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Application of Kalman Filter to Cricket based Indoor localization system

Sung-Ho Kim*, and Chong yi Zhang*

* College of Engineering, School of Electronics & Information Engineering,
Kunsan National University

Abstract

Cricket is an excellent indoor location system and it can successfully solve many critical problems such as user privacy, decentralized administration. But in some practical applications, Cricket sometimes didn't provide location with enough accuracy, and was unable to determine when it was giving inaccurate information. For getting high-accuracy tracking performance from location data contaminated with noise, some types of filters are required. 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 studies to validate the performance of the application of Kalman Filter to Cricket based localization system.

Key Words : Kalman Filter, Cricket based localization system

1. Introduction

Sensor technology plays an important and growing role in today's industry and life. Many automated and semi automated production processes rely on sensors for coordination and control. Sensors are crucial as part of security systems and also for monitoring environmental conditions or the structural integrity of buildings. Traditionally those sensors must be connected by wires to some central computing device which processes and interprets the sensor signals. This wiring is expensive and severely limits the flexibility and reusability of the sensors.

The advances of micro-chip technology make it now possible to produce small devices that combine sensing, data processing and wireless communication. Such devices are called motes and are in fact tiny computers. Because they communicate through radio, there is no need of wiring. Motes can exchange data and process it themselves, filtering and/or aggregating it. Radio communication has only a limited range. To effectively extend the range of communication of any given device the motes can forward messages over several hops according to the rules of some Routing Protocol until it reaches its destination. This way dozens, hundreds or even thousands of motes distributed in an area form a Wireless Sensor Network (WSN).

Physical location is an important attribute of a sensor's data stream in a large number of sensor network applications. In addition, geographic information, for instance in the form of node coordinates in some common coordinate system, is a useful primitive in routing protocols such as geographic routing [1], information dissemination protocols such as directed diffusion using location attributes [2], and sensor query processing systems [3].

In non-urban outdoor settings, nodes may obtain location information using an existing infrastructure such as Global Positioning System (GPS) [4]. However, GPS receivers may be too expensive, too large, or too power-intensive for the desired application. In many outdoor urban environments, and most indoor environments, GPS is not available. One solution to this problem is an alternative location infrastructure such as Active Bat [5] or Cricket [6] that works in places that GPS does not.

Kalman Filter has been studied about 40 years. Recently, it has 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 set up a personal localization system based on Cricket motes. In our system, the listener held by one man is connected with the PDA by the RS232 interface, the PDA can display the result of the localization by the program called Cricket View. After the track of the listener is recorded by the PDA, the

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data is transmitted to the host PC by Bluetooth. In the host PC, there is Kalman Filter algorithm to estimate the position of listener. The Kalman Filter is used to remove the noise of the signals. The measurement track of the listener and the estimate track are both shown in the host PC, compared with the true track.

In the next section, we will introduce the basic knowledge of Cricket system. In the section 3, we will introduce the knowledge of Kalman filter. In the section 4, we present the architecture of the comparative experiments. In the section 5, there are experiment results and some discussions about the result.

2. Basic of Cricket System

Traditional location system such as GPS requires a dozens of satellites and ground-based monitoring centers to provide location information for outdoor navigation. However, GPS is quite ineffective especially for indoor application because walls in buildings block the signals transmissions. To overcome this problem in GPS, location infrastructure such as Cricket has been proposed.

Cricket is an indoor location system that provides two kinds of information, space identifiers and position coordinates. The position coordinates are (x, y, z) Cartesian coordinates.

According to the state of nodes, Cricket nodes can be divided into two categories: beacons and listeners. Actively transmitting beacons are fixed on the indoor ceilings with their own definite coordinates and listeners are attached to host devices (handhelds, laptops, etc.) whose location needs to be obtained. The coordinates of any listener is still unknown before being computed whether it is moving or static[7].

