The Promise of New Technologies in an Age of New Health Challenges
A.J. Maeder et al. (Eds.)

doi:10.3233/978-1-61499-712-2-1

Passive RFID Localisation Framework in Smart Homes Healthcare Settings

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Abstract. In recent years, Smart Homes have become a solution to benefit impaired individuals and elderly in their daily life settings. In healthcare applications, pervasive technologies have enabled the practicality of personal monitoring using Indoor positioning technologies. Radio-Frequency Identification (RFID) is a promising technology, which is useful for non-invasive tracking of activities of daily living. Many implementations have focused on using battery-enabled tags like in RFID active tags, which require frequent maintenance and they are costly. Other systems can use wearable sensors requiring individuals to wear tags which may be inappropriate for elders. Successful implementations of a tracking system are dependent on multiple considerations beyond the physical performance of the solution, such as affordability and human acceptance. This paper presents a localisation framework using passive RFID sensors. It aims to provide a low cost solution for subject location in Smart Homes healthcare.

Keywords. Localisation, smart homes, healthcare, RFID, personal monitoring

Introduction

Life expectancy has been increasing dramatically over the last few decades and the trend is expected to continue into the future. Nine percent of the population are aged over 60 in developing countries and this figure may reach 19 percent in 2050 and 27 percent by 2100 leading to an excess of this group over the number of children [1]. In developed countries such as Australia, there is pressure on the population due to the increase in life expectancy and lower levels of fertility [2]. With the ageing population, there has been increasing demands on healthcare facilities globally that aim to improve health services for the elderly.

It is important to maintain monitoring of older individual' behavioral patterns and general health conditions on a daily basis to prevent health risks. Healthcare services are usually expensive and they often require the patients to stay at healthcare accommodation that adds further running costs for the amenities and for training health specialists. Smart Homes have been increasingly considered as a feasible option for healthcare monitoring and services for the elderly as well as for disabled people who prefer to stay comfortable in their homes.

The Smart Homes concept is defined as places of residence that are outfitted with computers and technological devices [3]. Smart Homes aim to provide not only comfort, convenience and a safe environment, but also the improvement of life quality, and assistance to, occupants on a daily basis, as well as connecting them to the world beyond [4]. Research in Smart Homes focuses in part on building advanced technological systems. Smart environments include applications that monitor the elderly unobtrusively via connecting sensors, and that warn them or their healthcare providers about abnormal conditions [5].

Indoor localisation systems based on underlying technologies such as RFID [6], Bluetooth [7], Zigbee [8], UWB [9] and Infrared [10] have been designed and employed to locate the movement of objects and subjects in the indoor environment. These technologies have been used in various indoor localisation applications such as healthcare and assisted living in the smart environment. Ambient assisted living systems help to recognize daily life activities and behavioural movement by measuring a set of their specified activities, such as standing, sitting, lying, walking and interacting with furniture or objects.

In this paper, we propose a cost-effective Passive RFID location framework for Smart Homes for localising subjects using an inexpensive passive RFID tag. The proposed system could help improve pervasive computing in healthcare by applying overlaid smart healthcare solutions to connect the subjects with external healthcare facilities and to enhance the quality of health services in residential settings.

1. Related Work

Tracking stationary movable objects and individuals is a problem which has interested researchers due to the challenges in implementing and optimizing of indoor positioning systems. Radio Frequency Identification (RFID) has been considered a promising technology in indoor positioning environments [11]. Several RFID-based systems have been exploited in the last decade by researchers in the areas of Smart Homes for finding favourable indoor positioning solutions for healthcare facilities, such as [4, 12-13] and others have explored pure RFID location awareness such as [14-19]. However, most systems have provided low performance in accuracy and efficiency while others have a relatively high cost. We discuss most related and noticeable works as follows.

LANDMARC [14] was a novel approach that introduced the concept of localisation using tag references at certain planned locations. Similarly VIRE [17] used the principle of LANDMARC in locating objects using the virtual reference elimination (VIRE) method for location estimation. The authors reported the least error estimation of 0.47m when compared to the LANDMARC system.

