INDOOR WIRELESS LOCALISATION NETWORK USING A DYNAMIC POSITION TRACKING MODEL

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Abstract: There has been great interest in using position location systems for indoor environments. Indoor environments present many challenges to using wireless localisation systems, due to the interference caused by metal beams and walls present. Current position localisation systems use wireless channel propagation characteristics, such as receive signal strength to localise a user's position. We present an inexpensive and robust wireless localisation network that can track the location of users in an indoor environment. Our localisation network uses a dynamic position tracking model to improve the real-time tracking of mobile nodes. The localisation network uses the Zigbee/802.15.4 wireless communications protocol. Reference nodes are placed at known positions in a building. The reference nodes are used by mobile nodes, carried by users to localise their position. Further work involves improving the dynamic position tracking model by incorporating the use of motion sensors to aid tracking and to investigate how large numbers of active users can be supported.

1 INTRODUCTION

The widespread usage of position localisation systems such as Global Positioning (GPS) has lead to a variety of location based services applications such as street map guide or asset tracking. Recently there has been great interest in position locating for indoor navigation applications. Indoor environments tend to cause interference for wireless devices due to the presence of obstacles such as metal beams or walls. This causes outdoor localisation technologies such as GPS to not function indoors. A variety of radio frequency localisation techniques have been developed such as Received Signal Strength or Time of Arrival. An example is the cellular phone network towers used by the GSM communications network (Otsason et al., 2005) for indoor positioning. The received signal strength indicator allows most RF wireless transceivers to be used as localisers.

Our paper presents a wireless localisation network that tracks the position of users in an indoor environment. Our localisation network was designed to track the position of users, in particular visually impaired people, within a building. A user carries a mobile node that tracks their current position. The mobile node allows the user to approximate view their location. The localisation network consists of reference nodes placed at predetermined coordinates in a building level. The reference nodes are used to determine the coordinates of the user within the region covered by the localisation network.

Using received signal strength or other wireless channel propagation properties may not be suitable for tracking users in real-time due to the lengthy time taken to accurately measure channel propagation parameters. This paper also looks at using a motion odometry model for tracking people with in a building. Odometry information includes directional-heading and speed which can be used to predict the next position of user.

The ZigBee/802.15.4 wireless communications protocol is used by the localisation network. Zigbee is a low data rate wireless communications protocol that can operate on devices with limited computing or power resources and cater for large networks of active devices (ZigBee Alliance, 2006).

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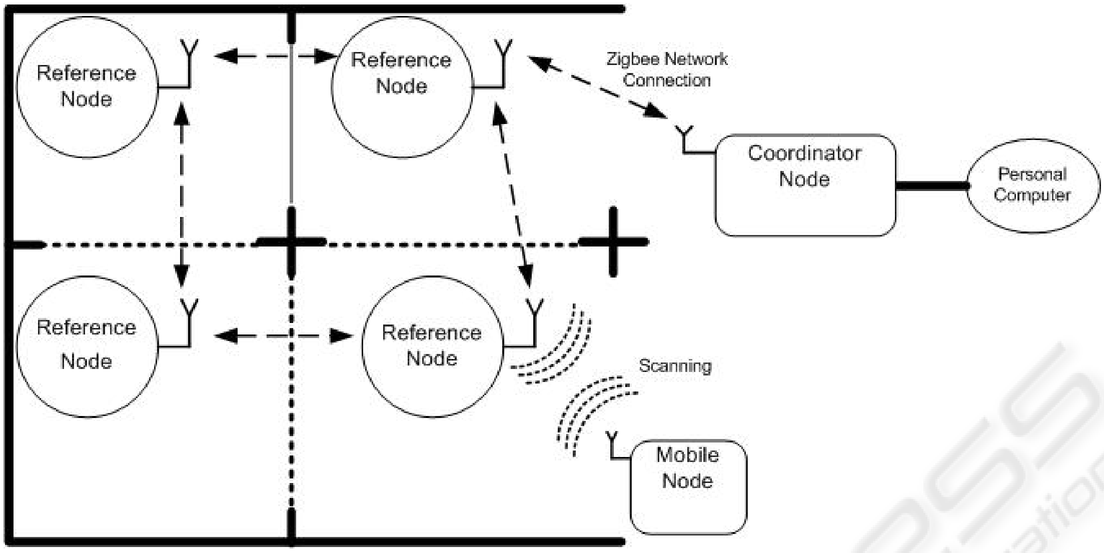

Figure 1: Localisation Network Overview.

