A Path Based System for Guidance in Pervasive Environment

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Abstract—A guidance capability in an indoor pervasive environment has many important applications ranging from guiding a visually impaired person to helping a search and rescue personnel. We propose a low cost and scalable solution that incorporates inexpensive RFID tags in the environment and asks the mobile users to carry an RFID reader to sense the environment. Our proposed solution will provide information to the user about the user's current approximate location, object of interest surrounding that location and a guidance information toward a specific destination. We use a system abstraction called virtual station which is a distributed component that creates a path abstraction among the virtual stations to provide adequate guidance information. We have presented the system architecture and a proof of concept implementation of our system. The evaluation of our system shows the feasibility of such a system in an indoor environment.

I. INTRODUCTION

We are observing an increasing number of location aware services with the advent of technology. There is a wide variety of applications based on location specific information for the outdoor world which uses widely adopted techniques like GPS [1]. There are still challenges remaining in the indoor applications that can guide us given a source to destination information. A visually impaired person asking for a way in a complex indoor environment (e.g. hospital building), a rescue personnel looking for an object of interest or an automated robot finding a path in an indoor building are example applications that can benefit from such guidance information.

There have been research work intended for indoor positioning systems such as the active badge location system [2], the Radar system [3], the Cricket system [4], LoTTrack [5] and Landmarc [6]. The goal of these systems is to figure out precise location information in an indoor setup. Our intention is complementary to these existing solutions. The goal is to provide guidance information rather than accurate position information. A more detail related work study is done at the related work section (please refer to section V).

An indoor environment that requires location and routing specific support must consider a solution that is low cost, reliable, easy to deploy and must meet the time sensitive nature of different applications. For example, a rescue personnel seeks for immediate responses in a disaster scenario where the response time is not very critical for the case of a tourist taking a self guided tour. Our solution approach considers deploying low cost RFID tags in the environment and a scalable system that creates a logical path to guide the various mobile users (e.g. handicapped person, rescue person) equipped with an RFID reader. We consider a data flow driven approach as our solution strategy. Mobile users in an indoor environment create a path from its initial location toward the destination location. A solution that is aware of the data flow at the system level should be able to provide various location and route specific services such as searching, routing, re-routing etc.

We propose the system abstraction virtual station which is the computational element of the middleware. The system may contain one or more virtual stations based on the geographic span of the application. The key abstraction the system uses is the path abstraction which gets created based on the user's input regarding the source to the intended destination location. The system is able to provide the user with valuable routing information based on the system's notion of path. In our proposed work, we study the requirements of an indoor location aware application and propose a middleware architecture that facilitates such application. We demonstrate the feasibility of our system by experimental testbed results in a real indoor environment.

The rest of the paper is organized in the following way, the use cases and requirement analysis is studied in section two, the system architecture is presented in section three which is followed by the evaluation in section four, section five discusses the related work and we conclude our work at section six.

II. USE CASES AND REQUIREMENT ANALYSIS

RFID tagged environment is considered for various application perspectives due to the low cost and ubiquitous nature of the RFID technology. Once such an environment is set up with reference RFID tags (for guidance) and object tags (to locate object of interest), various applications can be developed to take advantage of such an environment. The various use cases and the design goals for the middleware system are presented in the following subsections.
A. Use Cases

The possible use cases for the path based guidance are described in this section. We consider three specific use cases that requires path creation and routing specific input to the mobile user to navigate through the indoor environment. The environment is assumed to have reference RFID tags placed at various predefined locations. The mobile object, which can be a human or a robot that is able to navigate if provided with appropriate information, carries an RFID reader to realize the approximate current location and determine routing information.

In the first use case, we consider guidance for visually impaired person where a visually impaired persona faces the challenge to figure out a specific route to an intended destination in an unknown complex indoor environment. It can be a hospital, large office area or similar indoor environment comprised of multiple routes and options which can be challenging to explore. The second use case considers, search and rescue scenario where a human rescue personnel or robot equipped with important sensors (e.g. smoke detector) needs guidance through the scenario. It is extremely important to get environmental support to find out specific routes to reach a destination, be able to make an alternate route once a particular route is not approachable and to be able to share the information with others in the same environment. The robot guidance considers the proper support from the environment to create a specific route will allow a robot to make routing decisions and learn about the environment in various application specific context. The use cases are different but each have some common requirements - a guidance information is needed in all three scenario while the system response time requirements vary for different applications. For example, the system must respond in soft real time for the search and rescue applications which may be relaxed for the guidance for visually impaired person application.

