Fuzzy Logic Technique for RF Based Localisation System in Built Environment

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Abstract
Localisation for human or robots in built environment is one of impartation issue in many applications. Increasing mobile computing devices, that often require knowing where things are actually placed, can be utilised and can be used in localisation systems. To use such systems, various and different location systems and technologies have been developed. This paper studies the use of the radio frequency signal strength information extracted from a pre-installed wireless network as a localiser sensor to locate a mobile (human) user in built environment. A strategy based on a fuzzy logic technique to estimate the mobile user location in built environment has been investigated

Keywords: human localisation, RF, fuzzy logic, indoor environment.

1. Introduction
The capability of estimating a mobile user location in an indoor environment is the primary intention of the localisation systems studied. Such localisation systems could be used for tracking people like patients or locating doctors in a hospital for emergency or surveillance purposes. Furthermore, these may also be useful for tracking company’s personnel in a large environment in order to increase the individual productivity, saving time, assigning tasks to appropriate personnel at certain times depending on his or her location.

There are a number of possible ways to track people in dynamic environments. These range from instrument the environment with passive and/or active sensors or mounting sensors on the people or using a combination of these two approaches. This work investigates the feasibility, the accuracy and the performance of the fuzzy logic strategy for tracking the location of mobile users in an indoor environment using the radio signal strength information (RSSI) provided by a pre-installed wireless network in the environment. RSSI can be easily measured by interrogating the wireless access points that are used to provide wireless coverage. The use of existing infrastructure, that commonly available in many buildings, makes using this information for localisation an attractive proposition. It is envisaged that the user to be tracked will be carrying a small device that is in constant communication with the existing wireless network. Such system also can uses the standard software available for managing wireless networks, it is possible to find information such as (RSSI) to all the wireless access points (WAPs) within range of a mobile user using the medium access control (MAC) address, internet protocol (IP) address or hostname of the terminal, regardless of any precautions made at the application level [1]. Tracking a mobile user in an indoor environment requires constructing an accurate map representing its surroundings at different environment conditions. This paper is concerned with techniques for building such maps and estimating the location of a person in an extensive indoor environment that has complex geometry and noise conditions. To build an accurate localisation system in such indoor environment, the three issues need to be addressed; first one building map of the strength of the signal and the second one is estimate the location while the third is map updating.

Map building: Information on how the signal strength varies with the location is the map that can be used for location estimation. In typical robot localisation systems, the map represents the geometric layout of a building or the location of beacons installed in the environment to aid localisation. In case of the radio frequency signals, the relationship between the location of the radio transmitters and the signal strength at any point within the building is a complex issue. This information is, therefore, need to be gathered through experiments, and represented in a compact manner. The process of constructing the map from the highly non-linear character of the sensor in a large environment involves a significant challenge.

Location estimation through observations: Given the map, the location of the user need to be inferred using the observations of the signal strength as the user moves
in the environment. In case of people tracking, unlike in the case of robot localisation, internal sensor information to compute the egomotion is not available. Furthermore, for real-time operation in a very large environment, the computational complexity and storage requirements of the localisation algorithm need to scale in a reasonable way.

**Map update:** It is conceivable that the signal strength maps are subject to significant variations due to short term factors such as people density in the environment as well as long term factors such as changes in the layout of the furniture. It is necessary to capture these changes either through signal strength statistics or though refreshing the signal strength map.

This paper will answer about the possibility of building a reliable signal strength map of a typical indoor environment subject to human activities and varying environment conditions, and use this map to locate a mobile user?, Is it appropriate to use fuzzy logic technique with these maps and subsequently build the localisation system?, and to what degree of accuracy is achievable using RF based localisation system?

From the objectives above, the research presented in this paper focuses on the map building and location estimation through observations, the technique based on a fuzzy logic system is developed and experimentally evaluated to examine its suitability for people tracking.

The paper is organised as follows: section two reviews the existing literature in the field of localisation and tracking in built environments. Section three provides a localisation methodology background and the fuzzy logic technique proposed and outlines how this technique is adapted to solve the localisation problem. Experimental results are presented in section four together with the accuracy achievable and salient characteristics of the localisation system developed using fuzzy logic. Conclusions are presented in section five.

