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Real Time Localization of Victims at an Emergency Site: Architecture, Algorithms and Experimentation

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***Abstract*— During an emergency, determining accurate location of victims is crucial for expediting rescue efforts. In this paper, we present a mass-deployable active RFID RSSI-based real time locating system to localize victims at an emergency site. The system architecture, localization algorithms and experimental results are discussed in the paper.**

The system includes commercial off-the-shelf active RFID readers which are rapidly deployed at known points at the emergency site. A paramedic carrying around a bag of Active RFID tags attaches a tag to each victim as a part of the triage process. Our localization algorithm processes the unreliable RSSI values reported by the above tags using techniques such as tag calibration, tag averaging, time averaging and selective trilateration to estimate the location of the tagged victims. The system was tested in a number of experimental emergency scenarios with satisfactory results. The average error in estimated position of a tagged victim in a 100x100 ft emergency site setting was around 12 ft.

***Index Terms*— Active RFID, Emergency Response, Real Time Locating System, RSSI, Victim Localization**

I. INTRODUCTION

One of the greatest challenges faced by a community's emergency medical system is to effectively handle emergency response following a mass-casualty incident. Typically, during such scenarios, a large volume of responders arrive on-scene to provide assistance to victims. If not well coordinated, this influx of resources may lead to an inefficient utilization of much-needed assets, reducing the effectiveness of the response. In disaster medicine triage, determining the location of victims, relative to the location of available resources is crucial for expediting rescue efforts e.g., the DIORMA system [1]. Using this information, an offsite commander can visualize the scene and guide the onsite personnel in their efforts, thereby improving the effectiveness of response.

In this paper, we present an active RFID RSSI (Received Signal Strength Indication)-based real time locating system which can be mass-deployed at an emergency site to localize victims with satisfactory accuracy. There have been other systems addressing the problem of victim tracking and localization in disaster scenarios [2-4]. However, the following aspects make our system unique and practical:

a. Implementation: Our system uses off-the-shelf active RFID readers and tags for localization as opposed to other solutions with custom made hardware and expensive tags and software packages. This reduces implementation costs.

b. Deployment: The system components i.e. active RFID readers and tags can be rapidly deployed at a disaster scene with minimal setup while the complexity of other systems (custom hardware, fixed deployment techniques [2,3]) make them unsuitable for mass deployment.

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c. Algorithm: Our algorithm incorporates easy-to-implement techniques such as tag calibration, tag averaging, time averaging and selective trilateration to circumvent hardware limitations of RFID localization and achieve acceptable location accuracy. Also, we opt for the calibration/trilateration model rather than fingerprinting taking into account the ad hoc and real time nature of the problem.

The paper is organized as follows: Section II presents the system architecture. Section III discusses the limitations of RFID RSSI-based localization. Section IV presents the localization techniques employed by our algorithm to circumvent the limitations of RFID. The experimental results are reported in Section V and conclusions are discussed in Section VI.

I. SYSTEM ARCHITECTURE AND TECHNICAL DETAILS

At an emergency site, the active RFID readers are rapidly deployed at known positions (along with PDAs for communicating to a local server viz. a laptop). Then, during the triage process, a paramedic moves around with a bag of active RFID tags. Whenever a victim is found, he is tagged (just like with a traditional paper triage tag). The RSSI readings reported by the bag of tags as well as those from the victim's tag act as inputs to the algorithm.

The system architecture is depicted in Figure 1.

Here are the technical specifications of the components used:

- Active RFID reader - RFCode Mantis M220 mobile reader
- Active RFID tag – RFCode M160 wristband tag
- PDA – Motorola MC35 (for Bluetooth/Wi-Fi communication)
- A standard laptop (for running the algorithm)

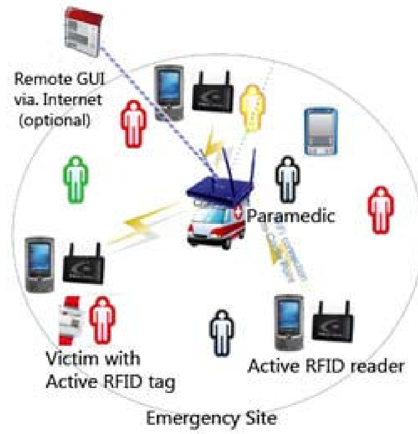

Figure 1. System Architecture

II. LIMITATIONS OF RFID RSSI-BASED LOCALIZATION

In order to demonstrate our algorithm, we first begin with a naïve approach to localization, conduct experiments, measure the localization error and explain the reasons (hardware limitations) behind the error.

For all the experiments, we use a 100 ft x 100 ft experimental grid (see Figure 2). We use five active RFID readers placed at coordinates (0, 0), (100,0), (0,100), (100,100) and (50,50)(shown as blue dots). They are used to localize the victims (marker cones were used during experiments) located at 20 different points within the grid (shown as green dots).

