Two Approaches for Successful Mapping GPS Data to Underlying Road Network in Location-based Services

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Abstract - **Latest data acquisition techniques facilitate the provision of real-time location-based services. With the coming about of miniature and cheap GPS receivers and cellular phones, new horizons have been opened for such services. The mobile telephony and Internet technology within the GIS environment has resulted in introducing new services and applications with higher degrees of user satisfaction. Recently, much work has been done in feasibility studies and identifying the type of services that can be offered to mobile persons in an environment equipped with these three. However, no equivalent attention has been paid to the data that will be used for running such services. The acquired data have some degree of uncertainty mainly due to error associated with acquisition devices and limitations in representing continuous data temporally. The central theme of this paper concerns enhancing accuracy of data obtained from GPS receivers by proposing mapping mechanisms, in which the underlying database/GIS that can match obtained data to actual locations in road networks, is taken into account and plays an important role.**

1 Introduction

Over the past few years mobile technology, the same as Internet, became so popular and essential to be an inseparable item of our daily lives. These technologies accompanied by GIS (Geographical Information System) result in introducing wide range of new services that have recently received quite some attentions. Real-time location-based services are one of such, in which one of the most challenging characteristics is mobility of the users. Recently, much work has been done in feasibility studies and identifying the type of services that can be offered to mobile persons in an environment equipped with mobile telephony, Internet technology and GIS. However, no equivalent attention has been paid to the data that will be used for running them.

Acquiring such data is not particularly a problem, as positioning technology is rapidly making its way into the consumer market, not only through the already ubiquitous cell phones but soon also through small, on-board positioning devices in many means of transport and types of portable equipment. It is thus to be expected that all these devices will start to generate an unprecedented data stream of time-stamped positions. However, like any other sorts of data, such data suffers from uncertainty, which may occur due to instrument errors, inappropriate data acquisition frequency, data transmission errors and bad data acquisition environment (data acquisition devices such as GPS typically cannot properly work indoors and in bad weather condition). Since uncertainty associated with the data can be propagated in later stage of data processing, consequently partially or completely wrong results can be obtained and the whole system may fail to best perform. Therefore, to avoid further malfunctioning of the system, uncertainty of the acquired data should be reduced to the best of our knowledge.

To do so, over years, different techniques have been used and integrated with the data acquisition devices to increase the data accuracy and till now the offered accuracy of 30 meters, 95% of the time [1] has been sufficient enough to generate a significant and increasing number of location-based services. However, there is still a need for further improvements, especially in car navigation applications, in which according to Institute of Transportation Engineering (ITE) lane widths are normally 12 feet [2] (about 3.6 meter) and having accuracy of 30 meter at the best, may result in mapping the data to the completely wrong side of the road or even not on the road at all. Two methods to enhance the accuracy of the mapping of GPS data to the underlying road network are proposed in this paper.

2 Mapping GPS Data to Underlying Road Network

There is no doubt that location-based services strongly depend on locality data about whereabouts of their users at any point in time. However, such data is not particularly so valuable without underlying database that can match such data to actual locations in the real world. Since, the data about whereabouts of users are acquired in discrete way, the medium via which they travel, plays an important role to determine their actual locations. This comes from the fact that the medium may or may not impose restrictions on where users go.

Since we do not measure the positions in-between two consecutive position samples, the best we can do is to limit the possibilities of where users could have been [4]. Considering the fact that users can only travel on road networks implies that acquired data about whereabouts of users can only be on the road network and nowhere else. This is already a great help to narrow the location domain for each locality data.

An essential assumption that we have made about data is that there is no error associated with time measurements, while the location data may have error. This can be a fair assumption since at each time (whether correct or wrong) there is a location for the user, while at a certain location (if it is wrong) there is no time that the user passes through. Since there is an uncertainty about the location of users at any point in time, we may not be able to answer the queries with absolute certainty; therefore a degree of probability may be used [5].

The idea behind our mapping mechanisms is to replace each locality data obtained from GPS receiver with its "most probable" location on the road network. The term "most probable" refers to the location that is closest to the actual location of the user on the road network. To do so, two following approaches are proposed.

