A Study on the Indoor Real-Time Tracking System to Reduce the Interference Problem*

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Abstract. The real-time tracking system is an essential component in the development of low cost sensor networks to be used in pervasive and ubiquitous computing. In this paper we address the interference problem of the sensor network platform that uses ultrasonic for location tracking. We also present a novel scheme reducing the error rate caused by interference, which is particularly suited for supporting context-aware computing. It is achieved by considering the speed variance of the mobile node and thereby correcting the interference errors. Performance evaluation using an actually implemented platform, Pharos, reveals that the proposed scheme outperforms the three existing schemes. It also identifies that error rate decreases as the number of packets transmitted for distance estimation increases, while it increases as the speed of the mobile node increases.

Keywords: Indoor tracking, interference problem, location-aware, sensor network, ubiquitous.

1 Introduction

The wireless sensor network is an emerging technology that may greatly aid humans by providing ubiquitous sensing, computing and communication capabilities through which people can more closely interact with the environment wherever they go. To be context-aware, one of the central issues in the sensor network is location-aware and tracking, whose goal is to monitor the path of a moving object. Ubiquitous and pervasive environment presents opportunities for a rich set of location-aware applications such as car navigation and intelligent robots, interactive virtual games, habit monitoring, logistics service, tracking, etc [1,2]. Typical indoor applications require better accuracy than what the current outdoor location systems provide. Outdoor location technologies such as GPS [3] have poor indoor performance because of the harsh

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nature of indoor environments. Indoor environments often contain substantial amounts of metal and other reflective materials that affect the propagation of radio frequency signals in non-trivial ways, causing severe multi-path effects, dead-spots, noise, and interference [4,5,6].

Cricket is an indoor location system for pervasive and sensor-based computing environments such as those envisioned by MIT's Project Oxygen [7]. Cricket has been widely adopted as the indoor tracking platform. It provides fine-grained location information such as space identifiers, position coordinates, and orientation to the applications running on handhelds, laptops, and sensor nodes. However, Cricket has serious interference problem when the cricket-based node moves.

In this paper we present a novel scheme reducing the interference problem of the location tracking system that is particularly suited for supporting context-aware computing. It is achieved by considering the speed variance of the mobile node and thereby correcting the interference errors. The proposed location platform is called Pharos and the new algorithm for interference problem is called IAA (Interference Avoidance Algorithm). Performance evaluation using the actually implemented platform, Pharos, reveals that the proposed scheme outperforms the three existing schemes in terms of the error rate in the location estimation. It also identifies that the error rate decreases as the number of packets transmitted for distance estimation increases, while it increases as the speed of the mobile nodes increases.

The rest of the paper is organized as follows. We first present the related works in Section 2. In Section 3 we describe the proposed new algorithm and system. Section 4 illustrates the performance evaluation of the proposed scheme. Our conclusions and future work are presented in Section 5.

2 The Related Works

2.1 Localization Method with Cricket

The researchers distinguish two different indoor location architectures. The active mobile architecture has an active transmitter on each mobile device, which periodically broadcasts a message on a wireless channel. The receivers deployed in the infrastructure like the ceilings and walls listen to such broadcasts and estimate the distance to the mobile device on each broadcast they hear. This architecture has a limited scalability in the ubiquitous environment. In contrast, the passive mobile architecture exchanges the locations of the transmitter and receiver. Here, the beacons deployed at known positions in the infrastructure periodically transmit their location or identity on a wireless channel, and the passive receivers on mobile devices listen to each beacon. Each mobile device estimates its distance to every beacon it hears and uses the set of distances to estimate its position [6,7]. There exist merit and demerit in the two methods above. Generally, mobile nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage. Therefore, Cricket employed the passive mobile architecture.

Cricket decided to use a combination of RF and ultrasound hardware to enable a listener to determine the distance to the beacons, from which the closest beacon can be more unambiguously inferred. Figure 1 shows how a cricket achieves this by

measuring the one-way propagation time of the ultrasonic signals emitted by a beacon, taking advantage of the fact that the speed of sound in air (about 1.13 ft/ms at room temperature) is much smaller than the speed of light (RF) in air. On each transmission, a beacon concurrently sends information about the space over RF, together with an ultrasonic pulse. When a listener hears the RF signal, it uses the first few bits as training information and then turns on its ultrasonic receiver. It then listens to the ultrasonic pulse, which will usually arrive a short time later. The listener uses the time difference between the receipt of the first bit of RF information and the ultrasonic signal to determine the distance to the beacon. Of course, the value of the estimated distance is not as important as the decision on which the closest beacon is. The use of time-of-flight of signals for measuring the distance is not a new concept.