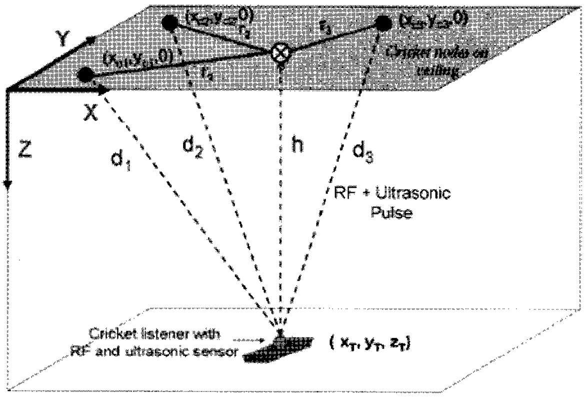


Fig.1 A listener calculates its position by using distance measurements from nearby beacons.

Each beacon is equipped with ultrasonic, RF and temperature sensors. Because RF travels about 10^6 times faster than ultrasonic, the listener can use the time difference of arrival between the start of the RF message from a beacon and the corresponding ultrasonic pulse to infer its distance from the beacon.

Triangulation algorithm is generally used for determining the absolute position of listener as presented in Fig.1 and is shown below.

$$(X_T - X_{Ci})^2 + (Y_T - Y_{Ci})^2 = r_i^2, i = 1,2,3 \tag{1}$$

$$r_i = \sqrt{d^2_i - h^2}, \quad i=1,2,3. \tag{2}$$

$$\begin{aligned} X_{T_{12}} &= X_{c1} + 1/d^2{}_c[d_{X_c} d^2{}_r \pm |d_{y_c}| \sqrt{r^2{}_2 d^2{}_c - d^4{}_r}] \\ Y_{T_{12}} &= Y_{c1} + 1/d^2{}_c[d_{Y_c} d^2{}_r \pm |d_{X_c}| \sqrt{r^2{}_2 d^2{}_c - d^4{}_r}] \end{aligned} \tag{3}$$

Where, $d_{X_c} = X_{C1} - X_{C2}$, $d_{Y_c} = Y_{C1} - Y_{C2}$

$d^2{}_c = d^2{}_{X_c} + d^2{}_{Y_c}$,

$d^2{}_r = (r^2{}_1 - r^2{}_2 - d^2{}_c)/2$

$$\begin{aligned} X_{T_{23}} &= X_{c2} + 1/d^2{}_c[d_{X_c} d^2{}_r \pm |d_{Y_c}| \sqrt{r^2{}_3 d^2{}_c - d^4{}_r}] \\ Y_{T_{23}} &= Y_{c2} + 1/d^2{}_c[d_{Y_c} d^2{}_r \pm |d_{X_c}| \sqrt{r^2{}_3 d^2{}_c - d^4{}_r}] \end{aligned} \tag{4}$$

Where, $d_{X_c} = X_{C2} - X_{C3}$, $d_{Y_c} = Y_{C2} - Y_{C3}$,

$d^2{}_c = d^2{}_{X_c} + d^2{}_{Y_c}$

$d^2{}_r = (r^2{}_2 - r^2{}_3 - d^2{}_c)/2$

In the above equation, (X_{Ci}, Y_{Ci}) is each Cricket node position, *d* is the distance between the listener and each Cricket node, *r* is the radius of circle that is drawn with each Cricket node position as its center including a listener (X_T, Y_T). Eq.(3) and Eq.(4) have two solutions (X_T, Y_T). According to the current position of the man and the listener, a reasonable solution can be appropriately chosen.

3. Basic of Kalman Filter

Our localization system makes use of Kalman Filter scheme to estimate the real-time position of the person. 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. In the following more particular descriptions on the work of Kalman Filter are presented. The Discrete Kalman Filter's time update equations [8] are given as :

$$X_k^- = A X_{k-1} + BU_k \tag{5}$$

$$P_k^- = A \times P_{k-1} \times A^T + Q \tag{6}$$

$$Z_k = H \times X_k + V_k \tag{7}$$

Where X_k is the system state, $\bar{X}_k^-$ is a priori state estimate at step k, and $\bar{X}_k$ is the posterior state estimate at the step k. P^-_k is a priori estimate error covariance and P_k is the posteriori estimate error covariance. 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's measurement update equations:

$$K_k = P_k^- \times H^T \times (H \times P_k^- \times H^T + R)^{-1} \tag{8}$$

$$\bar{X}_k = \bar{X}_k^- + K_k \times (Z_k - H \times \bar{X}_k^-) \tag{9}$$

$$P_k = (I - H \times K_k) \times P_k^- \tag{10}$$

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 (9), the final step (10) 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, $\bar{X}_k$ is a state vector obtained from 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.

