SPATIAL INFORMATION FILTERING FOR ADAPTIVE VISUALIZATION IN VEHICLE NAVIGATION SYSTEMS

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ABSTRACT:

Visualization has become an increasingly important manner to support vehicle navigation systems and other location-based services. However, the information display on these mobile devices is an essential and complex issue due to the limitations in mobile devices, dynamic usage contexts and the user's personalized preferences. Among these challenges, the main disadvantage is the limited size of the display screen, which is the important factor causing information redundancy and human cognitive burden. The objective of this study is to filter the irrelevant information for the sake of decreasing the map load and providing adaptive spatial information visualization. In this paper, we define the core filter components by exploring the user information needs in vehicle navigation systems and discussing the nature of them. Furthermore, we describe the filter mechanism by integrated these components from two aspects, focusing on building area of interest (AOI) and measuring the dynamic degree of interest (DDOI). Finally, we implement this filter mechanism with POI features and discuss the effect after spatial information filtering.

1. INTRODUCTION

In recent years, the rapid development in the fields of mobile map services, has led to high acceptance and an increase of theirs application. A typical one is vehicle navigation system, which provides various services (e.g., location, searching, route planning, etc.) with the help of digital map and global positing system (GPS). Meanwhile, the visual information on mobile devices is recognized as the most direct communication with the driver. Moreover, the simple and intuitive map expression can effectively help the driver acquire the necessary and relevant information.

However, the visualization on mobile devices still has many deficiencies due to the limitations in the mobile devices, user-centred design and dynamic usage contexts (Zipf, 2002; Hampe and Paelke, 2005; Mountain, 2007a; Meng, 2008). Among these challenges, the main disadvantage of mobile devices is the limited size of the display screen (Nivala and Sarjakoski, 2007), and even worst in the dynamic circumstance. If we don't filter the irrelevant information before taking on them, then the expression of navigation map will face seriously information redundancy. That is also the critical reason causing human cognitive burden and decreasing the artistry of map representation. Therefore, the spatial information filtering plays an important role in visualization for vehicle navigation systems. What's more, the progress of filtering the useless spatial information and highlighting the relevant ones can be regarded as an information adaptation, which is a core component of adaptive spatial information visualization.

The objective of this study is to filter the irrelevant information so as to decrease the map load, and provide adaptive maps for vehicle navigation systems. The previous researches mainly focus on the single spatial filters or fixed degree of interest, but little work has taken the user's requirements into account. In order to present a novel filter mechanism, we explore the user information needs in vehicle navigation systems, and further analyze the nature of them to discover the factors affecting the spatial information filtering. Normally, the general needs provided by navigators can fulfil the user's basic tasks, for example, positing where he/she is, searching the nearest gas station, planning an appropriate route to their destination and so on. Nevertheless, the different drivers have personalized needs due to their different preferences. In addition, the drivers prefer to use a dynamic map, which can satisfy their context driven needs. Based on these different needs, we analyze the filter components and propose our filter mechanism for adaptive spatial information visualization.

This paper is structured in the following manner. The next section provides the related work. Section 3 discusses the filter components and filter mechanism from the direction of user information needs. In section 4, we describe the performance of this filter mechanism and discuss the result of them. Section 5 points out some conclusions.

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2. RELATED WORK

Our study focus on research both in the fields of adaptive spatial information visualization and spatial information filtering. This section provides an overview of the related work.

2.1 Adaptive spatial information visualization

The adaptive spatial information visualization is defined as a user-centred system, which is able to predict the behaviour of its end user and accordingly provide him with the visualization that suits best his/her personal needs considering the user's behaviour (Wang, 2001). In other words, the adaptive visualization is a flexible change on the aspects of cognitive behaviour and user's needs according to the variety of end devices and application environment (Yu and Yang, 2009).

Reichenbacher (2001) introduces a conceptual framework of mobile cartography, and further presents an adaptive model and discusses the key components of adaptive spatial information visualization, including the information, user interface, technologies and representation (Reichenbacher, 2004). Similar to the former, Zipf (2002) argues that mobile maps should not only focus on adaptions to technical parameters, such as device characteristics, locations and so on, but propose that maps need to be dynamically generated according to a wider range of variables from user preferences and interests, the given task, and actual contexts. It is delicate that adaptive information visualization is far more than representation itself, and it care what to show, when to show and how to show. In recent years, the major adaptable components, such as user interface, representation and information, have been discussed in different mobile applications.