Zhang et al [18] implemented a localisation system named Tag-free Activity Sensing (TASA) using a hybrid approach (passive tags and active tags) which was more cost effective. They attempted to reduce the localisation error of tracking moving subjects caused by infrequent trajectories (abnormal activities) [18]. To achieve higher accuracy, the authors proposed a technique to reduce the error in RFID readings and recovery trajectories in an online manner with reference active RFID tags. Chawla [19] developed a localization framework that relied on a variation of the power level of antennas using the power modulating algorithm for location estimation. They used multiple tags to track moving robotic in real time. The system reported real-time accuracy of reasonably high (25cm and 18cm) for stationary tracking.

The aforementioned systems they have used multiple tags and more complex solution in a number of the tracking resources as well as the cost beyond these resources such as in deploying more active RFID for accuracy optimization. In our approach we provide a very simple solution to track movable entities using a single passive tag and three antennas to track the location of movable objects. Our objective is to provide a low cost solution with minimum tracking resources.

2. Framework

We introduced approach using a minimum antenna and only one single tag we receive reasonable good results in term of accuracy. Further, we have developed a framework for object localisation in Smart Homes health. This includes using various devices and technologies supporting localisation and tracking objects in Smart Homes. At the current stage, our system provides the ability for tracking stationary objects using single passive RFID tags. The system has been analysed in detail for stationary and is being extended to cater for moving subjects that can be applied to Smart Homes health care settings. Figure 1 shows our framework for the proposed tracking system using passive RFID tags. The three processes of the framework are presented as follows.

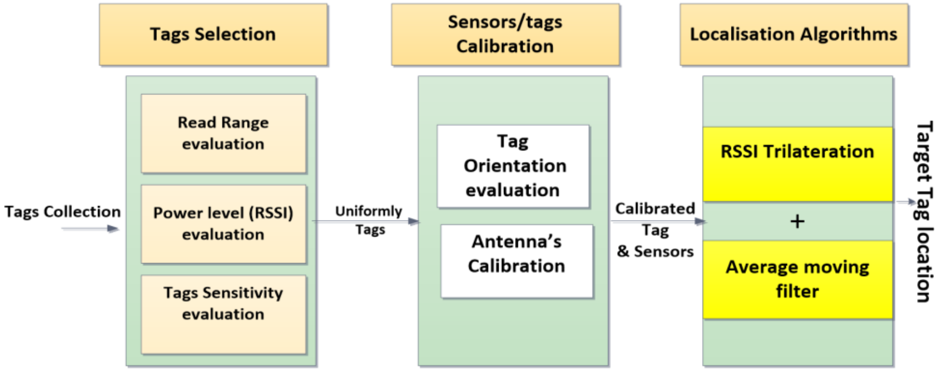

Figure 1. Localisation Framework for Smart Homes.

2.1. Tags Selection

The first stage of the localisation framework is to evaluate tags in the selection procedure to determine the most suitable and readable tags for localisation purpose. This involves two systematical sets of tests to define the candidate tags for the following processes. In the first set of tests, reading-range evaluation is examined for each type of tags according to various distances from the antenna. This process systematically determines the most far-reaching and most accurate tags for different type of antennas and tag readers. The following set of tests analyses sensitivity of the tags according to different power levels of the readers where the tags were set at fixed locations from the antennas. The tags' sensitivity tests determine the most suitable tags on various readers' power levels.

2.2. Tags Calibration

After the selection process, the candidate tags are tested further using various stationary locations and orientations to evaluate tags readings at different directions toward the antennas. This procedure is essential to select the suitable tags as the orientation is important in deciding the performance of a tag. In our experiment, all the antennas are located in fixed positions on a gridded floor. The three antennas are facing the target tags at the same height. Various power levels were set to find the optimal power level of each antenna. Other factors such as tags orientation and antenna angulation were examined to obtain the proper settings of our localisation platform.

