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THE RESEARCH ON INDOOR LOCATION SYSTEM BASED ON CRICKET

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Abstract:

In this paper, a novel decentralized architecture based on Cricket is presented. It can reduce the interference and consumption of beacons' energy efficiently. In addition, a simplified and easy method is used to obtain the distance between listeners and beacons. Then a method of computing coordinates in 3D space is given and the experiment result is provided.

Keywords:

Time-difference-of-arrival; Indoor location; Radio frequency; Ultrasound

1. Introduction

Cricket is an excellent indoor location system and it resolves many critical problems such as user privacy, decentralized administration, network heterogeneity, cost and room-sized granularity successfully [1, 2, 3, 4]. But the consumption of beacons' energy is not considered in these papers. In addition, along with the increasing of location space and Cricket nodes, the interference rate will raise greatly. In order to facilitate communication with much less energy and interference, a rational mechanism will be established in this paper. The accuracy of Cricket depends on other two important issues: one is the method to obtain the distance between listeners and beacons, and another is the algorithm of computing the listeners` coordinates. And these will be discussed in detail in this paper.

Signals of Cricket consist of radio frequency (RF) and ultrasound signals (US). But RF differs from US in essence, since RF carries messages such as ID, temperature and designated coordinates. US do not carry any information but a pulse. In the communication process, the distance between beacon and listener can be obtained without interference by the formula $s=(t_{US}-t_{RF})\dfrac{v_{RF}v_{US}}{v_{RF}-v_{US}}$ [2], in which t_{US} and t_{RF} are the interval time from the beacon to the listener with the velocity of v_{US} and v_{RF}. The time-difference-of-arrival (TDOA) [3] is equal to $(t_{US}-t_{RF})$. Since the velocity of RF is much larger than the velocity of US and $\lim\limits_{t_{RF}\to\infty}\dfrac{v_{RF}v_{US}}{v_{RF}-v_{US}}=\lim\limits_{t_{RF}\to\infty}\dfrac{v_{US}}{1-v_{US}/v_{RF}}=v_{US}$, we can consider the parameter $t_{RF}\approx 0$, the TDOA is equal to t_{US} approximately. When a listener receives {RF, US} that comes from the same beacon, the distance will be obtained and be used to compute coordinates in 3D space.

2. System architecture

According to the state of nodes, Cricket nodes can be divided into two categories: beacons and listeners [1, 2, 5]. Beacons are fixed on the indoor ceilings with their own definite coordinates. The coordinate of any listener is still unknown before being computed whether it is moving or static.

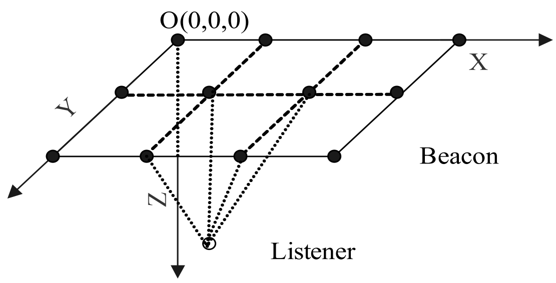

Figure 1. Layout of Cricket

For Cricket, the layout of beacons on ceilings is the most important factor. The optimal distance between any two beacons is 4 feet. That is to say every four beacons can form a square whose margin length is 4 feet. To obtain the coordinates of listeners, one of octant spaces is chosen as the workspace of the Cricket that expands from one corner of the ceiling as the origin [1, 4]. Obviously, any computed

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coordinate $p(x, y, z)$ must fall in this space, where $x \geq 0$, $y \geq 0$ and $z \geq 0$. The distribution of beacons is shown in Figure 1.

In this layout, the height from the listener to ceiling should be larger than 4 feet (e.g., 6 feet in [1, 6]). In this paper, the height is about 6 feet. The layout depends on the size of room and coverage of US, which determines the plane of the listeners. And the coverage is correlative to the transmitter of US because the transmitter sends US only at 45^{o} around its axis [1]. In figure 2, the reason is expressed in detail.

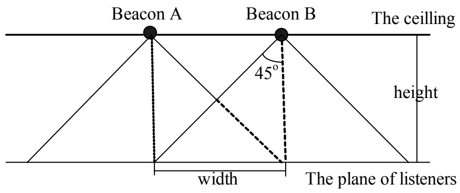

Figure 2. Coverage of US

Usually, the height from the plane to ceilings is larger than 4 feet at least. But the height should not be too large; otherwise the overlapping coverage of US will generate much more interference.

