Optimized Path Planning for a Mobile Real Time Location System (mRTLS) in an Emergency Department

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Abstract - Data collection methods used for localization in healthcare facilities involving human data collection often tend to generate inconsistent and ambiguous data. To address these issues, an automated ceiling mounted mobile Real-Time Location System (mRTLS) is proposed. The system utilizes mobile Radio Frequency IDentification (RFID) and is evaluated using agent based modeling. A prototypical agent model for an emergency facility is created using the AnyLogic simulation software. The model developed is based on the real hospital data to approximate patient flow in a real system. The emergency department model is outfitted with mRTLS using mobile ceiling mounted RFID readers in an emergency facility layout. Path planning and resource provisioning of mobile readers is accomplished using both multi objective genetic and simulated annealing algorithms. The genetic algorithm provides an initial placement of static readers extracted from areas of more frequently read RFID tags. The genetic algorithm solution initializes the input parameters for the simulated annealing algorithm. The simulated annealing algorithm provides the final optimized path for the deployment of mobile readers. The results generated by the model are analyzed in the simulation of the emergency facility augmented with mobile RFID readers. The applicability of the proposed model in a complex system like a healthcare facility is demonstrated through simulation.

Keywords: RFID, Agent based modeling, genetic algorithm, simulated annealing

1 Introduction

The collection of Emergency Department (ED) data is a crucial component of patient care. The decisions based on data such as priority setting, allocation and leveraging of resources, comprehensive planning, service delivery, and performance evaluation depends on qualitative and quantitative data collection [1].

The recorded data include medical records, vital events registration, and surveillance, recording of treatments in progress, overall length of stay and discharge or admittance disposition. Data manually collected and reported related to patient care and healthcare facility activities have been found to contain errors and discrepancies. These error prone data collection techniques, and issues therein, are amenable to improvement as they can affect patient care [2],[3]. Inaccurate data can have adverse effects on patient outcomes and the efficiency of resource allocation [4]. The proposed mRTLS addresses one aspect of the overall data collection process that being patient and resource localization and tracking.

Hirshon et al. [5] analyzed the data collection methods used in healthcare facilities such as EDs. One school of thought is to increase the automation of current data collection systems. Automated data collection methods are expected to improve accuracy and reliability of the data, thus improving analysis and aiding in efficient policy making, thereby improving ED throughput and patient care outcomes.

Many scientists and researchers such as Nelson et al. [6] have explored various asset tracking means to improve throughput and resource utilization. Among the wireless technologies, RFID and RTLS [7] have been suggested as leading contenders to aid in automated data collection. Ferrer et al. [8] discussed the use of RFID tracking technology in monitoring various environments. He et al. [9] demonstrated the provisioning of real-time data collection with RFID aids in logistics and resource tracking. RF data collected in a Texas hospital, is used to generate data for infection control, automated discharge and improve workflow, as reported by Baum [10]. This provides an indication that high quality healthcare data can be obtained using wireless automated data collection techniques that are more precise, reliable and time-saving for all involved. While commercial tracking systems are available and evolving, they are expensive solutions each with their own limitations.

The mobile RFID reader system proposed here is also not without difficulties of its own. The deployment of mobile RFID readers and the network planning to achieve two objectives is a non-linear multi objective optimization problem. Guan et al. [11] demonstrated that deployment of RFID in large scale environments requires solving a complex network planning problem. Bandyopadhyay et al [12] have developed a simulated annealing-based multi objective optimization algorithm (AMOSA) to find a solution to this problem. We also apply these methods while addressing the mobile RFID reader network planning problem.

Simulation and modeling is generally used for visualizing and assessing process flow of complex systems, and has been used in this manner by other researchers. Miller et al. [13] have used simulation experiments to demonstrate improvements to ED throughput. This supports the conjecture that simulation tools can accurately represent complex systems like EDs.
In our case, simulation and agent based modeling is useful as an inexpensive validation tool for the optimizations. Using AnyLogic simulation tools, an Agent Based Model (ABM) of an ED was developed. Using patient flow data acquired from Winnipeg Regional Health Authority (WRHA), the solution obtained by our algorithms is partially validated, without the need for expensive hardware installations.

2 Related Work

Many researchers believe RFID applications in medical institutions can help reduce medical errors and reduce labor costs [14], [15]. As such, RFID systems may also have the potential to improve the efficiency of medical services and improve patient outcomes.