### 2. Related Work

There has been significant research activity in the area of indoor location aware systems. Different techniques and methodologies have been used; each has advantages and disadvantages in terms of cost, scalability, maintenance, etc. In most of these systems a very simple differences in application constraints have led to fundamentally different design approaches. Main research work done in this area are

Bahl and Padmanabhan [2] present a system for tracking a user in an indoor environment. The system described in this paper depends on RF signal strength of an exiting wireless network. In this method the RSSI of the signal received by a mobile user carrying a laptop equipped with WLAN card is exploited to estimate the position of the user. The RSSI is measured from the signals received from three separate wireless Base Stations (BS1, 2, 3); that exist in the environment. A signal strength map is collected in advance and saved in a central server. Then, the signal strength received by a stationary or mobile user is analysed to find the best matches in the signal strength map using nearest neighbour in signal space (NSSS) using triangulation. The accuracy that is reported for stationary users is around 3 meters and for mobile users, it is around 3.5 meters.

Youssef, et. al. [3] also uses the RF signal strength. In this work, a method based on clustering is introduced for reducing the computational requirements of location determination techniques using the WLAN radio map to increase the scalability of the system. It is seen that the technique proposed may not be effective in environments where the RF signal strength map is subjected to large variations.

Harter, et. al. [4, 5] describes systems that use ultrasound sensors for location service. The localisation system estimates the mobile user location by calculating the differences in RF and ultrasound signal propagation times. Dedicated hardware for the ultrasound circuits as well as RF transceiver circuitry is used and the system requires the installation of an RF wireless network. The mobile user is carrying a device that consists of an RF transceiver and ultrasound sensor. An RF transmitter in installed in the building, and a grid of ultrasound receivers are mounted in the ceiling. Each ultrasound receiver has unique address and connected to a central computer on the wired network. The central station periodically sends a command to the mobile user transmitter to send an ultrasound pulse, the ultrasound receivers use the command from the central base to obtain the time between the received RF signal and the ultrasound pulse, which is used calculate the distance between the mobile user and each of the receivers. The accuracy in the order of centimetres can be achieved with no requirement for line of sight. The main drawbacks are the fact that the system depends on a central station and that there is high initial installation cost and poor scalability.

The Active Badge System [6] uses an IR sensor. In this system, the mobile user is provided with a badge which consists of an IR transmitter which sends its address periodically. There are IR receivers in each room, each IR receiver picks up the mobile user address and send it on a wired network to a central computer for localisation processing. However, there is significant cost involved; line of sight is required between the IR transmitters and the receivers. In addition, the IR sensitivity degrades in the presence of ambient light. Furthermore, the scalability is poor due to the limited range of the IR devices.

The SpotOn system [7] is based on RF identification (RFID) tag signal strength which is calculated relative to the distance from the tags and central RFID reader carried by the mobile user. However the accuracy depends on the number of tags installed in the environment, the more RFID tags installed the higher the accuracy that can be achieved.
There has also been some work in extending the widely available GPS systems to operate in indoor environments [8]. To achieve this, it is necessary to design GPS receivers that have very high sensitivity and equipped with circuits capable of a massive parallel correlation. For example, the circuit GL16000 described in [8] contains 16,000 correlators compared to 32 present in a normal GPS receiver. The need for special GPS receivers and other infrastructure required makes this strategy expensive at the current time; however, these problems may be overcome in the future.

Work described by Howard, et. al. [9] uses the exiting wireless network to localize two robots in an indoor environment equipped with four wireless base stations. In this work, a signal strength map is collected in advance using each of the robots and saved in the system central server. An algorithm based on the particle filter is used to obtain the robot location. Information from the encoders mounted on the wheels of the robot is also used. Although this work is similar to that presented in this paper, the presence of a simple motion model together with some dead-reckoning information significantly simplifies the problem. Furthermore, the localization algorithms presented is essentially one dimensional, providing the location of the robots along a narrow corridor.

Orr and Abowd [10] describe a localization system based on the load cells installed in the floor. The system localises a person by sensing his or her “unique” footstep force profiles when he or she presses the floor in particular position. The person doesn't need to carry any particular device but significant changes to the building floor are needed. Furthermore, the number of people that could be recognized is limited due to the likelihood that similar footstep profiles may occur when a least number of people are in the area.