The contributions of this paper can be summarised as:

- Deployment of a sensor network for indoor localisation and tracking.
- Analysis of a wireless channel propagation model for indoor environments.
- Development and testing of a dynamic position tracking model.

This paper is organised into 5 sections. Section 2 presents a review of related work. Section 3 discuss the localisation network implementation. Section 4 presents the findings of testing conducted on the localisation network. Conclusions and futher areas of investigation are discussed in Section 5.

2 RELATED WORK

Different types of wireless technologies, such as GPS have been investigated for outdoor and indoor location systems. Unfortunately, GPS is not suitable for indoor use and this has led to research into the use of other wireless technologies including UWB (Schwarz et al., 2005), ultrasonic and GSM (Otsason et al., 2005) platforms. Regulations are not clear for the use of UWB, and ultrasonic location detection still requires RF transceivers. GSM uses existing infrastructure, however accurate position resolution indoors is difficult.

Lamarca et al (Hightower et al., 2006, LaMarca et al., 2005) describe the Placelab geophysical location system which users can determine their position in an urban environment. Placelab uses the Received Signal Strength Indicators (RSSI) from Wireless LAN hotspots and GSM broadcast towers to determine a user's position. The Placelab software uses a database of known wireless LAN hotspots and GSM broadcast towers. The Placelab software can be used with a PDA or laptop with wireless LAN or GSM connectivity. Localisation accuracy is stated as being less then GPS, with 20-25m using wireless LAN and 100 to 150m for GSM broadcast towers. A similar technique of using RSSI is employed by the reference node network.

Klingbeil and Wark (Klingbeil and Wark, 2008) developed a wireless sensor network for monitoring human motion and position in an indoor environment. Mobile nodes with inertial and heading sensors were worn by a person inside a building. A Monte Carlo based localisation algorithm that used a person’s heading, indoor map information and static node positions was developed and tested.

3 LOCALISATION NETWORK

The localisation network as seen in Figure 1 consists of three different nodes, coordinator, reference and mobile. Mobile nodes are carried by users to determine their current location. The reference nodes are used to determine a mobile node’s position via trilateration. The coordinator node displays the current position of the mobile nodes in use, on a building floor-plan.

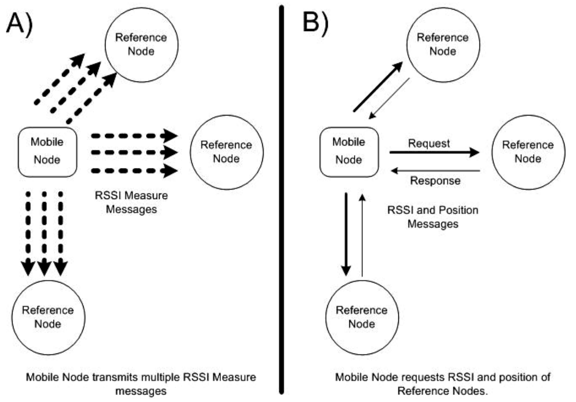

Figure 2: Mobile Node Position Localising Process.

3.1 Coordinator Node

The coordinator node tracks the location coordinates of each mobile node. The coordinator node communicates with the mobile node via the Zigbee mesh routing connection using the reference nodes. The coordinator is accessed by the Z-Location graphical user interface (Texas Instruments). It displays the current locations of users on a building floor-plan. The coordinator node was implemented using a CC2430 Zigbee/802.15.4 module on a SmartRF development board, (Texas Instruments). The coordinator node is connected via a serial connection to a Personal Computer and is also powered by standard mains electricity.

