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Artificial Neural Network Based Error Reduction in Cricket Compass: Indoor Localization Technique

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Abstract:The ability to determine the orientation of a device is of fundamental importance in context-aware and location-dependent mobile computing. By analogy to a traditional compass, knowledge of orientation through the Cricket compass attached to a mobile device enhances various applications, including efficient way-finding and navigation, directional service discovery, and "augmented-reality" displays.

Keywords: Cricket Compass, Neural Network, Back Propagation Algorithm, Learning Rate, Momentum Term

1. CRICKET COMPASS

The Cricket compass reports position and orientation indoors for a handheld, mobile device, and informs an application running on the device of the position and orientation in a local coordinate system established by the fixed set of beacons[1]. The operating environment in the Cricket architecture is instrumented with active beacons, each of which broadcasts its own known position over an RF channel together with an ultrasonic pulse. One RF receiver and several passive ultrasonic position receivers are precisely placed on compass board. Software running on-board uses the differentials in distances reported by the ultrasonic receivers to infer the orientation or heading of the device. Cricket requires a small number of beacons at positions in each room to instrum location and orientation for a device without requiring any user motion

2. DESIGN OF CRICKET COMPASS

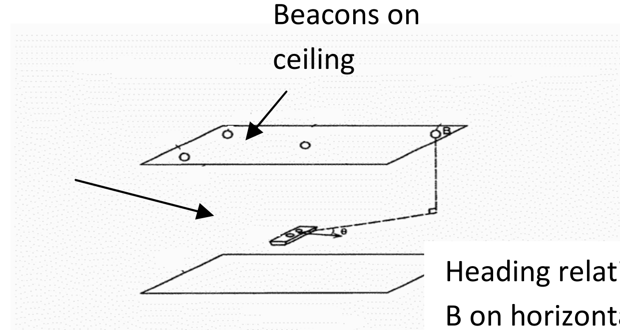

Fig: 3.1: Cricket Compass

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Figure 3.1 shows a user device with attached compass hardware in a room with beacons placed on the ceiling. When the device is held parallel to the horizontal plane, θ is the angle formed by the heading direction shown, with the point where the perpendicular from beacon B intersects the horizontal plane. We are interested in precisely estimating θ [3].

The basic idea is to use one RF receiver to receive coordinate information from the beacons, and multiple, carefully placed, ultrasonic receivers on the compass attached to the device to obtain the differential distance estimates of a beacon to each ultrasonic receiver. θ is a function of the differential distance of the linear distance of the compass from the beacon, and of the height of the beacon (ceiling) above the plane of the compass. We obtain per-beacon linear distance estimates by differencing the arrival times of coupled RF and ultrasonic signals sent from each beacon. To obtain the height of the beacon from the compass, we estimate the position coordinates of the compass from the position coordinates disseminated by multiple nearby beacons.

3. THEORY OF OPERATION

Figure 4.1 shows a beacon B, and a compass with two ultrasonic receivers, R1 and R2, which are located at a distance L apart from each other. The angle of rotation of the compass, θ, with respect to the beacon B, is related to the difference in distances d1 and d2, where d1 and d2 are the distances of receivers R1 and R2 from B. The vertical and horizontal distances from the center of the compass to B are denoted by z and x respectively. Figure 4.1 shows the beacon B from Figure 1 projected on to the horizontal plane along which the compass is aligned. In the figure 2, x1 and x2 are the projections of distances d1 and d2 on to the horizontal plane. We assume that the compass is held parallel to the horizontal plane.

From Figure 2:

$$x_1^2 = d_1^2 - z^2 \quad (1)$$

$$x_2^2 = d_2^2 - z^2 \quad (2)$$

$x = \sqrt{d^2 - z^2}$, where $d \approx \dfrac{d_1 + d_2}{2}$ when $d_1, d_2 >> L$.