3. RF Signal Strength

During the experiments, the mobile user, who was being instrumented or tracked, was carrying a laptop computer running Microsoft Windows XP and equipped with wireless network card based on Lucent’s popular WaveLAN RF technology. The wireless network operates in the 2.4 GHz license free ISM (Industrial, Scientific, Medical) band with data rate up to 11 Mbps [11].

The recorded information about the RF Radio Signal Strength Information (RSSI) for each WAP is extracted as a function of the mobile user's position against its MAC address which is unique for every WAP in the environment. For this process a program written in C++ was developed to read the log file created by the client manager (the client manager is a window based program comes with the wireless card to manage and monitor the wireless link activity and track the RF signal quality).

Building Geometry For the network coverage, our experiments conducted on level 5 of Building I at the University Of Technology in Sydney as shown in Figure 1, which is an ideal environment as it is very busy with students, has a large area surrounded with offices. This area has a pre-installed wireless network with three wireless access points (WAPs) mounted in the ceiling. Another WAP mounted in the level below is also accessible from some locations in level five. The environments are usually classified into three categories of environments. An open environment refers to Line of Sight connectivity between the transmitter and the receiver. The second type is Semi-open that refers to the environment with obstruction like thin partition walls within the office or concrete pillars which partially obstruct the RF propagation and finally the closed environment refers to fully obstructed RF link by bricks or concrete walls [12].

The environment that is seen in Figure 1 can be classified as an open environment in some areas and semi open in other areas where mainly the RF signal obstructed by reinforce concrete pillars. The pathway where the mobile user walked is represented a regularly spaced grid with fixed spacing of 0.5 meters.

Data Collection In the recording phase, five data sets were recorded to construct the signal strength map for the environment. The data sets were taken at different times of the day to capture all the variations in signal strengths that are naturally present. Each data set contains the mean of six consecutive RSSI readings at each position for WAP7, WAP8 and WAP9 respectively as shown there positions shown in Figure 1. A time delay of 6 seconds was used to record the next measurements at the next position on the grid. The mobile user (carrying the Laptop PC) walked from a position close to WAP7 and terminated at a position close to WAP8; the walking pace was 0.5 m along the pathway, shown in a dashed line in Figure 1.

Signals from another WAP (WAP10), which is mounted on the ceiling of level 4 of the same building, one level below where the experiments was conducted can also be received at some points along the path. Strengths of these signals were also measured and

![Figure 1 Map of level 5, building 1 at university of technology, Sydney](image-url)
recorded to be used as extra information to the localisation algorithms in order to examine the level of position estimation accuracy that could be gained with more information.

Finally, additional data sets (observations data or tests data) were also recorded at different times for the purpose of the evaluation and analysis of the fuzzy logic technique.

Characteristics of the Signal Strength Measurements: Figure 2(a) shows how the signal strength measured by the mobile user varies as the user moves along the path shown Figure 1, for each of the WAPs. It is clear that there is a distinct variation in the signal strength measured. Predictably, on the whole, the strength of the received RF signal for any WAP is stronger when the mobile user close to it [19]. However, the relationship between the user location and RSSI for a given WAP is not unique due to far/near field phenomenon and multi path effect [20]. Therefore more than one WAP in the environment is necessary to uniquely determine the location of the user.

The RSSI data sets were collected over five days and at different times with different numbers of people in the measurement area and it is clear that there are variations in the signal strength in different times. Figure 2(b) shows the signal strength variation for WAP9 along the same pathway at different times. In some positions the variation is high, and some areas the variation is low. This is mainly due to the movement of people and the furniture in and out of this area. However this variation is small compared to the overall trend of the RF signal strength for each of the WAPs in this environment. However, when the mobile users change their orientation, the RSSI level also changes for each WAP, depending on whether the wireless card antenna is in the LoS with WAPs or not. This is expected as the operating frequency for the wireless network is 2.4 GHz, which is close to the resonance frequency of water, and that the human body consist of around 80 % of water that affect the signal. Change in RSSI with respect to user orientation is also a function of the signal LoS at that orientation as well as signal reflection, scattering etc. due to surrounding objects in the environment. The highest change in the RSSI with the orientation is around 8dBm, as shown in Figure 2(c).