4. Configuration of the proposed Cricket-based personal location system

A basic personal localization system based on the Cricket nodes is set up in this paper. There are three beacons deployed on the ceiling, and the listener is connected to the PDA by RS232. The PDA and the listener are held by one person. The PDA will transmit the data to the host PC by Bluetooth.

The entire system framework is shown in Fig. 2.

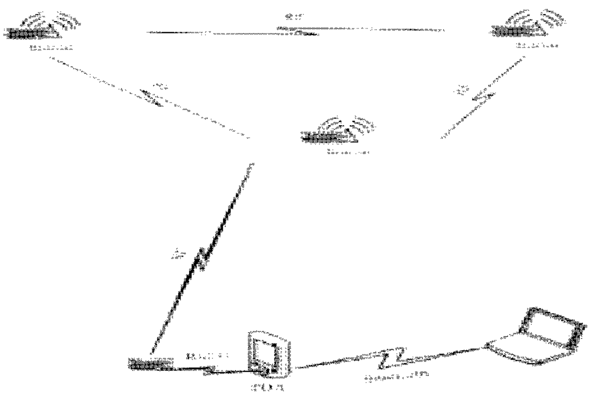


Fig.2 The system framework

The experimental Cricket-based personal localization system is composed of two parts. The first one is the Cricket-based sensor network and the second one is the software platform which can show and estimate the personal location.

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 [9].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 PDA.

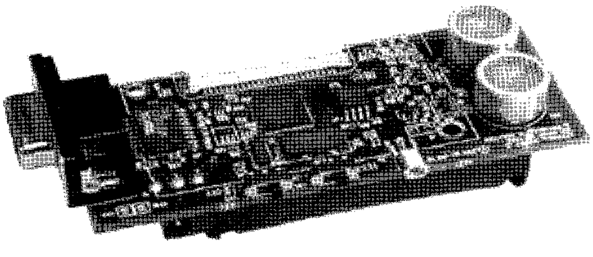


Fig.3 the MCS410CA unit

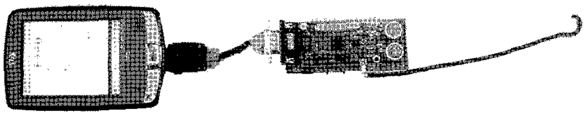


Fig.4 the listener is connected with the PDA by RS232

Beacons periodically transmit RF message containing the unique beacon-identifier. Listener listens to beacon's transmission and measures the distances by using the method called time difference of arrival[10] (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 processes 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.

4.2 Software Platform

In the PDA, there is a program called Cricket View. From the Cricket View, we can see the position of the person with the listener directly in the user interface screen.

In the PC, there is an experimental program GUI called Kalman Filter, written in C#. Kalman Filter is used in this program, and there are three tracks shown in the program: 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, the noise is eliminate from the measurement data.

5. Experiments and Results

Two experiments under different conditions are carried out to verify the performance of Kalman Filter in the track estimation. One test-bed is set up in the laboratory, there are many obstacles in the laboratory such as desks, book cabinets and so on. The other test-bed is set up in the hall, compared with the inside one, this environment is clear. From these two experiments, we can get a contrastive performance to present the effect of the Kalman Filter algorithm, and check the stability and accuracy of our system. We implement the experiments in the following situation: One person holds the PDA and listener moves in a predicted track, in the two experimental scenes, the predicted tracks are the same. The listener gets the distance values between the beacon and itself, then transmits the values to PDA by RS232. The position of the person can be calculated by the program Cricket View in the PDA, the real-time position value will appear in the Cricket View.

