Spatial relevancy algorithm for context-aware systems (SRACS) in urban traffic networks using dynamic range neighbor query and directed interval algebra

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Abstract. Spatial relevancy is one of the primary types of relevancies that determine whether a context is spatially related to the user or not. This paper specifically addresses the use of spatial relationships for detecting spatially relevant contexts. The proposed approach is restricted to the urban network and assumes that in such an environment, the user relates to contexts via linear spatial intervals. The main contribution of this work is that the proposed model is sensitive to the velocity and direction of the user and applies Directed Interval Algebra (DIA) and the Dynamic Range Neighbour Query (DRNQ) to introduce spatially relevant contexts according to their arrangement in space. The Spatial Relevancy Algorithm for Context-aware Systems (SRACS) helps the tourist to find his/her preferred areas that are spatially relevant. The experimental results in a scenario of tourist navigation are evaluated with respect to the accuracy of the model, performance time and satisfaction of users in 25 iterations of the algorithm on 25 routes in Tehran. The evaluation process demonstrated the efficiency of the model in real-world applications.

Keywords: Context-aware, spatial relevancy, spatial relationships, directed interval algebra, tourist

1. Introduction

Context appears as a fundamental key to enable systems to filter relevant information from what is available [5,9,18,19,37], to choose relevant actions from a list of possibilities [1,27,46], or to determine the optimal method of information delivery [6,43]. The major challenge of context-aware systems is the separation of the relevant from the irrelevant information [14,17,28,32,41]. This process requires finding an acceptable degree of information reduction, i.e., presenting as much information as needed and as little as required [41]. However, there are few reports concerning appropriate services to manage spatial relevancy parameters that determine whether a context is spatially related to the user or not.

Most of the current models for the spatial relevancy parameters in context-aware systems are based on the spatial relationships between the interacting objects [14,21,32,41]. Some studies have used the proximity relations between the user and the contexts to model the spatial relevancy and utilised K-N neighbourhood or range queries [11,32,35]. Such relations cover the inclusion of contexts in a distinct area or...
range and the distance to other entities [11]. Holzmann and Ferscha [14] defined a Zone-Of-Influence (ZOI) for any entity with a specified distance and direction and used the RCC5 [3] spatial relationships to model spatial relevancy which are disjoint, overlaps, inside, contains and equal. The position, direction and extension of both ZOI are also included in their model. The most important drawback of these systems is that they do not mention the characteristic of the user’s movement in an urban network which typically follows a linear route with a specific direction and velocity [39]. Moreover, these approaches do not apply all of the topological relationships such as order relationships (e.g., behind or in-front-of), which could be useful in providing spatially relevant context-aware services.

To model the spatial relevancy parameters in an urban context-aware system, which could cover the characteristics of the user’s movement in an urban traffic network and utilise all of the spatial relationships (metric, directional and topologic), the approach proposed in this paper is organised into two main steps as follows:

1) The quantitative representation of the moving user and his/her related contexts with spatial intervals. The spatial interval of the user is directed and will be dynamically updated based on the position, velocity and direction of his/her movement (DSI). The spatial intervals (SIs) of the related contexts are assumed to be static and unchanging.

2) Comprehensive representation of spatial relationships between the DSI of the user and the SIs of the related urban contexts that can be modelled with the Dynamic Range Neighbour Query (DRNQ) and Directed Interval Algebra (DIA).

The main contribution of this paper is the use of DIA for modeling spatial relevancy in an urban context-aware system. The model is called the Spatial Relevancy Algorithm for Context-Aware Systems (SRACS). The selection of DIA in this research is considered for the following reasons: (1) when the user is moving in an urban network, he/she has a directional linear route. Therefore, the position of the moving user can be effectively modelled through a directed spatial interval [36] that is adaptive to the user’s behaviour (it can be extended or shortened according to the user’s velocity). (2) In an urban area, one usually encounters solid objects; therefore, most of the related contexts of the user are considered with their external views and which is sufficient to abstract the contexts and show them with spatial intervals. In the proposed approach “related contexts” refers to the contexts that are preferred by the user. For example, the related contexts of a tourist are the attractive areas such as monuments, gardens and museums. (3) The relationships between the spatial intervals of the moving user and static contexts can manage all of the spatial relationships including topological, metric and directional relationships. Figure 1 shows the importance of each spatial relationship. (4) The algebra between directed spatial intervals could provide and introduce spatial instructions (related contexts) to the user based on their arrangement in space. For the latter reason, the algorithm is acted partially and followed up with the execution of a DRNQ. Indeed, DIA assesses the spatial relationships between the DSI and SIs which are selected by the DRNQ.