Localisation Using the Fuzzy Logic Model: Fuzzy logic is ruled-based technique and is suitable for uncertain or fuzzy information to a significant degree and is able to produce good results and is reasonably faster than other techniques when the operating conditions of the system fluctuate, the uncertainties in system parameters or observed variables are high, high degree of noise level and non linear characteristics [13, 14], which can be found at the RF sensor exhibits. Also the radio wave experiences frequent changes in the signal level or attenuation.

The Mamdani Controller has been chosen to implement the localisation system. With Max-Min for the inference engine [17, 18] and center of gravity for defuzzification for its suitability to the localisation system used [15, 16]. The fuzzy logic model has three inputs (3 WAP’s signal strength) to the controller and one output that used to infer the estimated location of the mobile user.

The first step was to build the fuzzy rule base using the data sets obtained from three WAPs (WAP7, WAP8 and WAP9). The path way was divided into 18 locations, 2.5m apart and with small overlapped portion with the next adjacent location to provide smooth transition among these locations. Furthermore, the fuzzy rules for the inference engine were chosen depending on the RSSI levels of the WAP’s within each classified location. An example of a fuzzy rules is:

If WAP9 is 71 dBm and WAP8 is 65 dBm and WAP7 is 80 dBm then the output is position 5.

Figure 3 shows a pictorial depiction of the fuzzy rules chosen for the two RSSI inputs from WAP 7 and 8 versus the output location estimates. These rules are then used in the location estimation. For example, when the RSSI input is 71 dBm RSSI input from WAP9,
Figure 3 Fuzzy rules for the WAP 7 and 8 versus the output (position).

65 dBm from WAP8 and 80 dBm from WAP7, the relative membership contribution of each WAP at this particular instance is used to estimate that the mobile user position is at position 5.

One of the advantages of using fuzzy logic model is that it doesn’t need to calculate any system parameters such as the RF signal variation or standard deviation, etc. Furthermore, fuzzy logic doesn’t require a motion model as in the case of the particle filter, as each location estimation is not dependent on the previous estimates. The disadvantage of course is that this technique does not provide an indication of the uncertainty of the location estimates computed.

Figure 4(a) shows the error in the mobile user location estimation. It is seen that the error is confined to +/- 5m most of the time. However, there are some estimations with a higher error, and the overall standard deviation for the error in position estimation is about 3.33 meters. The large errors are due to fact that the signal strength at these places is similar; making the fuzzy system activates many more rules.

For the second experiment with fuzzy logic, four WAP’s (WAP7, WAP8, WAP9 and WAP10) were used. The size of the grid along the path remained at 2.5 m. An example on fuzzy rules in this case is:

If WAP9 is 71 dBm and WAP8 is 65 dBm and WAP7 is 80 dBm and WAP10 is 78 dBm
then the output is position 5.

Figure 4(b) shows the error in the mobile user location estimation, which is confined to +/- 4m most of the time, showing an increase in accuracy as expected. The overall standard deviation for the error in position estimation is 2.55 m.

4. Results

The results of the experiment using fuzzy logic are promising. In this method, the map of the environment is effectively represented by the rule base in the fuzzy system. The large errors that were occasionally observed are due to the fact that more than one location gave similar patterns of signal strength observation, resulting in the firing of rules that represent two or more position that are far apart. Appropriate WAP placement may be able to overcome this difficulty. The main advantages of the fuzzy system are that computational efficiency, the fact that the rule base is easy to interpret and that a motion model is not required. The disadvantage is that the significant amount of information that is included in a motion model can not be exploited in this framework, resulting in a poor accuracy.

5. Conclusion

The fuzzy logic system provided comparable results with significantly less computations as most of the effort required for fuzzy logic method is concentrated on the building of the rule base. Therefore, research presented in this paper demonstrates the viability of using a fuzzy rule base for representing maps of an unknown environment. The main disadvantage of this technique is that the uncertainty of the resulting location estimate is not available. However, in case of people tracking, which effect the signal strength more the robot or machine tracking this may not be that significant. Increasing the number of WAPs in the environment clearly increases the accuracy. However, this will also increase the computational effort which is not effect in fuzzy logic technique but may affect the other technique. We are exploring more techniques to get better accuracy such us neural network and particle filter which each of them has its advantages and disadvantages.
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6. References