Implementation of Radio Tomographic Imaging based Localisation using a 6LoWPAN Wireless Sensor Network

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Keywords: Wireless Sensor Networks, Radio Tomographic Imaging, Indoor Localisation.

Abstract: Mobile localisation has numerous uses for logistics, health, sport and social networking applications. Current wireless localisation systems typically require the use of tracking devices to be worn or implanted. The use of tracking devices can hinder the types applications that can be used. Wireless localisation use wireless channel propagation characteristics, such as RF receive signal strength to localise a user's position, which requires the use of complex radio hardware. We developed a wireless tracking system using radio tomographic imaging to track people without wearing a mobile tracking device. We evaluated our wireless localisation network with users in an indoor environment. Our localisation network used the 6LoWPAN wireless communications protocol.

1 INTRODUCTION

Tracking technology has been used for many applications, including animal migration tracking and the advancement of security systems. However, traditional tracking methods involve visual image processing or inaccurate heat sensor technology. Both of these approaches have strong disadvantages such as the dependency on light conditions for image processing and the fickle nature of sensitivity calibration for infrared sensors. Radio Tomographic Imaging (RTI) uses inexpensive radios to track objects in a closed area without the need for radio tags. It exploits the ability of radio waves to travel through objects such as trees and walls.

Current localisation techniques depend on using sensing infrastructure already present in the environment such as visual markers, wireless LAN hotspots, cellular networks or GPS satellite coverage. RF localisation methods such as Received Signal Strength Indicator (RSSI) or Time of Arrival also experience inaccuracies and reliability issues when operating indoors.

Current wireless localisation systems typically require the use of tracking devices to be worn or implanted. The use of tracking devices can hinder the types applications that can be used. Current position localisation use wireless channel propagation characteristics, such as RF receive signal strength to localise a user's position, which requires the use of complex radio hardware.

We developed a wireless tracking system that used RSSI radio tomography to track people and objects without using a mobile tracking device. Our wireless localisation system used a low powered wireless sensor network infrastructure which consisted of reference nodes placed at predetermined coordinates. The network of reference nodes continuously measure RSSI and link quality parameters. These parameters are then used to form a tomographic image, showing the locations of significant RF signal attenuation.

RF signals that pass through the human body or solid inanimate objects are subjected to attenuation RF signals and hence will affect the RSSI and link quality between pairs of reference nodes. Locations of RF signal attenuation are then used to determine the position of a user or object. We developed a Radio Tomographic Localisation System (RTLS) that localises the positions of people and objects. We evaluated the RTLM in a typical and realistic indoor environment.

This article is organised into the following sections. Section 3 presents an overview of the wireless localisation network infrastructure used. Section 4 describes the operation of the RTLM. An evaluation of the RTLM is discussed in section 5. Conclusions and further work are presented in section 6.

Smallbon V., Potie T., D'Souza M., Postula A. and Ros M..
Implementation of Radio Tomographic Imaging based Localisation using a 6LoWPAN Wireless Sensor Network.
DOI: 10.5220/0005513400270032
In *Proceedings of the 12th International Conference on Wireless Information Networks and Systems* (WINSYS-2015), pages 27-32
ISBN: 978-989-758-119-9

2 LITERATURE REVIEW

Different types of wireless technologies have been investigated for indoor location systems. One such approach is the use of dead-reckoning, such as that by Klingbeil et al (Klingbeil and Wark, 2008) who developed an indoor localisation system using dead-reckoning with a hip-worn mobile node that detected a user's footsteps and heading and used a particle filtering process to estimate the position of the user. Widyawan et al (Widyawan et al., 2008) also designed a dead-reckoning system that used a foot-mounted inertial sensor for heading and footstep detection combined with a backtrack particle filtering process. Although dead-reckoning can achieve a sufficient accuracy, the disadvantage of such systems is the requirement of users to wear a mobile device.

Wilson et al (Wilson and Patwari, 2010) developed an RTI system for indoor tracking, using a wireless sensor network. Zhao et al (Zhao et al., 2013) used a kernel distance based estimation method for estimating link quality for RTI. This was found to be suitable for detecting moving people. We used a similar approach. Qiu et al (Qiu et al., 2010) and Hu et al (Hu et al., 2014) investigated the use of machine learning techniques for RTI, in order to reduce inaccuracies caused by noisy RSSI measurements.

Bonior et al (Bonior et al., 2015) developed an RTI system implemented using software radios, in order to validate the accuracy of using RSSI measurements for RTI. Wang et al (Wang et al., 2015) used, a Variational Bayesian Gaussian mixture model and K-means clustering to improve object tracking in an RTI system. Amendolare et al (Amendolare et al., 2014) developed an RTI system that used both static and mobile reference nodes for indoor environments in first responder scenarios Martin et al (Martin, 2015; Martin et al., 2014) presented a beam forming based RTI model in order to improve position accuracy and to reduce the image frame rate latency.