Fig. 4. 1: Angle of Orientation

From Figure 4.2:

$x_1^2 = (L/2 \cos\theta)^2 + (x - L/2 \sin\theta)^2$

$x_2^2 = (L/2 \cos\theta)^2 + (x + L/2 \sin\theta)^2$

$\Rightarrow x_2^2 - x_1^2 = 2Lx\sin\theta$

Substituting for x_1^2 and x_2^2 from Equations (1) and (2), we get:

$$\sin\theta = \frac{d_2 + d_1}{2Lx} . (d_2 - d_1) \quad (3)$$

This may be rewritten as:

$$\sin\theta = \frac{d_2 - d_1}{L\sqrt{1 - \left(\frac{z}{d}\right)^2}} \quad (4)$$

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Equation (4) implies that it suffices to estimate two quantities in order to determine the orientation of the compass with respect to a beacon: (i) (d2 - d1), the difference in distances of the two receivers from the beacon, and (ii) z/d, the ratio of the height of the beacon from the horizontal plane on which the compass is placed to the distance of the beacon from the center of the compass. In practice, however, no measurements are perfect. Our goal is to estimate each of these quantities with high precision, so as to produce a sufficiently accurate estimate of θ.

One way of precisely estimating (d2 - d1) would be to precisely measure d1 and d2 separately, but that is easier said than done. Consider, for example, a situation where L = 5cm, and θ = 10°, with a beacon at a distance of 2 meters and a height of 1 meter from the receivers. From Equation (4), the value of (d2 - d1) in this case is only ≈ 0:6cm, which is about an order of magnitude smaller than what current technologies can achieve in terms of linear distance estimates [8]. Since our goal is to devise a compass with physically small dimensions, comparable in size to handheld PDAs, and still achieve high directional accuracy, we need an alternative method to estimate this differential distance. Our solution to this problem tracks the phase difference between the ultrasonic signals at two different receivers and processes this information. We find that this approach allows us to obtain differential distance estimates with sub- centimeter accuracy.

The second quantity, z/ d, is estimated by determining the (x, y, z) coordinates of the compass with respect to the plane formed by the beacons (the x-y plane). We do this by placing multiple beacons in a room and estimating the time it takes for the ultrasonic signal to propagate between them and the compass. However, because the speed of sound varies with ambient temperature and humidity, we must estimate this quantity as well.

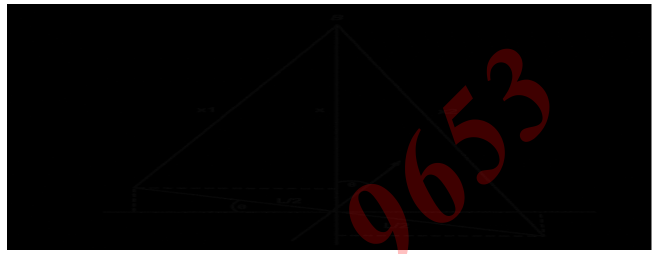

Fig. 4.2: Rotated Compass along Horizontal Plane

4. OUR CONTRIBUTION: EXPERIMENTAL SET UP

Measured Distance:

In back propagation algorithm, we are taking three different layers- input, hidden and output layer. Each layer consists of a single node. The measured distance values act as the inputs to the input layer neurons. The 19 different measured distance values in terms of meters are [-1.552,-1.544, -1.504, -1.392, -1.213, -0.985, -0.843, -0.516, -0.245, 0.021, 0.200, 0.477, 0.749, 0.931, 1.075, 1.256, 1.389, 1.459 and 1.485].

Actual distance values are the target outputs for the corresponding measured distances. The target values are [-1.600, -1.576, -1.504, -1.386, -1.226, -1.028, -.0.800, -0.547, -0.278, 0, 0.278, 0.547, 0.800, 1.028, 1.226, 1.386, 1.504, 1.576 and 1.600].

Weights:

The acceleration or retardation of the input signals is modeled by the weights. An effective synapse which transmits a stronger signal will have a correspondingly larger weight while a weak synapse will have smaller weights. Thus, weights here are

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multiplicative factors of the inputs to account for the strength of the synapse. These are any random values between 0 and 1. Here we have taken the weight to be 0.2. [4]

Learning Rate:

Learning rate coefficient determines the size of the weight adjustments made at each iteration and hence influences the rate of convergence [4]. Poor choice of the coefficient can result in a failure of convergence. We should keep the coefficient constant through all the iterations for best results. If the learning rate coefficient is too large, the search path will oscillate and converges more slowly than a direct descent. If the coefficient is too small, the descent will progress in small steps significantly increasing the time to converge. It ranges between 0 and 1.

