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Wireless Localisation Network for Patient Tracking

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Abstract

We present an inexpensive and robust wireless localisation network that can track the location of patients in an indoor environment and monitor their physical status i.e. walking, running, etc. Static nodes are placed at predetermined positions in a building. The static nodes are used to determine the presence of the user in an area of a building. The user carries a mobile node on them. The localisation network was implemented using the small sized Fleck Nano wireless sensor. This platform also measured a user's inertial movement using a three-axis accelerometer sensor. We also compared our localisation network to a commercially available indoor wireless localisation and tracking system. Further work involves developing a multi-hypothesis testing model tracking users, prediction human motion events and investigating the wireless network requirements of supporting large numbers of active users.

1. INTRODUCTION

There are significant challenges in determining a person's current position and motion state within an indoor environment. Position and motion activity data of people has a variety of uses. For example, motion accelerometer data can be used to monitor how patients are physically coping with tasks such as walking or standing. Position tracking information can be for ensuring the safety of aged-care patients.

Our paper presents a wireless sensor network that uses inertial sensors to determine and track a person's position and motion activity state in an indoor environment. The localisation network consists of static beacons placed at known positions throughout a building. The static beacons are only used to determine the presence of the user within a particular region of a building. The user's position is determined by their proximity to the nearest static nodes within range.

The localisation network infrastructure uses the FleckTM-3 wireless sensor platforms. Our sensor network architecture is based on the Localisation Network by Klingbeil et al [1]. One of the disadvantages of that Localisation Network was the use of direction heading information, which required multiple power consuming sensors such as a magnetometer

and gyroscope sensors to detect a user's heading with respect to magnetic north. Another disadvantage was the use of a relatively large mobile node, which was found to be too cumbersome to attach to people. Other disadvantages were the power and running lifetime of the mobile node.

Our localisation network uses the Fleck Nano wireless sensor platform for mobile inertial movement sensing. The Fleck Nano platform was designed to be a small, inexpensive wireless sensor with minimal computation resources that can be used to complement other sensor platforms. For biomedical applications, the small size and inertial sensor accuracy allows a variety of human movement to be monitored. The Fleck Nano platform is ideal for our purposes because it has an onboard integrated microcontroller and wireless transceiver, an accelerometer for measuring the inertial movement of a patient and also has a small form factor.

The contributions of this paper can be summarised as:

- Implementation of a localisation network for localisation and inertial sensor monitoring.
- Experimental use of small, unobtrusive, wireless sensors for position and physical movement monitoring.
- Comparison of two realtime localisation tracking mechanisms: network packet delivery ratio and received signal strength.

This paper is organized into 6 sections. Section 2 presents a review of related work. Section 3 discusses the location localisation network implementation. Section 4 describes the localisation detection model. Section 5 presents the findings of testing conducted. Conclusions and further areas of investigation are discussed in Section 6.

2. RELATED WORK

Current indoor wireless localisation research has focused on the UltraWide Band (UWB) [5], ultrasonic and GSM [3] platforms. Regulations are not clear for the use of UWB, and ultrasonic location detection still requires the use of RF transceivers. GSM uses existing infrastructure, however accurate position resolution indoors is difficult.

Fig. 1: Localisation Network Topology

Lamarca et al [8,9] describe the Placelab geophysical location system that allows users to determine their position in an urban environment. Placelab uses the Received Signal Strength Indicators (RSSI) of Wifi hotspots and GSM broadcast towers to determine a user's position. The Placelab software uses a database of known Wifi hotspots and GSM broadcast towers. The Placelab software can be used with a PDA or laptop with Wifi or GSM connectivity. Localisation accuracy is stated as being less than GPS, with 20-25m using Wifi hotspots and 100 to 150m for GSM broadcast towers.

A classical case of using wireless beacons for navigation is presented in [6]. The active badge project achieved a 5-10m accuracy using infrared. The main drawback of this platform was that it required line of sight between beacons. An extension of the Active Badge Project was the ORL location system by Ward et al [7], which developed a prototype network of ultrasonic beacons to perform realtime tracking of tagged mobile devices in an office environment. Other ultrasonic location systems such as the Cricket Mote [4] and the system by McCarthy et al [2], describes how a network of ultrasonic beacons using time of flight analysis can determine distance position locations.

Klingbeil et al [1] 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 OVERVIEW

The localisation network, seen in Fig. 1 consists of static nodes placed at known locations within a building. The

Fig. 2: Static Node Mounted on Wall

Fleck Nano compared to 20C Coin

Mobile Node ID	Static Node ID	Sequence Number	Accelerometer Data
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Beacon Message Packet Structure

Fig. 3: Fleck Nano and Packet. Format

mobile nodes are carried by users to localise their current position and measures their motion activity i.e. running, falling, etc. The static nodes are used to determine a mobile node's position. The base node displays the current position of the mobile nodes. This section describes an overview of the network topology and also describes the implementation of the localisation network.