2.1. Naïve Approach

As we already know that data should be on the road network, projection of each original locality data to its "closest" road segment can provide its "most probable" location. However, due to the error associated with the data, "closest" road segment might not necessarily be the road segment that the user was actually traveling on. The fact that road segments traveled by user should follow a logical order and in fact to be "accessible" by each other is the key to find any wrongly projected data. In situations, in which road segments with opposite directions (such as high way lanes) are located close to each other, the possibility of mis-projection dramatically increases. Our "consistency check" step aims at defining such mis-projections and determining the right road segment to project the original locality data on. In this approach, first distance (closeness) and then direction form the priority sequence in mapping the GPS data to the underlying road network. We assume road segments are one way. The naïve approach works on the basis of the following steps:

- Locking the data:
  Original acquired data are projected and locked to their "closest" road segment. To do so, a virtual buffer zone around each original data point is assumed. The area of such buffer zone may differ depending on the accuracy of positioning system. The normal projection between each original data point and road segments intersecting this buffer zone is defined. The road segment corresponding to the shortest projection is considered to be the closest.
- Assigning corresponding road segments:
  For each locked data, the road segment in which the data is locked to, is identified and assigned to the locked data.
- Consistency check:
  This step is explained in more details in section 2.1.1

- Resolve inconsistency and consequently update the original sequence of assigned road segments for each original data point
  Resolving inconsistency is explained in more details in section 2.1.2.

2.1.1. Consistency check

Due to error associated with the data, it is quite possible that data is projected to a "wrong" road segment. In a restricted movement in a road network, data about whereabouts of users follow a logical order. It means that a set of connected road segments that have sequentially been traveled form the user trajectory. This is important characteristic, which can be used to identify and correct any possible mis-projection of the data. To avoid any mis-projection and to assure the logical data flow, a consistency check is performed and final sequence of acceptable road segments are identified. Figure 1, shows acceptable and unacceptable sequence of road segments. As can be seen , one can immediately realize the mis-projected data, namely data point P_{i+4}. This comes from the fact that all data points together form the user trajectory and looking at data points as a whole, reveals the problem. However, only individual data points are concerned in the step of locking the data to the closest road segment and the relationship between data points are not considered. As we will show, consistency check looks at the projected data points as whole to discover any possible mis-projections. To check the consistency, earlier in [3] we proposed to examine three distinct consecutive road segments in the final sequence of assigned road segments at a time. However, later experiments showed although examining three distinct consecutive road segments at a time performs fine, examining two consecutive road segments is more effective. The key to accept a sequence is the connectivity of the two road segments. Let us assume two consecutive road segments, R_{j-1}, R_j from sequence of assigned road segments *S*. If *from*, *to* and *Size(S)* represent start and end nodes of a road segment and number of assigned road segments that are member of sequence *S*, respectively, consistency of S is checked on the following basis:

If [Size(S)=1] **then** S is consistent
If [Size(S)≥2 & $\forall$ R_{j-1}, R:((Out(from(R_{j-1})) $\cap$ In(from(R_j)) <>0)] **then** S is consistent

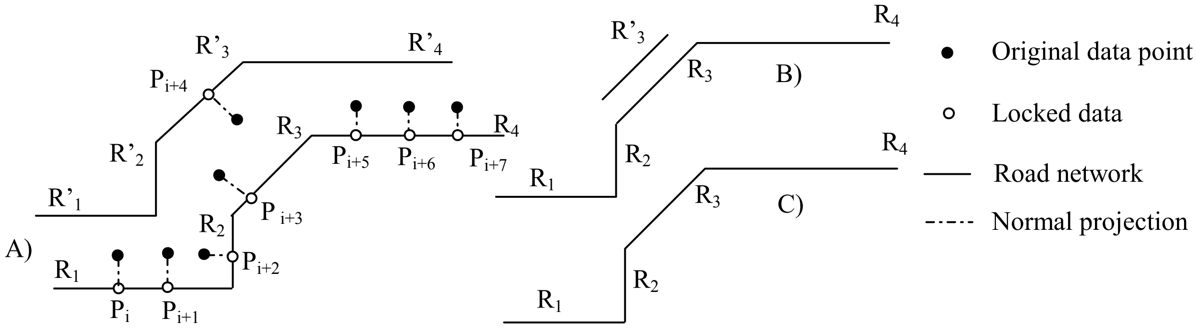


Figure 1. Unacceptable (B) as well as acceptable (C) road segment sequence for original trajectory shown in (A)

As soon as above condition fails to be met, corresponding road segments are believed to form unacceptable sequence and therefore a procedure for resolving the inconsistency is required.
Having unacceptable road segments sequence may be result of one or combinations of three cases:

1. Locking data to the wrong road segment:
   This case mainly occurs due to the error associated with original data. As a result, it happens that erroneous data is close to the road segment, which user actually was not traveling on.
2. Missing data:
   Lost connection between user and positioning system and/or bad weather condition are just two examples of possible obstacles in a continuous data flow of whereabouts of user. As a

result, the assumption of having data at all times is not a valid assumption. Therefore, since it is possible that no data has been acquired in one or more road segments, the consistency of road segments is lost. As we cannot ignore the possibility of loosing data in one or more road segments, it is highly required to predict the correct trajectory and consequently have reasonable understanding about which road segment to project the data to on the basis of implicit information while data is missing.