Our approach is implemented in two districts of Tehran, the capital of Iran, and we have focussed on an outdoor guided tour as an example. In this scenario, the user is a tourist who intends to visit some selected points of interest with a specified origin and destination.
It is assumed that the tourist is equipped with a PDA or a laptop computer, and a GPS for positioning, recognised by the system or identified by the user. The proposed algorithm guides the user from the origin to destination. Because the system is context-aware, the location information of other points of interest along the route of the user is automatically sent to the tourist, and the user determines if he/she wants to visit them.

The evaluation process is based on three factors: the accuracy of the results, the time performance of the algorithm and the satisfaction of the users with the navigation process. The accuracy assessment of the model is based on the comparison of the expected and the actual spatially relevant spatial objects detected by the model. The Chi-squared test is used to evaluate the goodness of fit. The experimental results show that the proposed approach can effectively model and accurately detect the spatially relevant contexts within a reasonable time frame. This approach also provides context-aware instructions for the user with a high percentage for user satisfaction.

The rest of this paper is structured as follows: Section 2 presents fundamental aspects concerning the spatial relevancy parameters and the principals of DIA theory and presents the research methodology and architectural design of the system. Section 3 presents a case study. The evaluation of the algorithm and the results obtained from the case study are explained in Section 4. Section 5 discusses the theoretical and practical issues of the proposed approach and attempts and gives a comprehensive comparison with related work. Finally, conclusions and directions of potential future research are considered in Section 6.

2. Materials and methods

In this section, the concept of spatial relevancy is described, followed by a description of the DIA theory and a description of the research methodology implemented in this study.

2.1. Spatial relevancy

Raper et al. [28] claimed that “…understanding the individual ‘geospatial relevance’ of information will be necessary for context-based services to provide appropriate information”. Saracevic [42] offers a general definition of relevance derived from its general qualities: “Relevance involves an interactive, dynamic establishment of a relation by inference, with intentions towards a context. Relevance may be and the route is constrained by a directed network. The origin and the destination of the user are defined as a criterion reflecting the effectiveness of exchange of information between people (or between people and objects potentially conveying information) in communication relationship, all within a context”. Reichenbacher [41] modelled relevancy parameters and proposed general rules of thumb for the assessment of relevancy for geospatial objects that build a type of hierarchy of relevant objects, also he claimed that the bases of finding relevant contexts are physical and spatial relationships [41].

Various contexts in pervasive systems can be classified into primary and secondary contexts [25]. The role of primary contexts in context management is obviously the indexing of the context information. Further information about entities can be accessed once they are found using the primary index. The identity of the entities, the location of the entities and the time are called primary contexts [11,12]. The additional context information such as user preferences, temperature, system properties and network are denoted as secondary contexts [16]. Following this perspective, three main relevancies in context-aware systems are identical relevancy, spatial relevancy and temporal relevancy [11]. Among these relevancies, the current position – ‘the here’ – is usually the centre of action, perception and attention. Thus, the context as perceived is strongly dependent on one’s position [4,7,8,12,14,22,31]. Moving the position is also a human way of selecting relevant contexts for the activity that is performed [7,30].

The identical information may be fully relevant at one position but irrelevant at another position [13,23,34]. As seen from these observations, the locality of the context is quite important and should therefore be included in context management as one of the basic relevant parameters, called the “spatial relevancy”. The spatial relevancy of an entity is dependent on the distance between the context and the user [7], their types of topological relationships and the direction of the user’s movement [15].

