LOCATING BUILDING COMPONENTS WITHIN A FACILITY USING RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

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ABSTRACT

In case of an emergency during operations and maintenance phase, there is a need to quickly locate a set of facility components. Locating a facility component visually can be difficult when most of the facility components are obstructed by other components in the environment. In addition, in certain cases, first responders to an emergency might not be familiar with the facility; making it harder to identify the relevant components. Thus, there is a need for providing guidance for the first responders to help them quickly locate relevant facility components in case of a problem. Radio frequency identification (RFID) technology provides an opportunity to provide guidance information to first responders due to its on-board data storage capability and long detection/reading range. The objective of this study is to formalize the information needed to guide the first responders to get approximate locations of components under time constraints, and to assess whether signal strength can be utilized for identifying where components are. We conducted a field test on identifying and locating fire valves within a facility at Carnegie Mellon University. The results demonstrate that signal strength data from RFID tags can be used, with some further enhancements, to locate a component.

KEY WORDS

Radio frequency identification, automated location detection, facility management, building information model, signal processing.

INTRODUCTION

In case of an emergency within a facility, there might be a need to immediately locate a set of facility components, such as fire valves, in reaction to the emergency situation. A first responder to a given situation, who is typically either a facility management worker or an emergency response personnel, might not be familiar with a given facility, and thus might not be able to quickly identify critical facility components to remedy the situation. Even if the first responder is a worker in a facility, s/he might not have survey knowledge of the building to navigate effectively (Moeser 1988). Locating a facility component is especially difficult when most of the facility components are obstructed by other components in the

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environment. For example, in case of a broken sprinkler, the fire valve that feeds the sprinkler could be underneath a ceiling panel and hence, might not be visible from outside. Failing to locate a facility component in a short time can result in a large damage to the facility, such as causing flooding in case of a broken sprinkler. Thus, there is a need for guidance for the first responders, who might not be familiar with location of facility components, to help them quickly locate a facility component in case of a problem.

Radio frequency identification (RFID) technology provides an opportunity to guide first responders to some important locations within a facility and to identify the location of related components due to its on-board data storage capability and long detection/reading range. Since RFID tags have limited memory capacity, currently it is not possible to store drawings on RFID tags. However, it is possible to store textual information that can give first responders some directions to components from entrance points of a facility. The research study described in this paper considers utilizing RFID to guide the first responders in (1) approaching the vicinity of a relevant component by making some key location information derived from a building information model available on the tags strategically placed at different locations in a facility, and (2) finding the exact location of a component by using RFID signal strength data. The objective of this study is to formalize the information needed to guide the first responders to get approximate locations of components under time constraints, and to develop reasoning mechanisms to utilize signal strength data for identifying exact location of each component.

To formalize the information needed for finding components and to assess the capability of RFID in helping to pinpoint the location of a component, we have developed an approach for guiding the first responders to the relevant locations within a facility. This approach requires reasoning about the signal strength of tags to pinpoint the locations of the components. We have conducted some initial field tests within a facility at Carnegie Mellon University to assess how reliable the signal strength data is under real operating conditions. The results demonstrate the reliability of signal strength data from RFID tags to locate a component.

BACKGROUND RESEARCH AND RELATED TECHNOLOGIES

Various systems, are being used to locate objects/users within an environment. These systems build on infrared, ultrasound, global positioning (GPS), and radio frequency identification (RFID) technologies (Bahl and Padmanabhan 2000, Bulusu et al. 2000, Hightower et al. 2001). Infrared and ultrasound technology based systems are usually directional, thus do not perform well for finding a component that has an unknown location (Hightower et al. 2001). In addition, infrared systems have limited range, thus have high installation and maintenance costs since they need to be spread densely within a facility (Bahl and Padmanabhan 2000). Systems based on GPS can only operate outdoors since GPS requires line of sight with satellites. RF based systems can both operate indoors and enable longer detection ranges. Several metrics, such as signal time of flight, angle of arrival and signal strength are used for locating objects/users within an environment. Due to complexities in propagation of radio signals, various location finding algorithms and architectures are used to process the metrics (Pahlavan et al. 2002). Among those metrics, measuring signal strength has been identified as the most cost-effective solution since it does not require precisely installed base-stations, centralized control and complex hardware for processing signals (Hightower et al. 2001). While most of the research studies on using RF based systems for locating purposes have focused on locating mobile objects/people in a facility (Bahl and Padmanabhan 2000, Bulusu et al. 2000, Hightower et al. 2001), less attention has been given to locating stationary facility components by a mobile user.