3. U-turns and/or backward movements:
   U-turns and backward movements as can be seen in Figure 2., are two especial cases in user trajectory, which result in unconnected road segment sequences. As connectivity plays an important role in the naïve approach, it fails to identify these.

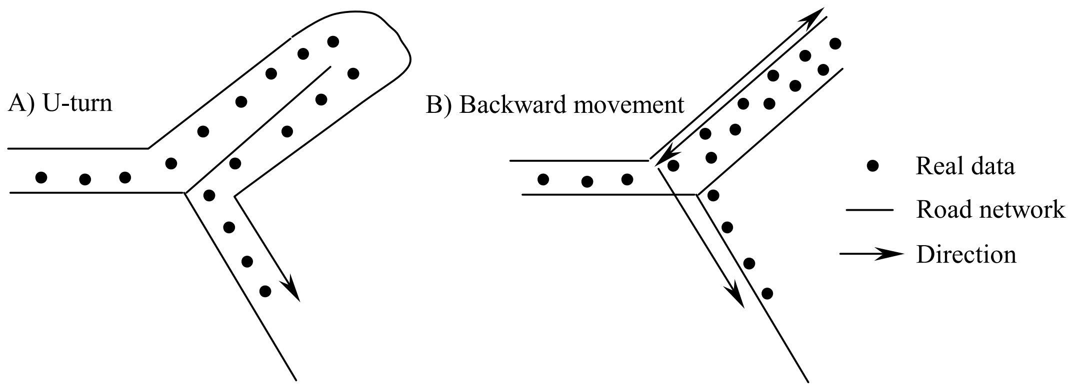
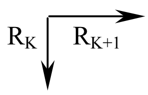


Figure 2. U-turn and backward movement

2.1.2. Resolve inconsistency

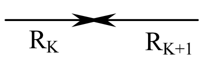
Consistency check results in determining the road segments that original data have been wrongly projected to (if any). While correcting mis-projections, we should note that a user who has been traveling on a road segment can only continue his journey on another road segment if and only if there is an intersection connecting the two road segments. This fact is one of the key issues in resolving inconsistency, as it is explained in this section.
By analyzing the direction of road segments taking part in failed consistency check, following cases are distinguished and the remedy procedure is proposed. Let us assume R_k and R_{k+1} are the two road segments, in which consistency condition is not met:

a) *from*(R_K) = *from*(R_{K+1})



   In this case road segment (R_K) is marked as the wrong road segment and its corresponding data points are re-projected to the road segment whose direction is the closest to the direction between the last data point locked to R_K and the first data point locked to (R_{K+1}).

b) *to*(R_K) = *to*(R_{K+1})



   In this case road segment (R_{K+1}) is marked as the wrong road segment and its corresponding data points are re-projected to the road segment whose direction is the closest to the direction between the last data point locked to R_K and the first data point locked to (R_{K+2}) (meaning the next road segment in the original sequence of assigned road segments). If R_{K+1} is the last element of the sequence, its corresponding data points are re-projected to R_K.

c) [*from*(R_K) <> *from*(R_{K+1})] & [*to*(R_K) <> *to*(R_{K+1})] $\xrightarrow[R_K]{}$ $\xrightarrow[R_{K+1}]{}$

As it was explained earlier, existence of a road segment intersection is technically required to allow the user to change the road segment he is traveling on to another. In this case of having completely unconnected road segments, we need to look for such intersection between the last data point assigned to R_K and the first data point assigned to R_{K+1} . If this intersection does not exist, road segment R_{K+1} is marked as the wrong road segment and its corresponding data points are re-projected to the road segment R_K. On the other hand, if such intersection exists, we need to find the sequence of connected road segments that *from*(first road segment) is *to*(R_k) and *to*(last road segment) is *from*(R_{k+1}). After this sequence is found, it is added to the road segments sequences to form the complete user trajectory.