Laskowski et al. [16] designed an ABM for patient tracking and assessment of error/uncertainty of low cost, fixed RFID in an ED. The limitations associated with the fixed RFID readers in the study conducted by Laskowski et al. relates to the degree of uncertainty or error that depends on the number of readers provisioned in the ED. An issue addressed here is the high cost and maintenance associated with a large number of static RFID readers deployed in the ED. Anusha et al. [17] and Xie et al. [18] are of the view that expensive deployment of fixed readers gives broad coverage, however, complete coverage might not be essential in real world, practical applications. Xie et al. [18] support the idea that efficient use of mobile readers may cover the area sufficiently, with the advantage of reduced cost of deployment due to fewer readers being required. Similarly, in order to address the issue of increasing cost and reducing patient and asset localization uncertainty in an ED, a mobile RFID/RTLS system is proposed. The proposed mobile RTLS aims at minimizing the cost by reducing the number of readers while minimizing the error in tracking the RFID tags in an ED. A significant difference here from most mobile RFID systems is that the readers in the ED would be ceiling mounted as a means of keeping the system as noninvasive as possible to the normal operations of a busy ED.

The application of evolutionary algorithms to address multi objectives and constraints optimization issues has shown promising results in research studies. The studies conducted by Guan et al. [11] and Seo et al. [19] support solving RFID network planning optimization problems by evolutionary algorithms. Guan et al. [11] applied a genetic approach to overcome complex problems such as interference of multiple readers, undesirable mutual coverage and variability in propagation environments. Guan et al. [11] are of the view that uplink signals from tag to readers should be taken into account while solving complex RFID network optimization problems. Seo et al. [19] designed a genetic algorithm based resource allocation for an RFID system to resolve the reader to reader tag collisions and interference complications. The system designed by Seo et al. [19] optimizes RFID resource allocation and the related tag recognition issues. Weijie et al. [20] analyzed RFID network features and multi objective optimization built on genetic programming. These multi objective genetic programs or algorithms typically generate the best fit layout/deployment of static readers.

3 Methodology

3.1 Agent Based Modeling

A preliminary 3-D ABM was integrated with a tracking system based upon RFID. This effort led to the idea to improve the effectiveness of the system using mobile RFID readers as an alternative to the more traditional static reader scenario. The objective of mobile RFID/mRTLS is to minimize number of readers and minimize the tracking error incurred simultaneously by finding the best path to layout the tracks or rails that the mobile readers would traverse. Actual cost of mobile RFID readers, their installation and maintenance cost is not estimated, though it is assumed that fewer readers will be significantly less costly to install. In addition, a mobile reader system is more easily upgraded as an existing track infrastructure is a more permanent fixture requiring only the upgrade of the readers themselves.

![Figure 1. A screen shot of augmented RFID RTLS ABM Simulation.](image-url)
Figure 1 provides a visual of patient movement during the course of treatment based on the real data from an ED. The data is essentially a record of start and stop of events that a patient would undergo. In addition, the data provides for an accurate model in terms of arrival rates. The flow of patients and states is approximately as shown in figure 2. The patient initially arrives in the Triage room and gets tracked by the moving mobile reader running on the ceiling tracks. The identity and timings of each individual tag is maintained by all the mobile readers in a central repository.

A standard layout is assumed for the facility, which can be modified to be applicable to any real-world ED floor plan. Installation of fixed RFID readers to obtain adequate coverage is costly primarily due to the number of readers that would be required and the space and layout constraints in the healthcare facilities. Mobile readers on the other hand act as patrolling devices to track resources (or patients) instead of waiting for the resource to come within the range of fixed readers. A mobile system would also be costly to install initially but could be reused as reader technology advances. It is conceded that the accuracy of RFID tracking systems is better in the case of sufficiently large number of fixed readers. Effectively, the level of accuracy is traded for a reduced number of readers in the case of the mobile RFID reader system. The conjecture is that as the mobile readers may still provide sufficient coverage at a significantly reduced cost.

The optimization of mobile readers is initialized by positioning a large number of static readers in the facility to cover the entire area as shown in Figure 3. This instance allows a base line for reader error to be estimated against the movement of patients and resources extracted from the ABM. Errors are essentially a non-tracking event. That is, a patient is in a known location but not read as they may be out of reader range.

![Figure 2. The flow of patients in ED simulation model.](image)

![Figure 3. Initial placement of 27 static readers.](image)

![Figure 4. The parameter optimization of a static RFID reader model using a Genetic Algorithm that illustrates the high RFID read areas.](image)

![Figure 5. The dynamic parameter optimization of the mobile RFID reader model using Simulated Annealing that generates optimized paths which the mobile readers traverse.](image)

3.2 Multi Objective Algorithms

A multi objective genetic algorithm (GA) is designed using static parameter variations to find the high traffic areas of the agents and asset flows. Through this algorithm, an optimized layout of static readers is obtained. The optimized solution, in the form of a reader location string from the GA, shows areas of frequent traffic within the facility (figure 4). Based on the tracker or reader string (genetic sequence), the locations of most active fixed readers is determined. These
locations will be used as endpoints in the path segments followed by mobile readers.