2.2. Directed intervals algebra

Being similar to the well-known Interval Algebra developed for temporal intervals [2,26]; it seems useful to develop spatial interval algebra for modelling spatial relationships especially in an urban traffic network. There are several differences between spatial and temporal intervals that have to be considered when extending the intervals described by Wang et al. [38].
Interval Algebra (IA) describes the possible relationships between convex intervals on a directed line. The default application of Interval Algebra is temporal, so the directed line is usually considered to be the timeline [29]. 13 base relationships, namely: before (<), after (>), meets (m), met-by (mi), overlaps (o), overlapped-by (oi), during (d), includes (di), starts (s), started-by (si), finishes (f), and finished-by (fi) describe a combination of topological relations (disconnected, externally connected, partially overlapping, equal, non-tangential proper part, tangential proper part, and the inverse of the last two) and order relationships (<, >). The topological distinctions are exactly those which are made by RCC8. Therefore, RCC8 is often considered as the spatial counterpart of the IA. From another point of view, the given direction of one-dimensional line is the key feature of IA and distinguishes IA from RCC8 [29].

This given direction naturally imposes a direction on the intervals. However, because of its original and temporal interpretation, the direction of the intervals has never been considered in IA [29], leading to the definition of Directed Intervals Algebra (DIA), which consists of 26 base relationships as given in Renz [29] and modified in this paper (Table 1).

This modification is related to the properties of spatial intervals that are defined by Renz [29] and the characteristics of spatial intervals which are described in this paper. In Renz’s approach, both of the spatial intervals of the user are directed, however in SRACS the spatial interval of the user is directed but the spatial intervals of the related contexts are not directed. Therefore, although we have 26 spatial relations in this paper but the concept of these relationships and the approach of their computation are modified.

### 2.3. The proposed spatial relevancy model

The objective of this paper is to develop an approach for modelling spatial relevancy in an urban context-aware system based on directed interval algebra.

#### 2.3.1. The proposed algorithm

The main steps of the proposed spatial relevancy model are summarised as follows:

1) The first step of the proposed algorithm is performing a dynamic range neighbour query [45], with the centre of the user’s position. The results of this step are the related contexts which are near to the user based on the introduced radius. The radius of DRNQ is changed based on the velocity of the user. It is computed as \( r_{DRNQ} = \frac{V \times t}{x_1} \), where \( V \) is the velocity of the user (m/s) at the moment of updating and \( t \) (s) is the duration time of updating which is considered to be 6 seconds in this research.  6 seconds is the average of minimum time claimed by the users that they need to assess the instruction in navigation process while they were unfamiliar with the visiting area (Fig. 2);

2) The next step is the specification of the characteristics of the directed spatial interval of the user including its extension and direction which should be updated when the user moves. The positive and negative directions of the directed intervals are specified as shown in Fig. 3, in which the direction of the interval is determined

| Spatial relations between the DSI of the user and the SI of contexts |
|-------------------------|-----------------|-----------------|
| Spatial relations       | Positive direction | Negative direction |
| SI                      | DSI before SI | DSI after d(c)  | DSI meets from behind SI |
| DSI                     | DSI meets in front of SI | DSI overlaps from behind SI |
| DSI                     | DSI overlaps in front of SI | DSI is contained by SI |
| DSI                     | DSI contains SI | DSI starts by SI |
| DSI                     | DSI finishes by SI | DSI equals SI |
Based on its bearing of the interval (the computing approach of the bearing is presented in Appendix A). Since ‘0 degrees’ and ‘180 degrees’ are the points that the user generally intends to turn in positive and negative direction respectively, therefore it is assumed that if the bearing of the intervals is between 0° and 180° (0° ≤ bearing < 180°), then the direction of the interval is positive (dir\(_I\) > 0°) and if the bearing of the intervals is between 180° and 360° (180° ≤ bearing < 360°), the direction of the interval is negative (dir\(_I\) < 0°). Equation (1) illustrates the algorithm for determining the user’s direction. The extent of the interval of the user is calculated using Eq. (1) [49]:

