

Abstract

Spatial Alarms are an important class of personalized location based services (LBSs) that are triggered by a specific location of a moving user, instead of time. A pedestrian may plan to buy a medicine from a pharmacy while walking through a city or a tourist may want to have the dinner at a restaurant while taking a scenic walk at a unfamiliar place. Spatial alarms enable users to know if a point of interest (POI) such as a pharmacy or a restaurant comes within a specific range of the pedestrian. In this thesis, we introduce an efficient approach to evaluate spatial alarm queries in the obstructed space. Existing work in this area has focused mainly on the Euclidean space and road network models. However, the movement of a pedestrian is restricted with many obstacles like buildings, fences or vehicles. To trigger the spatial alarm for a pedestrian, an LBS needs to continuously check whether the specific type of POI is within the specific range of the current location of the pedestrian, which incurs high query processing overhead. We exploit geometric properties to refine the POI and obstacle search region in the total space and develop a technique to identify the area, where a pedestrians movement does not need to retrieve any new POI or obstacle from the LSP. Our approach avoids the retrieval of same POIs and obstacles from the LSPs databases. We perform extensive experiments using real data sets and show that our approach is significantly faster and requires less IO than a nave approach.

Chapter 1

Introduction

The high availability of smart phones has led to the proliferation of location based services. Starting from static LBS (Location Based Service) such as finding the nearest pharmacy for a user's location, now-a-days LBSs are tailored for moving users. According to many, the next step in location based services is Spatial Alarms. Many believe this particular feature is going to dominate the future mobile-phone computing systems. Spatial alarms are an extension of time-based alarms. It is, however, triggered by a specific location irrespective of time. "Remind me if I'm within 100 meters of a pharmacy" is a possible example of a spatial alarm. It is a personalized location based service which can vary from user to user.

It is noteworthy that spatial alarms are quite dissimilar to spatial range query. Spatial alarms are based on a fixed location thus applying the techniques that are used in answering spatial range queries is both inefficient and wasteful for the two dominating reasons, Firstly, in spatial range query as the user is the main point of interest, continuous re-evaluation of her location is needed in case of a mobile user. In contrast, spatial alarms need only be re-evaluated when the user is approaching a specific location. Secondly, in spatial alarm, the main point of interest is a static location. So the user's location is not relevant at all times. It is quite clear that applying spatial range query techniques in evaluating spatial alarms is going to result in wastage of resources. If we start to evaluate spatial alarms as soon as the user is on the move even if the user is far away from her desired location our efforts will be futile.

1.1 Problem Setup

Existing research has categorized spatial alarms into three types: Public, Shared and Private. Public alarms are alarms which are active for every user within the system, such as an alarm must be sent to everyone within 100 meters of a building on fire. Private alarms are user defined alarms which can be viewed by the user, such as a user might set an alarm to alert her if she is within 100 meters of her favorite coffee shop. Shared alarms are shared between specific groups of people. In the previous example if a user chooses to share the alarm for the coffee shop with some of her friends it becomes a shared spatial alarm. In [BLIY09] spatial alarms has been categorized into three different types: 1) Moving subscriber with Static target, 2) Static subscriber with Moving target 3) Moving subscriber with Moving target. In this paper we are only considering the first type, that is Moving subscriber with Static target. In [ML10] spatial alarm region have been approximated by rectangular bounding box, in our approach we are considering the spatial alarm region as a circle with radius r .

Obstructed Space Path Problem [SHK14] denotes the problem of finding the shortest route between two query-points in Obstructed Space where non-intersecting 2D polygons represent *obstacles* and where the route does not traverse through any obstacles. The length of the Obstructed route between points a and b is called the *Obstructed Distance* between a and b , denoted by $dist_o(p_i, q)$.

A **Spatial Alarm Query in Obstructed Space** is formally defined as follows: Given a moving query point q and a range r for an alarm, a Spatial Alarm Query returns $\forall p_i \in P = \{p_1, p_2, p_3 \dots p_n\}$ which have $dist_o(p_i, q) < r$

1.2 Preliminaries

Spatial alarms are location-based, user-defined triggers which will possibly shape the future mobile application computations. They are distinct from spatial range query and do not need immediate evaluation after the user has activated them. The spatial alarm evaluation strategies are judged based on two features, High accuracy and High system scalability. High accuracy refers to the quality

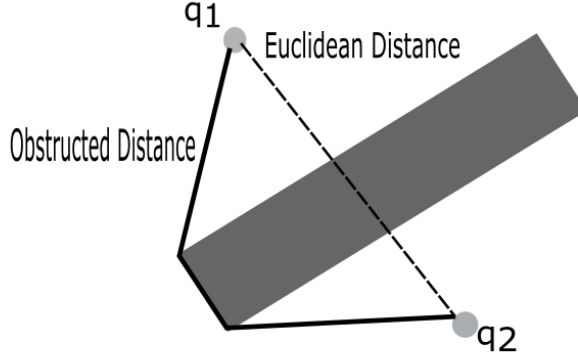


Figure 1.1: Obstructed Distance

that guaranties no alarms are missed. And High scalability is the feature that ensures that the system can adapt to a large number of spatial alarms.