Fig. 1. Measuring the location of a Cricket

2.2 Interference Problems

While Cricket has an attractive property that its decentralized beacon network is easy to configure and manage, it comes in the absence of explicit coordination. There is no explicit scheduling or coordination between the transmissions of different beacons that may be in close proximity, and the listeners do not transmit any information to avoid compromising privacy. This lack of coordination can cause RF transmissions from different beacons to collide, and may cause a listener to wrongly correlate the RF data of one beacon with the ultrasonic signal of another, yielding false results. Furthermore, ultrasonic reception suffers from severe multi-path effects caused by reflections from the walls and other objects, and these are orders of magnitude longer in time than RF multi-path because of the relatively long propagation time for sound waves in air. In fact, this is one of the reasons why it is hard to modulate data on the ultrasonic signal, which makes it a pure pulse. Thus, the listener's task is to gather various RF and ultra-sound (US) samples, deduce and correlate the {RF,US} pairs that were sent concurrently by different beacons, and choose the space identifier sent from the pair with the smallest distance [7].

To better understand the effects of interference and multi-path (due to reflected signals) on distance estimation, we characterize different RF and ultrasonic signals that a listener can hear in Figure 2. Consider the RF and ultrasonic signals sent by a beacon, A, and an interfering beacon, I. The listener potentially hears the followings. We only need to consider the cases when a US pulse arrives while some RF signal is being received. The reception of the first ultrasonic signal US-A, US-RA, US-I, or US-RI while RF-A is being received will cause the listener to calculate the distance to A using the time interval between the detection of RF-A and the particular ultrasonic signal. This is because the listener, after receiving the RF signal from a beacon, waits for the first occurrence of an ultrasonic pulse to determine the distance. All subsequent ultrasonic receptions during the reception of the RF message are ignored. Of course, if the direct signal US-A is the first one to be received, the listener correctly estimates the distance to A. However, wrong correlation of any other ultrasonic signal with RF-A could be problematic. RF-A is the RF signal from A, US-A is the direct ultrasonic signal from A, US-RA is the reflected ultrasonic signal from A, RF-I is the RF signal from I, US-I is the direct ultrasonic signal from I, and US-RI is the reflected ultrasonic signal from I, respectively.

Fig. 2. The effect of interference problem

2.3 The Existing Solution for Interference Problem

Priyantha et al. [8] developed and compared three simple algorithms determining the closest beacon and overcoming the interference problem discussed above. These algorithms are useful with fixed or slowly moving nodes.

- **Majority Algorithm**

This is the simplest algorithm, which pays no attention to estimating the distance but simply picks the beacon of the highest frequency in the received data set. This algorithm does not use ultrasonic signals for determining the closest beacon, and as we find from our experiments, its performance is not good. We consider this algorithm primarily for the comparison with other algorithms.

- **MinMean Algorithm**

Here, the listener calculates the mean distance from each unique beacon for the set of data points. Then, it selects the beacon with the minimum mean as the closest one. The advantage of this algorithm is that it can be computed with small information as a new sample updates the mean in a straightforward way.

The problem with this algorithm is, however, that it is not immune to the multi-path effects that cause the distance estimates to display modal behavior; where computing a statistical metric like mean (or median) is not reflective of any actual beacon position.

- **MinMode Algorithm**

Since the distance estimates often show a significant modal behavior due to reflections, this approach of highest-likelihood estimate computes the per-beacon statistical modes over the past n samples (or time window). For each beacon, the listener then picks the distance corresponding to the mode of the distribution, and uses the beacon that has the minimum distance value among the modes.

3 The Proposed System

The aforementioned interference avoidance algorithms show good performance for only slowly moving node. Especially, referring to the result above, the MinMode algorithm performs the best. However, since the nodes have relatively high mobility in real-life, a different log is chosen for the mobile node to correctly distinguish the real data from the noise provided by a same beacon, disregarding any presence of interference.

The log value increases proportionally to the speed of the mobile node; the faster the mobile nodes move, the greater the log value is. In this paper we consider the speed variance of the mobile node and propose a technique for correctly measuring the distance of the mobile node by correcting the interference errors.

3.1 Interference Avoidance Algorithm (IAA) Using Speed Prediction

Figure 3 shows a mobile node moving from $A(X_A, Y_A)$ to $B(X_B, Y_B)$ during a time interval $\Delta T(T_B - T_A)$. The beacons are placed apart with a constant distance M . If D_A and D_B are the distance measured at time T_A and T_B , respectively, the speed prediction ΔV_{real} can be derived with the following equation.

$$\Delta V_{real} = \frac{B - A}{\Delta T} \quad (1)$$

The mobile node is considered to be out of range if ΔT does not satisfy the following equation.

$$\Delta T \leq \frac{M}{V_{real}} \text{ (if } \Delta T \times V_{real} \geq M, \text{ then out of range)} \quad (2)$$

The speed of the mobile node moving from A to B can be predicted using the following equation.

$$\Delta V_{pred} = \alpha \Delta V_{last} + (1 - \alpha) \Delta V_{history} \quad (0 \leq \alpha \leq 1) \quad (3)$$

The predictive value D_{pred} of D_B can be derived by applying the reversed trilateration to Eq. (3). Eventually, any value exceeding D_{pred} is regarded as an error caused by interference and thus excluded from the calculation to obtain correct D_B value.