\[
I_u = \begin{cases} 
  x_{cu_i} &= x_{ui} - (V \times t)\sin B_{i,i+1} \\
  y_{cu_i} &= y_{ui} + (V \times t)\cos B_{i,i+1} \\
  x_{cu_{i+1}} &= x_{ui} + (V \times t)\sin B_{i,i+1} \\
  y_{cu_{i+1}} &= y_{ui} + (V \times t)\cos B_{i,i+1}
\end{cases}
\]

where \(I_u\) is the moving interval of the mobile user, \(x_{ui}\) and \(y_{ui}\) are the coordinates of the user’s position, \(B_{i,i+1}\) is the bearing (B) of the direction\(_{i,i+1}\), \((x_{cu_i}, y_{cu_i})\) and \((x_{cu_{i+1}}, y_{cu_{i+1}})\) are the coordinates of the start and end points of the directed interval respectively.

As the velocity of the moving user in an urban traffic network varies, we consider \(V\) as the velocity of the user at the moment of an update and assume 6 seconds as the minimum time required by the user to make each decision during the navigation task. \(V \times t\), which is equal to distance travelled during decision making process, is used the coefficient of the bearing. Figure 4 shows a schematic view of the directed intervals.

The appropriate spatial relationships between the DSI and the SIs (which are determined by step 1) are specified based on Table 1. The important aspect of the achieved instructions is that they will be sorted based on the distance to the user which is ranked after the execution of the DRNQ on step 1. It is fundamental that the user meets the nearer contexts before meeting the contexts that are farther away.

The procedure is repeated after every message update that is provided by the movement of the user. In this research we periodically update the position of the moving user every 6 seconds [20]. However the update of the position is done only when the user is on the move; when the user stops no update is performed. The direction of spatial interval of the user is
updated based on the position update of the user. The relations of DIA are calculated based on the Bearing of DSI and comparison between the x, y coordinates of the two endpoints of DSI and SIs. Since the mapping of both DSI and SI is based on the bearing angle this comparison could model the DIA relations effectively (see more on Appendix B). There are three different modes for this comparison based on the value of bearing angle of DSI: (1) bearing = 0 or bearing = 180, (2) 0 < bearing < 180, and (3) 180 < bearing < 360 (Fig. 5).

Whenever the position of the user is updated, the spatial interval of the user is constructed and the spatial relationships between the user and the nearest contexts (which are determined by the DRNQ) are evaluated. Based on the spatial relationships between the user and the detected contexts, the appropriate instruction is sent to the user. For example, if the relationship is ‘met from behind’ then the instruction is ‘now you will arrive at place A’. The pseudo-code for the proposed spatial relevancy algorithm is given in Fig. 6.

2.4. Architectural design of the system

The proposed spatial relevancy model is independent of the software and the programming language. In this study the user is a tourist with a specified scenario and the software is designed accordingly.

2.4.1. System scenario

In this research, the user is a tourist who is supposed to be guided from a hotel, which is his/her origin; if the location of the origin is not known, the user should introduce his/her current location to the system. After inputting the information about the origin, the user selects his/her point of interest (destination) based on his/her preferences (the characteristics of the places are introduced textually).

The system determines the optimum route between the origin and the destination. While moving, the tourist can be provided with location information of the other points of interest that are along the route of the user (including the characteristics of the places shown on the user screen). The algorithm first pre-computes a route between the origin and a destination which is introduced by the user. But when the user intends, he/she could continue the other route. Indeed the system sends the appropriate instruction to the user based on the position, velocity and direction of user in the case study area. Keeping track of the locations of services along the route, the tourist can get an overview of the place where the points of interest are located. Moreover the context-aware system can direct the tourist when he/she is near such a spot. Figure 7 depicts a schematic view of the tourist scenario.

2.4.2. Hardware architecture of the system

The hardware architecture of the system consists of three main units for the correct display of context-aware services (Fig. 8).

