Filters for RSSI-based measurements in a
Device-free Passive Localisation Scenario

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Abstract—There are a number of techniques used in modern Location aware systems such as Received Signal Strength Indicator (RSSI), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Angle of Arrival (AOA). However the benefit of RSSI-based location positioning technologies, is the possibility to develop location estimation systems without the need for specialised hardware.

The human body contains more than 70% water which is causing changes in the RSSI measurements. It is known that the resonance frequency of the water is 2.4 GHz. Thus a human presence in an indoor environment attenuates the wireless signal. Device-free Passive (DfP) localisation is a technique to detect a person without the need for any physical devices i.e. tags or sensors. A DfP Localisation system uses the Received Signal Strength Indicator (RSSI) for monitoring and tracking changes in a Wireless Network infrastructure. The changes in the signal along with prior fingerprinting of a physical location allow identification of a person’s location.

This research is focused on implementing DfP Localisation built using a Wireless Sensor Network (WSN). The aim of this paper is the evaluation of various smoothing algorithms for the RSSI recorded in a Device-free Passive (DfP) Localisation scenario in order to find an algorithm that generates the best output. The best output is referred to here as results that can help us decide if a person entered the monitored environment. The DfP scenario considered in this paper is based on monitoring the changes in the wireless communications due to the presence of a human body in the environment. Thus to have a clear image of the changes caused by human presence indoors, the wireless recordings need to be smoothed. We show results using algorithms such as five-point Triangular Smoothing Algorithm, Moving Average filter, Lowess filter, Loess filter, Robless filter, Rloess filter, 1-D median filter, Savitzky-Golay filter, and Kalman filter.

Index Terms—Wireless Sensor Networks, Smoothing Algorithms, IEEE 802.15.4, Device-free Passive Localisation, Indoor RSSI.

I. INTRODUCTION

The possibility of estimating a position represents a crucial component currently. Estimating the position can be very useful for many applications such as determining the location of assets, monitoring patients in a hospital, security, tour guides, conference guides, shopping guides and information, network access based on the user’s location, and games [1], [2]. The localisation technologies proposed in the literature can be separated into indoor and outdoor localisation systems. The Global Positioning System (GPS) was first used for military applications [3]. GPS is a popular technology worldwide for outdoor location estimation [1], [4], [5], [6], [7]. The number of devices which use a GPS is increasing every year due to the current low cost of implementing GPS technology. However GPS does not work indoors, in cities with tall buildings, or between mountains due to the requirement of Line-of-Sight (LoS) for the communication with the satellites. Thus, there is a need for accurate indoor location estimation technologies [4].

Various approaches such as location fingerprinting (scene analysis), triangulation, trilateration, hyperbolic lateration, proximity, and dead reckoning [1], [3], [8], [9] were used in location sensing systems. The metrics used frequently for developing tracking systems are: Received Signal Strength Indicator (RSSI), Time of Arrival (TOA) / Time Difference of Arrival (TDOA), and Angle of Arrival (AOA) or Direction of Arrival (DOA). Possible technologies for indoor systems are: WLANs, Through Wall Imaging (TWI) using Ultra-wideband (UWB), Field strength systems, Radio-frequency Identification (RFID), and Next-generation indoor positioning systems [10]. The RSSI-based localisation techniques are considered more attractive because of their simplicity and robustness in environments affected by multipath compared to the techniques based on metrics like time or angle [11]. Indoor localisation systems based on signal strength have the advantage of using the existing WLAN infrastructure, and therefore do not have any extra deployment costs [12].

Location tracking techniques can be classified into two categories: 1) systems requiring tracked persons to participate actively; and 2) systems using passive localisation. The two classes are also known as active and passive tracking systems. By participating actively we refer to the tracked person as carrying an electronic device sending information to the system, information used to infer the user’s position. In some cases the electronic devices can also process recorded data and send the results for further processing to an application server running the localisation algorithm. In the passive localisation case the position is estimated based on the variance of a measured signal or video processing.

Many of the proposed technologies use the fingerprinting method to estimate the location of a tracked person. Fingerprinting in location estimation systems refers to a method that compares the fingerprint of some characteristic of a signal that is location dependent. This algorithm has two stages: the offline stage and the online stage [1], [9], [13], [14], [15]. The techniques that employ database comparison are fingerprinting, pattern recognition, or pattern matching [8], [16]. The fingerprint method is presented in [17] as a map of the coverage area of the network obtained by measuring received signal strength indicator (RSSI).
The AT&T Cambridge’s Active Bats system [18] uses physical devices such as ultrasonic badges. Ubisense and Ekahau are commercial location estimation systems. Ubisense has a very high precision approximately 15 cm due to the use of the active tags signal triangulation [19], [20]. The Ekahau systems, RADAR systems [1], and LA200 systems [21] use WLAN fingerprinting which is considered to be the most successful method. MIT Cricket system uses tags incorporating RF radio chip, a microcontroller, and an ultrasonic receiver [22].