From the aspect of user interface adaption, lots of works focus on modelling the user and his or her characteristics (Ling, 2005; Zipf, 2006; Reichenbacher, 2004, 2008), and using different operational types in zooming, panning, rotating, selection, etc. (Brown et al, 2001; Burigat, et al., 2008). As for representation adaption, changing colour scheme (Zipf, 2002); changing symbolization styles (Reichenbacher, 2004; Nivala and Sarjakoski, 2007); and changing in scale, level of details and generalization degree are the favourite manners to implement adaptive information visualization. When it comes to information adaption, the classification (Reichenbacher, 2004), filter (Carmo, et al., 2004), and aggregation (Carmo, et al., 2008) mechanisms are normally used to satisfy the information visualization. The classification is a typical method to define the different class of information by attributes. Aggregation is an alternative method to integrate the results by group the elements that are geographically close. Compared to the classification and aggregation, filter is the effective method to reduce the quantity of information content by all kind of filters.

The HCI (Human Computer Interaction) groups have done many works in user interface adaption, and the representation adaption is the central research direction for the last ten years in mobile maps, while litter literates discuss the information adaption, especially in spatial information filtering.

2.2 Spatial information filtering

The spatial information filtering can be regarded as an important technology in information adaption. It aims at reducing the irrelevant information and providing enough space for the useful information in the limited display screen. Normally, spatial filters are defined to determine the information relevant to the user, and these filters rely on not only the position of the user, but various dynamic context. In this section, we will discuss the different spatial filters and the filter function.

2.1.1 Spatial filters

For the purpose of increasing the result of spatial information retrieval, Mountain (2007b) presents four types of spatial filters, composed of spatial proximity, temporal proximity, prediction and visibility. Spatial proximity specifies a Euclidean distance between the individual's current location and the retrieved objects. The temporal proximity is an alternative distance in space, where results are filtered on the basis of the time taken to travel from the user's current location to the destination. Prediction is based on the user's future location by means of mobile individual's speed and heading. The visibility filters perform a visibility analysis on the user's current location and determine what information can be seen in visibility areas. These filters mentioned above only consider the user's current location, but little work takes the dynamic context into account. Ahlers and Boll (2009) point out that beyond the user's position, the spatial context plays an important role in a mobile information retrieval system. Route information is an extended spatial context for the user, especially in the mobile application. Based on this, a set of extended spatial filters are proposed to improve spatial query. Extended filters for spatial proximity, such searching at departure, on the route, at destination and the sum of them are available manners while the user is moving along a route. If the users are travelling on a route that cannot turn, it will define the search with a direction distance, just as the prediction filter. Similar to temporal proximity filter, a detour minimization as a query is proposed and the distance metric is defined by repeatedly applying a road network distance on all points of the route. In addition, the single spatial filter cannot suit all the complex situations. Thus, a combined spatial filter will be a better extension than the former.

2.1.2 Filter function

The spatial filters and extended ones mainly pay an attention to the user's location and their surrounding context, such as the route information. With these different spatial filters, it can acquire the relevant information in a given area by making use of spatial proximity, temporal proximity, prediction or extended filters, etc. Meanwhile, the degree of importance of these information associates with the user can be obtained by measuring the spatial distance or travel time. However, it is unsuitable to determine the importance of information for the user. For one thing, the distance metric or travel time is a range about the degree of relevance. That will cause the result that a large number of information contents still remain in the limited display space if the density of the information is high, what's more, the threshold of distance or time duration is hard to determine. For another, the relevance is not only the distance (e.g., Euclidean distance, travel time etc.) between the user's location and destination object, but the degree of user's interest and different attributes of object are also should be considered. Furans (1986) introduce a function that quantifies the user's interest in a given point according to current task, called "degree of interest". The value of this function in a point x depends on the a priori importance of the point, API (x), and on D (x, y), which is the distance between x and the point y, then the function DOI (x | y) = API(x)-D (x, y). Other researchers have similarly defined the functions to quantify the interest of data for retrieval and query. Keim and Kriegel (1994) determine the relevance of each element of a database in a query by means of calculating the distances between the values of its attributes and the values of the selection predicates. Reichenbacher (2004) proposes a relevance function that is applied to calculate the importance of the features to the user in his/her usage situation according to the spatial distance, temporal distance and topical distance. Based on the former researches, Carmo, et al. (2008) adapt a extended DOI function that measures the degree of interest of the user on a given point p_j as the average of user's interest (UI) in specific values of k different attributes a_i, i=1,2,3…K, and further add a category weight w_{cat} to the DOI function:

