrasonic receiver circuitry, like that's shown in Figure 1.The radio transceiver operates in 433MHz ISM band, has a byte-level interface and provides an effective radio data rate of 19.2 kbps. The Cricket runs a specialized operating system, called TinyOS, which addresses the sensor nodes' concurrency and resource management

In our system, there are two kinds of Cricket nodes: 1. as actively transmitting beacons, they are deployed on the ceiling; 2. as the listener, it's attached to the person. Beacons periodically transmit RF message containing the unique beacon-identifier. Listener listen to beacon transmission andmeasure the distances by using the method called TDOA. Then the listener transfers the noisy distances to the PDA by RS232.There is one experimental GUI program in C# in PDA. So PDA will process the distance values using the algorithm called triangulation. In our system, there are three beacons deployed on the ceiling, they are deployed in a square shape, the distance between each node is 1.5 meters.

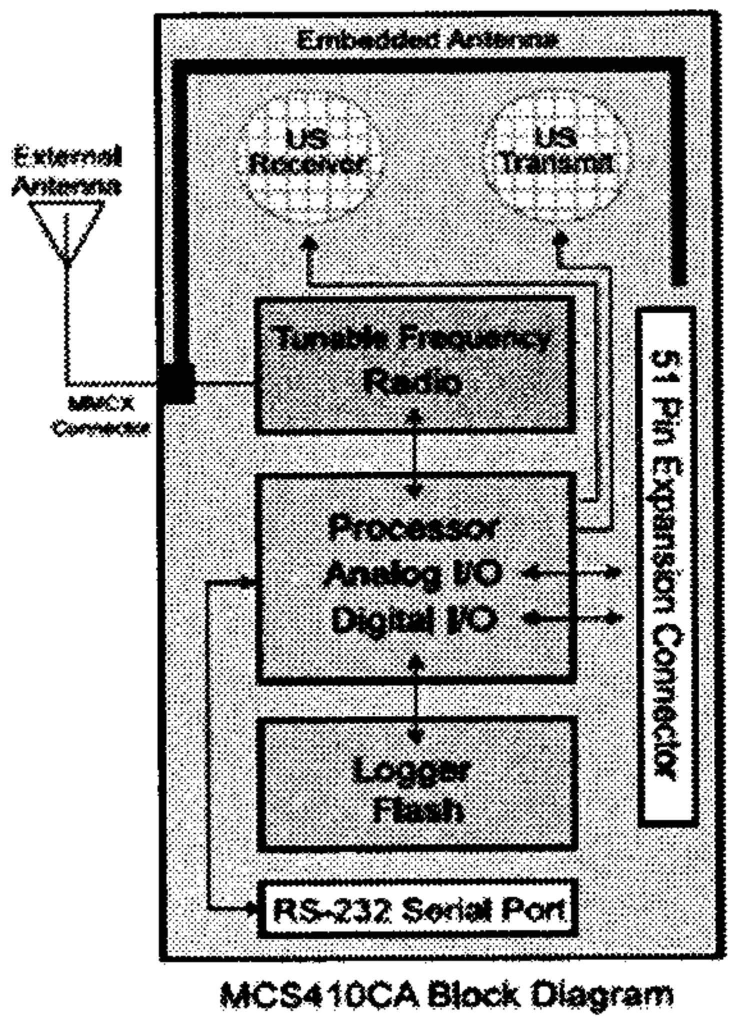


Fig. 2. the circuit diagram of the MCS410CA

4.2 Software Platform

In the PC, we have an experimental program GUI, written in C#. We will use Kalman Filter in our program, and there will be three tracks shown in the programme, the true track, the measured track got from the PDA and the estimated track from the Kalman Filter. From the mixed graphics, we can compare the estimate track with the true track, because of implementing Kalman Filter, we can eliminate the noise from the measurement data

5. Experiments

We conduct two experiments conditions to implement Kalman Filter in the track evaluation. One test-bed is built in the laboratory, there are many obstacles in the laboratory such as desks, book cabinets and so on. The other test-bed is builtin the hall, compare with the inside one, this environment is clear. From these two experiments, we can get a contrastive performance to validate the effect of the Kalman Filter algorithm used on our localization system, and check the stable and accuracy of our system. We implement the experiments in the following situation: the PDA with listener moves according to a predicted track, in the two experiment scenes, the tracks are the same. The listener gets the distance values from the beacons and transmits the values to PDA by RS232. Simultaneity the PDA sends out the position data calculated by the triangulation algorithm to the host PC by bluetooth. The measurement track will be recorded in the host PC, and there is another GUI programme to use Kalman Filter algorithm in the host PC.