B. Requirements

We discuss the application requirements in this section. From the user’s perspective, the middleware service should be able to provide information about the environment to mobile objects. The current location information service considers that the mobile object should be provided with its current location information within a certain bound of error. The route specific information specifies, given a source and destination location, which is in most of the cases, the current position of mobile object to a destination location, the system should be able to provide adequate routing information. The map of current location asks that the system should be able to provide a map of a particular geographic region in case the mobile agent is interested in location objects of interest on its own. The surroundings information provides that the system should be able to provide location aware services offered in object’s current location along with important landmarks, references in the current region. The application should have the flexibility to define the granularity of the region. And finally, the information sharing requires that the system must provide a scope where incoming mobile objects interested in information sharing can be discovered and contacted by other such mobile objects. The system architecture and implementation must take into account various application requirements with respect to the use cases discussed in this section. The detailed architecture is presented in the next section.

III. Proposed Architecture

The proposed system architecture presented in Figure 2 considers the required services mentioned in the previous section. We propose a distributed architecture for scalability, especially when the deployment involves large geographic area. The system consists of the distributed computation element virtual stations (VS), a name server, the mobile objects (MO) and the pervasive environment (PE).

A. Pervasive Environment (PE)

The pervasive environment is where the mobile object (MO) gets served. It is divided into subdivisions named regions and each of the regions are equipped with reference tags. The regions are defined as \( R = \{ r_1, r_2, r_3, ..., r_n \} \). Every VS is in charge of a particular region. Although the mobile objects...
travel through distinct regions, internally the VSs maintain some overlap among the regions for improved performance. The regions are divided among the VSs based on the maximum probable mobile objects \(M_{max}\) in a particular time of operation and the VSs capacity to respond to the queries within a predefined time window \(t_{win}\). Each region \(r_i\) contains set of reference tags for that particular region defined as \(T(r_i) = \{t_1, t_2, t_3, ..., t_n\}\). The virtual stations are responsible for making proper guidance decisions based on the reference tags and mobile object positions.

B. Virtual Station (VS)

The virtual station is the distributed service provider. Each VS is in charge of serving the users in a particular geographic region. The VS provides guidance information to the MO based on the information provided by the MO about its current approximate location. Initially, the VS uses a four step process: evaluate current location, initial path creation, dynamic path update and if necessary, re-initialize path creation. The VS first figures out the initial location of the MO and based on that information creates a path across the region. As the MO traverses through the path and updates its surrounding information - the VS needs to update the path dynamically according to the MO movement and may need to instantiate a new path creation request if the current route no longer corresponds to the initial path creation.

1) Approximate Location Information: Given a mobile user’s Reader power information and corresponding set of visible tags \((\text{Power}_1, \text{tags}_1\{t_1, t_2, ..., t_x\})\), \((\text{Power}_2, \text{tags}_2\{t_1, t_2, ..., t_y\})\) ... \((\text{Power}_n, \text{tags}_n\{t_1, t_2, ..., t_z\})\), the VS provides an approximate position of the user within the time window \(t_{win}\). Ideally, a VS should be able to approximate the current location based on the set of the visible tags with the minimal power level. But the RFID reader encounters false negative reads where the reader is unable to read an item within its physical reading range and false positive reads where the reader reads an item beyond its physical reading range that complicates the entire process. The algorithm to find out approximate location is very straightforward which follows the three consecutive steps.

- **Power Adjustment Step:** The reader adjusts its power level to a minimal level \(\text{Power}_{min}\) where it is able to read at least \(\rho\) tags surrounding it. The reader starts this step by setting its power level to its minimum detection range. Then the reader increases the power level until it is able to read its surrounding tags. The number of surrounding tags to read can be set by the application program depending on the accuracy requirements.

- **Reader Orientation Adjustment Step:** In this step, the reader orientation is adjusted based on the current readings. The reader reads the individual tag readings by each of its antennas and makes an assumption of its current orientation based on the list of tags. This step is important as the reader orientation plays an important role in tag detection as well as the system will provide guidance information based on the initial orientation information.

- **Sampling Step:** The last step requires to take samples of tags based on an allowable error threshold value \(\epsilon\). The value \(\epsilon\) can be determined by the application, an \(\epsilon\) value of 0.3 indicates the system must make sure that 70% of the samples are consistent in terms of items read. The system keeps taking samples of tags until the set of visible tags are stabilized to detect set of tags \(\text{tags}_{\text{detected}}\{t_1, t_2, ..., t_p\}\). The approximate tag location is determined as a function of the \(\text{tags}_{\text{detected}}\) tags. In a grid type spacing, the location can be determined by the average of the locations of the \(\text{tags}_{\text{detected}}\) tags and the error of this method depends on the inter tag distance and is bounded by \([\text{interTagDistance}/2 – \text{average}(\text{tags}_{\text{detected}})]\).