In this paper, We propose a novel approach to evaluate spatial alarms in obstructed space which ensures both High accuracy and High scalability.

We define three different type of regions: *Known Region*, *Reliable Region* and *Safe Region*

Known Region:

The region within which all POIs (alarms) and obstacles are known to the client We define two different known regions for the POIs and the obstacles. Both of the known regions are represented by a parabola whose focus point is the users location q , with the equation $y^2 = 4ax$ where $a = mr$ which is bounded by a straight line.

Reliable Region:

Within which region, no further query to the server has to be done to compute a consistent set of answers, that is termed as a reliable region. The reliable region is also a parabolic region bounded by a straight line, where each bounding point of the parabolic curve is at a distance r from the known regions parabolic curve. $\forall p_i = (x, y)$ in the known region, $\forall p_j = (x_r, y_r)$ in the reliable region, $dist_E(p_i, p_j) \geq r$. By this definition no further queries to the server has to be done to compute a consistent set of answers. Because, for any $q = p_j$ $dist_E(q, p_j) \geq r$ where p_j is a point on the boundary of the reliable region. And for all other points p_i inside the reliable region $dist_E(q, p_i) > r$

Safe Region:

A safe region is the region located inside reliable region within which the answer set of POIs remains unchanged for a moving client. We will denote the radius of the safe region as r_{safe} . Given the user's previous location P_1 and the current location P_2 , if $(P_1 - P_2) < r_{safe}$, then no recalculation is needed to compute the answer. If the safe region surpasses the reliable region at some points

The key idea of our approach is to calculate a dynamic *safe region*, within which no computation has to be done to provide an accurate alarm trigger. We will use an R-tree structure to index both obstacles and POI's in our approach. Our spatial alarm processing system has two different modes for efficient and effective processing of spatial alarms, namely, Bandwidth saving mode and Computational Cost Saving mode.

We assume that the system is based on a client-server architecture and the POIs as well as the obstacles are stored using independent R-trees at the server. We also assume that all users have access to some sort of localization service such as GPS or Wi-Fi that queries the server with the client's pinpoint location. Here, the client application is a thin-weight application that communicates with the server on any specified event to retrieve necessary information about POIs and the obstacles. We assume that the user can use any device such as smart-

Table 1.1: Symbol Table

Symbols	Meaning
P	Set of POIs
O	Set of Obstacles
q	Location of user
r	Alarming range
V_G	Visibility Graph
$dist_E(p,q)$	Euclidean distance between points p and q
$dist_O(p,q)$	Obstructed distance between points p and q
r_{safe}	Radius of safe region
m	Real number in the range $[2, \infty)$
n	Real number in the range $[1, \infty)$
θ_i	Angle between consecutive path segments
S	Users path history as a set of straight lines
(m_i, c_i, l_i)	A line with slope m_i , intercept c_i and length l_i

phones or PDA.

1.3 Contributions

Our approach accounts for both accuracy and efficiency by focusing on (1) No alarms being missed in user's proximity (2) Avoiding wasteful computation in client side (3) Minimizing data transfer between server and client. In summary the our main contributions are:

- We introduce an efficient algorithm for evaluation of spatial alarm queries in obstructed space.
- We provide a spatial alarm evaluation system for mobile user.
- We provide an algorithm to calculate a dynamically changing region to accurately evaluate spatial alarm queries without any computation.
- We provide an extensive experimental analysis to compare the accuracy of our approach with other naive approaches based on different parameters.

1.4 Thesis Organization

The next chapters are organized as follows. In Chapter 2, related works are discussed. In Chapter 4 and 3, we present a naive approach and our approach, respectively, to evaluate Spatial Alarm in Obstructed Space queries. Chapter 5 shows the experimental results for our proposed algorithm. Finally, in Chapter 6, we conclude with future research directions.