3.2 Reference Node

Each reference node communicates to the coordinator node via a Zigbee network connection. The position of each reference node has to be initialised by the coordinator node. The reference nodes are used by the mobile nodes for triangulation.

The reference node was implemented using the CC2430 Zigbee/802.15.4 wireless transceiver module from Texas Instruments (Texas Instruments). Each CC2430 module has a unique 64-bit network address which is used as the reference node's identifier. The reference nodes are powered by rechargeable batteries.

3.3 Mobile Node

The function of the mobile node is to determine a user's position. The mobile node detects reference nodes in near proximity, to determine a current user's position. The mobile node uses the RSSI values of nearby reference nodes to calculate its position. More details are given in Section 3.4. The mobile node was implemented using the CC2431 Zigbee/802.15.4 Location Engine Module from Texas Instruments (Texas Instruments).

3.4 Position Localisation

As mentioned earlier, the mobile node uses the coordinates of nearby reference nodes and RSSI values to localise the user's current position. Figure 2 shows the process in which the mobile nodes interact with the reference nodes. The mobile node periodically transmits "RSSI Measure" messages to all reference nodes within range (Figure 2a). The reference nodes use the RSSI Measure messages to estimate the received signal strength. Typically 5 messages are needed to calculate an averaged RSSI value. As seen in Figure 2b, once a cycle of RSSI Measure messages has been transmitted, the mobile node will then broadcast an "RSSI and Position request" message to all reference nodes in range. Each reference node will then respond with its calculated RSSI value and coordinates.

The RSSI value from the reference node is used to calculate the distance between the mobile and reference nodes using the channel propagation equation as shown in equation (1).

$$d = 10^{(RSSI - A)/n} \quad (1)$$

Where:

- *RSSI* = Received Signal Strength Indicator of Reference Node (dBm),
- *d* = Separation Distance between Reference and Mobile Nodes ,
- *n* = the pathloss coefficient of the channel,
- *A* = Absolute Power received at a distance of 1m from the transmitter (dBm) ,

Once the separation distances between all detected reference nodes and the mobile node has been calculated, a trilateration algorithm (Texas Instruments) is used to compute the position of the mobile node. The trilateration algorithm uses each reference node's coordinates and separation distance. The mobile node's CC2431 Zigbee transceiver has an onboard location engine module that computes the position when given the RSSI and coordinates of detected reference nodes (Texas Instruments). The CC2431 Zigbee transceiver has special registers that allow the propagation channel model to be configured (Texas Instruments).