$$DOI(p_j) = \frac{\sum_{i=1}^{k} UI(a_i, p_{ji})}{k} * w_{cat} \in [0,1] \qquad (1)$$

where w_{cat} is the weight defined for the p_j's category. And the Function UI is presented as follows:

$$UI(a_i, p_{ji}) = 1 - Dist(a_i, p_{ji}) * w_i,\ w_i \in [0,1] \qquad (2)$$

where the Dist function represents the distance between the value selected by the user for the attribute a_i and the value of the attribute in the point of interest p_{ji}; and w_i is the weight of attribute a_i, which can be defined by the user to specify the importance of attribute in the applications.

Although these different spatial filters and DOI functions can be applied to filter the less relevant information to some extent, the adaptive information visualization depends on the dynamic context and user current needs in application, that means the fixed spatial filters and DOI functions cannot satisfy user's needs. In order to provide an appropriate filter components and mechanism, we should analysis the user information needs and present the filter method consider their needs.

3. FILTER MECHANISMS BASED ON USER INFORMATION NEEDS

3.1 User information needs in vehicle navigation systems

In this paper, we will analysis the user information needs from three aspects: general information needs, personalized needs and context driven needs.

3.1.1 General information needs

In the process of using vehicle navigation systems, the general information needs of the user normally respond to the basic services, i.e., address location, route planning, route guidance, search, and so on. All of these functions are driven by human's task in hand. What's more, it is no doubt that all kinds of information are needed in order to fulfil these services. Address location aims to determine the user's current position according to the GPS sign, moreover, the salient information, such as landmarks, can help the user know where he/she is, especially in a foreign environment. Route planning resolves the problem that which route can satisfy the user needs from his/her specified origin to the destination. Meanwhile, the planned route is an important spatial context for other information shown on the vehicle devices. Guiding the driver through the origin to their destinations is a typical route guidance service. As for the search, which is the necessary function in vehicle navigation system, and other services are normally implemented associate with it. It can be a simple static point search, a dynamic search along the driving route, or a search with different direction and speed.

3.1.2 Personalized needs

When it comes to the personalized needs, it is a reflection of the user's preferences, and can be regarded as the affective level of user needs. On the one hand, a person may have different interest with various contexts (location, time, task, etc.). On the other hand, different user may deal with the same task in different ways. The former needs can be reduced to a part of context driven needs. The latter one is normally driven by the abilities, knowledge, preference and cultural background of the user. Therefore, the visual information on navigator should vary with the user's personalized needs to provide adaptive information visualization.

3.1.3 Context driven needs

With respect to the context driven needs, it means that the user have to select the suitable information to satisfy their needs for variety according to the complex and dynamic environment as well as their current situation. On one hand, the environment is complex, e.g. weather, light, different driving circumstances, and the real-time traffic condition. These factors will affect the information needs of drivers when they are driving in different circumstances. On the other hand, changes in information needs vary with the dynamic user's task in hand. In addition, user's situation and preference also can be regarded as a context. The user's future location can be predicted in virtue of other information (e.g., current speed, route and driving direction). User's preference investigation and user modelling enables the application developers to determine specific preferences of individual users to best suit their task requirements (David, 2010).