Chapter 2

Related Works

In this chapter, we give a description of previous works related to this thesis. Spatial alarm processing technique in Road Network and Euclidean Space has been extensively studied in recent years. In this chapter, we first show the related works on Spatial Alarm queries in Road Networks in 2.1, then we show the related works on different queries in the Obstructed Space in the section 2.2 finally in 2.3 we show the effectiveness of R-tree as an data structure.

2.1 Spatial Alarm Queries

Extensive research has been performed and various effective algorithms have been proposed [LYL⁺13],[ML10],[BLIY09] to process spatial alarms in Euclidean space and road network in recent years. Euclidean space considers the straight line distance between two points irrespective of obstacles between them on the other hand in road networks navigation is limited along predefined roads.

Again, comprehensive research [DLNV10] has been conducted to make spatial alarm evaluation energy-efficient and effective in road networks.

However, to the best of our knowledge no research work has yet been published on the topic of spatial alarms in obstructed space. In this section we present the related research work in the computation of spatial alarms in the following subsections.

In [LYL⁺13] the authors argue that spatial alarm queries are best approximated by road network scenarios as the clients movement is more likely to follow some specific road network. They show that the road network distance-based spatial alarm is best modeled using road network distance such as segment length-based and travel time-based distance. In their opinion, a road network spatial alarm is a star-like subgraph centered at the alarm target. [LYL⁺13] introduced road network based spatial alarm and provided several optimization techniques to make spatial alarm computation in road network efficient.

Murugappan et al. in [ML10] have studied a middleware architecture for energy efficient processing of spatial alarms on mobile clients, while maintaining low computation and storage costs. Their research on spatial alarms provides two systematic methods for minimizing energy consumption on mobile clients. They introduce the concept of safe distance the number of unnecessary mobile client wakeups for spatial alarm evaluation. Their approach enables mobile clients to sleep for longer intervals of time in the presence of active spatial alarms. Murugappan et al. have studied the computation of spatial alarm using a middleware architecture in the road networks. In [BLIY09] a safe region based approach has been introduced to effectively compute spatial alarms. The authors argue that, the conventional computation of spatial alarm queries using server centric architecture can be improved upon by introducing a distributed safe region based approach. The safe region based approach delegates some of the computational overhead to the client and results in optimal usage of resources. In this thesis, we adapt the concept of safe region and the distributed architecture in processing spatial alarms. Bamba et al. in [BLIY09] have given three different approaches to compute the safe region. However, none of them are tailored to be used in obstructed space. In each of the above mentioned research works efficient and effective techniques have been studied to process spatial alarm queries in road networks and euclidean space. However, to the best of our knowledge, no research work has yet been published for the computation of spatial alarms in the obstructed space.

2.2 Different Queries in Obstructed Space

In this section we study various spatial queries that have been extensively researched in the obstructed space. Some of these queries have very little in common with spatial alarm queries, nevertheless we study the obstructed distance computation techniques used in them. Papadias et al. in [ZPMZ04] have provided approaches to compute several important spatial alarm queries in the obstructed space, which include range search, nearest neighbors, e-distance joins and closest pairs. They use R-tree for indexing both data points and obstacles. Zhang et al in [GYC⁺11] have introduced reverse nearest neighbour queries in obstructed space. Given a datapoint q , a reverse nearest neighbor finds all the points/objects that have q as their nearest neighbor. In [GYC⁺11] the authors have introduced obstructed reverse nearest neighbour. They use effective pruning heuristics (via introducing a novel boundary region concept). However, spatial alarm queries and RNN queries are distinct from each other. A spatial alarm query returns all the points p that are within an alarm radius r of q . It can be argued that spatial alarm queries can be processed using RNN query solving algorithms, but it will not be as effective and efficient as a query that is specifically tailored to handle spatial alarms. Nutanong et al. in [NZTK09] have studied moving knn queries in detail. Mknn queries can be defined as follows, given a set of datapoints P and a moving query point q , an MkNN query retrieves the k nearest data points of q from P . As the client is moving the answer set may need to be recomputed as the client moves. They have used the concept of safe region, reliable region and known region in their paper. They use the safe region to reduce unnecessary checks for knns near the user. They have also introduced known region and reliable region to find the safe region for a specific location of a client. They have used a unique V^* diagram approach to compute knns in their paper. The V^* diagram is constructed using $(k + x)^{th}$ nns' of a user. The V^* diagram computes two types of safe regions: Safe region with respect to a data point and fixed rank region. Then both of them are intricated to form a intricated safe region. Many qualities of [NZTK09] have been adapted in [LGQ⁺] which is discussed next. In this thesis we also use the terms, safe region, reliable region and known region. But our thesis is distinct from [NZTK09] on these points