A type of RF-based system, RFID technology, provides an opportunity to locate stationary facility components via individual RFID tags that can be attached to each component. RFID has two main components; a reader and a tag. A tag, which consists of an electronic chip coupled with an antenna, is attached to an object. Reader, combined with an external antenna, communicates with the tag via radio frequency and transfers data to a host computer. Reading and writing ranges depend on the operation frequency (low, high, ultra high, and microwave) and whether the tag needs a battery to operate (active) or not (passive). Active tags have typically longer reading ranges; however, they have a limited life-time requiring battery replacement periodically.

One of the advantages of an RFID tag is to support automatically identification of a component. Another advantage is the data storage capacity within a tag; which is currently up to 32 KB. This can allow for storing key information that guides a first responder to a location. An RFID tag can also be used to locate a component that is within the vicinity of the user by using signal strength data received from the tags. Some tags have LED that notifies the user with a blinking light when they are in communication. This feature can also be used to locate a component visually provided that the user is very close to the tag and the tag is not blocked by another building component.

Previous studies on locating mobile objects/people in a facility using RF-based systems developed algorithms based on triangulation of signal strength data, which is received from one mobile object/people and collected by multiple readers/sensors in the environment. This approach cannot be used for finding stationary facility components since in this scenario there is only one reader that can collect data from a tag. Within the construction domain, only one research effort focused on locating the materials that are scattered on a construction site using RFID and a single reader. This study combined active UHF RFID and GPS technologies to utilize proximity techniques (Song et al. 2005). While this approach provides approximate locations of materials on a construction site, it does not work indoors and does not provide real-time feedback to the user about locations of components-of-interest. Therefore, there is a need to develop an approach to find stationary facility components using one single reader.

Since the reading range of RFID technology is typically limited and smaller compared to the size of a facility, a user will need some guidance that will enable him/her to approach to the vicinity of the components-of-interest before detecting and reasoning about the signal strength of RFID tags attached to the components. Previous research on way-finding shows that receiving directions is more advantageous than use of maps (Satalich 1995). This points out a need for directions available to the user as the user enters a facility.

PROPOSED GUIDANCE SYSTEM

The proposed guidance system utilizes RFID tags for three purposes: (1) *For giving directions,* by conveying location information of facility components and directions to that location to assist the user in approaching to the vicinity of those components, (2) *For guidance*, by notifying the user of the key points on the route as the user follows the directions, (3) *For identification*, by automatically and/or visually identifying the component when the user is close to the component. The proposed system with an example use case is shown in Figure 1.