2.3. Localisation Algorithms

Our localisation approach targets passive tags (i.e. movable and non-expensive) that can be easily attached to impaired individual assistive devices such as wheelchair, walker stick, etc. To achieve this goal, multiple algorithms have been studied including Trilateration algorithm [23, 24] for distance estimation and filtering algorithms. We now present the localisation algorithms.

To determine Received Signal Strength Indication (RSSI) values, loss path propagation model [20] derived from Friis Transmission Equation [21] was studied to estimate the tag backscatter signal power received (PR). In experiments, Friis equation converted to an approximate linear logarithmic distance equation [22].

After measuring the distance of the passive RFID targeted tag using the above-mentioned methods, the well-known Trilateration algorithm [23, 24] is applied to estimates three distance-points from each antenna in relation to the targeted tag. The system performs the trilateration to estimate the location of the targeted tag in real time. The position of target tag is calculated by the intersection of the three circles.

Due to the noise and the major changes in RSSI values, filtering is essential to ensure the quality and smoothness of the reading signals. Although there are many different types of available filter algorithms, at this stage, we only apply moving average filter to reduce the noises from the readers. The filter takes the average of every (N) of sequential from each RSSI sample. Then it reduces the mean of the distance variance of each estimate and the actual position [19].

3. Experimental Evaluation and Results

To evaluate our RFID localisation framework, we have implemented an experimental setup using *Impinj Speedway R420* development kit with UHF RFID Reader running in 920-926 MHz frequency. The location system was deployed in our Smart Home infrastructure at the Telehealth Research & Innovation Laboratory at School of Computing, Mathematics and Engineering (SCEM), Western Sydney University. The experimental area for testing was 2.75m × 3.0m. We used the passive Gen2 tag of type (MONZA 4D) as a target tag. The floor was divided into several grids for better measurement where each grid size is 0.6m × 0.6m. Three antennas were set using adjustable stands. The antennas were faced to each other at the same direction as a triangular shape.

3.1. Experimental on Tag Selection and Sensors Calibration

The experiments were carried out to examine the performance of Gen2 passive tags. The results showed that each tag has a different level of performance over the three tag selection measurements (see Figure 2). We have noticed that the tags with small antenna circuits generally give a poorer reading performance according various distances, power levels and sensitivity level tests. To ensure that the tags statistically meet the selection procedure requirement, we verified this by several tests, including tags distance reading range, tags RSSI readings and tags sensitivity test. From the experiments we found the tag Monza 4D type A, has the most desirable reading range over different positions from all antennas. It also provides various orientations from the antennas. We have considered the Tag (Monza 4D) as the most suitable tag for our localisation experiments.