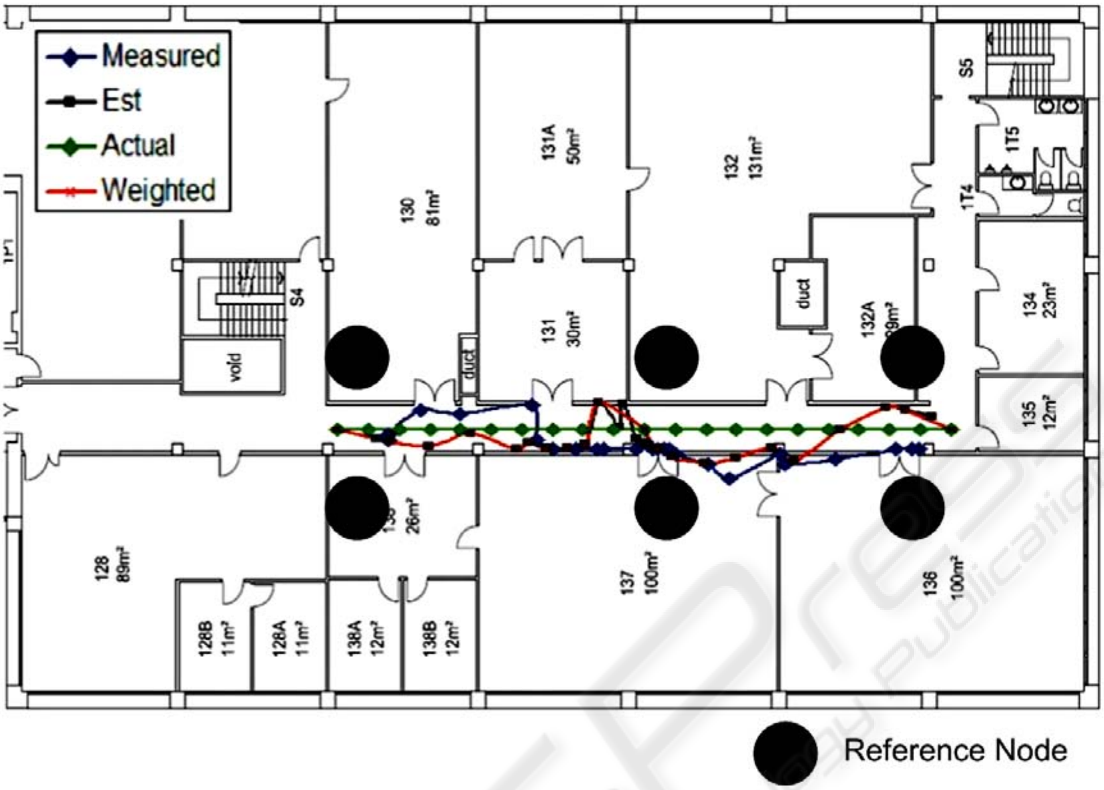

Figure 3: Test Deployment of Localisation Network.

3.5 Dynamic Position Tracking

One of the key aims of the localisation network is to track a person in real-time. One of the drawbacks of using RSSI as a localisation mechanism is that the receive signal strength must be averaged over a period of time. Averaged RSSI values are needed to provide suitable accuracy. However lengthy averaging periods can lead to localisation inaccuracies. For example a moving mobile node will distort the average received signal strength values calculated by reference nodes.

One way to improve the accuracy of real-time tracking is to use other odometry information such as a person's directional-heading and speed to predict the next position of user. Odometry motion models have been used for localisation tracking by Klingbeil et al, (Klingbeil and Wark, 2008) and E. Lau et al (Lau and Chung, 2007). We implemented the Dynamic Position Tracking model used in (Lau and Chung, 2007), to localise a person's position. The dynamic position tracking model used the speed and current position to predict the person's next position. The dynamic position tracking model was implemented using the following equations of motion:

$$\hat{R}_{est(i)} = \hat{R}_{pred(i)} + a(\hat{R}_{prev(i)} - \hat{R}_{pred(i)}) \quad (2)$$

$$\hat{V}_{est(i)} = \hat{V}_{pred(i)} + \frac{b}{T}(\hat{R}_{prev(i)} - \hat{R}_{pred(i)}) \quad (3)$$

$$\hat{R}_{pred(i+1)} = \hat{R}_{est(i)} + \hat{V}_{est(i)} T_s \quad (4)$$

$$\hat{V}_{pred(i)} = \hat{V}_{est(i)} \quad (5)$$

Where:

$\hat{R}_{est(i)}$ = The *ith* estimated Range,
$\hat{R}_{pred(i)}$ = The *ith* predicted Range,
$\hat{R}_{prev(i)}$ = The *ith* measured Range,
$\hat{V}_{est(i)}$ = The *ith* estimated Velocity,
$\hat{V}_{pred(i)}$ = The *ith* predicted Velocity,
a, b = Gain Constants,
T_s = Time Update Period

Equation (5) is an iterative process, which uses Equation (3) to adjust the position calculated by the mobile node until the position error has been sufficiently reduced. The speed value was initially set to the average human walking speed of 1.3m/s (Murray et al., 1964) for Equation (4). The next section will examine the accuracy of the dynamic position tracking model. A prototype of the dynamic position tracking model was implemented on the Personal Computer connected to the Coordinator node. The current prototype of the dynamic position tracking model does not yet perform tracking in real-time. However we intend to incorporate the model into the coordinator node's graphical user interface as part of our ongoing future work.