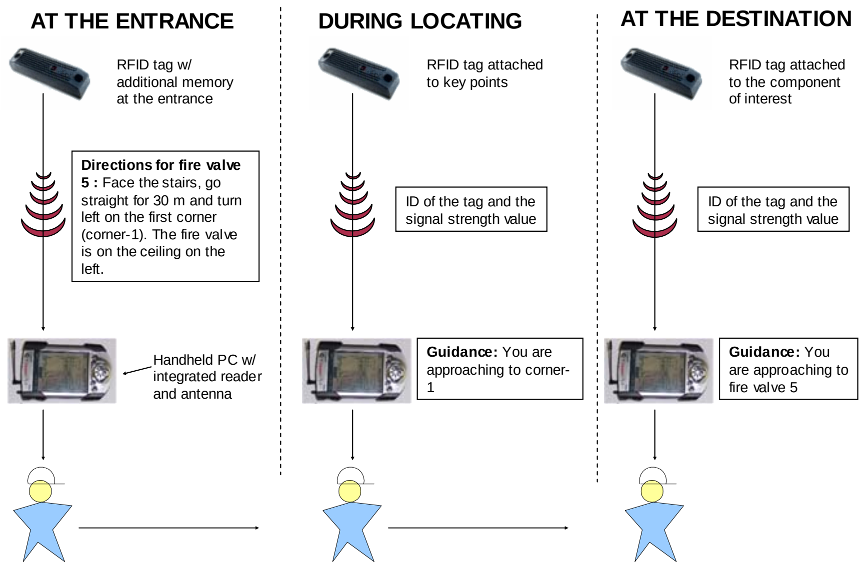


Figure 1: Proposed system with an example use case

Downs and Stea (1973) proposed that way-finding is performed in four steps: Orientation, route decision, route monitoring, and destination recognition (Satalich 1995). The proposed system will assist the users in following these steps as explained below using the example use case given in Figure 1.

- "Orientation" of the user is to determine one's location with respect to nearby objects and target location at the beginning of way-finding. We assume that in case of an emergency, user enters to the facility through one of the entrance doors of the facility. Thus, in assisting the user for orientation, entrance doors will be considered as a starting point, and guidance information will orient the user with respect to a key point close to that entrance door, e.g., turn your back to the entrance door and face the stairs.
- "Route decision" is deciding which route to follow to locate a component. Butler et al. (1993) demonstrated that users prefer the shorter routes, regardless of how complex they are (Satalich 1995). In our case, shortest route is even more preferable due to the time constraint. To prevent the user losing time in choosing a route, directions for only the shortest route to the component of interest will be included in the guidance system. The route information includes: (1) Direction of walk, e.g., walk straight ahead, turn left, (2) Length of walk, e.g., walk straight ahead for 5 m., (3) Key points (landmarks) on the route, e.g., turn right at the second corner.

- "Route monitoring" is ensuring that one is on the correct route. In wayfinding, users can make three major errors: turning in the wrong direction, turning on the wrong hallway, and passing the destination. To help a user to minimize first two errors, RFID tags will be placed at key points on the routes, where a user makes a turn, i.e., corners. Signal strength values of RFID tags will be used to notify a user when the user is within the vicinity of each key point, e.g., you are approaching to corner-1. A proposed solution for the last type of error is explained in the next paragraph.
- "Destination recognition" is recognizing that one has reached the correct destination, or at least to a point nearby. To help users in recognizing the destination point: (1) key points that are nearby will be included in the route information, and (2) signal strength values will be used to notify the user when the user is in the vicinity of the component, e.g., you are approaching to fire valve 5.

A building at Carnegie Mellon University was chosen to test the feasibility of the proposed approach. The building was chosen due its large gross area (22,300 m^2) with multiple entrances and thirteen fire valves scattered throughout. Figure 2a shows the layout of the first-floor including locations of fire valves and entrance doors, and proposed location for guidance tags and direction tags with their reading range. Direction tags are placed at points where their reading range covers the area around the entrance doors. To help in monitoring the route, guidance tags are placed at corners where user needs to make turn.