3. Implementation and case study

The proposed spatial relevancy model for an urban context-aware system is implemented in the windows application environment with the Vb.Net. programming language, using a four-stage configuration wizard (Figs 9a–d), and is delivered as the SRACS software in the form of an exe. (or set-up). The set-up file has a feature for downloading the data of the region of interest. The applied spatial data are in vector format; however, we also considered a raster map as a background. The required data can be classified into static and dynamic data which are described as follows:

3.1. Static data

Static data are the information whose spatial characteristics are fixed during the navigation process. We have a raster map of the region as the background and a generalised geo-referenced vector map with the following layers (all data used are at the scale of 1:2000):

- **Graph of road network**: It consists of the centreline of urban roads directed based on the urban rules (such as one-side and two-side).
- **Spatial intervals of the tourist points of interest and urban facilities**: Because the spatial rela-
relationships are calculated with respect to the spatial intervals of the related contexts, they should be stored in the system to have a context-aware instruction. The SIs are represented by straight lines that cover the external boundaries of artefacts. The related contexts of the tourist are categorised as: (1) the tourist’s points of interest, which consist of restaurants, coffee shops, parks, green spaces, shopping centers, downtown centers, monuments, historical places, cultural heritage sites, universities, libraries, exhibitions, sport sites, museums and hotels.

(2) The urban facilities that may be used by the user, such as petrol stations, hospitals, care centres, metro stations, bus stations and airports.

The external boundary of the related contexts is digitised as a spatial interval, and the coordinates of the start and end points of the line are stored in the database of the system.

3.2. Dynamic data (real-time data)

Dynamic data are information that should be updated periodically with the user’s movement. The computation process is carried out based on variations in the data. In this study the position and velocity of the user are the dynamic (real-time) data.

4. Experimental results and evaluation

The spatial relevancy model is implemented in two districts of Tehran, the capital of Iran. Districts 3 and 6
Context-aware services:
- Access to any related information (relevant objects).
- Guiding the user to the points of interest.
- Delivering the new situation information.
- Informing the user if there is new, useful information in the field.
- Reporting and preparing appropriate layouts.

Fig. 8. Overview of the system architecture.

Fig. 9. The configuration wizard of the implemented system: a) welcome page, b) introduction of the origin and the destination to the user, specification of the preferences and the start of the navigation task, c) representation of context-aware instructions to the user and highlights of the spatially relevant contexts, d) illustration of pictures and characteristics of the selected area.
cover some attractive areas for a tourist and are considered for our case study. To investigate how the model would perform in a real-world application, according to the opinion of some of the experts in statistics, 25 visitors are selected for traversing of 25 different routes with different origins and destinations. It should be noted that all of the visitors was quite unfamiliar with the case study area. This fact was held to have the same conditions in evaluation of system regarding satisfaction parameter. Each route was traversed by a visitor equipped with a laptop, a GPS and the software designed based on the proposed model. This paper evaluates the results of the experiments based on three parameters namely; the accuracy of the results, the performance of the model and the satisfaction of the users.

4.1. Accuracy of the results

The metric employed for accuracy assessment of the proposed model is based on a comparison of the count of the number of contexts detected by the model and the control contexts. The control contexts are the related contexts or preferred places that are on the traversed routes by the tourists. The Chi-squared ($\chi^2$) statistic is selected for testing the proposed approach. Chi-squared test of goodness of fit establishes whether an observed frequency distribution differs from an expected distribution.

To test this parameter, 25 tourists traversed 25 different routes with different origins and destinations. In each route the related contexts selected by the tourist via the user’s preference options are specified as control points.

The system is run while the user moves, and the user is guided based on the spatially relevant contexts with ordered instructions. Then, the number of detected contexts in each route is compared with the control contexts. Figure 10 graphically depicts the difference between the two diagrams of the detected contexts and the control contexts.

Chi-squared goodness-of-fit test was used to compare the expected spatially relevant contexts; the results demonstrate the efficiency of the model based on the accuracy of the detected relevant contexts at 95% and 99% confidence levels. Table 2 shows the values of Chi-squared tests at 95% and 99% confidence levels. A comparison between the value of Chi-squared statistics shown in columns 3 and 4 of the Table 2 specifies the accuracy of the Chi-squared proposed algorithm.