4 EVALUATION

An initial trial of the localisation network used six reference nodes, a mobile and coordinator nodes. The localisation network was deployed in a building floor corridor and covered a space of $72m^2$. The aim of the trial was to evaluate the channel propagation and the dynamic position tracking accuracy. The test deployment can be seen in Figure 3.

4.1 Channel Propagation Estimation

We estimated the channel propagation parameters for Equation (1): pathloss coefficient (*n*) and absolute transmitted power (*A*), by conducing range tests. This involved moving the mobile node in a straight direction-heading from a reference node. At specific separation distances, the RSSI was measured and recorded. Maximum range testing of the mobile node showed that it had a range of at least 20m indoors.

Using the measured RSSI values and calculated positions, we were able to estimate suitable values for n and A. We found that that $n=3.375$ and $A=40$ from the linear relationship between the RSSI and separation distance. Our testing also showed that the channel propagation parameters are dependent on the surrounding indoor environment and the positions of the reference nodes. Walls and other metal fittings will cause multipath fading to occur. Incorrect calibration of *n* and *A* values will cause large errors in estimating position.

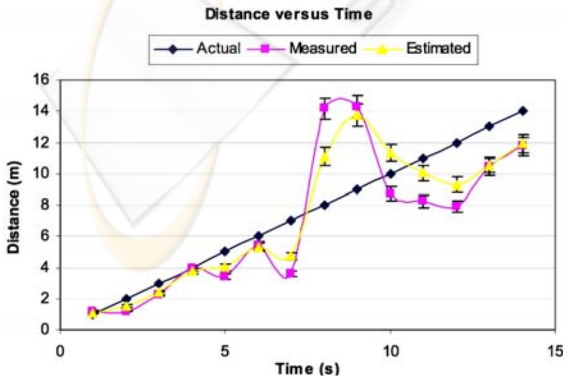

Figure 4: Distance vs Time with a Constant Velocity.

4.2 Dynamic Position Accuracy

We conducted a series of experiments to test the accuracy of the dynamic position tracking model used by the localisation network. The first experiment involved moving the mobile node in a straight line in the test deployment area at a constant walking speed. Figure 4 shows the actual, measured and estimated travelled distances of the mobile over time. The distance is the displacement of the mobile node from a starting point. The measure distances are calculated directly from the mobile node's coordinates (using RSSI) and the estimated distance is computed by using the dynamic position tracking model. The maximum error in position is 75% using the mobile node's coordinates. Using the dynamic tracking model, the maximum position error was 55%. Using the dynamic position tracking model produced a smaller error in the position estimation the mobile node.

The second experiment was similar to the first experiment except that a delay of 15s was introduced midway during the test. This was done to test how the localisation network responds to changes in movement. Figures 4 & 5 show the actual, measured and estimated distances with constant velocity and changing velocity.

Two estimated distances were calculated by varying the gain constants: *a* and *b*, in dynamic position tracking equations' (1) and (3). As seen in Figure 5, the dynamic tracking model is better at tracking the position of the mobile node than by only relying on the mobile node's coordinates. Also

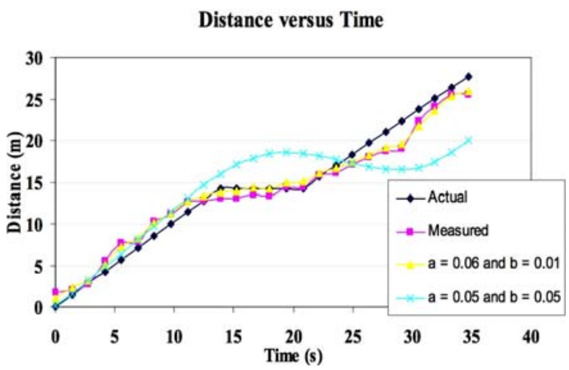

Figure 5: Distance vs Time with a Changing Velocity.

is the large position inaccuracy (50%), if the gain constants a and b are not calibrated correctly. Using *a=0/06* and *b=0.01* was found to produce the best results.