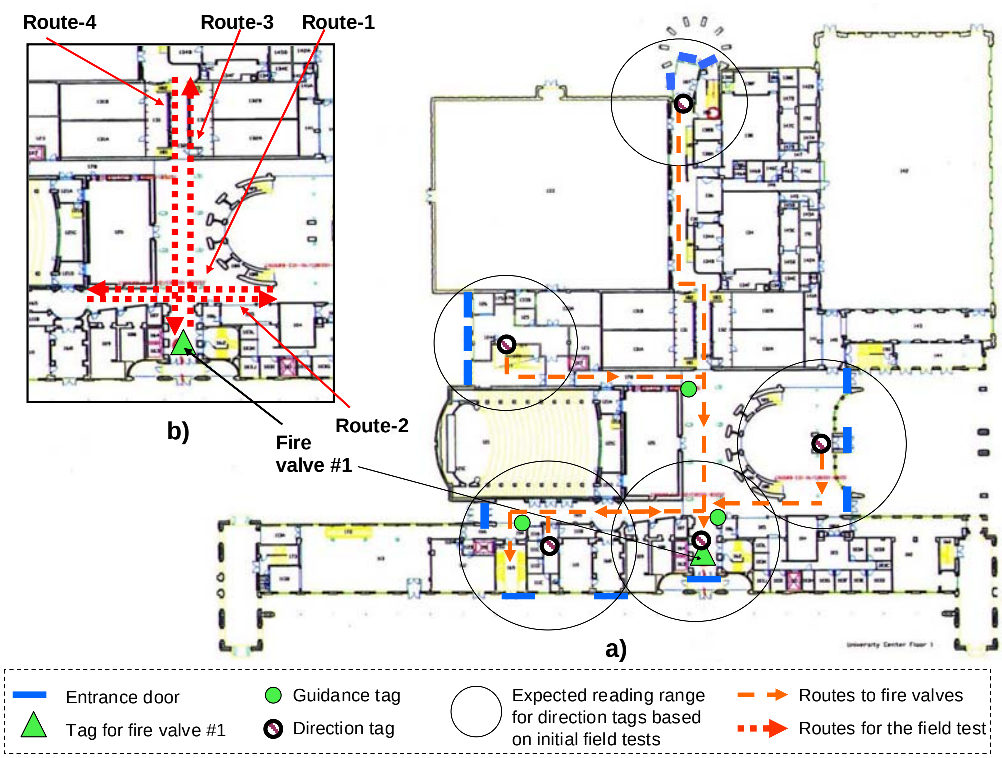


Figure 2: a) Examples of utilization of RFID tags in the field study, b) Routes that the tester followed during the field tests

To test the feasibility of the proposed system, we first decided to test the reliability of signal strength data within the context of the facility since that is a critical component of the proposed approach. The other components of the proposed approach can be adjusted by changing the numbers of and the locations of tags used for giving directions. A field test was performed by collecting signal strength data from a RFID tag and results were analyzed to determine if signal strength data can be used for guiding users in a facility.

TECHNOLOGY SELECTION

To store directions minimally for ten facility components in a text file, data storage capacity needs to be at least 5 KB for tags providing direction information. Reading/detection range of the tags should also be long (>5-10 m) and non-directional to allow for locating the tag once the user gets to the approximate location using the directions. We identified active UHF RFID technology as the most suitable technology due to its longer non-directional reading distances and large memory capacity. We selected a technology supplier that provides two types of encapsulated tags (normal power and high power) designed to work effectively around metal with a large memory (32 KB) and a long reading distance up to 30 m and 90 m respectively. The tags also have a LED that allows for visual recognition. The entire RFID system is composed of a reader, an antenna and a tag. The reader is in the form of a PCMCIA card which is plugged into a laptop or a pocket PC. The 1/4 wave dipole (linear) zero-gain antenna is directly attached to the reader, and reader communicates with tags through this antenna.

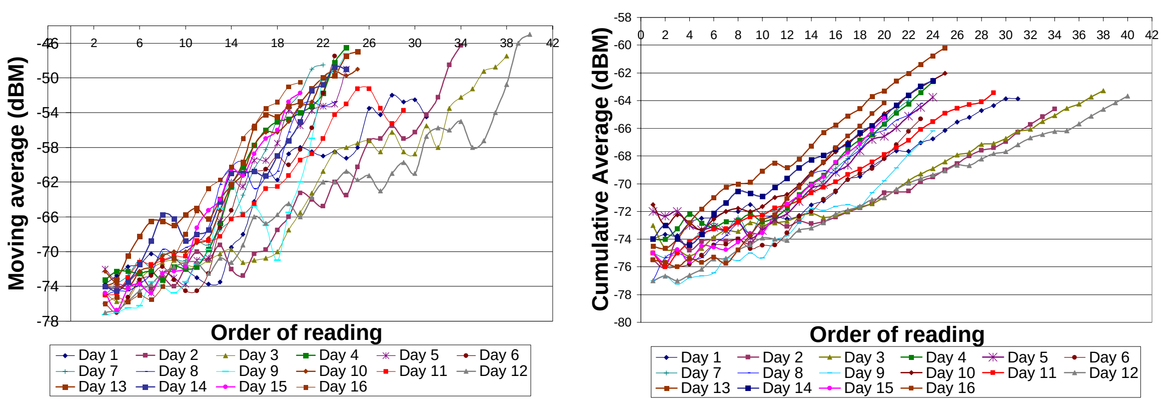
A set of tests performed in the field as part of a previous study showed that reading range decreased to 3-27 m and 8-44 m for normal and high power tags respectively compared to 30 m and 100 m specified by the manufacturer due to other building components in the environment (Ergen et al. 2005). However, the observed reading distances still met the requirements identified.