The RSSI measurements used to build a fingerprint are strongly dependent on the line-of-sight (LOS) between the sending device and the receiving device. Therefore in most of the systems which use fingerprint methods, RSSI is recorded for different orientations (north, south, west, east or 0°, 90°, 180°, 270°) at each point in the environment. RSSI-based position estimation techniques can be classified as terminal assisted, terminal based, and network based [23]. The terminal assisted mode is based on RSSI measurements taken by the target and sent to a server which is managing the radio map and is also running the algorithm to compute the target’s location. In the terminal based mode the radio map is built on the terminal and used to determine the target’s position. The network based method uses RSSI measurements taken by the Access Points (APs) or Base Stations (BSs) listening to the beacons in the environment.

The rest of the paper is organized as follows: Section II gives a brief presentation of some related technologies proposed in the literature. Initial measurements are outlined in Section III. Section IV presents the evaluation of the proposed DfP system. Section V concludes the paper.

II. DEVICE-FREE PASSIVE LOCALISATION (DFP)

The Device-free Passive (DfP) Localisation technique (or variance-based tomographic imaging (VRTI)) focuses on identifying a person’s location without the use of sensors, thus it can be included in the spatial locations subcategory [5], [6], [7], [24], [25], [26]. It is called ‘passive localisation’ as the person being tracked is not carrying any electronic device such as tags or sensors. VRTI is an extension to the technology denoted in the literature “radio tomographic imaging” and is so-called due to its analogy to medical tomographic imaging.

Work in [5], [6], [7], [27], [28] presents various functions that could be implemented for DfP localisation systems. These functions can be classified as follows: tracking, identification, multi-person and automatic construction of a passive radio map. An alternate tag-free localisation technology is ultra-wideband (UWB) through-wall imaging (TWI) (also called through-the-wall surveillance) [25], [29]. Through-wall imaging has garnered significant interest in recent years for both static imaging and motion detection. The goal of through-wall imaging is the ability to monitor objects or persons through building walls and other obstacles which has become a very important aspect for law enforcement agencies [26]. High resolution images showing the object location and other parameters like shape can be accurately reproduced using multifrequency data [24]. Many applications could be developed using passive localisation: such as detecting intruders in the home or any other area of particular security interest [5], [6], [7], helping emergency responders, military forces, or police arriving at a scene where entry into a building is potentially dangerous [25], [29].

Ultra-wideband (UWB) through-wall imaging has attracted recent interest due to its ability to penetrate walls. In [25] the authors present imaging results based on the virtual elliptic curve imaging method using the UWB pulse system. The systems based on UWB TWI methods can reproduce images with very high resolution. The UWB methods use short duration pulses with frequencies for TWI assigned by Federal Communications Commission (FCC) at below 960MHz and from 1.99GHz up to 10.6GHz, frequencies with the ability of walls’ penetration. Two other approaches that can be classified as sensor-less passive localisation are considered to be computer vision and physical contact [7].

Authors in [27] presents a simple and low cost two-dimensional location estimation system based on capacitance measurements. The system measures the changes in the capacitance between floor tiles and two types of receiving electrodes (plate electrode and wire electrode). The accuracy of the system using 9 tiles with 5 mm spacing between the tiles, providing an area of 1.8 x 1.8 m is 15 cm for a person standing and approximately 41 cm for a person walking. The solution is considered to be low cost due to the fact that the transmitting electrodes can be constructed using plain aluminium foil with a plastic cover. The hardware used is also not very complex or expensive. They use a Capacitance-to-digital converter AD7746, the ATmega8 microcontroller and a multiplexor. The update rate of the system is 10 Hz. However increasing the number of tiles will affect the update rate.

Computer vision is considered to be a DfP system because the tracked person is not carrying any devices or tags. The focus for such a system could be transforming a simple environment into an intelligent environment [28]. The EasyLiving project aims at developing a system that could trigger events based on the location of a person, such as: locating and switching on a device near to the user, understanding the behaviour of the person in a room in order to invoke user’s preferences like light in the room and playing music. The system is using 3 PCs and two sets of colour cameras. Each camera is connected to a PC, the third PC being used for running the person tracker algorithms. The system estimates the location with a 10 cm error and allows partial occlusions. The update rate is about 3.5 Hz. Examples of applications for computer vision systems are face recognition, game development, intelligent environments and security scenarios.