3.1.4 The nature of user information needs

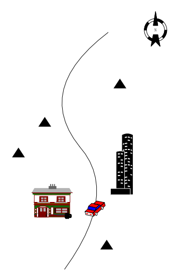
In order to establish the basic filter components, we have further analyzed the nature of these different needs. First, the general information needs are driven by various navigation functions, and all the information is limited in a spatial context. Meanwhile, they are of use in a temporal duration, that is, the drivers are more concerned about the information in current or predict period. Furthermore, we may realize the fact that the relevant features related to our service are contained in a continuous space and temporal duration, which can be defined similar to the mobile space-time envelopes (Brimicombe and Li, 2006). Second, the personalized needs are mainly focus on the different user's preference. On one hand, user's different preferences are built on various attributes of information, which is the semantic aspect of user information needs. On the other hand, the selective criteria of the user are a cognitive issue, that is, the different users have their favourite categories, level and other attributes. So the personalized information needs is influenced by the semantic aspect of information and the cognitive preference of the user. The two factors can be added to the DOI function as the weight of user interest. Third, the context driven needs reflect the dynamicity of user information needs. It is obviously that the characteristic of driver using the vehicle navigation system is mobility. The driving environment, user's situation, current tasks are the dynamic factors and vary with the mobile progress of vehicles.

3.2 Filter components and mechanisms

Although the former researchers have tried to filter the irrelevant information by means of spatial filters, DOI or Extend DOI functions, limitations still remains and cannot be directly implement in the vehicle navigation application. In this section, we will discuss our filter components and mechanism.

3.2.1 Filter components

According to the former work, we know that the driver's tasks are associated with a space-time envelop, contains the spatial area (e.g., geometrical distance, route) and temporal duration (e.g., travel time). Take the basic functions in vehicle navigation system for example, Figure 1 presents the address location function, positing the user where he/she is, and enhance the spatial context with landmarks. Figure2 shows the search service with different area: the left one, circle A and circle B are static search along the route with different radius, and the middle one C and D are search with a direction along the route, and consider the speed factor can extend with a longer radius, just like E; the right one combine the spatial context, direction and speed, the low speed F, middle speed G, and high speed H. In addition, the route planning and the route guidance normally is the integration of the former situation.



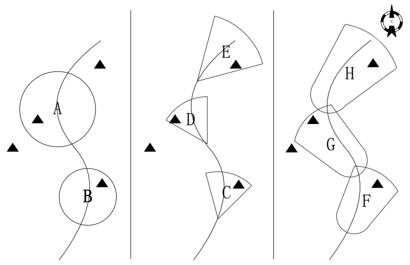


Figure 1. Location   Figure 2. Searching with different Area

Except the spatial and temporal components, the semantic aspect of information plays an important role in the filter progress. To some extent, the reason that the user pay more attend to the information normally is concerned about the one or several attributes of them. Different categories of POI are the nominal attribute that can distinguish from others. Moreover, to make a distinction on the importance of the different category, the numerical value or the further nominal attribute can be added to the information (Ahlers and Boll, 2009). Given the preference of cognitive aspects, we know that the user's preference can acquired by implicit or explicit relevance feedback methods, such as questionnaire, the user appoint or interactive. The semantic and cognitive components are also the core factors affecting the information filter progress, so modelling them and extending the UI function will enhance the measurement of DOI. In spite of this, the dynamic context should not be ignored, because the user information needs are used to vary with these different contexts. Therefore, the weight of semantic attributes and the user cognitive preference should be changed with the dynamic context variable, and the DOI can be further extended into DDOI (dynamic degree of interest).

3.2.2 Mechanisms

Establishing suitable filter components is an important part before filtering the irrelevant information. Meanwhile, a critical issue is how to set the appropriate filter mechanism. As mentioned above, the spatial area, temporal duration, semantic attributes, cognitive preference and dynamic context are various factors affect the filter progress. We can filter the less relevant information from every aspect of the filter components, but the results may not satisfy the user's requirements due to the limitation in single filter rules. Considering this, we build up our filter mechanism by integrated them from two aspects, focusing on AOI and DDOI.

AOI: Obviously, the services provided by the vehicle navigation systems are limited in a mobile space-time envelop, so the spatial and temporal filters can form an AOI, which aims to narrow down the searching area and reduce the quantity of information. Although the AOI may vary with the different navigation functions, the geometric components of it can be constructed from core and extended regions by means of user's current situation, speed and direction. As shown in Figure 3, the core region use a circular zone of radius *d* around the user's location, and it can be regarded as the static AOI without speed. When the user is driving on the route with different speed and direction, the AOI can be extended by a sector area to show the location the user will access for a while, and the space of the extended region is limited by the distance that the user can arrive in a temporal duration with current speed. The extension envelop is an area that the user can arrive in *t* minutes at the velocity *v*, and the arrowhead is the driving direction of the user. The AOIs with different speed and orientations are similar to the right one in the figure 2.