A. Network Topology

The static nodes are all connected to the base node via a wireless multi-hop network. The wireless mesh network employs the Link Quality Multi-Hop Network Routing communication protocol [10]. The advantage of using a wireless multi-hop network is that static nodes only have to be within range of at least one other static node. This allows static and base nodes to be easily deployed in an indoor environment. Each static node will relay a received message to either the base station or the nearest static node neighbour.

Fig. 4: Fleck Nano measured Accelerometer Sensor Data of stair climbing motion (uncalibrated).

B. Static Node

The static nodes were implemented using the FleckTM-3 wireless sensor platform [11]. This platform has been used for a variety of wireless sensor applications particularly for environmental monitoring [11]. The FleckTM-3 uses the Atmega128 micro-controller along with the Nordic NRF905 radio transceiver operating in the ISM band. The FleckTM-3 also incorporates a real-time clock chip to reduce micro-controller overheads for timing operations.

An operating system called Fleck Operating System (FOS) was used to provide a priority-based, non-preemptive (cooperative) threading environment. This has the advantage of a simple concurrent programming model and does not require semaphores. All application software on the static and base nodes ran on top of FOS. The static node can be seen in Fig. 2.

C. Mobile Node

The Fleck Nano platform is used to implement the mobile node. It consists of a Nordic 915Mhz RF transceiver, onboard microcontroller and 3-axis accelerometer for motion detection. Fig. 3 shows the Fleck Nano as a mobile node. It uses a coin cell battery as a power source. The dimensions are 25mm x 20mm. The Fleck Nano's small physical profile and onboard accelerometer is advantageous for our application because it is unobtrusive. The range of the Fleck Nano's RF transceiver's range was limited to approximately 7m by setting the lowest transmission power level and using a small PCB strip antenna. This allows the mobile node to be detected to within a region of 7m, hence improving the localisation resolution.

Fig. 4 shows acceleration measurements from stair climbing which was captured by the Fleck Nano's onboard accelerometer. In this case the Fleck Nano was mounted on a

Fig. 5: Fleck Nano Packet Delivery Ratio (%) vs Antenna Angular Direction

shoe. Fig. 4 shows the X,Y & Z axes. The peaks are greatest in the vertical up and down Z direction.

The directional sensitivity of the Fleck Nano was measured in terms of antenna angular direction and packet delivery ratio. Delivery ratio was used as a measurement because the Fleck Nano's Nordic RF transceiver does not detect the RSSI of intercepted transmissions. Fig. 5 shows the angular direction sensitivity of the Fleck Nano's antenna, which was tested by rotating the Fleck Nano away from a static node. The static nodes have omni-directional antennas. The Fleck Nano has a high delivery ratio in its forward direction (0 degrees) but poor a delivery ratio in its reverse direction (180 degrees).

D. Base Node

The base node is also implemented using the Fleck. The base node is connected via a serial connection to a Personal Computer (PC). The PC implements the localisation detection model to determine the region that the mobile node is located in. The localisation detection model displays a building floor-plan with the region the mobile node is currently in, highlighted.

4. LOCALISATION DETECTION MODEL OPERATION

The localisation network allows the tracking of mobile nodes within the network of static nodes. The mobile nodes periodically transmit a beacon message, every 50ms. The static nodes that receive the beacon message, will forward it to the base node via the wireless network. The localisation detection model uses the number of received beacon messages from each static node to triangulate a region that the mobile node is located in. As noted previously, the mobile nodes have a short range of 7m and the static nodes are placed such that mobile node will be detected by at most 3 static nodes at any one time.

The format of the beacon message is shown in Fig. 3. It consists of the mobile node's ID, sequence number, recipient static node ID and accelerometer data. The static nodes that

receive the beacon message will insert its node ID into the <recipient static node ID> field and then forward the message to the base node via the wireless network.

The mobile node periodically transmits a beacon message, every 50ms but only increments the sequence number every second. The localisation detection model uses the number of received beacon messages per static node that has the same sequence number to determine which static nodes are in proximity to the mobile node. Using the static nodes as geometric end-points, Delaunay triangles are used to create a grid of possible regions the mobile node could be in. If three static nodes are found to be in proximity, the corresponding Delaunay triangle is used to determine the region mobile node is located in. The centroid of the Delaunay triangle is used to approximate the position of the mobile node.