3. Communication mechanism

3.1. Collision occurring

The interference of RF has no relevance to their positions. Namely, if any beacon sends the message by RF, all listeners will hear it.

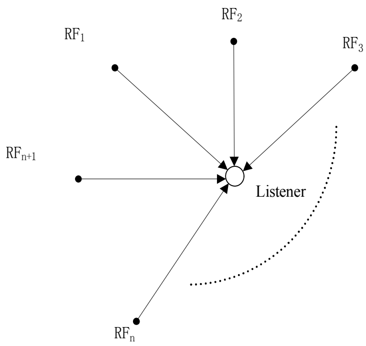

Figure 3. Global interference of RF

In Figure 3, when more than two RF signals arrive at one listener at the same time, the collision occurs. This collision impacts the whole system and generates the global interference.

The "collision of US" includes the true collision and unidentifiable collision, that is, when a listener receives RF from beacon A and US from beacon B, the listener will consider the RF and US as a pair in error. However, the interference of US only impacts the local space of system. If there are more than two US that their coverage cannot overlap each other, the listener will work normally. Usually, serious interference of US is caused by the working beacon with its neighbors. As shown in Figure 4:

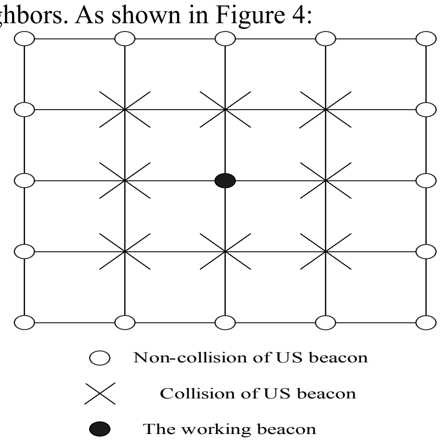

Figure 4. Local interference of US

3.2. Collision avoiding

If only {RF, US} goes to the listeners in a certain period of time, interference will be avoided possibly. To avoid collision with RF, it is a good method that other beacons send messages after random delay, and allow only one of them to work and another one won't begin until this beacon has sent {RF, US}. In the paper, a novel measure is taken to activate some beacons in the coverage of listeners' US. Namely, when one listener is working, it must send {RF, US} to notice the beacons in coverage by its US. The {RF, US} is called request. RF of listener is used to express that it is a listener to beacon so as to activate the beacons in its coverage. The new measure will save energy largely. Lastly, a table must be created according to Figure 4. In this table, all beacon's neighbors are recorded and called collision-table. When a listener receives RF, the table can tell the listeners that US comes from which beacon in sequence. The working processes of beacons and listeners are the follows:

- The working process of beacon
  - (1). Detecting RF. If there is a request from listeners, the process will come to state (2). Or it will be in state (1).
  - (2). Using random delay to send RF and US. If the RF is detected in collision-table, extra delay will

go on; otherwise, skip this step; else go to state (3).

(3). Sending the RF and US

In the working process of beacon, there are three key parameters: random delay of RF, extra delay and time-out of US. Random delay may be generated according to local-time of beacon and it depends on the number of beacons in the whole Cricket system; the extra delay depends on the layout of beacons; In this paper, it is the longest time from beacons to listeners with the velocity of US, and it ensures US of other beacon has enough time to arrive at listener; time-out is about 1.5 times to the extra delay.

- The working process of listener
  (1). Detecting whether RF comes from beacon or not. If yes, it will come to step (2), otherwise, it is going to wait. If time-out happens, it will send a request.
  (2). Open the receiver of US, and then the timer starts to work. If US come, the process will come to step (3), otherwise skip to step (1).
  (3). Compute the distance between the beacon and the listener based on TDOA with the distance and the other information of ID and timestamp.

Run (1) to (3) repeatedly. There is a beacon to work at least in the coverage of listener's US, and the working beacon may be changed consequently and normally with saving energy to some extent.

4. Obtaining distance

4.1. Fundamental principle

The equation $s \approx t_{US} \times v_{US}$ indicates that the distance between the beacon and the listener can be computed as long as the time of US from beacon to listener is obtained. However, we found that cricket node spends an extra period of time in computing distance. So the equation can be transferred from $s \approx t_{US} \times v_{US}$ to $s \approx (t_{US} - t) \times v_{US}$ in which t can be called computing-time (the extra time to compute). The computing-time depends on the performance and the time complexity of the Cricket, and it can be avoided by using the method of pattern classification. Besides, a datasheet can be made based on the data from the sensor, but this method cannot be changed with the variation of temperature flexibility. In this paper, the distance between the beacon and the listener can be computed accurately only if we can find the relationship between the computing-time and the arrival interval of US.