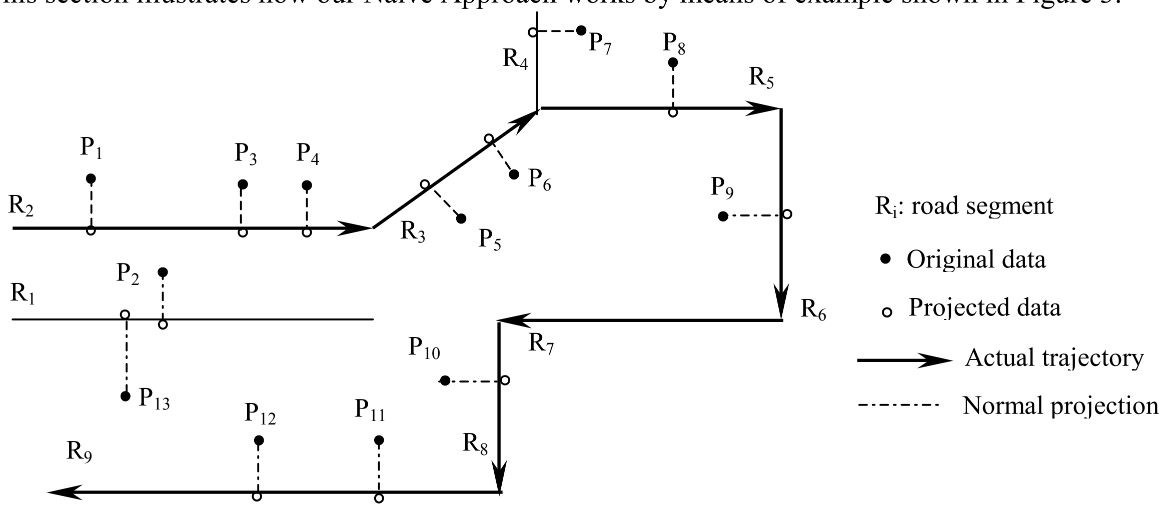
2.2. More Advanced Approach

An important observation in mapping GPS data to the underlying road network is that time to time to assure having an accurate mapping we scarify distance for direction or vice versa, just to keep the logical flow of the data. Therefore, the key for successful mapping is "connectivity" or "accessibility" of road segments.
As mentioned before, narrow road lanes increase the possibility of mis-projections in the naïve approach. An improvement can be done by considering the direction at the time of projection rather than checking the direction after projection by means of consistency check. Following steps are carried out in a more advanced approach:

- Locking the first data point to the road segment whose direction is closest to the direction between the first and the second data
- Identifying the closest intersection to the locked data on the assigned road segment and in the direction of the movement (direction between first and second data points), $IntSec_s$
- Locking the last data point to the road segment whose direction is closest to the direction between the one before last and the last data
- Identifying the closest intersection to the locked data on the assigned road segment and in the opposite direction of the movement(direction between last and one before last data points), $IntSec_e$
- Finding all possible paths between $IntSec_s$ and $IntSec_e$
- If there is more than one possible path, the one which in average is the closest to the data points is selected and the original data are projected to

3 *An Example to Illustrate* Naïve Approach

This section illustrates how our Naïve Approach works by means of example shown in Figure 3.



P#	**P_1**	**P_2**	**P_3**	**P_4**	**P_5**	**P_6**	**P_7**	**P_8**	**P_9**	**P_{10}**	**P_{11}**	**P_{12}**	**P_{13}**
R#	**R_2**	**R_1**	**R_2**	**R_2**	**R_3**	**R_3**	**R_4**	**R_5**	**R_6**	**R_8**	**R_9**	**R_9**	**R_1**
Modification		**R_2**					**R_3**						**R_9**

(1): Distinct road segment sequence: [R_2, R_1, R_2, R_3, R_4, R_5, R_6, R_8, R_9, R_1]
(2): Consistency check (1): R_2, R_1: not consistent: case (c): no intersection between P_1 and P_2 is found, therefore R_1 is the marked as wrong and P_2 is re-projected to R_2.
(3): New distinct road segment sequence: [R_2, R_3, R_4, R_5, R_6, R_8, R_9, R_1]
(4): Consistency check (2): R_2, R_3: consistent
(5): Consistency check (3): R_3, R_4: not consistent: case (b): R_4 is the marked as wrong and P_7 is re-projected to R_3.
(6): New distinct road segment sequence: [R_2, R_3, R_5, R_6, R_8, R_9, R_1]
(7): Consistency check (4): R_3, R_5: consistent
(8): Consistency check (5): R_5, R_6: consistent
(9): Consistency check (6): R_6, R_8: not consistent: case (c): intersection between P_1 and P_2 is found and consequently R_7 is found.
(10): New distinct road segment sequence: [R_2, R_3, R_5, R_6, R_7, R_8, R_9, R_1]
(11): Consistency check (7): R_7, R_8: consistent
(12): Consistency check (8): R_8, R_9: consistent
(13): Consistency check (9): R_9, R_1: not consistent: case (c): no intersection between P_{12} and P_{13} is found, therefore R_1 is the marked as wrong and P_{13} is re-projected to R_9.
(14): Final distinct road segment sequence: [R_2, R_3, R_5, R_6, R_8, R_9]

4 Conclusion

In this paper, two methods for successful mapping GPS data to underlying road network in location-based services have been proposed. They play an effective role to reduce the error associated with the data and consequently define a more accurate user trajectory, which is a basis for providing more accurate services to the users.

References:

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