A Location-Based Service Using Geometric Location Methods to Unite Mobile Users

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ABSTRACT

Since the introduction of iPhone in 2007, many location-based services (LBSs) have been created and new LBSs are found every day. This research proposes yet another LBS, which is practical and was not found before to the best of authors' knowledge. The problem is described as follows. It happens all the times while several groups of people are traveling towards a destination, they lose contact from each other on the way. This research tries to have the groups travel as closely as possible until they reach the destination. It uses a method of minimum covering ellipses to find whether the groups are separated by more than a threshold/distance. If they are, the system will find a convenient rendezvous for all groups by using a method of geometric median. After meeting at the rendezvous, the groups reset the service and continue their journey. By using this LBS, travelers do not need to worry about losing connections with others. This method can also be applied to the problem of finding a convenient meeting place for mobile users.

Keywords: Location-Based Services (LBSs), Mobile/Handheld/Spatial Computing, Geometric Location Methods, Minimum Covering Ellipses, Geometric Median.

1. INTRODUCTION

The worldwide PC and mobile phone sales in the past years are given in the Table 1 according to various market research reports [1]. The number of smartphones shipped worldwide has passed the number of PCs and servers shipped in 2011 and the gap between them is expected to keep bigger. The emerging smartphones have created many kinds of applications that are not possible or inconvenient for PCs and servers, even notebooks. One of the best-seller applications is location-based services (LBSs) according to the following market research:

- According to MarketsandMarkets [2] in 2015, the major LBS and RTLS (real-time location system) applications include navigation, local search, enterprise services, mobile advertisements, location-specific health information, tourism, consumer tracking, and other location-based Business Intelligence (BI). The worldwide market is expected to grow from USD 11.36 billion in 2015 to USD 54.95 billion by 2020, at a CAGR (Compound Annual Growth Rate) of 37.1%.
- Gartner, a market research company, identified the LBSs are one of the top three consumer mobile applications and services in 2012. It also predicted the most popular LBSs would be navigation, location search, and friend finder/social networks [3].
- GNSS (Global Navigation Satellite System) applications could be simple such as determining a position, or could be complex blends of GNSS with communications and other technologies. The GNSS market is expected to thrive with new technological applications and to grow at a CAGR of 9.4 percent during 2014-2020 according to GPS World [4].

Table 1. Worldwide PC and cellphone sales.

Year	***Number of Units Shipped (Million)***				
	Mobile Phones	**PCs and Servers**	**Smartphones**	**PDAs** (without phone capability)	**Tablet PCs**
2002	432	148	—	12.1	—
2003	520	169	—	11.5	—
2004	713	189	—	12.5	—
2005	813	209	—	14.9	—
2006	991	239	64	17.7	—
2007	1153	271	122	—	—
2008	1220	302	139	—	—
2009	1221	306	166	—	1
2010	1609	346	286	—	17
2011	1775	353	486	—	73
2012	1746	352	698	—	128
2013	1806	296	968	—	195
2014	1879	314	1245	—	227

Various location-based services have emerged because of the great popularity of smartphones. A common problem that may arise during a party tries to travel to a destination is some groups may be lost if the party is divided into several groups. Many times the whole party has to halt, find a place to convene, and restart the journey. It is time-consuming and inconvenient. This research is to automate the procedure and minimize the impact. It has the mobile users stay closely while on the move. Once the users are separated by more than a threshold/distance, the system will find a rendezvous convenient for everyone. People then meet at the rendezvous and reset the service and restart the journey. The following two major algorithms are used by the research:

- Check whether the users stay closely enough by using a method of finding minimum covering ellipse. If the area of the ellipse is over a threshold, it means the users do not stay closely enough.
- Find a rendezvous by using a method of finding the geometric median and the Google Place Search API. The geometric median gives the smallest sum of distances from users to a meeting location. However, not all meeting locations are convenient for users. The Google Place Search API is then used to find a rendezvous such as nearby landmark or park based on the location.

How to have mobile users travel closely is a common problem and causes tremendous headache for travelers. This research tries to solve the problem by incorporating several disciplines including (i) mobile/handheld/spatial computing, (ii) location-based services, (iii) databases, and (iv) human behavior recognition. It is worthwhile research. In addition, this research also finds a convenient rendezvous for mobile users to meet after they are separated by a distance. The design and planning show the proposed method is effective and convenient, but further implementation and testing are required to validate this claim.