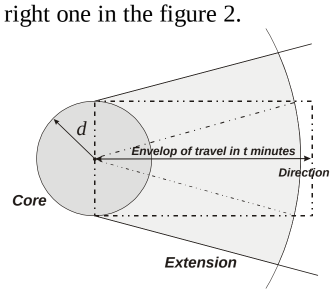


Figure 3. Geometric components of AOI

The purpose of setting up an AOI is to restrict the search space for filtering, and the next step of our filter mechanism focus on the average user's interest of the objects with the user by measuring the DDOI, which is based on the DOI function and further extended considering the dynamic context.

DDOI: The DOI function can calculate the degree of interest of a given point, and the weights in attributes can extend the function to distinguish the important attributes and less important ones. Meanwhile, it can further add a category weight to determine the degree of importance between the different categories. Nevertheless, the driving circumstances, the user's tasks and other dynamic factors are able to affect the user's interest (UI), so the w_i cannot effetely represents the user current needs. In order to extend the UI function, we present our method from two aspects. On one hand, we define a context set to describe the set of the attributes and their weight associated with the user's current context. The form of context set can be represented as:

$$UContext = \{(a, w) \mid a \in R_a \wedge w \in [0,1]\} \qquad (3)$$

where R_a is the set of available attributes, *a* represent the element of R_a and the *w* is the weight of it, range from 0 to 1. On the other hand, we prefer to use the $w_i * dist(OJ)$ instead of the w_i to distinguish the importance of objects in the AOI, and the function *dist(OJ)* as follows:

$$dist(OJ) = \begin{cases} 0, \text{if the } p_j \notin AOI \\ \sqrt{\left(\frac{x_o - x_j}{\max_x - \min_x}\right)^2 + \left(\frac{y_o - y_j}{\max_y - \min_y}\right)^2}, \text{if the } p_j \in AOI \end{cases} \quad (4)$$

The function depends on the position of point j whether is in the AOI and the normalized Euclidean distance between P_j and the user's location, where (x_o, y_o) is the position of the user, and the (x_j, y_j) is the location of the P_j. The maximum and minimum coordinate are also the points in the AOI. So the DUI function can represent like this:

$$DUI(a_i, p_{ji}) = 1 - Dist(a_i, p_{ji}) * w_i * dist(OJ), w_i \in [0,1] \quad (5)$$

where the *Dist* (a_i, p_{ji}) functions are similar to the ones mentioned in Carmo, et al. (2008).

And the DDOI function is:

$$DDOI(p_j) = \frac{\sum_{i=1}^{k} DUI(a_i, p_{ji})}{k} * w_{cat} \in [0,1] \quad (6)$$

4. RESULT AND DISCUSSION

In vehicle navigation systems, the expression of POI features is the direct factor influencing the visualization because of their complex types and large amount. So the spatial information filtering for adaptive visualization mainly attends to the selection and filter of POI features.

Our strategies to filter the irrelevant POI focus on setting up the AOI and measuring the DDOI, according to the user's location, speed, direction and the current information needs. The following experiment, we will discuss our filter mechanism based on a scenario. It is suppose that the user would like to go to buy a TV set, and the requirement is as follows: 1) The price of the TV set is below 5000 Yuan; 2) The reputation of store is 3 to 5 star; 3) There are enough parking spaces in the store; 4) After shopping, they will have a lunch.

Figure 4. Navigation map before spatial filter

Figure 5. Spatial filter with space-time AOI

As shown in figure 4, it is a navigation map without any operation. In this map, there are large numbers of POI features and the classes of them are more than five. According to the user's requirement, it is easy conclude that many of POI features are less relevant to the user's current task. In order to help the user to find a suitable store, we have to filter the useless POIs on the map and show the important ones near the user's current location. Figure 5 is the result after filtering by AOI, and the centre of circle envelope is the position of the user. Meanwhile, the extension envelop are formed in the light of the user's driving speed and direction, which can acquire from the GPS sign. Furthermore, the spatial distance can calculate the importance of POIs in the AOI.