3 WIRELESS REFERENCE NODE NETWORK

The wireless reference node network was based on typical wireless sensor network infrastructure. Wireless sensor networks are used for a sensing and actuation applications. Wireless sensor network infrastructure are used for low powered indoor and outdoor based applications and are designed to be portable and easy to deploy, compared to other wireless LAN network infrastructure. used to provide realtime received signal strength measurements. The network consisted of wireless reference nodes placed around the tracking zone. The base node was placed outside the tracking zone. The tinyOS 6LoWPAN based BLIP communications protocol was used by the wireless reference node network.

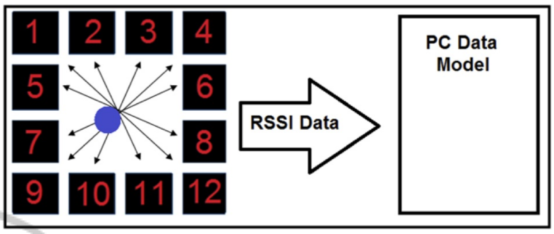

Figure 1: Overview of Wireless Reference Node Network.

The wireless reference node network as seen in Figure 1 consisted of two types of nodes: base and reference nodes. The reference nodes are placed around the boundaries of the zone in which users are tracked in. The reference nodes are used to measure the radio received signal strength from the base node. The server connected to the node node displays the current position of the person. The reference and base nodes used the Zigduino platform (Logos Electromechanical LLC, 2013) with TinyOS (TinyOS, 2013). The Zigduino uses the Atmega128RFA1 Wireless System on Chip (SoC) that has an Atmega128 microcontroller and a 2.4GHz Zigbee/802.15.4 transceiver (Atmel Corporation, 2012). The 6LoWPAN protocol was used to provide a wireless communication link between the base and reference nodes.

3.1 Reference Node

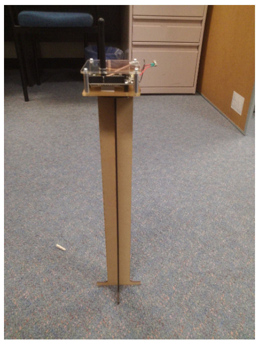

Figure 2: Reference Node.

The reference node, seen in Figure 2, communicates to the base node using a 6LoWPAN network connection. The reference nodes are by the RTLM to locate people and objects in the tracking zone. The position of each reference node is known by the base node. Each reference node has a predetermined ID which is included in each packet transmitted. The reference node is powered by a rechargeable battery. As mentioned previously, the reference node is implemented using the Zigduino platform with the Atmega128RFA1 SoC. The Atmega128RFA1 has a receiver sensitivity range of 88dB with 1dB resolution and has a minimum signal power detection threshold of -90dBm (Atmel Corporation, 2012). The transmission power can vary from 3.5dBm to -16.5dBm. The reference node used a transmission power setting of -16dBm.

3.2 Base Node

Figure 3: Base Node.

The base node, seen in Figure 3, receives and processes packets from each reference node. The base node is connected by a USB connection to a server computer. The server computer tracks the position of the person using the RTLM. The server computer used is a Raspberry Pi embedded linux platform (Raspberry Pi Foundation, 2013). A graphical user interface, written in Python was used to display the current status of the reference nodes (transmitting or receiving) and the heatmap. This is shown in Figure 4.

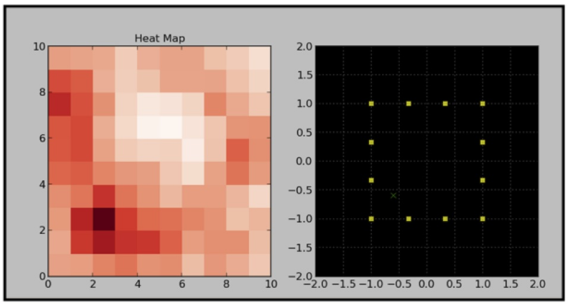

Figure 4: Graphical User Interface showing Heatmap and Node Status.

3.3 Reference Node Protocol

The Reference Node Protocol (RNP) was developed to provide maximum received signal strength resolution required by the RTLM. The RNP was used by each reference node to measure the RSSI and to synchronise the transmission of each reference node. The protocol was required to minimise radio interference and to be self regulating. RNP was implemented using 6LoWPAN with the TinyOS BLIP library. RNP used the IP protocol User Datagram Protocol (UDP) to transfer packets between the nodes.