Delaunay Triangulation is a geometric method for determining triangular vertices of a set of given points. Delaunay Triangulation has been used for wireless access point localisation [12]. Given a set of known static node locations, we can form a set of Delaunay triangles d_i as shown in Fig. 6, we choose the triangle $\hat{d}$ which is most

Fig. 6: Illustration of the set of Delaunay triangles formed from a group of static nodes. The numbers next to each node indicate the packet delivery ratios measured at a particular instant in time from a mobile node. These are used to choose the most likely triangle which bounds the location of the mobile node.

likely to provide a boundary for the location of the mobile node as:

$$\hat{d} = \arg \max_i \sum_j d_i^j$$

where d_i^j is the packet delivery ratio at the node forming the j^{th} vertex for triangle d_i .

Fig. 7: Localisation Detection Model Map Triangulation and Readings

Fig. 10: Distance between Mobile and Static Nodes (m) vs Delivery Ratio(%)

5. EVALUATION

Testing of the localisation network involved placing static nodes in the level of a building and having a user walk through while carrying a mobile node. In order to compare our localisation network with existing solutions, we also conducted experiments with the commercially available Texas Instruments CC2431 Zigbee Location Engine [13]. The CC2431 transceiver use RSSI measurements as a means of localisation. This section compares and discusses both localisation systems.

E. Localisation Network

The localisation network was evaluated using a single mobile node. Fig. 7 shows the mobile node's predicted position on the building floor plan and number of sequence numbers, received by the static nodes used by the localisation detection model. As shown in Fig. 7, three static nodes detected the beacon message from the mobile node. The Delaunay triangular region encompassed the area the mobile node was located. In each case, the closest static node to the mobile node was found to receive a higher proportion of the transmitted beacon messages or packet delivery ratio. As shown in Fig. 10 there is a linear relation between separation distance (Mobile and Static nodes) and packet delivery ratio.

F. CC2431 Zigbee Location Engine Network

The CC2431 Zigbee location network consisted of reference nodes used to triangulate a blind node's position [13]. The blind node functions in a similar fashion to the localisation network's mobile node. The reference nodes were placed in the same positions as the static nodes. The blind node transceiver measured the RSSI of the detected reference node transceivers.

Fig. 9: CC2431 Location Engine RSSI Measurements (dBm)

Fig. 8: Distance between CC 2431 Location Engine Blind and Reference Nodes (m) vs RSSI (dBm)

The blind node periodically transmits beacon messages to all reference nodes within range. The reference nodes use the beacon messages to compute the RSSI and typically need at least 5 beacon messages to compute an accurate averaged RSSI value. Once a cycle of 5 beacon messages has been transmitted, the blind node will then transmit an "RSSI request" message, to which all reference nodes in range, will respond with its calculated RSSI value.

Testing of the blind node showed that it had a range of at least 20m and this was found to be sufficient to detect all the static nodes present on the building level. Fig. 9 shows the RSSI values approximated by the blind node from each reference node. As shown in Fig. 8 there is also a linear relation between separation distance (Blind and Reference nodes) and RSSI. However, the relation was found to have a larger standard deviation at a distance of 2 to 4m when compared to the relation for distance vs packet delivery ratio.

G. Analysis

The main difference between the FleckTM-3 based localisation network and the CC2431 based Location Engine Network is

that the former uses packet delivery ratio to determine position approximation while the later uses RSSI. The advantage of using delivery ratio to determine position is that there is a clear distinction of closest static node in proximity (greater than 50% delivery ratio). This is not the case with using RSSI, as seen in Fig. 9 there was no clear distinction between the closest reference nodes over 4m away.

Although RSSI is a good indication of link quality, it requires multiple broadcasts by the same transmitter. This is a disadvantage for multiple blind nodes in range of the same reference nodes. It was observed that multiple blind nodes can distort and fluctuate the averaged RSSI value. The use of delivery ratio has the advantage of allowing filtering using the sequence number and address of the transmitting node.

6. CONCLUSION AND FURTHER WORK

In this paper we presented a localisation network system that tracks users in an indoor environment. The localisation network consisted of static nodes placed at known positions throughout a building. Users carry a mobile node to allow their current position and physical status to be monitored. A patient's physical status was determined by measuring their inertial movement using a three axis accelerometer. The static nodes were implemented using the FleckTM-3 platform. Our localisation network uses the Fleck Nano platform for mobile inertial sensing. The Fleck Nano platform is ideal for our purposes because it has an onboard integrated microcontroller and wireless transceiver, an accelerometer for inertial sensing and also has a small form factor.

The range estimation of two localisation systems were compared: our developed localisation network that used packet delivery ratio and the CC2431 Location Engine that used RSSI. Our preliminary results showed that the use of packet delivery ratio rates had an advantage over RSSI in that it was easier to distinguish which static nodes were closer to the mobile node. The packet delivery ratio also allows filtering on the packet sequence number and transmitter address, which is not available on the CC2431 transceivers.

Further work involves developing a multi-hypothesis testing model to accurately predict and track user position. Hidden Markov models will also be looked at to accurately predict human motion. 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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