FIELD TESTS

A high power UHF RFID tag was attached to a fire valve located underneath a metal ceiling panel on the first floor of a three-storey building. The area, where the ceiling was located, was surrounded by two walls and a door. One side of this area is open where two hallways cross. Four routes were designated for the tester to follow (Figure 2b). Route-1 goes to West and Route-2 goes to East, and both are on the same hallway (Hallway 1) that runs perpendicular to another hallway which goes directly towards the tag (Hallway 2). Route-3 goes away from the tag to the North and Route-4 comes towards the tag to the South on Hallway 2. A tester followed those routes for 28 days and collected signal strength data from the tag for each route. To collect signal strength data, we developed an application using API of the RFID software. The application gets signal strength data from the reader at every two seconds and sends it to a database with a timestamp. 25-40 signal strength data sets were collected at each route for a given day.

ANALYSIS

Collected signal strength data was analyzed to determine if signal strength data can be used to locate components. The analysis showed that irregularities exist in the signal strength data. For example, at certain times, as the experimenter approaches the tag, signal strength value decreases instead of increasing. A major challenge in eliminating the irregularities is associated with the need for providing real-time feedback to the user as data was being collected. This need does not allow for analyses, such as trend analyses, that can be performed once entire data is collected. To eliminate the irregularities, we calculated "moving averages" based on the last four data sets given in a situation and "cumulative averages" for the whole group of data that was collected for each route. Moving average is a statistical technique used to analyze time series. Moving average approach calculates the averages of the last n number of data, and when calculating successive values, a new value comes into the sum and an old value drops out. Cumulative average calculates the average of all the data collected up to that point. The graphs for moving average and cumulative average approaches are given as an example in Figure 3. Those signal strength data sets were collected on an approaching route (Route 4) for the first sixteen days. As seen in the graph, irregularities still exists, but it has especially less in the cumulative average values (Figure 3b).



a) b)

Figure 3: a) Moving average and b) cumulated averege values calculated for signal strength data on an approaching route (Route 4)

To analyze if moving average or cumulative average can be used to guide the user, the ratio of correct guidance was determined for both approaches and compared to the correct guidance provided by raw data. Correct guidance is correctly informing the user if s/he is approaching to the fire valve or walking away from the fire valve. Overall performance of the cumulative average approach (86%) was better than the moving average approach (76%) and raw data (62%) (Table 1). Therefore, we focused on the cumulative average approach in the rest of the analysis.

Table 1: Percentage of correct guidance

Data type	Hallway 1		Hallway 2		Total
	Route 1 (%) (approach & walk away)	**Route 2 (%)** (approach & walk away)	**Route 3 (%)** (walk away)	**Route 4 (%)** (approach)	**(%)**
Raw data	66 %	66 %	60 %	58 %	62 %
Moving average	74 %	81 %	72 %	76 %	76 %
Cumulative ave.	77 %	84 %	96 %	85 %	86 %