2) Path Creation: The path creation process takes place in several stages. At the **initialization phase** the path creation process is initiated by the name server which keeps the information about all the active VSs and corresponding geographic location based information. The name server creates an initial request to the corresponding VSs in the geographic span from the MOs current location to the destination location. Each VS responds to the name server once the corresponding VSs agree to serve in the path creation process in the **VS selection phase**. In the **path creation phase** each VS crates a sub path in its region based on reference tags and the VSs collaboratively create a complete path as a sequence of reference tags \{ \text{start}, t_1, t_2, ..., t_{\text{end}} \}. Finally, in the **guidance phase** this sequence of reference tags is then translated to the mobile user as a sequence of relative movements from it’s current location. The path creation can take place statically at the initialization of the system and dynamically while the objects are in motion and require frequent update or to respond to route specific query.

3) Query Management, Map Creation and Information Sharing: The VS is in charge of query management where the system is able to provide information about the current approximate location of a mobile object given tag specific information in reader’s vicinity, there can be route specific queries and information about the surroundings of a particular MO. A request for **map creation** for a particular geographic location requires one or more VS coordination. The set of VSs involved for the particular region are defined and corresponding tags in that region are presented along with the relative positions of the tags. The mobile user may use the map to explore the region on its own. There are applications where mobile users are interested to coordinate among themselves (e.g., a rescue scenario where rescue personnel need to coordinate) for **information sharing**. The mobile user can query for the current locations and contact points of the mobile users where the information is updated within the time window \(t_{win}\) through the name server.

C. Mobile Object (MO)

The mobile object MO contains an RFID reader device \(\text{Reader}(\text{Power})\) which is defined by the power parameter. Here the reader \(\text{Power}\) can be adjusted into a operating power level allowed by the manufacturer and is within the given range.
as: \( \text{Power}_{\text{max}} \leq \text{Power} \leq \text{Power}_{\text{min}} \) where the reader is able to read in its maximum strength with \( \text{Power}_{\text{max}} \) and minimum strength with \( \text{Power}_{\text{min}} \) respectively. The mobile user is equipped with a limited capacity computational and communication device \( D \) that communicates to a particular \( VS_i \) when the user resides in region \( r_t \). The MO registers itself to the name server once it enters the environment. It queries the appropriate VS through the name server for various services offered by VSs.

D. Name Server

Name server keeps the global information about the list of VSs and the active MOs to improve the overall system performance. It initiates the path creation process that aides guidance service through the VSs.

IV. Evaluation

The system evaluation presented here is limited with respect to the use cases. The study presents a preliminary evaluation of the read accuracy of the proposed architecture with various tag placement options.

A. Implementation

The current setup consists of a pervasive indoor environment equipped with 24 reference tags, a single virtual station and a mobile object that communicates to the virtual station using blue tooth interface. We have considered two different tag placement strategies: in the single tag placement strategy, we have placed equally distant single tags in a grid like manner; in the multiple tag placement strategy, we placed three tags in a grid like fashion. The system parameters for the experiment are presented in Table I.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader</td>
<td>Mobile Active RFID reader (M220)</td>
</tr>
<tr>
<td>Reader Position</td>
<td>Mobile</td>
</tr>
<tr>
<td>Reader Sensitivity</td>
<td>-58 dB to 108 dB [22]</td>
</tr>
<tr>
<td>Reader Power Level</td>
<td>Eight factory programmable range settings with 5 dB increment</td>
</tr>
<tr>
<td>Tags</td>
<td>24 Active RFID tags</td>
</tr>
<tr>
<td>Tag Placement</td>
<td>In a ( 2 \times 2 ) grid uniformly spaced</td>
</tr>
<tr>
<td>Inter Tag Distance</td>
<td>Variable</td>
</tr>
<tr>
<td>Tag Position</td>
<td>Static</td>
</tr>
</tbody>
</table>

B. System Evaluation

The pervasive environment is studied in terms of adequate placement of reference tags for approximate location information and guidance capabilities in this subsection. We refer to the following terms in our discussion: false positive which refers to readers ability to read beyond is physical reading boundary and false negative which refers to the inability of a reader to read a present object within its boundary.

1) Approximate Location Information: There are three factors that play the important role in the approximate location detection: the number of sample reads, the reader power level and the inter tag distance. We present our study on these factors here.

- Read Samples: The individual tag reading contains false positive and false negative reads. The read accuracy of the reader can be increased by taking into account multiple read samples. Figure 3 illustrates how the cumulative sampling reduces the error distance in detecting the approximate location. The study presents the mean square error along with the actual deviation of reading using a setup where the tags are placed 20 cm apart from each other. It shows how the cumulative number of sample reads deviate from the actual position using the mean square error distance and the decreased error distance for individual samples. The sampling has been conducted with the same setup but varied with time. The system has to trade off accuracy with execution time. For example, the system is able to calculate a location value that has 95% tolerance value using 750 sample reads which requires 2.37 seconds of sampling time.