- We use the known region and reliable region not only to help compute the safe region, but also to reduce duplicate data transfer and number of server queries made.
- We use the concepts of these regions to efficiently compute spatial alarms. Here we would like to point out, that although spatial alarm queries can be solved using an extension of moving mknk queries, those extensions will result in wastage of resources and efficiency, as they are not specifically tailored for spatial alarms.
- We have used the above mentioned regions with respect to obstacles which is not considered in [NZTK09]

Li et al. in [LGQ⁺] have proposed an algorithm to efficiently compute moving Knn queries with respect to obstacles. However in their paper, Li et al. have proposed a safe region based approach, so that no recomputation is needed as long as the user is within the safe region. In [LGQ⁺] no predefined trajectory of client is assumed. The algorithm proposed in [LGQ⁺] can be summarized as follows:

- At the start of the query the algorithm first computes a list of $k+x$ nearest data points of q , where the x extra data point serve as a cache to reduce the number of safe region recomputation.
- After every movement of client the algorithm uses the *obstructed safe region* and the *obstructed fixed-rank region* to determine whether a safe region recomputation is required and which data points need to be accessed for the recomputation.

Obstructed safe region w.r.t. datapoint is a region where the movement of q will not cause p to be removed from the $k + x$ nearest neighbors of q .

Obstructed fixed rank region The obstructed fixed-rank region of a list L_{k+x} of $k + x$ data points ordered ascendingly by their distances to the query point at q_b , is a region in an obstructed space that, when q moves inside the region, the distance rank of the data points in L_{k+x} to q is fixed.

In this paper they have also formulated an *obstructed known region* with the help of an *obstructed disk*. When the query point q is at position q_b and its

$(k + x)^{th}$ nearest data point is z , the obstructed known region of q , is defined as a region where the obstructed distance from any point t to q_b is less than or equal to the obstructed distance of z to q_b . An obstructed disk in obstructed space is a disc where the points distances to q_b are less than or equal to r .

In this paper the concept of safe region and fixed rank region have been adapted from [NZTK09]. In this thesis we have also adapted some of our key concepts from the same and manipulated them for using in the obstructed space. However, it is noteworthy that our approach and [LGQ⁺] are distinct from each other. Apart from the obvious fact that our thesis and [LGQ⁺] deal with two different type of spatial queries all together we would also like to point out two principle differences between them:

- Firstly, we adapt the concept of known region and reliable region from [NZTK09] in obstructed space. In this thesis, two different known region for POIs and Obstacles have been introduced to reduce duplicate and frequent data retrieval from the server. Our definition of known region is distinct from [LGQ⁺].
- Secondly, We have developed an efficient approach to accurately answer the spatial alarm queries in obstructed space by predicting the user's next direction of movement, a prospect that has not been considered in [LGQ⁺].

In [SHK14] an efficient approach to solve the obstructed group nearest neighbour query is introduced. A GNN(Group Nearest Neighbor) query is a query that enables a group of users to meet at a point with minimum aggregate travel distance. Obstructed distance computation is a inexplicable part of any query in obstructed space. To find the obstructed distance between two points we need the visibility graph [SHK14]. Usually, visibility graph construction is an $O(n^2)$ time consuming algorithm. To overcome this particular hurdle, we have adapted the approach of incrementally constructing the visibility graph used in both [SHK14] and [LGQ⁺]. In this approach only the datapoints and obstacles that are absolutely necessary to our query is kept in the visibility graph. At first an initial visibility graph is constructed and then only the obstacles and that are relevant in the obstructed distance computation of the active datapoint set are kept in the visibility graph, all other obstacles are removed. This initial

visibility graph is incremented or decremented with necessary datapoints and obstacles as per our query.

B-tree [?] is a popular data structure that is often used in file systems and database systems because of its logarithmic insertion and deletion running times and as its child nodes can be accessed at the same time. However, B-tree can not store new type of data (i.e. geometrical data, multi-dimensional data). So Guttman [?] provided R-Tree for this task. R-tree has the following main properties

- R-Trees represent data as a minimum bounding rectangle MBR which enables it to store any dimensional data
- It is height balanced.
- Each node bounds its children. A node can have many objects in it.
- The leaves point to the actual objects which are stored on the disk.