The results of the comparison between the values shown in Table 2 indicate that in 25 iterations of the algorithm in 25 different routes, the p-value of the Chi-squared test is significant. In other words, the value of $\chi^2$ which is equal to 3.784, is smaller than of errors at a 95% confidence level (13.091) and 99% confidence level (10.196). Thus, the statistics demonstrate that the proposed approach can accurately model spatial relevancy in a context-aware system.

4.2. Performance of the model

In this section, the results of tests that have been performed to show the run-time efficiency of the algorithm are presented. Three performance tests were conducted, for which a Windows 7 Ultimate system (Intel® Atom (TM) CPU N270 and 2GB RAM) was used. The first set of results shows how much time is needed for updating a DRNQ based on the user’s position (Table 3). The second evaluation reveals the measured time that is required for providing context-aware instructions, which consists of updating the directed spatial interval of the moving user based on the position, direction and velocity of the moving user (Table 4). The final performance evaluation parameter is the required time for implementing the proposed model in any updating procedure including (1) running a DRNQ, (2) updating the DSI of the user, specifying of the type of spatial relationships between the DSI and the SIs and giving appropriate instructions to the user (Table 5).
The archived results reveal that the processing time depends on the number of related contexts (SIs) around the user; however, similar times have been measured for a smaller number of SIs with a correspondingly large number of related contexts.

Up to 12 SIs in the study area around the user area have been considered (based on the constraints in an urban network, 12 is the maximum number of SIs that are detected in the updating algorithm). The measured time for building a DRNQ, updating the DSI of the user and providing context-aware instructions and the total time for the whole procedure are shown in Figs 11–13. The aim of the performance evaluation was to investigate how much time is needed for a particular test system for performing the respective tasks with variable numbers of SIs. The results achieved demonstrate that the total computation time of SRACS performance in the study area is less than 1 s and users have 5 s for decision making.

### 4.3. Satisfaction of the users

The final parameter for the assessment of the system model is the satisfaction of the user with the system assistance procedure. The user’s satisfaction with the services provided is a key issue in modelling context-aware systems. It is obviously crucial for adoption and acceptance of such technologies [10,40]. This study considered five elements for estimating user satisfaction, namely: (1) the usefulness of the context prediction in the user’s decision making process for choosing his/her related contexts [33], (2) the usefulness of the presentation of contexts that have spatial relationships behind the user and in the opposite direction, (3) the effect of the context introduction based on the velocity (this factor is derived from the “adapt to varying situations of the user” parameter pointed by [10,33], (4) the order of the context presentation and (5) the responding time of the algorithm to the user [10,44].

To achieve this goal, a questionnaire was designed and given to each visitor. All 25 tourists completed the questionnaire at the end of the process and gave a yes or no score for each parameter. For every parameter, the number of visitors who agreed or disagreed with the satisfaction factor was obtained. Table 6 shows the percentages of the visitors who agreed and those who disagreed for each parameter.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Time in (s) for selecting related contexts based on the distance parameter with the DRNQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of related contexts</td>
<td>1–4</td>
</tr>
<tr>
<td>Time (second)</td>
<td>0.05–0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Time in (s) for updating DSI of the user and introducing spatially relevant contexts to the user in any update</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of spatially relevant contexts</td>
<td>1–4</td>
</tr>
<tr>
<td>Time (second)</td>
<td>0.03–0.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Time in (s) for introducing spatially relevant contexts to the moving user in every update</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time (second)</td>
<td>1–4 instruction/s</td>
</tr>
<tr>
<td>Time</td>
<td>0.06–0.45</td>
</tr>
</tbody>
</table>
The statistical analysis of the results obtained from questionnaires completed by the visitors demonstrated that on average more than 88% of the visitors agreed with the method implemented in SRACS for presenting approach of navigation instructions (Fig. 14). The results shown in Table 6 indicate a high level of user satisfaction with the proposed model.