4.2. Linear regression method

Let the collected data be the set S. The set S consists of different parts of $S_1, S_{2,}, ..., S_n$, and the data of S_i are in the same line and next to each other, where $i = 1,2,...,n$.

Supposing that the total arrival interval is t, and the computing-time gets every time t_i in $S_1, S_{2,}, ..., S_n$, the velocity of the US is v. The unrevised distance is L_D by Cricket, and the real distance is L_T in S. Consequently the error is ΔL_i corresponding to the every error of S_i, where $i = 1,2,...,n$.

$$L_T - \Delta L_i = v(t - t_i) \text{ , Where } vt = L_D; \quad (1)$$

Let $k_i = 1 - \frac{t_i}{t}$; Then

$$L_{T_i} = vtk_i + \Delta L_i; \quad (2)$$

Even though we can get that $\lim_{t \to +\infty} k_i = \lim_{t \to +\infty} (1 - \frac{t_i}{t}) = 1$, but k_i may not be the same and only states that all k_i varies around 1. In order to get rational k_i, in the sets $S_1, S_{2,}, ..., S_n$, let a mid-point of S_i be L'_{D_I} corresponding to the real distance L'_{T_I} and the error $\Delta L'_i$; where $L'_{D_I} \in L_D$ and $L'_{T_I} \in L_T$.

Let $k_i = \dfrac{L'_{T_{I+1}} - L'_{T_I} - (\Delta L'_{i+1} - \Delta L'_i)}{L'_{D_{i+1}} - L'_{D_i}}$.

Then

$$k_i = k_j - k_{j_o} \text{, Where } k_{j_o} = \frac{\Delta L'_{i+1} - \Delta L'_i}{L'_{D_{i+1}} - L'_{D_i}},$$

$$k_j = \frac{L'_{T_{i+1}} - L'_{T_i}}{L'_{D_{i+1}} - L'_{D_i}} \text{ And } i = j; \quad (3)$$

The equation above can be transferred to as follows:

$$L_{T_j} = vtk_j - k_{j_o} + \Delta L'_j \quad (4)$$

Let $M_j = -k_{j_o} + \Delta L'_j$, then equation (4) is changed to:

$$L_{T_j} = vtk_j + M_j \quad (5)$$

Let $\bar{k}_j = \frac{1}{n-1}\sum_{j=1}^{j=n-1} k_j$; Get M_j according to $\bar{k}_j$ in (5).

Get $\bar{M}_j = \frac{1}{n}\sum_{j=1}^{j=n} M_j$; and then bring $\bar{k}_j$ and $\bar{M}_j$ into (5) to replace k_j and M_j

$$L_{T_j} = vt\bar{k}_j + \bar{M}_j \tag{6}$$

The formula $L_{T_j} = vt\bar{k}_j + \bar{M}_j$ is final result, where the velocity of the US $v = (331.4 + 0.61c)/10000$ in which c denotes the centigrade currently; the velocity of US at 0°C is 331.4m/s; the unit of v is cm/s; and the unit of t is ms. In fact, the formula works well according to temperature.

5. Computing coordinate

Since the Cricket performance is less than PDA or computer, the distances between beacons and listeners are always transmitted to computer. Let transmitted distances be the set $\{d_1, d_2, ..., d_n\}$ from the different beacons with revision of timestamp. The first three or four shortest distances are very useful from the set $\{d_1, d_2, ..., d_n\}$ according to the communication mechanism. Supposing that the first three shortest distance d_1, d_2 and d_3 can be got, corresponding to the coordinates of beacons are $p_1(x_1, y_1, z_1)$, $p_2(x_2, y_2, z_2)$ and $p_3(x_3, y_3, z_3)$. The unknown coordinate of the listener is $p(x, y, z)$.

Then

$$\begin{cases} \sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2} = d_1 \\ \sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2} = d_2 \\ \sqrt{(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2} = d_3 \end{cases} \tag{7}$$

According to the formulas (7), $p(x, y, z)$ is obtained easily [7]. But under some circumstance, the result is not unique when the $p_1(x_1, y_1, z_1)$, $p_2(x_2, y_2, z_2)$ and $p_3(x_3, y_3, z_3)$ are in the same line.