Fig. 3. The relationship between the velocity and distance measurement

3.2 Hardware Architecture

Figure 4 shows the Pharos system developed for real-time tracking of localization in indoor environments. The Pharos is compatible with MIT's Cricket. The Pharos contains a TI MSP430 processor with 8 kilobytes of flash memory for program and 512 bytes of SRAM for data. It uses a 2.4GHz RF wireless transceiver and three LEDs for output indication. A low power 40 KHz ultrasonic transceiver is used for distance measurement.

Fig. 4. The Pharos real-time tracking platform and hardware block diagram

4 Performance Evaluation

The experiment aims at determining the system performance when the listener is mobile. For a mobile listener, being able to obtain accurate location information in short time is important. The listener crosses the boundary at two speeds each time ($v_l = 1, 3$). Each time the listener crosses a boundary, a transition event and a timestamp are logged. Once crossing the boundary, the listener remains standstill for a short period of time to determine how long it takes to stabilize to a correct value, and then the experiment is repeated for the next boundary. When analyzing the data, the logged

transition events are used to determine the node's actual location with respect to the location reported by the listener. Note that in this experiment, the listener is always located relatively close to the boundaries.

Fig. 5. The error rates for a mobile Pharos listener

Figure 5 shows the location error rate at the listener for the four algorithms compared. The error rate is calculated over the number of packets during which the listener moves around a location with a velocity (vt). Referring to the result above the proposed IAA performs the best among the four inference algorithms. Figure 5(a) shows that the IAA reduces the error rate to below 5% when the number of packets is larger than 60. Note that the error rate of the interference avoidance algorithms increases if the moving speed of the node increases. It is also evident that large number of packets transmitted to estimate the location provide better results than with small number of packets, which is expected since a larger transmission counts provides the algorithm with more information to work on.

5 Conclusion and Future Work

We have studied how to overcome the problems in the existing methods measuring the distance in indoor ubiquitous environment. Through actual experiment, we found that real-time tracking is difficult because of interference between the sensor nodes. In this paper we have presented a new IAA (Interference Avoidance Algorithm) for reducing the error in the location identification due to interference within the infrastructure based sensor network by considering the velocity of the moving node. The proposed IAA calculates the distance using the velocity predicted based on the previously measured velocity. The calculated distance corrects the error induced by interference. We also proposed a formula for velocity prediction and implemented a real platform. The experiment results show that the proposed IAA can reduce the error to below 5%, and it is always better than the existing interference avoidance algorithms. As the speed of the moving object grows, the results show that the error rate slightly increases as expected.

The proposed Pharos is intended for use indoors or in urban areas where outdoor systems like the Global Positioning System (GPS) do not work well. It can provide distance ranging and positioning of the precision of between 1cm and 3cm. Our future work directions include extending the prototype and using it for further applications. We also plan to develop a more efficient inference algorithm. We hope that the findings in this paper will be helpful for design and implementation of real-time tracking system in ubiquitous computing environment.

References

- [1] P. Bahl and V. Padmanabhan, "RADAR: An In-Building RF-Based User Location and Tracking System," in Proc. of the IEEE INFOCOM'00, Vol.2, pp. 755-784, March 2000.
- [2] J. Hightower, G. Boriello and R. Want, "SpotON: An indoor 3D Location Sensing Technology Based on RF Signal Strength," University of Washington CSE Report 2000-02-02, Feb. 2000.
- [3] J. Liu, P. Cheung, L. Guibas, and F. Zhao, "A Dual-Space Approach to Tracking and Sensor Management in Wireless Sensor Networks," in Proceedings of ACM WSNA'02, pp. 131-139, Sept. 2002.
- [4] J. Cadman, "Deploying Commercial Location-Aware Systems," in Proceedings of 2003 Workshop on Location-Aware Computing, pp. 4-6, Jan. 2003.
- [5] D. Ganesan, B. Krishnamachari, A. Woo, D. Culler, D. Estrin and S. Wicker, "Complex Behavior at Scale: An Experimental Study of Low-Power Wireless Sensor Networks," Technical Report UCLA/CSD-TR 02-0013, Jan. 2002
- [6] A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, and J. Anderson, "Wireless Sensor Networks for Habitat Monitoring," in Proc. of ACM WSNA'02, pp. 88-97, Sept. 2002.
- [7] N. Priyantha, and H. Balakrishnan, "The Cricket Indoor Location System: Experience and Status.," in Proc. of the 2003 Workshop on Location-Aware Computing, pp. 7-9, Jan. 2003.
- [8] N. Priyantha, A. Chakraborty, and H. Balakrishnan, "The Cricket Location-Support System," in Proc. of 6th Annual ACM International Conference on Mobile Computing and Networking (MOBICOM), pp. 32-43, Aug. 2000.