5. Discussion

This study proposes and verifies a new approach to model the spatial relevancy parameter in context-aware systems constrained by directed urban traffic network. The proposed model has some specific characteristics that make this model distinctly different from current models. The first key feature of this model is the consideration of the influence of the moving user with a directed spatial interval despite of considering it as a point or a region. A directed spatial interval can model the movement characteristics of the user in an urban network effectively because it includes the direction of the user, which is needed for deciding about continuing/returning/stopping the route. Such a model can also characterise the velocity of the user’s movement by decreasing and increasing the size of the user’s directed spatial interval; thus, whenever the velocity increases, the DSI is extended, and when the velocity decreases, the DSI is shortened. Therefore, in the former case, the more SIs are considered to have spatial relationships with the DSI and the user have sufficient time to make a decision about whether to visit the related spatial contexts. In the latter case, because of the low velocity of the user, the fewer spatial contexts are found, and the user can decide to visit a place for a longer time (Fig. 15).

To evaluate the model in real-world applications, three metrics were considered (Sections 6.1–6.3). The results of the evaluation demonstrated that the algorithm is able to accurately detect the spatially relevant contexts of a moving user in an appropriate run-time and with a high level of user satisfaction with the system’s performance.

<table>
<thead>
<tr>
<th>Percentage of satisfaction</th>
<th>Level of satisfaction</th>
</tr>
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<tbody>
<tr>
<td>0–25</td>
<td>Low</td>
</tr>
<tr>
<td>25–50</td>
<td>Moderate</td>
</tr>
<tr>
<td>50–75</td>
<td>Good</td>
</tr>
<tr>
<td>75–100</td>
<td>High</td>
</tr>
</tbody>
</table>

The results shown in Table 6 indicate a high level of user satisfaction with the proposed model.

Fig. 14. The comparison of the rate of satisfaction.

Fig. 15. Dependency of the size of the DSI to the velocity of the user: a) at a higher speed, b) at a lower speed.

While the advantages of the proposed spatial relevancy model are clearly evident, there are also some limitations to this research which should be addressed in future studies. Although the model handles spatial relevancy in a reasonable manner, it does not treat temporal relevancy in a context-aware system. Moreover, this method may not be suitable for a pedestrian user and may be not applicable in spaces that do not have directed networks, such as a museum.

5.1. Comparison with related works

This section gives an overview of the related works that address the use of qualitative and quantitative spatial relationships to select relevant objects. The comparison is performed based on the characteristics of the SRACS with regard to other closely related studies and projects. One of these studies is the research of Holzmann and Ferscha [14], who defined ZOI for entities and specified the direction, distance spatial relationships between related sensors. Gellersen et al. [24], expressed the quantitative relationships by the distance between devices and the orientation angle, and the qualitative relationships by the spatial arrangement of one device with respect to another. The Spatial Audit Policy Model (SAPM) introduced the concept of the spatial audit rule and supported the homogeneous representation of all spatial aspects involving objects and contextual informa-
tion such as the user’s position, with a 9-intersection topological approach [47]. The comparison of these projects with respect to the different aspects concerning spatial relationships and adaptation parameters is given in Table 8.

As seen from Table 8, using spatial relationships is a common technique for spatial relevancy modelling but in no case are all of the spatial relations such as metric, directional and topological (with all mutually ordered relationships) considered. In adapting the model to the user’s movement characteristics there is no method that incorporates the velocity of the user in providing spatially relevant objects to the user. The consideration of the influence domain is an essential assumption in the recent studies, but the innovation of this paper is the definition of linear spatial intervals for a user and his/her related contexts. Also it can be deduced that presenting spatial related contexts in a real order is needed for user convenient which is considered in the proposed approach effectively.

6. Conclusions and future directions

This paper has presented a Spatial Relevancy Algorithm for Context-aware Systems that guarantees the adaptation of the guiding navigation applications to new spatial contexts. The model enables context-aware services to be managed without the user’s prior knowledge of the area. Adaptation of the application to the user context is based on the Dynamic Range Neighbour Query and Directed Interval Algebra. The 26 spatial relationships between the user and context intervals are specified to detect the spatial relevant contexts.

The main contribution of this paper is the specification of a model for spatial relevancy, which is adapted to the characteristics of moving user in an urban traffic network, and its implementation in a tourist guide system.