5 CONCLUSIONS AND FURTHER WORK

In this paper we presented a localisation network system that tracked users in an indoor environment. The localisation network consisted of reference nodes placed at known positions throughout a building. A user carried mobile node that tracked their current position.

A dynamic position tracking model for real-time tracking of users was also developed. We found that using received signal strength or other wireless channel propagation properties was not suitable for tracking users in real-time due to the lengthy time required to sample the channel propagation parameters.

An initial trial of the localisation network was conducted using six reference nodes, a mobile and coordinator nodes. We deployed the localisation network along a building floor corridor and covered a space of $72m^2$. We measured the channel propagation parameters and the dynamic position tracking model accuracy. We found that by using the dynamic position tracking model, the maximum error in position location was reduced from 75% to 50%.

Further work involves developing a multi-hypothesis testing model to accurately predict and track user position. We will also look at incorporating human motion sensors such as accelerometers to accurately determine walking speed. We will also be looking at a larger scale deployment over multiple building levels and investigating how the network's capacity to facilitate large numbers of active users.

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REFERENCES

Hightower, J., LaMarca, A. & Smith, I. E. (2006) Practical Lessons from Place Lab. *Pervasive Computing, IEEE,* 5**,** 32-39.

Klingbeil, L. & Wark, T. (2008) A Wireless Sensor Network for Real-Time Indoor Localisation and Motion Monitoring. *Proceedings of the 7th international conference on Information processing in sensor networks.* IEEE Computer Society.

LaMarca, A., Chawathe, Y., Consolvo, S., Hightower, J., Smith, I., Scott, J., Sohn, T., Howard, J., Hughes, J., Potter, F., Tabert, J., Powledge, P., Borriello, G. & Schilit, B. (2005) Place Lab: device positioning using radio beacons in the wild. *Pervasive Computing. Third International Conference, PERVASIVE 2005. Proceedings (Lecture Notes in Computer Science Vol. 3468). Springer-Verlag. 2005***,** 116-33.

Lau, E.-E.-L. & Chung, W.-Y. (2007) Enhanced RSSI-Based Real-Time User Location Tracking System for Indoor and Outdoor Environments. *Convergence Information Technology, 2007. International Conference on.*

Murray, M. P., Drought, A. B. & Kory, R. C. (1964) Walking Patterns of Normal Men. *J Bone Joint Surg Am*, 46**,** 335-360.

Otsason, V., Varshavsky, A., LaMarca, A. & de Lara, E. (2005) Accurate GSM indoor localization. *UbiComp 2005: Ubiquitous Computing 7th International Conference, UbiComp 2005. Proceedings (Lecture Notes in Computer Science Vol. 3660) . Springer-Verlag. 2005***,** 141-58.

Schwarz, V., Huber, A. & Tuchler, M. (2005) Accuracy of a commercial UWB 3D location/tracking system and its impact on LT application scenarios.

Texas Instruments *CC2430 System-on-Chip Solution for 2.4 GHz IEEE 802.15.4 / ZigBee™*, accessed 2009, http://focus.ti.com/docs/prod/folders/print/cc2430.html.

Texas Instruments *CC2431 ZigBee Development Kit,* accessed 2009, http://focus.ti.com/docs/toolsw/folders/print/cc2431zdk.html.

Texas Instruments *CC2431System-on-Chip (SoC) Solution for ZigBee/IEEE 802.15.4 Wireless Sensor Network*, http://focus.ti.com/docs/prod/folders/print/cc2431.html.

ZigBee Alliance (2006) *ZigBee Specification*, http://www.zigbee.org/en/spec_download/.