Chapter 3

Naive Solution

To compare the efficiency of our approach, we present a straightforward solution for processing Spatial Alarms in Obstructed Space. The naive approach is a straight forward approach with region computation. This approach searches for a new alarm in the known region as soon as the client changes its position.

In Section 3.1, we give an overview of the naive solution. Section 3.2 presents the algorithm of the solution.

3.1 Overview

In this naive approach, the server is frequently queried to get the POIs and obstacles within the Euclidean distance r . Then the client checks the obstructed distance of each POI to be within r obstructed distance and fire alarm if that is reached.

3.2 Algorithm

In the Algorithm 4, the $\text{GETALLPOI}(q, r)$ function populates the set P of POIs within the radius r centring the query point (the client's current location) q . Similarly, $\text{GETOBSTACLESET}(q, r)$ function returns the set of all obstacles within the radius r centring q .

MAKEVISGRAPH(P, O) function returns the *visibility graph* V_G with the set of POIs P and the set of obstacles O .

Here, a **Visibility Graph** is a graph $V_G(V, E)$ where each $v \in V$ is either a POI or a data-point and for each $(u, v) \in E$, there is an edge e between u and v if and only if it does not intersect with any obstacles *i.e.* u and v are *visible* to each other along the edge e .

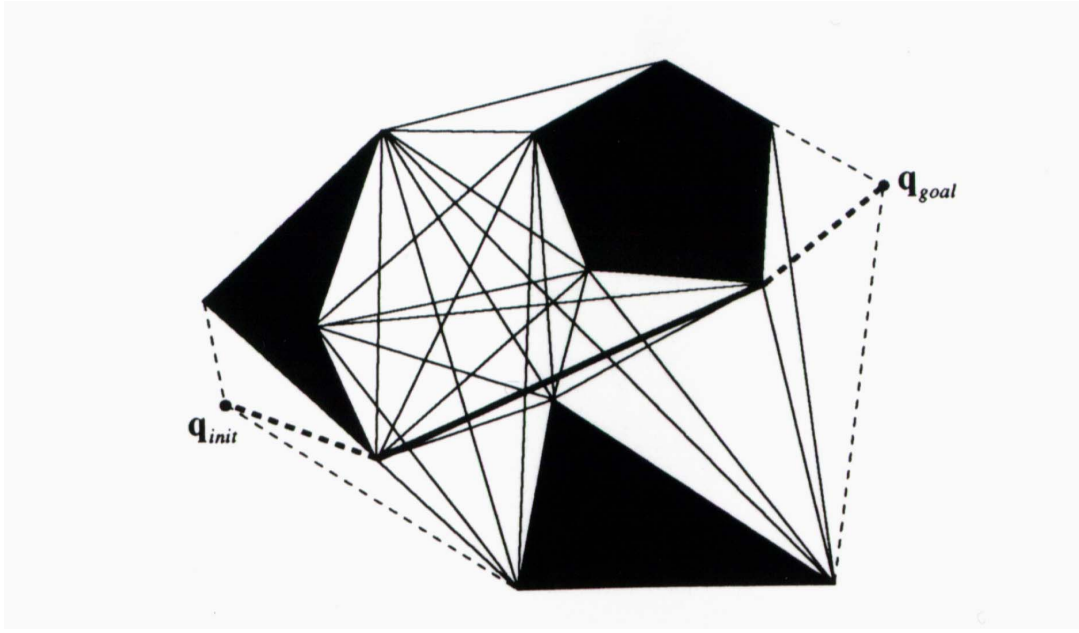


Figure 3.1: Visibility Graph

MAKEANSWERSET(q, V_G) function returns a heterogeneous data-model consisting of its all parameters to be used by the caller client-side program.

Algorithm 1: GETALARMABLES(q, r, A_{prev})

Input : Query point q and the search radius r

Output: The visibility graph V_G

- 1 $P \leftarrow \text{GETALLPOI}(q, r)$
 - 2 $O \leftarrow \text{GETOBSTACLESET}(q, r)$
 - 3 $V_G \leftarrow \text{MAKEINCREMENTALVISGRAPH}(P, O, A_{prev}, V_g)$
 - 4 $D_O \leftarrow \text{GETALLOBSTRUCTEDDIST}(q, V_g)$ **return**
 $\text{MAKEANSWERSET}(q, V_G, D_O)$
-

The following method is triggered on any change of the user's location by the system checking whether to give any alarm to the client or not along with the check of necessity to fetch more POI and obstacle when the client goes outside of the farthest POI's alarming zone. Here, the function $\text{ALARMUSER}(p_i)$ triggers an alarm to the user since the respective POI p_i is reached and also marks p_i to be reached in the set of POIs P .