The rest of this paper is organized as follows. Section 2 gives the background information of this research including two themes: (i) minimum covering areas, and (ii) smallest sum of distances. Section 3 introduces the proposed system. The method of minimum covering ellipses used in this research is explained in Section 4. Section 5 gives algorithms of the geometric median, which is used to find a rendezvous after the area of the minimum covering ellipse is over a threshold. Some experimental results are given in Section 6. The last section summarizes this research and discusses the current status of mobile computing.

2. BACKGROUND AND LITERATURE REVIEW

This research is to build a location-based service using geometric location methods. Therefore, two themes, an LBS architecture and related geometric location methods, are discussed in this section.

An LBS Architecture

A location-based service is a service based on the geographical position of a mobile handheld device [5]. Two of the LBS examples are finding a "best" direction and recommendations of nearby events and attractions. Popular LBS include mapping and navigation, search and information, social networking, entertainment, and tracking [6]. A nice introduction of LBS technologies and standards is given in the articles [7][8]. A system structure of location-based services, shown in Figure 1, includes five major components:

(a) Mobile handheld devices, which are small computers that can be held in one hand. For most cases, they are smartphones.
(b) Positioning system, which is a navigation satellite system that provides location and time information to anyone with a receiver.
(c) Mobile and wireless networks, which relay the query and location information from devices to service providers and send the results from the providers to devices.
(d) Service providers, which provide the location-based services.
(e) Geographical data providers, which are databases storing a huge amount of geographical data such as information about restaurants and gas stations.

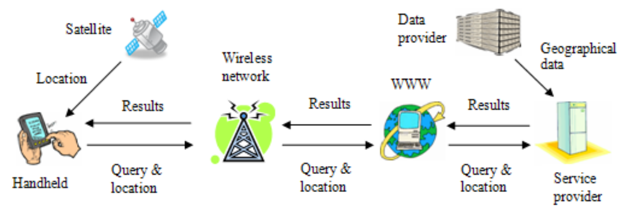

Figure 1. A system structure of generic location-based services.

Related Geometric Location Methods

This research tries to connect mobile users by using geometric location methods [9][10], where geometric locations are physical positional information including latitude, longitude, and height. Two of the methods, minimum covering areas and smallest sum of distances, related to this research are given next. A list of geometric methods can be found from the article by Lee and Preparata [11].

Minimum Covering Areas: In order to find whether the mobile users stay closely enough, the method of a minimum area covering a set of objects is used in this research. The shapes could be ellipses, disks, polygons, etc. Silverman and Titterington [12] used an exact terminating algorithm to find the ellipse of smallest area covering a given plane point set V. Figure 2 shows the five steps used by them. Other related research could be found from the articles such as [13][14].

Finding the Minimum Covering Ellipse

1. Find the convex hull of V, a set of points, and eliminate all but the extreme point V_E from further consideration.
2. Choose a 3-point subset S_0 of V_E.
3. If the mth test support set is S_m, check whether each of the points of V_E lies outside ME(S_m), the smallest generalized ellipse that contains S_m.
   - 3.a If no point lies outside, then S_m is a support set of ME(V); exit.
   - 3.b Otherwise choose v in V_E outside ME(S_m) and set $S_m^* = S_m \cup v$.
4. Find a support set $S_m^\dagger$ of ME(S_m^*).
5. Set $S_{m+1} = S_m^\dagger$. Go to Step 3.

Figure 2. An algorithm of finding the minimum covering ellipse from Silverman and Titterington [12].

Smallest Sum of Distances: Once the mobile users are separated by more than a threshold/distance, a rendezvous convenient for all mobile users is computed. This research finds a rendezvous by using the geometric median, which is the point minimizing the sum of distances to the sample points. Bose, Maheshwari, and Morin [15] describe a quadtree-based data structure that preprocesses a set S of n points so that the sum of distances of points in S to a query point q can be quickly approximated to within a factor of ε. Figure 3 shows the algorithm, where v is a node of the quadtree on S, c_v denotes the center of C_v, a hypercube, $d(q,c_v)$ is the distance between q and c_v, and card(v) denotes the number of points of S contained in C_v. Lin and Vitter [16] present approximation algorithms for median problems by using a new method for transforming an optimal solution of the linear program relaxation of the *s*-median problem into a provably good integral solution. Related methods can be found in the articles like [17][18].

```
COMPUTE-SUM(q, v)
if v is a leaf or d(q,cv) > lv/ε+lv√d/2 then
    return card(v) · d(q,cv)
else
    s ← 0
    for v' ∈ children(v) do
        s ← s + COMPUTE-SUM(q,v')
    end for
    return s
end if
```

Figure 3. An algorithm of approximating the geometric median from Bose, Maheshwari, and Morin [15].