![Fig. 3. Error in Tag Detection for 20 cm Inter Tag Spacing](image)

- Reader Power Level: We have set the reader to its minimum power level (power level 1) which is increased gradually until the next tag is not detected. The reader is able to detect all the tags irrespective of its power level when the tags are placed within the range of 10 cm. That is why we studied the reference tag placement using an inter tag spacing of 20 cm and onwards. The reader requires to increase its power level to at most power level 2 in our limited laboratory setup. A higher power level is not able to distinguish the relative positions of the tags in the environment.

- Inter Tag Distance: The inter tag distance plays a very important role in determining the approximate position of the object. We have considered placing a single tag placement in this study. Figure 4 presents the error in percentage associated to the approximation based algorithm. Initially, we have considered the tags based on highest
power levels to determine the border tags, the tags that are surrounding the Mobile Object. As can be seen, the system incorporates around 50% of error to determine the approximation based location of the reader. We have used a method to eliminate some false positive readings based on our prior knowledge of tag placement. In this method the system tries to determine four tags surrounding the object. This method works well when there is only one false positive read with high power level.

![Fig. 4. Error in Tag Detection Varying Tag Distances](image)

C. Guidance

We have studied the system’s capability of guiding a mobile object in an “L” shaped setup (only one turn to take from source to destination) as shown in Figure 5. Individual tag placement mechanism shows many false negative and false positive reads. The system is able to minimize the effect of false positive reads using the predefined tag placement information and the signal strength information of the tag reads. But the false negative readings provide challenges to the system. We have placed redundant reference tags in the environment instead of single tags to mitigate the false negative reads. Figure 6 (a) presents the individual false negative and false positive readings comparing the single and multiple tag placement strategy. We have used three reference tags in the multiple tag placement technique. Placing multiple tag increases the probability of detecting a reference location as shown in Figure 6 (b). Here a reference information is achieved in the case of multiple tag placement if any one of the three reference tags which shows 100% detected items compared to 81% detected items in the case of single tag placement strategy.

Our study provides insight toward the applicability of RFID technology for a pervasive environment and various parameters to take into account when such an environment is setup.

V. RELATED WORK

It is interesting to note that work related to ours falls across fairly diverse domains. We briefly review each of these related areas in this section.

A. Positioning Systems

There are research work aimed for item location that is able to provide location support using various sensor technologies. The active badge location system [2] location system is developed to track people in the office space. It uses IR signal which has the drawback of the line of sight problem along with the support for short range of signals. Radar [3] uses RF signal based location information and considers the signal strength information gathered at multiple locations to triangulate user location information. The Cricket [4] system uses ultrasound signals to find out precise location information. It proposes a scalable infrastructure where infrastructure transmits signals to a passive mobile device and the device calculates possible distance from the input it receives. The objective here is to find out precise location. LotTrack [5] uses multiple modality of sensors for accurate location information. Landmark [6] uses active RFID readers and reference tags as an inexpensive solution for indoor location sensing. The positioning systems mentioned above aim to provide precise location information. Our work is complimentary to the mentioned research efforts. Our middleware architecture may be laid on top of any of these location systems. Designing a new location system is not the objective of our work. We have used a low cost RFID based approximate location system to lay out our middleware architecture. Our proposed solution strategy considers the middleware level requirements to support guidance information to applications.
B. RFID Based Systems and Path Abstraction

There have been research work that focuses on middleware for RFID based systems. The systems like Savant[11], RFIDStack [9], High Fan-in Systems [10] and WinRFID [8] considers item tracking applications as opposed to guidance applications. RF2ID [7] exploits the data flow for item tracking applications as opposed to guiding techniques. The concept of path is used in many different contexts including fault tolerance [21], profiling distributed systems [15], [16], and resource allocation [17], [18]. Scout OS [19] defines path abstraction to navigate through the layers of the network stack and Ninja project [20] utilizes path abstraction as a way to compose multiple services distributed on the Internet into a single logical unit. Our work is inspired by the use of paths in these various contexts.

VI. Conclusions and Future Work

RFID based technology can be a low cost solution to provide a pervasive environment that is able to provide guidance information for various applications. We propose a solution that will have inexpensive RFID tags installed in the environment and a mobile object equipped with an RFID reader can get guidance information from the system. We propose two major system abstractions, virtual station that is the geographically distributed computational element and the path that creates the logical path among the virtual stations. We have designed the basic system architecture that is able to meet the various applications that require guidance specific information in real time. We have implemented a proof of concept system in small scale that uses the basic system architecture and evaluated it for its performance. We have studied the systems capability of providing approximation location information and guidance information based on various tag placement methods and the system is able to provide adequate guidance information showing the feasibility of the proposed system. We plan to extend this experimental testbed to include multiple virtual stations and mobile objects to study the scalability as our future work.

REFERENCES