The inputs to this algorithm are the current client-location q and the answer set A consisting of the region's center q , POI set P , obstacle set O , and the visibility graph V_G .

Algorithm 2: $\text{UPDATECLIENT}(q, A)$

Input : Client's current location q , latest answer set A

```

1 foreach  $p_i \in P$  do
2   if  $\text{dist}_O(q, p_i, V_G) > p_i.u$  then
3      $\text{ALARMUSER}(p_i)$ 
4 if  $\text{dist}_E(A.q, q) > A.d_u$  then
5    $\text{GETALARMABLES}(q, 100)$ 

```

In this naive-approach, the visibility-graph is constructed more times than necessary to hold accuracy, each of which constructions requires $O(n^2)$ [ML10], where n = the number of edges of the obstacles. A huge overhead is also sufficed to make P and O sets using such procedure. Again, the Algorithm 4 can also be run much less time than in this approach, which is improvised in the later approach.

Chapter 4

Our Approach

During building up the main approach, it is observed that spatial alarm evaluation can be optimized using three key feature:

- Firstly, reducing the number of device wake-ups;
- Secondly, reducing any re-computation;
- Thirdly, reducing the data communication overhead between the server and the client.

For the first strategy to be successful, we propose an algorithm in this section which will compute an optimal safe-region. The second optimization technique is realized by passing optimal parameters among different functions as well as between the client and the server, while the third one is achieved by passing minimal parameters between the client and the server and in some cases recomputing some values in each side.

However, the second and the third options have some collisions in some cases and therefore cannot be achieved simultaneously. For this reason, we have separated some parts of our main approach within two different modes, namely - *Bandwidth Saving Mode* and *Computation Saving Mode*. In Section 4.1, we give an overview of the computation of the regions necessary for our approach. Section 4.2 presents the algorithm of the Bandwidth Saving Mode. Section 4.3 presents the algorithm of the Computational Cost Saving Mode.

4.1 Computation of the regions

The known region is bounded in one side by a parabola, whose focus is the user's location q , the equation of the parabola being $y^2 = 4ax$ where $a = mr$. First we estimate a direction vector for the user's next movement using previous path history of the user. We take this direction vector as the major axis of the parabola. The exposure of the parabola depends on m . If the user is likely to move along a straight line, the exposure of the parabola need not be very high. But if the user is likely to move away from the major axis of the parabola, the exposure should be accordingly large. A function will be defined later on which estimates the value of m from the changes in user's direction in his previous trajectory. However, the function will ensure that the minimum value of m will be 2. This parabola is bounded on the other side by a straight line parallel to the latus rectum of the parabola. The distance of this straight line from the user's current location is dependent upon the previous history of the user's movements. Thus, we will position the bounding straight line of the known region at a distance nr from the focus. where the value of n is dependent on the user's previous trajectory. Intuitively we can see that, if the user moves fast, our known region should be larger, as the user is likely to move through the region quickly. Thus n is proportional to user's velocity v . We define a function later in the paper, which will compute the value of n . The minimum value for n is 1.

The computation of reliable region is comparatively less complex. We simply create a bounded region by subtracting r from each vertex of known regions boundary.

The safe region is computed using the nearest POI p , where $dist_E(p, q) > r$, then the safe region is the intersection of the circle centered at q with radius $dist_E(p, q)$ and the reliable region.

4.2 Bandwidth Saving Mode

In this mode the main focus is to reduce the bandwidth of communication between the server and the client. This mode is designed to operate in three parts - *client-initialization from server side*, *alarm-configuration* and *update on any minimal amount of location change*. The Algorithms ??, 5, 6 show the algorithmic-steps for these three parts respectively.