3. STRUCTURE OF THE PROPOSED SYSTEM

The proposed location-based service is to have the mobile users stay closely while on the move. It checks whether the mobile users are separated by more than a threshold value from time to time. If the threshold value is passed, the system will find a rendezvous. Mobile users then convene and re-start the journey. Figure 4 gives the system structure including the following three essential entities: handheld devices, the proposed LBS, and a geographical database:

- Handheld devices are most likely smartphones including the client-side LBS, which provides the user interface and sends and receives data to and from the server.
- The proposed LBS including client and server -side parts, where the server-side part is responsible for the heavy computation such as finding the minimum covering ellipses and geometric median.
- A geographical database (GDB) is located at the server and stores the geographical data. However, this entity may be skipped if Google Place Search API is used.

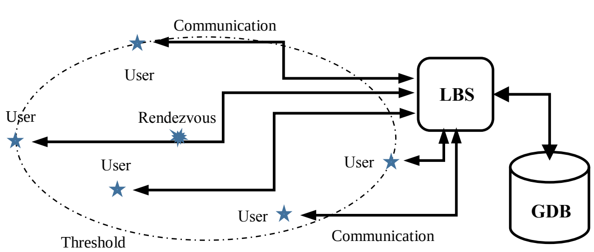

Figure 4. The system structure of the proposed system.

The steps below are taken to solve the problem:

1. The mobile users sign up the LBS.
2. Once sign in, the users send their current locations to the service from time to time. The LBS works on the background, so the regular device functions like texting and phone calls will not be interrupted.
3. The next step is activated when the users are separated by more than a threshold/distance. The method of smallest covering area is used to find whether the threshold is reached. A threshold is represented by the dashed ellipse in the Figure 4, where all users are on or within the threshold.
4. If the area of the ellipse is over the threshold, it means a rendezvous is needed for users to convene. The service then recommends a rendezvous based on various features such as landmarks, distance, and convenience by using the method of minimum sum of distances.
5. The LBS shows the directions between users and the rendezvous.

4. MINIMUM COVERING AREAS

This research is to have moving objects stay closely. Many methods can be applied to this application. One of the methods, minimum covering ellipses, is used and introduced in this section.

Minimum Covering Ellipses

One of the minimum covering areas methods, minimum covering ellipses [12], is modified and used in this research. The traditional method of minimum covering ellipses is applied to a set of fixed subjects. On the other hand, the objects dealt in this research are moving objects. Therefore, the revised algorithm is given in Figure 5.

Minimum Covering Ellipse for Moving Subjects

1. *Collect the current locations of all subjects.*
2. *Use the algorithm of minimum covering ellipses from [12] to find a minimum covering ellipse for the subjects.*
3. *Adjust the covering ellipse if any of the subjects moves out of the ellipse.*
4. *Calculate the area of the ellipse.*
5. *If the area is over the threshold, call the next step, finding a rendezvous.*

Figure 5. An algorithm of a minimum covering ellipse for moving objects.

Figure 6 shows an example of five mobile users and their corresponding covering ellipse. Four of the travelers are on the border of the ellipse and one traveler is inside the ellipse. This figure is made easy for readers. There should have more users inside the ellipse in real cases.

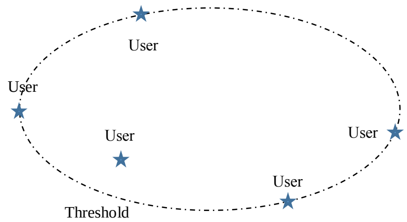

Figure 6. An example showing five mobile users within or on a covering ellipse.

5. SMALLEST SUM OF DISTANCES

Many methods can be used to find a meeting place such as geographic midpoint [18] among many people. This research tries to find a meeting place with a shortest sum of distances to all users.

Geometric Median

Once the travelers are separated by more than a threshold/distance, this research finds a rendezvous based on the methods of smallest sum of distances such as geometric median [15], which is defined as the point minimizing the sum of distances to a set of points. The rendezvous is then found as a nearby landmark of the geometric median by using Google Place Search API. The algorithm is given in Figure 7.

Nearby Landmark Based on Smallest Sum of Distances
1. *Collect the current locations of all subjects.*
2. *Use the method of geometric median approximation from the article [15] to find the geometric median.*
3. *Find a rendezvous by using the Google Place Search API based on the found geometric median.*
4. *Each device displays a direction between the device and the rendezvous by using Google Directions API [21].*

Figure 7. An algorithm of finding a rendezvous.

Figure 8 shows an example of a rendezvous among five users. The rendezvous is a landmark found by using Google Place Search [19] nearby the geometric median. In order to use Google Place Search API, developers provide a location, the maximum distance from the location you want results from and optionally the type of places you want to search for. The list of supported place types include gas stations, parks, restaurants, and shopping malls.