In this research the tourist guide is equipped with a PDA or Laptop system and a tool for positioning system like GPS. The tourist could execute this program in his/her device and receive the expected context-aware service conveniently. The experimental results show that the proposed approach could detect spatial relevant contexts at the right position at the right time with a high level of satisfaction. The right position of the context is evaluated with accuracy parameter and the right time of the context-aware services are assessed through time performance. Also the evaluation of filled questionnaire forms of users indicated that the proposed approach could satisfy the

Table 7
The percentage of the satisfaction of the users with each parameter

<table>
<thead>
<tr>
<th>No.</th>
<th>Satisfaction parameter</th>
<th>Score</th>
<th>Yes</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Usefulness of the context prediction</td>
<td></td>
<td>92%</td>
<td>8%</td>
</tr>
<tr>
<td>2</td>
<td>Usefulness of the presentation of contexts that have spatial relations behind the user and in the opposite direction</td>
<td></td>
<td>84%</td>
<td>16%</td>
</tr>
<tr>
<td>3</td>
<td>Effect of the context introduction based on the velocity</td>
<td></td>
<td>88%</td>
<td>12%</td>
</tr>
<tr>
<td>4</td>
<td>The order of the context presentation</td>
<td></td>
<td>92%</td>
<td>8%</td>
</tr>
<tr>
<td>5</td>
<td>Response time</td>
<td></td>
<td>84%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Table 8
The comparison between a few related projects

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance relations</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Topological relations</td>
<td>9-Interaction Model</td>
<td>left-of, right-of, approaching, moving away</td>
<td>RCC5</td>
<td>RCC8 and ordered through DIA</td>
</tr>
<tr>
<td>Directional relations</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Velocity of the user</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Consideration of the influence domain</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Arrangement of the contexts in spatial dimensions</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
user in providing and introducing context-aware services.

As a continuation to this work, it is planned to work on modeling time as a context to present a spatio-temporal model for detecting spatio-temporal relevant context and developing our algorithm for the cases which do not follow a network path. In the future directions it would be interesting to know if there are plans to extend the algorithm to the 2-dimensional case.

Appendix A

In this section we explain an approach of bearing computation for a directed line. Consider a line (L_{AB}) with the origin of A and destination of B. Indeed the direction of L_{AB} is from A to B. Bearing of L_{AB}(B_{AB}) is a clockwise angle from the magnetic north to the directed line (Fig. A.1) which is computed as Eqs (a)–(d) [48]:

\[
\begin{align*}
\text{If } \Delta x > 0 \text{ and } \Delta y > 0 & \text{ then } B_{AB} = \arctan(\Delta x / \Delta y) \\
\text{If } \Delta x > 0 \text{ and } \Delta y < 0 & \text{ then } B_{AB} = 180^\circ - |\arctan(\Delta x / \Delta y)| \\
\text{If } \Delta x < 0 \text{ and } \Delta y > 0 & \text{ then } B_{AB} = 180^\circ + |\arctan(\Delta x / \Delta y)| \\
\text{If } \Delta x < 0 \text{ and } \Delta y < 0 & \text{ then } B_{AB} = 360^\circ - |\arctan(\Delta x / \Delta y)|
\end{align*}
\]

where \(\Delta x = x_B - x_A\) and \(\Delta y = y_A - y_B\)

Appendix B

The coordination of DSI and SIs in a Cartesian coordinate system are as illustrated in Fig. B.1, where the Y-axis is aligned with the origin of bearing angle (magnetic north). Also the DSI of the user is aligned with the centerline of the street and the spatial relations between the DSI and SIs are deduced from the comparison of their x, y coordinates.

References

N. Neysani Samany et al. / SRACS in urban traffic networks using dynamic range neighbor query and directed interval algebra


[16] D. Bonino and F. Corso, What would you ask to your home if it were intelligent? Exploring user expectations about next-generation homes, Journal of Ambient Intelligence and Smart Environments (JAISE) 3 (2011), 111–126.


[48] zn.wikipedia.org/.