Comparison of the percentage of correct guidance for cumulative average approach in each individual route shows that routes in Hallway 2 (Routes 1 and 2) are observed to perform better (96% and 85%) than the ones in Hallway 1 (For routes 1 and 2, 77% and 84% respectively). To investigate the reason behind this behavior, incorrect guidance information is classified as "false negative" and "false positive" guidance, and percentage of false negative and false positive guidance was determined for cumulative average approach (Table 2). False negative guidance includes the instance where the tester is incorrectly informed that she is moving away from the tag when in fact she is approaching to the tag. False positive guidance occurs when the tester is told that she is approaching to the tag although she is walking away from the tag. Percentage of false negative guidance is calculated as the ratio of false negative guidance to the total guidance among the data that was collected as the tester is approaching to the tag. Same approach is used for calculating percentage of false positive guidance.

Table 2: Percentage of false negative and positive values in the cumulative average approach

	False negative (%)	False positive (%)
Route 1	14	28
Route 2	13	20
Route 3	-	4
Route 4	15	-

Percentage of false positive guidance is observed to be significantly higher in Route 1 and 2 as compared to percentage of false negative and to other false values in Routes 3 and 4 (Table 2). The reason is determined as the types of movements that the user performs with respect to the tag in Route 1 and 2. In Hallway 2 on Route 3, the tester is walking away from the tag while on Route 4, she is walking towards the tag. Thus, there is only one trend for signal strength data for those routes: for Route 3, signal strength data is in a decreasing trend and for Route 4, it is in an increasing trend. In Hallway 1 on both Route 1 and 2, the tester is first approaching to a tag up to a point where she is in line with the tag, and from that point on she starts to walk away from the tag. This results in an increasing trend followed by a decreasing trend in signal strength data. Having two trends in the data set distorts the performance of the cumulative average approach. While the tester is walking away from the tag, increasing trend in data that was collected when she was approaching, is still included in the calculation of the average. The investigation of false positive results that shows that this inaccuracy is especially observed at the peak points where the tester has just passed the tag. Approximately 60% of false positive data in Route 1 and 50% of false positive data in Route 2 is observed in some or all of three readings following the peak point. The reason is that right after these peak points, most of the collected data is still in an increasing trend due to approaching motion which has just been finished.

To minimize the number of false guidance in this approach, we analyzed the false guidance information pattern and identified that false values occur mostly one, two or three times in a row (85% of the time). If the guidance feedback to the user is provided after processing four data sets, changes in the guidance information (approaching vs. walking away) will be reported to the user only if the same guidance information is received more than three times. With this approach, the number of false guidance will decrease approximately by 85%.

CONCLUSIONS

Proposed guidance approach assists a user in way-finding (orientation, route decision, route monitoring, and destination recognition) in a facility in case of an emergency. It utilizes RFID tags for three purposes: (1) *For giving directions*, by conveying location information of facility components and directions to that location to assist the user in approaching to the vicinity of those components, (2) *For guidance*, by notifying the user of the key points on the route as the user follows the directions, (3) *For identification*, by automatically and/or visually identifying the component when the user is close to the component.

To test the feasibility of the proposed system, the reliability of signal strength data in real-life environment was tested on fire valves located in a building at Carnegie Mellon University. The collected signal strength data was analyzed to determine if applying moving average and cumulative average techniques could eliminate irregularities and enable reliable guidance to the users. Moving average values for the last four signal strength data and cumulative average values for data was calculated. The results showed that overall performance of cumulative average approach (86%) was better than the moving average approach (76%) and raw data (62%).

To minimize the number of false guidance in this approach, we analyzed the false guidance information pattern and identified that false values occur mostly one, two or three times in a row (85% of the time). If the guidance feedback to the user is provided after processing four data sets, the number of false guidance is expected to decrease approximately 85%.

Future research includes performing more detailed field tests by attaching tags to fire valves in other locations and collecting additional data to statistical analysis. In addition, to increase the reliability of signal strength data, signal strength values from multiple tags will be collected in the environment and will be correlated.

ACKNOWLEDGMENTS

The authors also greatly appreciate the assistance and support received from Martin Altschul, Don Coffelt and Carnegie Mellon University facility management group.

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