However, limitations taking the spatial distance to measure the importance of these POIs in the AOI cannot be neglected. In this scenario, we know the user's interest is the POIs associated with the shops, thus the other POIs are less relevant for his/her current task and they can be filtered by user's interest. That means we can reduce the number of POIs by means of building the AOI, but it is hard to distinguish which stores can satisfy our needs. In figure 5, there are 11 POI features, composed of 5 types, including 4 restaurants, 5 stores, 1pub and 1 lie fallow. Compared to the figure 4, the numbers of POIs have been reduced by constructing the AOI, to some extent. Nevertheless, several irrelevant POIs still remain in the AOI, that affect the expression of map, what's more, lot of them cannot satisfy the user's needs.

In order to enhance the usability of filtering the irrelevant information for adaptive visualization, we further implement the DDOI for the POIs after the AOI filtering. The critical issue of this step is measure the value of DDOI by means of the appointed attributes. Normally the attributes can be set before user using the vehicle navigation system. For example, the user can recommend the categories of POI features they are interested in when they are driving, and these recommended ones can be regarded as a nominal type. What's more, they can appoint the range of values if the attributes of POI are numerical types. On behalf of the attributes and their weight, we can further calculate the value of DUI and DDOI. Meanwhile, the attributes and their weight can be adjusted to suit the user's current context, which can be implemented using context modeling and reasoning. In our work, we only appoint several fixed contexts to simulate the dynamic context.

According to the user's requirements, we can set the information as attributes and specify the weight of them to calculate the value of DDOI. In this scenario, the user aims to buy a TV set, so the stores, such as Carrefour, Wal-Mart. Metro etc., will be a favorite places for user. And the stores are more important POIs than others, so the w_{cat} is high in the function DDOI. We can set the attribute of category concerned with the store as the primary attribute, which is a nominal type. Furthermore, the price below 5000 Yuan and enough parking spaces can be regarded as other attributes, while the reputation of store is able to determine the degree of importance between the different stores, all of these can set the w_i in DUI.

Figure 6. Spatial filter with DDOI

Figure 7. DDOI filter with current context

Figure 6 is the result after measuring the DDOI of these POIs and filtering the unimportant ones in the AOI. Shown in the map, we can see that the irrelevant types of POI (e.g. restaurant, serving, entertainment, etc.) and the less important stores are filtered, and the left ones are more related to the user's needs. Mentioned in the requirements, the user would like to have a lunch after buying a TV set. In this situation, the user's interest has changed, and then the value of DUI and DDOI should vary with the new context, which regarded as a subset of *UContext*. For on thing, the *UContext* can be appointed by the user, for another it should be extended by user's feedback information to improve the *UContext* set. A mapping table can establish a relation between the user's current context and the set of *UContext*. According to the set of attributes and weights, it can calculate the DUI and DDOI, and further determine the visual POIs for the user. In this scenario, the user wants to have a lunch after buying a TV set, and then the map has to adaptive change in order to satisfy the new needs. Figure 7 shows the result with respect to the user's needs considering the restaurant POIs. Other irrelevant POIs are filtered for the purpose of increasing the relevance of features and improving the map expression. Therefore, it is convenient for the user to find the appropriate restaurant for lunch using the map after spatial information filtering.

5. CONCLUSION

In this paper, we have discussed a novel spatial information filter mechanism for adaptive information visualization based on the vehicle navigation application. Our work focus on built an AOI and measure the DDOI. The AOI is the region associated with the user's current situation, e.g., location, speed and direction, while the DDOI is extend the traditional DOI with dynamic context and considering the space limited in the AOI. With building the AOI, we can reduce the search and visual region, and further acquire the relevant POI by calculate the DDOI between the POIs and the user by means of the user's current context. Based on a scenario, we have discussed the implementation of our filter mechanism. The navigation map after spatial information filtering can not only improve the relevance between the visual features and the user, but decrease the map load. From the effect of visualization, we can see that the legibility and artistry of navigation maps are better than the ones without filtering.

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