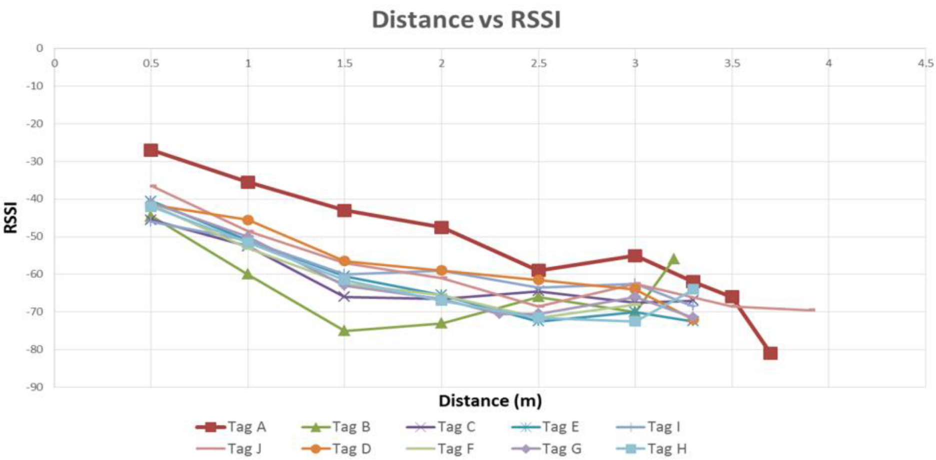

Figure 2. Performance of the tags at various distances over variations in power level (dBm) where Tag A = Monza 4D type 1, Tag B = Monza 4D type 2, Tag C = Monza 4E type 1, Tag D = Monza 4E type 2, Tag E = Monza 5 type 1, Tag F = Monza 5 type 2, Tag G = Monza 4U type 1, Tag H = Monza 4U type 2, Tag I = Monza 4D type 3, Tag J = Monza 5 type 3.

3.2. Localisation Experiments

Due to the limitation of passive RFID tags, it is challenging to produce accurate results due to factors of tag's orientation, tag's spatiality, metal and liquid occlusion, and ambient interference [24]. We applied a diversity of tag location tests on various tag's orientation from the RFID Antennas as well as different tag's placement on an attached object (e.g. an assistive walking stick). We also carried out several experiments to determine the best position of the tags in stationary localisation. We found that the closer tag to centre of the platform, the higher accurate results we got. From our experiments we experienced interference issues caused by the other environmental surroundings (e.g. desks, chairs and mobile signals etc.). We also calibrate the amount of power level going through the antennas as well as the antenna's height so that the best results could be reached. We found that the power level of 31dBm was the most reasonable for the localisation platform, and (0.5m) antenna height from the floor was the ideal height of our platform when the tag was located around 0.2m from the ground.

Systematical tests were carried out to determine the accuracy of the localization system. In these tests, the tag was positioned on varying points, mostly the central area. Estimated location coordinates were programmed and simulated with a graphical interface using JAVA programming language. The coordinates were calculated and then were compared to the real position in order to determine the accuracy.

Figure 3 shows the average performance in accuracy of the tag according it different positions, illustrated the performance of our localisation platform. The results indicate that high accuracy points are located in the central area of the gird. The green dots represent the average accuracy above 90% with (Mean M = 94.27%, Standard Deviation SD = 2.08%) in an average error of 16.5 cm. The highest accuracy is 98% which is at the central point of the grid (e.g. with less than 2 cm of error). Dark blue and light blue dots are mostly located in the outer area of the gird. These dots represent accuracy of 80% to 90% (M = 84.81%, SD = 2.81%) and 70% to 80% (M = 76.45%, SD = 2.83%) respectively. Yellow, orange and red dots represent the accuracy 60% to 70%, 50% to 60% and below 50% respectively. These dots are mostly located at the far outer of the grid.

This figure also indicates the limitation. The far outer areas are filled with red dots representing the low accuracy area. These are the blind spots. This is caused by the limitation of the coverage area for each antenna. If the tag is placed at the edge of the coverage area in the grid, the RSSI reading of the tag will change rapidly or even unreadable by at least one of the antenna. The trilateration method requires tag location coordinates from each antenna in order to calculate the actual location of the tag. If one of the coordinates is missing, the accuracy will be significantly decreased.