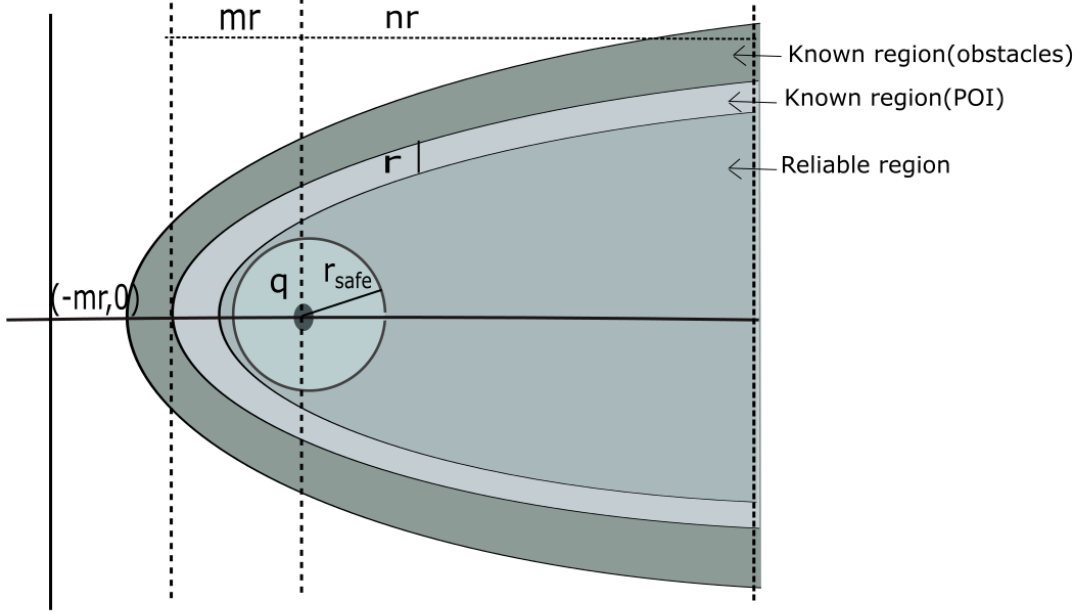


Figure 4.1: Different regions

The input to the client-initialization algorithm (Algorithm 3) is the current location of the client q , query radius r , current velocity of the client v , path history as a set of straight lines $S = (m_1, c_1, l_1), (m_2, c_2, l_2), (m_3, c_3, l_3), \dots (m_n, c_n, l_n)$ and the last answer set $A_{prev} = q, u, m_p, m_o, n$, where u is the vertex of the . This algorithm makes the frequent queries more efficient and accurate and needs much less server communication.

In the following algorithms, $PREDICTDIRECTION(S)$ function returns a vector by interpolating all the line segments given in a set S as the client's path history. During the linear interpolation, the oldest path is given the minimum weight, while the later ones get the incrementally higher weights eventually giving the latest path segment the maximum weight and predicting the client's current direction most likely to be towards the latest paths.

The $GETVERTEX(q, s_{dir})$ returns the vertex point u of the parabola having focus at q and the axis along the vector s_{dir} .

The function $\text{VARIANCEOFPATH}(S)$ returns a real number within the range $[2, \infty)$ which is proportional to the variation of the client's path directions given the directed path segments in the set S . This value is assigned to the multiplier m_p to construct the parabola $y^2 = 4 * (m_p * r) * x$, since the more variation in the client's path requires more cross-section area of the known region parabola.

The $\text{GETOBSTACLESET}(q, m_o * r, n_p)$ returns all obstacles within the parabola $y^2 = 4 * (m_o * r) * x$ which is again bounded by a straight line at $(n_p * r)$ distance from the focus q and perpendicular to the axis of the parabola.

In this algorithm, $\text{ATTACHTOVISGRAPH}(V_G, P, O)$ function adds the POIs and obstacles in the sets P and O respectively to the provided visibility graph V_G , so that minimal re-computation is needed.

The output of the Algorithm ?? is an answer set A which consists of the radius of the known regions of POIs and obstacles (r_{kp} and r_{ko} respectively), the set O of all obstacles within radius r_{ko} and the set of all POIs within radius r_{kp} centring q . Since it is a bandwidth saving mode, the visibility graph is not sent to the client as long as it can be computed using the existing data in the client side.

Algorithm 3: $\text{INITCLIENT}(q, r, v, S, A_{prev})$

Input: Query point q , query radius r , velocity v , path history as a set of straight lines S , last answer set A_{prev}

- 1 $s_{axis} \leftarrow \text{PREDICTDIRECTION}(S)$
 - 2 $m_p \leftarrow \text{VARIANCEOFPATH}(S)$
 - 3 $n_p \leftarrow \text{MAX}(\ln(e + v), \ln(e \times v))$
 - 4 $u \leftarrow \text{GETVERTEX}(m_p \times r, s_{axis})$
 - 5 $A \leftarrow A \cup \text{GETKNOWNREGIONDATA}(q, r, s_{axis}, A_{prev}, m_p, n_p)$
 - 6 $pi_r \leftarrow \text{GETRELIABLEREGIONPARABOLA}(A.pi_p, m_p, n, r)$
 - 7 $\text{CONFIGUPDATE}(q)$
-