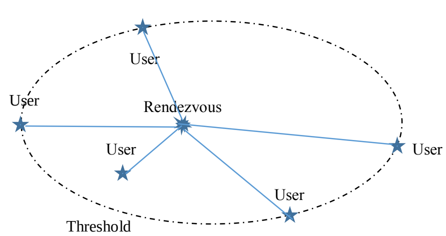

Figure 8. An example showing a rendezvous among five users.

6. EXPERIMENTAL RESULTS

This section shows some experimental results of our proposed method of uniting mobile users. A location-based service is not attractive if an interactive map is not used. Therefore, the results are generated by using Android SDK (Software Development Kit) [22] and Google Directions API (Application Programming Interface) [21].

Checking How Far Away Users Are Separated

In order to use this service, users must sign up the service. Participants' locations are then sent to the server for processing from time to time. Figure 9 shows a screenshot of mobile user locations by using the Google Maps API on a user's device, where the locations are sent by the server. This research uses a minimum covering ellipse to discover whether the users are far away from others. If the area of a minimum covering ellipse is more than a threshold, the next step of finding a rendezvous is activated.

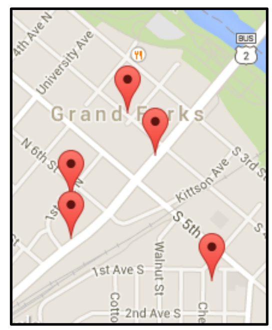

Figure 9. A screenshot showing the user locations.

Finding a Rendezvous

This research tries to unite travelers at a rendezvous based on their geometric median, which is the location having a minimum sum of distances to all travelers. The rendezvous can be found by using some advanced algorithms like the one proposed by Duckham, Winter, and Robinson [20]. However, the Google Place Search API has made this function easy by finding nearby landmarks such as gas stations and restaurants according to the user inputs and current location. Figure 10 shows the rendezvous (the black disk) among five mobile users.

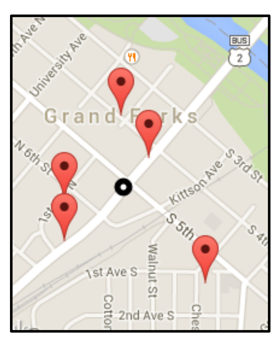

Figure 10. A screenshot showing the markers of users (red) and a rendezvous (black circle).

A Direction between a User and the Rendezvous

Finding a direction between two locations is never a trivial task because it involves current status of roads. Fortunately, this task has also been made easy by the Google Directions API [21], which only requires the two locations to find a direction. Figure 11 shows a direction between a user and the rendezvous displayed on the user's device, where the user location is found by the GPS (Global Positioning System) and the rendezvous location is sent by the server. Once all users convene at the rendezvous, they reset the service and restart their journey towards the destination.

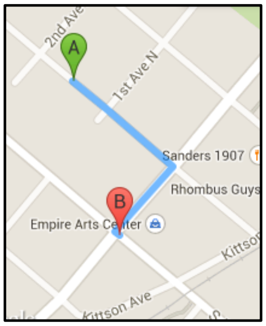

Figure 11. A screenshot showing a direction from a mobile user A to a rendezvous B.

7. CONCLUSIONS

A location-based service (LBS) is a service based on the geographical position of a mobile handheld device. LBSs are popular and some of the LBS examples are

- Finding a nearby ethnic restaurant or gas station,
- Locating people on a map displayed on the devices,
- Locating a nearby store with the best price of a product,
- Location-aware mobile advertising,
- Road or street navigation,
- Recommending social events in a city, and
- Traveling route anomaly detection.

The high popularity of LBS is because of some of the following reasons:

- Increased apps store usage like Apple's App Store and Google Play,
- High smartphone and GPS (Global Positioning System) device adoption as 1,245 million smartphones shipped worldwide in 2014,
- New hybrid positioning technologies including GPS, cell tower signals, wireless internet signals, Bluetooth sensors, etc., and
- High interest in user's private location information services.

This paper proposes a kind of location-based research for uniting mobile users. Two of the several contributions made by this project are

- Two of geometric location methods, minimum covering ellipses and geometric median, are studied, enhanced, and applied to this research.
- The proposed application solves the common problem of travelers. By using this application, travelers can easily connect to each other without worry.

In addition, human travel behavior is useful and has been applied in many applications such as city and street design and planning. This research studies various issues related to human travel behavior; e.g., what are the frequent routes from location A to location B and which part of city has the highest probability of travel anomalies?

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