The implementation of a multi-person tracking for active localisation systems is relatively straightforward with the aid of electronic devices such as tags or sensors. The challenge however is implementing multi-person DfP systems. The DfP vision system [28] can track multiple persons using two sets of colours cameras. However the multi-person multi-camera method has limitations such as the number of people in the room at the same moment and the tracking is problematic if the persons are wearing similar coloured clothes. The work in [27]...
Fig. 1. The model of human body using a perfect electrically conducting (PEC) Cylinder [36]

describes a location estimation system based on capacitance measurements. The authors discuss the possibility of multiple person detection. It is possible with their system if the people are separated by at least one tile. The test bed used has only nine tiles, thus the implementation of the multi-person tracking is not possible but simply considered as future work for a large scale implementation.

This research introduces a DfP Localisation approach using a wireless sensor network (WSN). The Device-free Passive (DfP) Localisation technique (or variance-based tomographic imaging (VRTI)) focuses on identifying a person’s location without the use of sensors [30], [31], [32], [33]. The wireless signal indoors suffers from noise due to reflection, diffraction and transmission through the human body. Results in [34], [35], [36] showed that the human body can be modelled as a perfect conducting circular cylinder in order to obtain similar level of scattering, shadowing and transmission (see Fig. 1).

The main objective of this research is to identify the presence of a human body in a room by monitoring the changes occurring in the environment. In the proposed system the radio frequency used by the nodes to send beacons is 2.4 GHz. The human body contains more than 70% water and it is known that resonance frequency of water is 2.4 GHz [6], [37]. Thus the human body is reacting as an absorber attenuating the wireless signal.

### III. Initial Measurements

RSSI measurements are very noisy, thus the signal amplitude representations are not smooth. The aim of smoothing the recorded data is to obtain a signal which can clearly show the variance of the signal when a person is walking or standing causing interference in the wireless communication. Having data with a lower noise level can be helpful for setting up a threshold. When the signal exceeds this threshold, an event can be triggered showing the presence of a person in the indoor environment.

Tests were conducted and the results are shown in Fig. 2. We considered a small window from our recordings in order to show how the smoothing algorithms perform on this type of data.

The recorded RSSI values were smoothed with a five-point triangular smoothing algorithm (Fig. 3) using the `fastsmooth` Matlab function:

\[
s = \text{fastsmooth}(data, width, type, edge) \quad (1)
\]

where \(s\) is a vector which returns the smoothed data, \(data\) represents the vector containing the RSSI measurements, smooth \(width\) is a positive integer and \(type\) refers to the type of the smoothing algorithm. In our case \(width=5\) and \(type=2\) for a five-point smoothing algorithm. If \(type=1\) than we have a rectangular smoothing algorithm and for \(type=3\) a pseudo-Gaussian smoothing algorithm.

The results in Fig. 4, Fig. 5, Fig. 6, Fig. 7 and Fig. 8 were plotted using the following Matlab function:

\[
yy = \text{smooth}(y, span, method) \quad (2)
\]

where \(yy\) is the smoothed data, \(y\) is an array containing the RSSI values, \(span\) represents the number of values considered for the smoothing algorithm and \(method\) is the smoothing algorithm used. The smooth function can implement six types of smoothing algorithms: Moving Average filter, a local regression using weighted linear least squares and a 1st degree polynomial model (Lowess), a local regression using weighted linear least squares and a 2nd degree polynomial model (Loess), Savitzky-Golay smoothing filter, a robust version of ‘lowess’ that assigns lower weight to outliers in the regression (Rlowess), a robust version of ‘loess’ that assigns lower weight to outliers in the regression (Rloess)[38].

In Fig. 9, a median filter was used to filter the noise in the signal. The filter was applied on the same data as the previous filters. The `medfilt1` function from Matlab was used to obtain the results presented in Fig. 9.

The syntax of the 1-D median filter is given by:
where $x$ is the vector containing our RSSI data. If $n$ is odd $y(k)$ is the median of $(x(k-(n-1)/2), x(k+(n-1)/2)$ and if $n$ is even $y(k)$ is the median $(x(k-n/2), x(k-(n/2)+1), \ldots, x(k+(n/2)-1)$.