The RNP packet can be seen in Figure 5, consists of a sender ID and the RSSI values of neighbouring reference nodes detected. RNP uses a round robin slot scheme, in which each reference node will only transmit, depending the reference sender node ID last received. The RNP used a slot time period of 300ms.

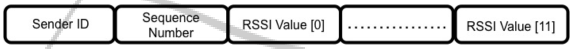

Figure 5: Reference Node Protocol Packet Format.

4 RADIO TOMOGRAPHIC LOCALISATION SYSTEM

The Radio Tomographic Localisation System (RTLS) estimates a person's position using RSSI attenuation measurements. RSSI is the measured received signal strength between a transmitter/receiver reference node link. RF signals that pass through the human body or inanimate objects are subjected to attenuation or reflection, which affects the RSSI and between a transmitting and receiving reference node link. The RTLM uses the network of reference nodes to continuously measure RSSI and link quality parameters. The RTLM forms a tomographic image of RF signal strength and determines the locations of significant RF attenuation. Locations of attenuation are then used to determine the position of a person in the tracking zone.

Figure 6 shows an overview of the RTLM. The RTLM was based on kernel distance estimation as used by Zhao et al (Zhao et al., 2013). The RTLM first estimates the attenuation between pairs of reference nodes using RSSI histogram filtering and link attenuation estimation. Once the link quality between the reference node links has been computed, a tomographic image showing the heatmap of signal attenuation can be formed. Areas of significant attenuation are then used to determine the location of objects and users. A grid averaging is then used to reduce distortions in the tomographic image, caused by fluctuations in link attenuation estimates.

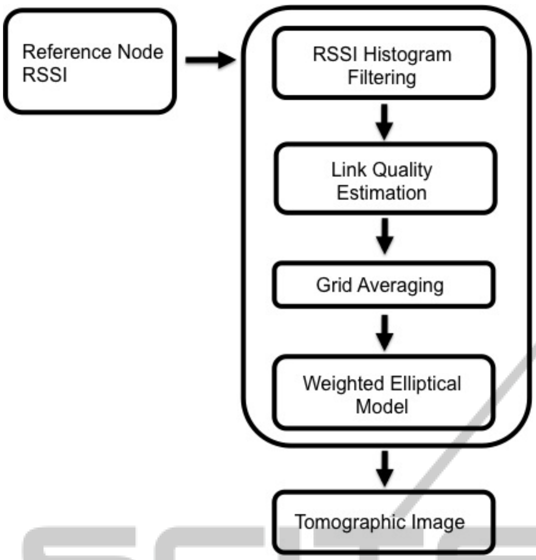

Figure 6: Radio Tomographic Localisation System Overview.

4.1 RSSI Histogram Filtering

The RSSI readings for a link between reference nodes is used to determine the level of attenuation between the reference nodes. For each link, two histograms were created to track the distribution of RSSI values. The histogram is used to measure the occurrence of RSSI values. For each link, a short and long time histogram was used. The short term histogram keeps track of the most recent RSSI values while the long term histogram tracks the long RSSI values over a longer period of time. The use of two histograms is advantageous as it allows dynamically moving objects to be detected with more certainty as discussed in (Zhao et al., 2013).

4.2 Link Attenuation Estimation

The link attenuation is used to determine if a person or object is between the nodes. For each link, the link attenuation is calculated using the difference between the long and short term histograms. The difference between the long and short term histograms is a measure of the change of attenuation that has occurred for a particular link. The kernel distance is used to calculate the difference between the long and short term histograms. The change in attenuation is then used to form a tomographic image.

4.3 Grid Averaging

Link attenuation can fluctuate significantly, which can cause distortions in the tomographic image. In order to reduce fluctuations in link attenuation, a grid averaging method was used. The tracking zone is divided into an evenly spaced grid, as shown in Figure 7. The link attenuation estimates of each link that crosses a particular grid are averaged and then assigned the same averaged value.

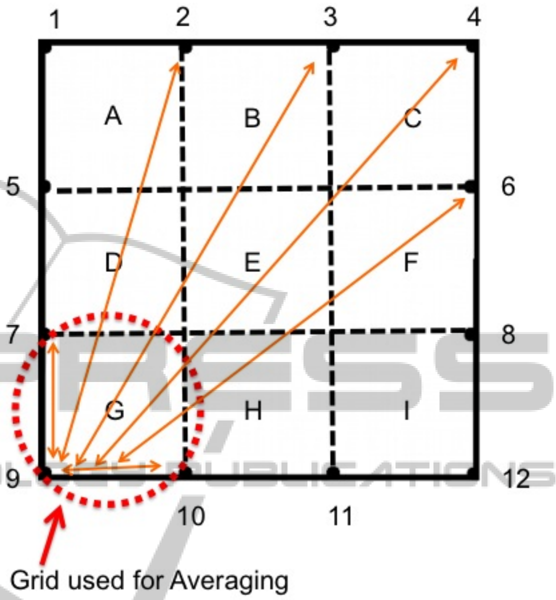

Figure 7: Grid Averaging.