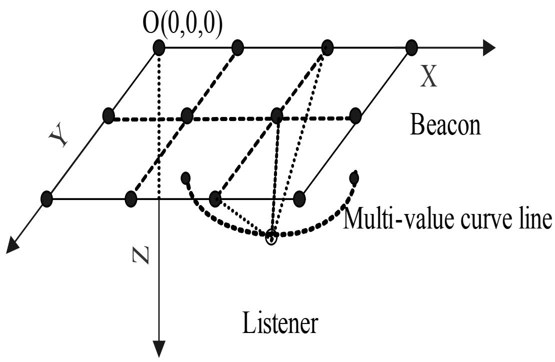

Figure 5. Non-unique value phenomenons

Once the Non-unique value occurs as shown in Figure 5, and then one of the distances must be abandoned, or compute coordinates again.

6. Experiment

6.1. Temperature impact on distance

At 23°C ~ 35°C, 1 listener and 1 beacon are considered, their distance varies from 1cm to 600cm.

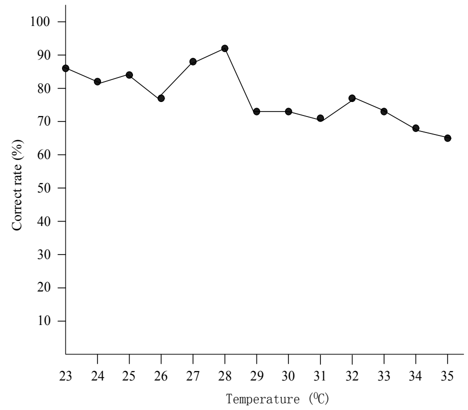

Figure 6. distance correct rate and temperature

Figure 6 shows the relationship between temperature and correct rate. It is obvious that the correct rate is maximal when the temperature is equal to 28°C, in which the linear regression is made.

6.2. Listener number and speed impact on coordinate

At 28°C, 12 beacons are used to form a square with

8×12 feet according to Figure 1.

6.2.1. Impact of listener number

Put one listener below each of six squares as Figure 1. In each experiment, turn on one more listeners until all the six listeners are in working.

As the increasing of the working listeners, the number of beacons that receive request also increases in the beginning. And the listener can get enough information from beacons to compute its coordinate to make the error rate low. However, with the increasing of working beacons, they have to wait for more delays than before; so error rate increases again slowly as shown in Figure 7.

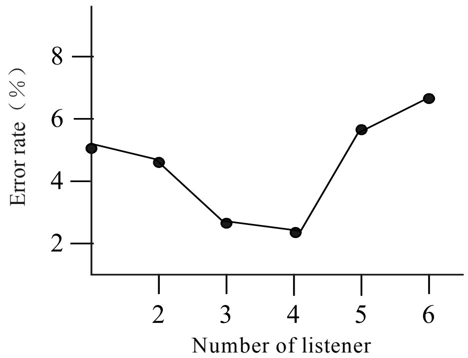

Figure 7. Impact of listener number on performance

6.2.2. Impact of listener speed

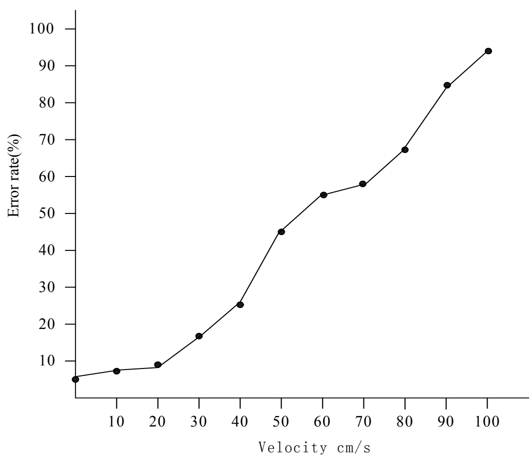

Figure 8. Impact of listener speed on performance

Figure 8 shows that the listener is easy to receive RF and US from the different beacons with high speed. Another reason depends on the random delay (in 3.2), if the listener is moving into the other squares, in which the beacon has no time to be activated by listeners. Or when it sends {RF, US}, the listener has moved into another square. Since listener cannot get enough data to compute, it always abandons all of the collected distances or has to wait for another effective data. The speed of listeners has an obviously impact on the whole Cricket system. When the listeners move at a high speed, system abnormality or collapse will occur frequently. But high speed is worthless for this system without huge space in a room.

7. Conclusions

Our communication mechanism implements the goal of saving energy of Cricket sensors; and the simplified linear regression method makes the Cricket location-support system much easier.

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