In order to find best path covering among all the segments, a multi objective best solution, generation algorithm is used. The optimal static solution from the multi objective genetic algorithm is used as an initializing parameter to the simulated annealing algorithm that is implemented as a dynamic parameter variation experiment. The multi objective SA algorithm produces an optimized path for all the readers in the layout. The improved solution is generated that further optimizes cost by reducing the number of readers while attempting to minimal tracking errors. The flow of the multi objective optimization using GA and SA algorithms is demonstrated in Figure 6.

4 Experiments and Results

The two multi objective optimization algorithms are integrated within the AnyLogic simulation software to experimentally validate the proposed mRTLS reader system. The parameter variation experiments on the models enables “what-if” scenario verification and visual observations. The multi objective evolutionary algorithms are implemented in Java.

The optimization algorithms allow customization of their parameters. Population size, number of readers in an individual solution, rates and types of crossover and mutation operators are modifiable. The selectivity of the best solution, also known as elitism, is customizable. The implemented RFID agent model with mobile readers provides an option to change the reader range, velocity of the mobile RFID and number of readers.

The hospital data imported in the designed model can be changed and the simulated data can be imported for the purpose of analysis so the output of a large number of runs of the simulation can be statistically analyzed.

As mentioned, the best solution generated by multi objective GA is used as input for the multi objective SA algorithm to further improve optimization of the required number of readers and the best path that ensures fewer errors.

The experimental results demonstrate a decrease in tag tracking error with a concomitant reduction in the number of mobile RFID readers when compared with a greater number of static readers, even with those readers placed at high traffic locations. This is attainable by the designed error model. The readers in a high traffic area can accurately track an individual or an asset but lose the track of it as soon as it is out of range. In the error model developed, the reader that is moving effectively extends their range thereby reducing the tracking error. This is believed to be primarily due to the fixed trackers only reading tags in their proximity, while a mobile reader is able to get a better estimate of tag movement largely attributable to the time constants associated with relatively slow patient movement in an ED. This can be attributed to read hotspots being found in waiting rooms and hallways. Since the mobile trackers not only cover the hot spot locations, but also the territory between these locations, more information in regards to origin, destination and movement patterns of tags can be discerned.

Figure 6. The optimization process (GA followed by SA).
Another influence of this perhaps unexpected result is the way in which error is defined within the system. Tags essentially operate as state machines, operating in either a non-error state or an error state, depending upon when the tag was last discovered by the tracking system and its movements since that time. A tag is put into the error state upon arrival at a new destination, and will remain in this state until seen by a reader. Once discovered, it will transition to the non-error state, and remain that way until moving to new destination.

Using this error model puts static readers at a disadvantage, as discussed above, due to the location of the hotspots. But it is believed that this error model more accurately reflects the ability of generating valid, useful data than others which were tested.

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<th>Time (in model time units)</th>
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<td>Algorithm</td>
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<td>1000 (120 Gens.)</td>
<td>Genetic Algorithm</td>
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<td>1000 (200 Iters.)</td>
<td>Simulated Annealing Algorithm</td>
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Table 1: Optimization of two objectives for the best mobile RFID solution.

5 Conclusion

A novel RFID RTLS is presented that uses mobile readers and delivers an optimized path for actual deployment of a minimal number of mobile readers. The RFID augmented ED model and the two proposed multi objective algorithms are used for developing path planning strategies. The two objectives achieved for the proposed agent based model are to minimize the number of RFID readers (i.e., minimize the cost) and to maximize the coverage.

The designed agent based model verifies the optimal path planning of mobile and fixed RFID surveillance system while achieving both objectives of minimizing cost and errors. The proposed model is optimized using GA and SA algorithms. The algorithms effectively optimize the RFID mobile reader network. The reduction in number of readers is from 27 in the full static reader deployment case, which is brought down to 10 static readers using the GA and further reduced to 5 mobile readers on fixed tracks or segments. It is concluded from the parametric variation experiments that the optimized solution evidently minimizes the cost by using fewer readers to achieve sufficient coverage determined based on maintaining a minimum error rate comparable to a greater number of static readers. There are obviously unavoidable tracking errors in any RFID tracking system but an mRTLS system based on mobile readers may offer a cost-effective alternative with acceptable error rates.

Future work includes deploying and testing of the proposed multi objective algorithms for mobile RFID readers navigating on the ceiling mounted tracks in a controlled or constrained or legalized reader track environment.

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7 References