Fig. 10 present the results using a Savitzky-Golay smoothing filter which is also called a digital smoothing polynomial filter or a least-squares filter. The Savitzky-Golay filter usually performs better than the standard averaging filters which tend to filter out signal’s high frequency together with the noise. Although the Savitzky-Golay filters are effective preserving the signal’s high frequency, they are not as successful as standard averaging filters at rejecting noise. The graphics were plotted using Matlab’s function for the Savitzky-Golay filter with the following syntax:

$$y = \text{sgolayfilt}(x, k, f)$$

where $x$ is a matrix, in our case the recorded RSSI measurements, $k$ represents the polynomial order which must be less than the frame size, $f$. In the case $k=f-1$ no smoothing will result. The same results can be obtained using the smooth function presented above with the parameter method equal to 'sgolay'.

The Kalman filter [3] was also used for smoothing the data recorded from one of the free-range node. The results in Fig. 11 are plotted using an implementation of the Kalman filter in Matlab.

The Kalman filter is known to be used for noisy measurements and has two distinct sets of equations: Time update (prediction) and Measurement update (correction).
Fig. 10. Savitzky-Golay Finite Impulse Response (FIR) smoothing filter

Fig. 11. Smoothing RSSI data using Kalman Filter

Fig. 12. Error between the Raw RSSI and three selected smoothing algorithms

Fig. 13. Experiments: a) current test bed; b) future test bed

Fig. 12 shows the error between the original/raw RSSI measurements and the smoothed signal. We have selected three of the smoothing algorithms based on the smallest average error: 1-D median, Rlowess and Rloess filters. The average error was computed for each case and the results show that the 1-D median filtering has the smallest average error compared with the rest of the filters due to the fact that small variations of the signal are considered to be zero. Kalman filter had the biggest error. However the event caused by the human presence is clearer in Fig. 11 using the Kalman filter compared to the rest of the algorithms presented in this paper. The filters can be optimized further by modifying or adding more parameters. However at this moment this is not necessary.

Future work will investigate the use of other smoothing algorithms. We will continue to focus on finding the algorithm which filters the RSSI data and offers us the best output for choosing a threshold necessary to trigger an event when the presence of a person is detected.

IV. EVALUATION

The test bed in Fig. 13 (a) consists of two free-range Sunspot motes with fixed positions sending beacons every 200 msec. This test bed was used in order to obtain the preliminary results presented in our paper. The messages sent by each node contain the following parameters: RSSI, node ID, battery voltage and battery level. The battery voltage and the battery level are being measured due to the fact that wireless communication could be affected if the node’s battery is running low.

The nodes are placed 1.5m away from the base station with a distance of 1.5m separating the nodes and a 1m height. Fig. 13 (b) shows the future test bed. Current work involves investigation of the firmware that will run on the four free-range Sunspot nodes. In order to implement an application using WSNs, it is necessary to take into account the design and resources constraints which are specific for WSN nodes. The protocols need to be carefully designed in order to preserve as much energy as possible putting the nodes into sleep mode whenever they are not used. It is also important to consider WSNs specific limitations such as short communication range, bandwidth, processing power and storage space.

The free-range Java Sunspot nodes are built from four components: 1) the sunroof; 2) a sensor board including a 2G/6G three-axis accelerometer, a temperature sensor, eight LEDs, a light sensor, two programmable switches, I/O pins, and four output pins; 3) a processor board running a 180 MHz 32 bit ARM920T core - 512K RAM/4M Flash; 4) an internal 3.7V 720mA lithium-ion rechargeable battery.

V. CONCLUSION

A review of various DfP systems was presented explaining the effects of the human body on the wireless communication.
Nine types of smoothing algorithms were used for filtering the data. Examples of more complex methods which could be considered in the future as smoothing algorithms are Hidden Markov Models (HMM) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) architectures.

The average error was computed for each algorithm presented and the results showed that the 1-D median filtering has the smallest average error compared with the rest of the filters due to the fact that small variations of the signal are considered to be zero. The error between three selected algorithms and the raw data were presented. However it seems that the result obtained after using a Kalman filter is clearer compared with the other algorithms presented in the paper. The filters can be optimised further by modifying or adding more parameters.

The future test bed is under development. The test bed is based on a WSN deployed using four Sunspot nodes with bidirectional wireless communication, a sink (Base Station) collecting the data from each node and the computer running the host application. The reason to deploy such a WSN is to improve the accuracy of the proposed system. The usage of a bidirectional wireless communication will increase the number of links that are affected by a person being present in the environment.

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REFERENCES