(The circle is the listener, S1, S2, S3 are the Cricket nodes, and the numbers on the dashed lines are the distances between the listener and the beacons)

Synchronously the PDA sends out the position data calculated with the triangulation algorithm to the host PC via Bluetooth. The measurement track will be recorded in the host PC, and there is another GUI programme called Kalman Filter to implement to process received data by using Kalman Filter algorithm in the host PC.

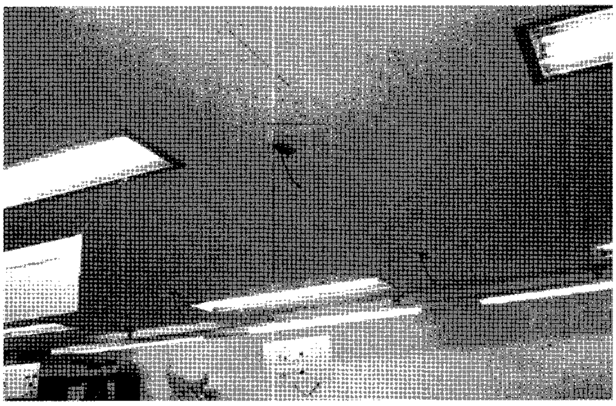


Fig.5. The test-bed in the laboratory (the square is the Cricket node)

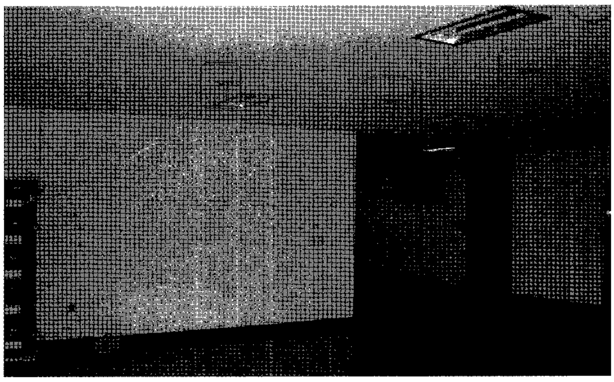
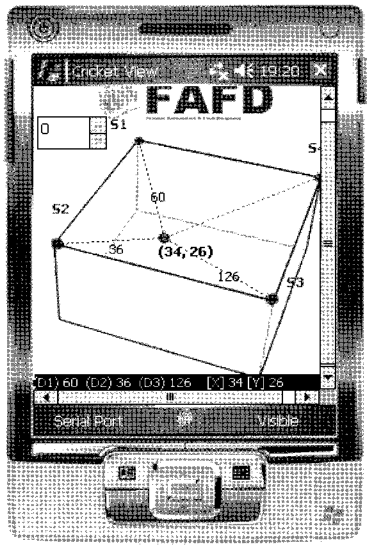


Fig.6. The test-bed in the hall (the square is the Cricket node)



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(D1) 60 (D2) 36 (D3) 126 [X] 34 [Y] 26
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Fig.7. The User interface screen of the PDA

In the Fig.8 and Fig.9, the blue line is the plot of actual movement track of target, the flexural green line means the measurement track with noise, and the red line represents the output data processed by Kalman

Filter algorithm. In the two figures Fig.8, Fig.9, the red line and the blue line are almost the same. Obviously the Kalman Filter can successfully estimate the actual movement in the case of noise effect.

Comparing with the above two cases, the measurement plot in case of inside of laboratory is more complex than that of hallway. It is because there are many obstacles inside of the laboratory. However, Kalman Filter still successfully estimates the movement of the object in the laboratory environment.

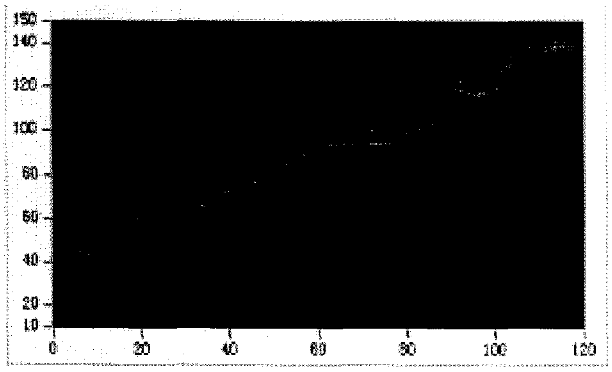

Fig.8. The graphs generated by Kalman Filter program in case of installing cricket system in the hallway

In the Fig.9, there is a big shock wave in the green line, this big wave indicates a significant error of the measurement data. The Kalman Filter can minimize such effects, as the smaller shock wave in the red line shown. Specially in the Fig.8, the red line almost superposes the blue line, this situation shows that the Kalman Filter plays an effective action.