Momentum Term:

Adding some inertial or momentum to the gradient expression improves the rate of convergence. This can be accomplished by adding a fraction of the previous weight change to the current weight change [4]. The addition of such a term helps to smooth out the descent path by preventing extreme changes in the gradients due to local anomalies. Here, α is the momentum coefficient. The value of α should be positive but less than 1. Typical values lie in the range of 0.5-0.9.

5.1 Differential distance error reduction:

For differential distance error reduction we have taken into consideration the existing actual and measured differential distance[9]. The array A consists of the measured d2-d1 values and is taken as input to the input layer. The array B consists of the actual d2-d1 values and is assumed to the required output. The momentum factor is taken as m=0.4 and the learning coefficient is taken as n=0.3. The change in the weight between the input and the hidden layer is taken to be dv=0. The change in weight between the hidden layer and the output layer is taken to be dw=0. To perform the back propagation random weights are initialized as v=[0.1] and w=[0.2]. Then the back propagation algorithm is applied on the inputs to get the required output thereby reducing the differential distance error. Here we have performed 10 iterations and observed that the differential distance is gradually reduced by the application of the back propagation algorithm.

The values used as the input and the required output are:

A=[-1.552, -1.544, -1.504, -1.392, -1.213, -0.985, -0.843, -0.516, -0.245, -0.021, 0.200, 0.477, 0.749, 0.931, 1.075, 1.256, 1.389, 1.459, 1.485]

B=[-1.6, -1.576, -1.504, -1.386, -1.226, -1.028, -0.800, -0.547, -0.278, 0,0.278, 0.574, 0.800, 1.028, 1.226, 1.386, 1.504, 1.576, 1.6]

X-axis represents the number of iterations performed and Y-axis represents the differential distance error in meters. After 10 iterations we observed that the distance error reduced from 3.12 m to 0.0029 meters which is a significant improvement by the application of Back Propagation algorithm.

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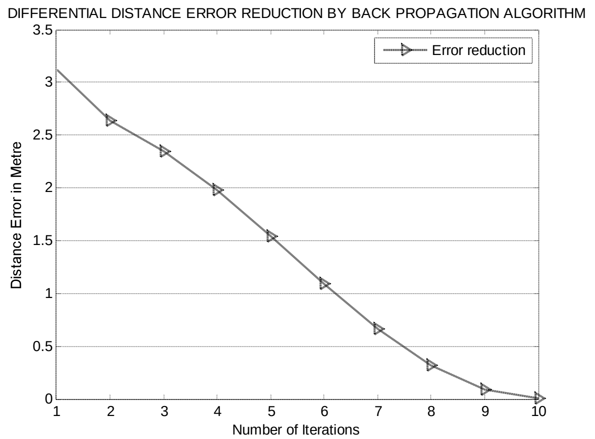

Fig. 5.1: Differential Distance Error reduction by Back Propagation Algorithm

5.2 Angular error reduction:

For the reduction in the angular error we have taken into consideration the calculated angle range in [9]. Then we have applied the back propagation algorithm to reduce the angular error and results show that angular error have been minimized in each set of experiments. For better analysis we have performed different sets of experiments.

The angle range is the same as discussed in [9] i.e -90 to 90 degree.

We have taken the derived Theta estimates as the reference and used the back propagation algorithm to obtain the new Theta and plot the difference. The observations show that the algorithm has reduced the error which in turn will help in accurate position estimation in Wireless Sensor Network.

The estimated theta value used in the algorithm are:

Estimated Theta: [-76.21, -74.021, -70.350,-60.485, -49.319,-38.021,-31.786, -18.894, -8.821, 0.57,7.184,17.359, 27.929, 35.573, 42.202, 51.756, 60.317, 65.759, 68.196]

The differential distance 'd' is generated randomly and the value of reduced theta after applying the back propagation algorithm are:

DelTheta: [-14.9905, -14.7666, -14.0751, -12.8779, -11.1345, -8.8218, -6.0651, -3.190, -0.8979, 0, 0.8979, 3.4747, 6.0651, 8.8218, 11.1345, 12.8779, 14.0751, 14.7666, 14.9905]

Fig. 5.2 Reduced Estimated Angle as compared to Cricket Compass

6 CONCLUSION

Thus, we can conclude that by applying the Artificial Neural Network the differential distance error as well as the angular error can be reduced remarkably and we can conclude that this device can further be enhanced to be used in outdoor localization thereby reducing the error in the position estimation in the presence of noisy environment.

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