In the Fig.3, the blue line is the plot of actual movement of target, the flexuous green line shows the measurement track with noise, and red line represents the output of Kalman Filter. Obviously the Kalman Filter can successively estimate the actual movement in the case of effect of noise.

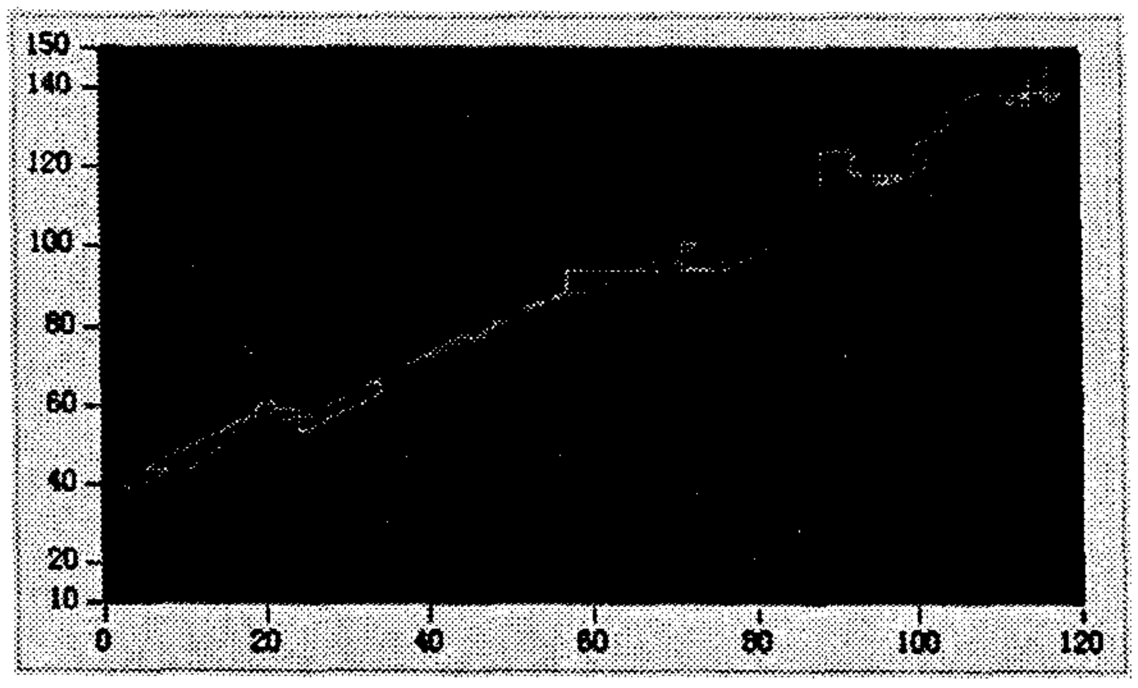
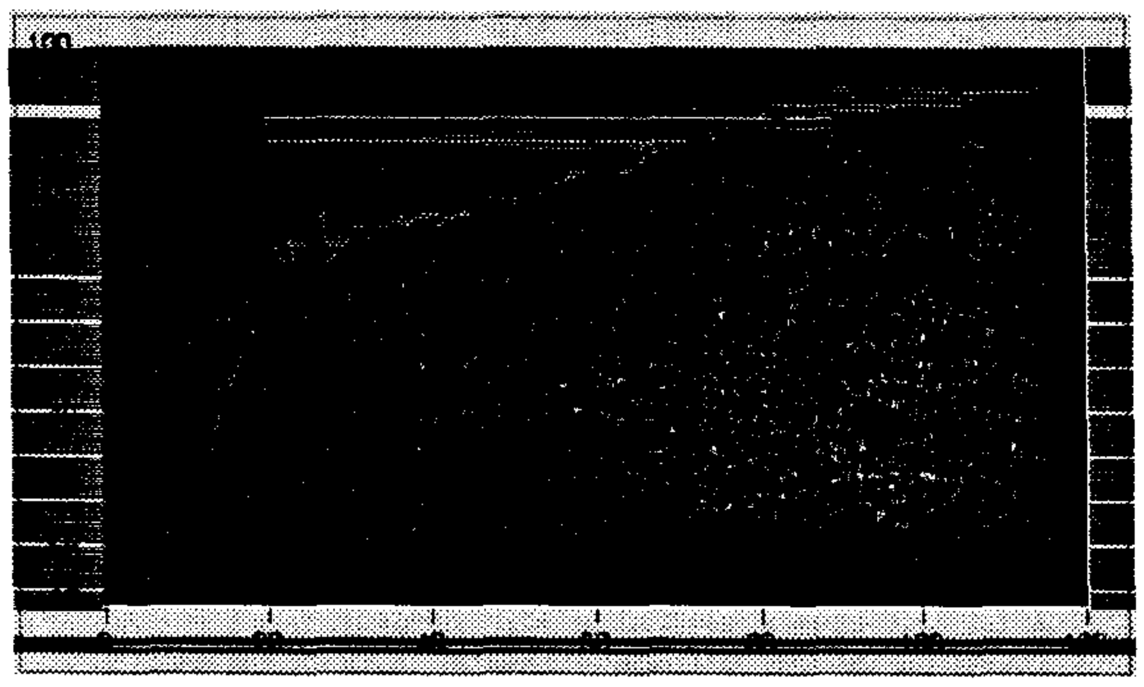