4.4 Weighted Elliptical Model and Tomographic Image

A tomographic image of the tracking zone is formed using the link attenuation estimates. A weighted elliptical model using the link attenuation estimates is formed, as shown in Figure 8. Using the a wighted elliptical model, an image can be formed where each pixel is assigned a value, if it falls within the ellipse formed by the reference nodes in the link. Each pixel value corresponds to a heat map colour value.

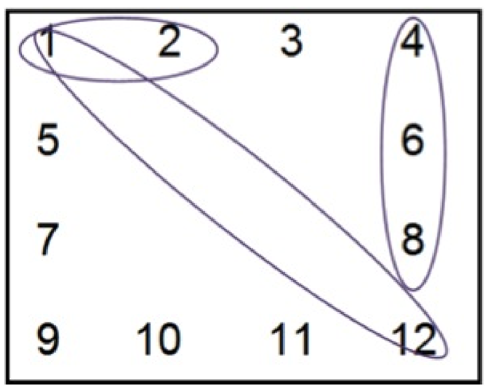

Figure 8: Example of Weighted Elliptical Model using Reference Node IDs.

5 EVALUATION

The RTLM was tested in an indoor environment shown in Figure 9. The reference node network was setup in a 5m by 5m open space. We tested the RTLM by having a person stand and walk, within the tracking zone. Figure 10 shows the person standing in the middle of the lower boundary. Figure 11 shows the person standing in the middle of the right boundary. Figure 12 shows the person in the top right corner of the tracking zone.

Figure 9: Reference node Localisation Network Deployment.

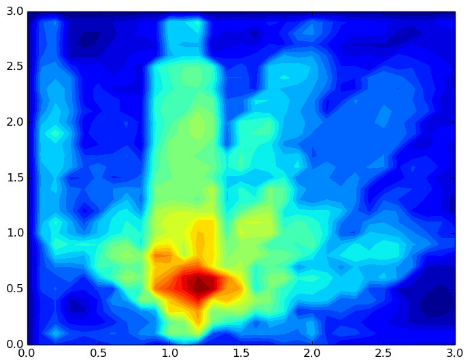

Figure 10: Person Standing in the Middle of the Lower Boundary.

6 CONCLUSIONS

We presented a wireless indoor localisation system that tracked people in an indoor environment, using radio tomographic imaging. We developed the RTLM which formed a tomographic image using RSSI link quality estimation. The RTLM used a 6LoWPAN based wireless sensor network, to measure link attenuation between a pair of reference nodes. The link attenuation was then used to form a tomographic image, showing the locations of significant RF signal attenuation.

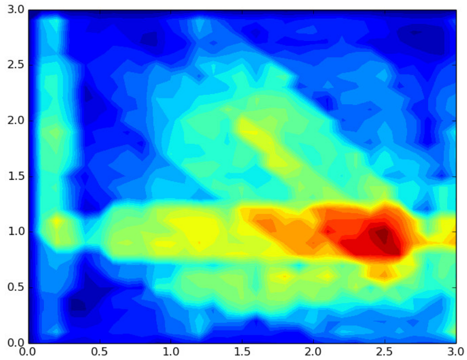

Figure 11: Person Standing in the Middle of the Right Boundary.

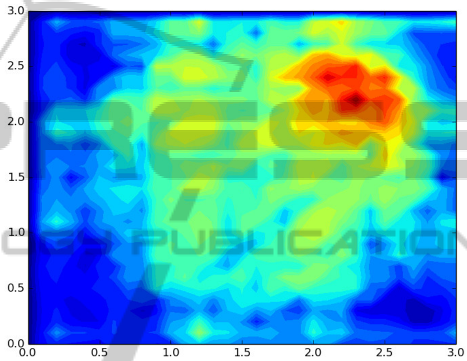

Figure 12: Obstacles in the upper left boundary.

Locations of RF signal attenuation are then used to determine the position of a user or object. We evaluated the RTLM in an realistic indoor environment. The RTLM was able to detect people and obstacles in the tracking zone. Further work involves, developing a self power calibration mechanism, allow for multiple people tracking and to track users in large indoor office environments. We are also investigating the use of a tablet interface to view the heatmap and tracking information.

ACKNOWLEDGEMENTS

The authors would like to thank the School of ITEE at The University of Queensland and the Pervasive Computing Group at CSIRO for their support in this project.

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