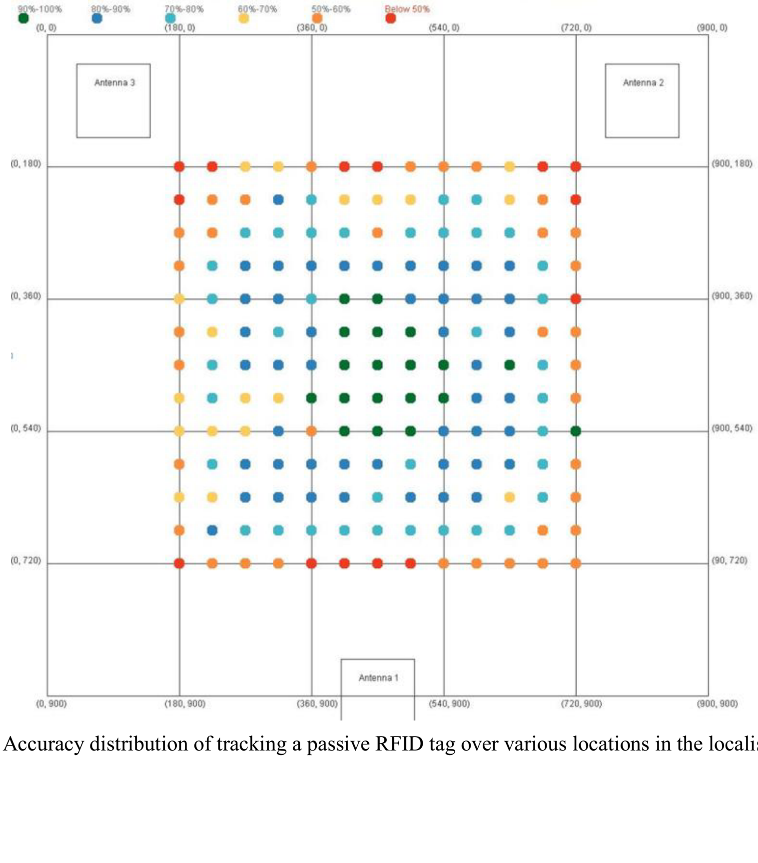

Figure 3. Accuracy distribution of tracking a passive RFID tag over various locations in the localisation area.

4. Discussion

Observing from the experimental tests, low accuracy results were recorded outside central area as well as the blind spots. The current localisation configuration consists of only three antennas in a triangular format that results in blind spots, not covered with antennas. The orientation of the tags and the antennas also plays a significant role in the accuracy outputs. The current configuration only uses one passive tag so that the orientation of the tag affects significantly the RSSI readings. Results showed that the relationship between RSSI and AoA (Angle of Arrival) varies significantly during the measurement. The results indicate that the RSSI reading gets its peak performance when the tag is facing directly towards the corresponding antenna (i.e. AoA is 0^{o} or 180^{o}). When the tag is facing the antenna's sideways, the reading decreased dramatically. This suggested that this type system is suitable for operations that track subjects within the area of 1.10m × 1.20m.

Despite the challenges that we faced during the experiments, our proposed framework was able successfully to track subjects' movement. We applied a RFID tag on a walking stick in the space of 60cm × 60cm. A person is acting as an elder and moving the walking stick slowly in the area. We visualized the movements on the JAVA platform and determined its accuracy. Results suggested that the accuracy is still over 90% in the central area, even with human and objects interferences. However, there were a few spikes during the experiment. This could be resulted by the sudden change of movement from the person moving the walking stick. The experiment positively shows that our system performs well with high accuracy in the central and near central areas. Reasonably good results were achieved considering the simplicity of our system that uses minimal tracking resources: three antennas and one "almost nil cost" passive RFID tag. We have validated our hypothesis in real experiments and we have received a promising results compared to the existing systems. We also carried out a successful tracking experiment that used one passive RFID tag which was attached to an assistive walking tool. It did not require the individual person to wear it or attach the tag to his/her body. In addition, by using passive tag, our system does not need frequent maintenance compared to the active tags that use of the battery.

Conclusion

In this paper, we have introduced a low cost tracking system using a single RFID tag and three antennas with promising results in term of accuracy. We proposed a potentially cost-effective localisation framework to localise movable subjects and to perform subject or object location determination at stationary settings. The used passive tags are significantly cheaper and less obstructive (i.e. much smaller and less weight) than the active tags. Although there are still limitations in the current system, the results are reasonable and promising. We are going to improve our location system by addressing localisation blind spots and improve the accuracy by using more antennas and RFID tags. We will also implement more advance filtering algorithms to enhance the signal processing. Finally, we will optimise the localisation of mobile subjects in real-time and tracking individuals in real-life scenarios.

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