Fig. 3. Estimation property of Kalman Filter in case of installing cricket system on the hallway

Fig.4 shows the estimation property of Kalman filter in case of inside of laboratory.



Fig, 4. Estimatin property of Kalman Filter in case of installing cricket system on inside of the laboratory

Comparing with the above two cases, the measurement plot in case of inside of laboratory is more complex than that of halway. It is because there are many obstacles inside of the laboratory. However, Kalman Filter can successively estimate the movement of the object in both cases.

6. Results

From the experimental results, we can find out the inside measurement track contains more noise than the hallway case. This is the representative problem in the localization system based on the Cricket system. Because in the laboratory, there are many obstacles, the ultrasonic may reach the listener after bending over an edge (refraction) or after reflecting off of some obstacles. Both refraction and reflection cause the sound to travel a longer distance than the Euclidean distance between the beacon and the listener, resulting in distance measurement errors. However, the hall is a clear environment, so the distance measurement is more correct.

From the experiment results, we can conclude that the accuracy of our localization system is desirable.

This research was financially supported by the Ministry of Commerce, Industry and Energy(MOCIE) and Kore Industrial Technology Foundation(KOTEF) through the Human Resource Training Project for Regional Innovation.

Reference

[1] IT Roadmap to a Geospatial Future. http://www.nap.edu/html/geospatial_future/, 2003.

[2] (R.Want, A. Hopper, V. Falcao, and J. Gibbons. The Active Badge Location System. ACM Transactions on Information Systems, 10(1):91 - 102, January 1992.)

[3] (A. Harter, A. Hopper, P. Steggles, A.Ward, and P.Webster. The Anatomy of a Context-Aware Application. In Proc.5th ACM MOBICOM Conf., Seattle, WA, August 1999.)

[4] (N. Priyantha, A. Chakraborty, and H.Balakrishnan. The Cricket Location-Support System. In Proc. 6th ACM MOBICOM Conf., Boston, MA, August 2000.)

[5] P. Bahl and V. N. Padmanabhan, "RADAR: An in-building RF-based user location and tracking system," in INFOCOM, April 2000, pp. 775 - 784.

[6] A. Harter, A. Hopper, P. Steggles, A. Ward, and P. Webster, "The
anatomy of a context-aware application," in Mobile Computing and
Networking, 1999, pp. 59 - 68.

[7] R. Want, A. Hopper, V. Falc˜ao, and J. Gibbons, "The active badge
location system," ACM Transactions on Information Systems, vol. 10,
no. 1, pp. 91 - 102, 1992.

[8] Ubisense Limited, http://www.ubisense.net.

[9] Hari Balakrishnan, Roshan Baliga, Dorothy Curtis, Michel Goraczko," Lessons from Developing and Deploying the Cricket Indoor Location System"

[10]http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/MCS410_Cricket_Datasheet.pdf

[11] Greg Welch and Gary Bishop. 2006.An Introduction to the Kalman Filter. Chapel Hill, NC 27599-317