The input to the Algorithm 5 is the current location of the client q and the

Algorithm 4: GETKNOWNREGIONDATA($q, r, s_{axis}, A_{prev}, m_p, n_p$)

Input : Query point q , query radius r , axis of the parabola s_{axis} , m_p, n_p
last answer set A_{prev}

Output: The answer set, $A \leftarrow \{q, u, m_p, n_p, m_o, n_o, P, O\}$

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1  $s_{dir} \leftarrow \text{GETDIRECTRIX}(s_{axis}, u, q)$ 
2  $s_b \leftarrow \text{GETBOUNDINGLINE}(s_{axis}, n_p \times r)$ 
3  $pi_p \leftarrow \text{BOUNDEDPARABOLA}(q, s_{directrix}, s_b)$ 
4  $P \leftarrow \text{GETPOISWITHINPARABOLA}(pi_p)$ 
5 if  $A_{prev}.V_g == \text{NULL}$  then
6    $aprev.V_g \leftarrow \text{CONSTRUCTINITVISGRAPH}(P)$ 
7  $R_t \leftarrow \text{GETOBSTACLERTREE}()$ 
8  $D_O \leftarrow \text{GETOBSTRUCTEDDIST}(A_{prev}.visGraph, q, P, R_t)$ 
9 return  $\text{MAKEANSWERSET}(q, P, A_{prev}.visGraph, D_O)$ 
```

answer set got from the Algorithm ???. This algorithm is also responsible for triggering an alarm to the client if the client is within the alarming distance of any POI.

Algorithm 5: CONFIGUPDATE(q, A)

Input : Query point q , answer set A

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1  $P \leftarrow \text{GetPOIs}(V_G)$ 
2  $O \leftarrow \text{GetObstacles}(V_G)$ 
3 foreach  $p_i \in P$  do
4    $p_i.d_O \leftarrow \text{dist}_O(q, p_i)$ 
5   if  $p_i.d_O < r$  then
6      $\text{ALARMUSER}(p_i)$ 
7   else if  $p_i.d_E < r_{safe}$  then
8      $r_{safe} \leftarrow p_i.d_E$ 
9 return  $r_{safe}$ 
```

In this algorithm, the visibility graph is computed using the answer sets P and O got as return of the ??? from the server side. The input to the algorithm 6 is the current location of the client q , the radius of the safe region(r_{safe}) and finally the already computed answer set A . The output of the algorithm is the

minimum distance d_u to trigger this algorithm the next time.

Algorithm 6: UPDATEONLOCCHANGE(q, r_{safe}, r_{rel}, A)

Input : q, r_{safe}, A

Output: d_u

```

1 if ISOUTSIDERELIABLEREGION( $Q, A$ ) then
2    $A \leftarrow \text{QUERYALARMABLES}(q, d_q)$ 
3    $r_{safe} \leftarrow \text{CONFIGALARM}(q, A)$ 
4 if  $d_q > r_{safe}$  then
5    $r_{safe} \leftarrow \text{CONFIGALARM}(q, A)$ 
6 return  $d_u \leftarrow r_{safe}$ 

```

4.3 Computational Cost Saving Mode

The algorithms run in this mode almost similarly as in the "*Bandwidth Saving Mode*" with all the 3 described parts - *client-initialization from server side*, *alarm-configuration* and *update on any minimal amount of location change* as demonstrated in the Algorithms ??, 5, 6.

However, the main difference with the previously described mode from this mode is - the Algorithm ?? returning the computed V_G as another element of the answer set A from the server side and the algorithm 5 not reconstructing this V_G in the client side during running the Algorithm 5, whereas the Algorithm 6 remains all the same.

Therefore, an $O(n^2)$ computation overhead for computing the V_G is saved in the client-side in cost of a one-time communication overhead in transferring the V_G in the Algorithm ??.

Chapter 5

Conclusion

In this paper we have addressed evaluation of spatial alarm in obstructed space for the first time. We have proposed two variations of our approach to incorporate both accuracy and efficient communication bandwidth. Our experimental setup provides a comparative analysis between our approach and the naive approach on different parameters. The results of the experiment conducted shows that our proposed approach is better than the naive approach in execution time, IO access and number of server queries.

5.1 Future Directions

In the future we wish to extend our thesis work in several directions.

- In future, we aim to manipulate the geometrical properties of the regions to find a larger safe region.
- We wish to find a better prediction function for approximating the clients' next direction.
- In the future we wish to provide authentication and privacy while accessing the user's location.

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