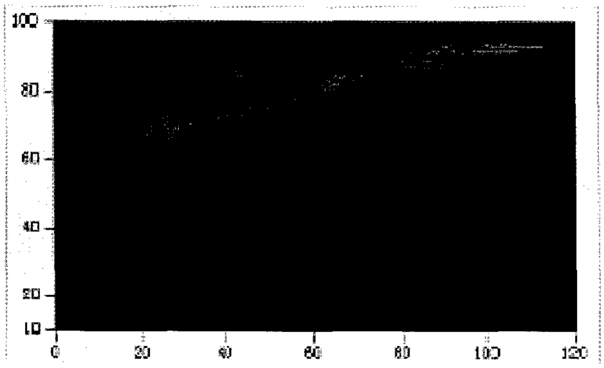

Fig.9. The graphs generated by Kalman Filter program in case of installing cricket system inside of the laboratory.

6. Conclusion

From the experimental results, we can find out that measurement data obtained from Cricket installed in laboratory contains more noise than that of the hallway environment. 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 obtained results, Kalman Filter for localization and tracking seems highly promising, and is certainly worthy of further investigation to indoor Cricket system's applications especially with an implementation on PDA. In the future, we want to make the Cricket system be easily adapted into different types of scenarios with the implementation on the PDA or some smart phone.

Reference

[1] J.Li, J.Jannotti, DE D.Couto, D.Karger, and R.Morris,"A Scalable Location Service for Geographic Ad-Hoc Routing",*In Proc. 6th ACM MOBICOM Conf.* Boston, MA, Aug. 2000.

[2] C.Intanagonwiwat, R.Govindan, and Estrin, D.Directed Diffusion, "A Scalable and Robust Communication Paradigm for Sensor Networks", *In Proceedings of the Sixth International ACM Conference on Mobile Computing and Networking (MOBICOM)* pp. 56 - 67, Boston, MA, 2000.

[3] S.Madden, M.Franklin, J.Hellerstein and W. Hong, "TAG: a Tiny AGregation Service for Ad-Hoc Sensor Network.", *In Proceedings of the Fifth USENIX Symposium on Operating Systems Design and Implementation (OSDI),* Boston, MA, December 2002.

[4] I.Getting, "The Global Positioning System",*IEEE Spectrum 30,* 36 - 47, 12 ,December 1993.

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

[6] N.Priyantha, A.Chakraborty, and H.Balakrishnan. "The Cricket Location-Support System", *In Proc. 6th ACM MOBICOM Conf.* Boston, MA, Aug. 2000.

[7] Roshan Bantwal Baliga, *"Rapid Coordinate System Creation and Mapping Using Crickets"*,Massachusetts Institute of Technology, June 2004

[8] Greg Welch and Gary Bishop. *An Introduction to the Kalman Filter.* Chapel Hill, NC 27599-317.2006.

[9] http://www.xbow.com/Products/Product_pdf_files/

Wireless_pdf/MCS410_Cricket_Datasheet.pdf

[10] Hari Balakrishnan, Roshan Baliga, Dorothy Curtis, Michel Goraczko," Lessons from Developing and Deploying the Cricket Indoor Location System", MIT Computer Science and Artificial Intelligence Laboratory, November 7, 2003

저 자 소 개

Sung-Ho Kim
Professor, Department of Electrical Engineering and Information Technology Kunsan National University

Phone : +82 16 610 1224
E_mail : shkim@kunsan.ac.kr

Zhang Congyi
Master Student, Department of Electrical Engineering and Information Technology Kunsan National University

E-mail : zcy@kunsan.ac.kr