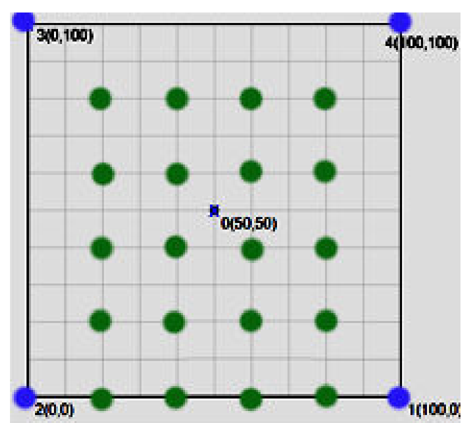

Figure 2. Experimental setup

A. *Naïve approach to localization*

Ideally, there should be a unique mapping from signal strength to distance. Then the distance between the tag and the reader can be calculated accurately from signal strength reported by the readers. With distance measurements from multiple readers, a simple trilateration algorithm can be used to estimate the location of the tags. The results are depicted in Table 1.

Table 1: Localization results for naïve approach

Victim Tag ID	**Actual**	**Estimated**	**Error (in ft)**
807	(60,20)	(53,24)	8
606	(80,20)	(128,29)	49
Mean			31.65

We observe a mean error with a naïve approach is 31.65 ft. We identified several causes leading to such large localization errors. RFID based localization is based on the attenuation of RFID signal strength governed by radio signal propagation models. However, in reality, the measurements are very noisy. It is due to the following reasons:

- Multi-path fading
- Shadowing effect
- Different orientations and heights of the RFID tags and readers: If the RFID tag stays at the same distance from the RFID reader but the RFID tag orientation changes with actions such as playing with the tag, turning around etc., the reported RSSI changes drastically.
- Signal attenuation and interference due to human and other obstacles
- RSSI-distance estimate becomes inaccurate at large distances: By virtue of RFID signal propagation path loss, the noise at larger distances becomes comparable to the signal strength. Hence, the RSSI-distance estimate becomes highly inaccurate.

One measurement from a single tag is too noisy to produce an accurate location estimate. To reduce noise and improve localization accuracy, we average over multiple RSSI readings from multiple tags in a time window. In the next section we present an improved localization algorithm based on these techniques.

III. ALGORITHMS TO IMPROVE LOCALIZATION ACCURACY

Taking into account the observations mentioned in the previous section, we modified the naïve approach that we presented in the previous section by incorporating the following techniques:

A. *Tag Calibration*

We perform tag calibration by using a bag of tags (gives a much smoother curve than when a single tag is used for calibration) to derive the RSSI-to-distance conversion equation. It is as follows:

$$d = p1*S^3 + p2*S^2 + p3*S + p4 \qquad (1)$$

where S is in –dbM, d is in feet. p1, p2, p3 and p4 are the calibration parameters.

B. *Tag Averaging*

We estimate the signal strength at a distance using a set of tags rather than a single tag. However, it is not feasible to tag a victim with a large number of tags. We circumvent this problem by taking into advantage the nature of the triage process itself. Whenever a paramedic P comes to tag a victim A, he carries a bag of tags along. Now, we localize the bag of tags rather than the victim's tag and attribute that RSSI (and thereby the distance) to victim A.

C. *Time Averaging*

We take the time average of RSSI values reported by a tag rather than process individual values. Based on empirical feedback, a set of 10 readings from a tag give a reliable average. Since the beacon rate (frequency) of the active RFID tag we use is 2 sec, the window works out to be 2*10= 20 sec.

Since the paramedic would be in motion for a considerable part of this 20 second window, it helps to achieve diversity and thereby better accuracy.

D. Selective Trilateration

At any coordinate in the grid, the tag (or set of tags) is close to a few readers while it is far from the others. The RSSI values reported by the far away readers are high. As mentioned in the previous section, the RSSI values become innacurate at large distances. Therefore, the distance estimated by them is inaccurate. Hence, we arrived at an algorithm which assigns weights to the RSSI readings reported by the readers for each tag. For instance, if readers R1, R2, R3, R4 and R5 report signal strengths S1, S2, S3, S4 and S5 and S1>S2>S3>S4>S5, we attach a weight of 1 to S1, S2 and S3 and a weight 0 to S4 and S5. In other words, we consider the top-three RSSI readings reported to estimate the position.

Using the new localization algorithm that incorporates the four techniques presented above, we repeated the experiment discussed in the previous section. In each experiment we changed the number of tags used for averaging the RSSI as well as the time window for averaging. The results are reported in Table 2.

Table 2: Localization results for new approach

Number of Tags used for averaging	**Time window for averaging**	**Mean Error – (ft)**	**Variance (ft)**
10	4	22	57
10	8	16.8	39
15	16	12.1	25
15	25	10.3	19

As noticed from Table 2, the location estimation accuracy improves compared with the naïve approach for all cases. Moreover, we observe that the location accuracy (mean and variance) improves as the number of tags as well as the time window increase.

IV. CONCLUSION

This paper presented a mass-deployable active RFID RSSI-based real time locating system to localize victims at an emergency site. The system architecture, localization algorithms and experimental results were discussed in the paper.

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