A Mobile Computing Approach for Navigation Purposes

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Abstract. The mobile computing technology has been rapidly increased in the past decade; however there still exist some important constraints which complicate the use of mobile information systems. The limited resources on the mobile computing would restrict some features that are available on the traditional computing technology. In almost all previous works it is assumed that the moving object cruises within a fixed altitude layer, with a fixed target point, and its velocity is predefined. In addition, accessibility to up-to-date knowledge of the whole mobile users and a global time frame are prerequisite. The lack of two last conditions in a mobile environment is our assumptions. In this article we suggest an idea based on space and time partitioning in order to provide a paradigm that treats moving objects in mobile GIS environment. A method for finding collision-free path based on the divide and conquer idea is proposed. The method is, to divide space-time into small parts and solve the problems recursively and the combination of the solutions solves the original problem. We concentrate here on finding a near optimal collision-free path because of its importance in robot motion planning, intelligent transportation system (ITS), and any mobile autonomous navigation system.

Keywords: Mobile GIS, Mobile computing, Navigation, Free-collision path, Optimization.

1 Introduction

Mobile agents and movement systems have been rapidly increased worldwide. Within the last few years, we were facing many advances in wireless communication, computer networks, location-based engines, and on-board positioning sensors. Mobile GIS as an integrating system of mobile agent, wireless network, and some GIS capabilities has fostered a great interest in the GIS field [13]. Without any doubt navigation and routing could be one of the most popular GIS based solution on mobile terminals. Due to this fact the mobile GIS is defined as an area about non-geographic moving object in geographic space [19].

Although the mobile computing has been increasingly growing in the past decade, there still exist some important constraints which complicate the use of mobile GIS systems. The limited resources on the mobile computing would restrict some features that are available on the traditional computing. The resources include computational

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resources (e.g., processor speed and memory) user interfaces (e.g., display and pointing device), bandwidth of mobile connectivity, and energy source [2], [10], [19], and [32]. In addition, one important characteristic of such environment is frequent disconnection that is ranging from a complete to weak disconnection [10] and [38]. The traditional GIS computation methods and algorithms are not well suited for such environment. These special characteristics of mobile GIS environment make us pay more attention to this topic.

In this paper, finding a path without any conflict which is so-called collision-free path is highlighted. It is an important task of routing and navigation. Collision-free path and its variants find applications in robot motion planning, intelligent transportation system (ITS), and any mobile autonomous navigation system. It will be concluded that Wayfinding which is a fundamental spatial activity that people experience in daily lives, could be solved by this method.

Within the framework of this paper we attempt to apply an idea to treat moving objects in mobile GIS environment based on partitioning in space and time. The idea is, to divide space-time into small parts and find solution (e.g. collision-free paths and wayfinding procedure) recursively. The connecting results will be the collision-free path. This paper addresses the problem of finding collision-free path in mobile GIS environment. The rest of this paper is organized as follows: Section 2 reviews the related works. Section 3 describes our suggested methodology. Then, section 4 explains how one can find a collision-free path by an optimization problem. Finally, we give concluding remarks.

2 Related Works

An overview of collision detection, mathematical methods, and programming techniques to find collision-free and optimal path between two states for a single vehicle or a group of vehicles can be found in [7], [16], and [34], respectively. In the field of robot motion planning potential field methods introduced by Khatib, are widely used [17]. The main attraction of potential method is its ability to speed up the optimization procedure. Path planning techniques using mixed-integer linear program were developed earlier, especially in the field of aerial vehicles navigation (see e.g. [27-28], [29-30], and [33]. The reader who wants to see more related topics is referred to [11]. In almost all works it is assumed that the moving object cruises within a fixed altitude layer, with a fixed target point, and its velocity is predefined. In addition, accessibility to up-to-date knowledge of the whole mobile agents and a global time frame are prerequisite. The lack of two last conditions in distributed mobile computing environment is a well-known fact.

A method for reducing the size of computation is computation slice [12] and [25]. The computation slicing as an extension of program slicing is useful to narrow the size of the program. It can be used as a tool in program debugging, testing, and software maintenance. Unlike a partitioning in space and time, which always exists, a distributed computation slice may not always exist [12].

Among others, two works using divide and conquer idea, called honeycomb and space-time grid, are closer to our proposal. The honeycomb model [8] focuses on temporal evolution of subdivisions of the map, called spatial partitions, and gives a formal semantics for them. This model develops to deal with map and temporal map only. The concept of space-time grid is introduced by Chon et al. [4-6]. Based upon the space-time grid, they developed a system to manage dynamically changing information. In the last work, they attempt to use the partitioning approach instead of an indexing one. This method can be used for storing and retrieving the future location of moving object.

In the previous work of the first author [20-23] a theoretical framework using Influenceability and a qualitative geometry in the mobile environment with application in the relief management was presented. This article can be considered as an empirical extension of them.

3 Algebraic and Topological Structure

Causality is a well-known concept. There is much literature on causality, extending philosophy, physics, artificial intelligence, cognitive science and so on (e.g. [1, 14, 34]). In our view, influenceability stands for spatial causal relation, i.e. objects must come in contact with one another; cf. [1]. Although influenceability as a primary relation does not need to prove, it has some exclusive properties which show why it is selected. Influenceability supports contextual information and can be served as a basis for context aware mobile computing which has attracted researchers in recent years [9] and [26]. This relation can play the role of any kind of accident and collision. It is well-known that the accident is the key parameter in most transportation systems (for example see [31]). As an example the probability of collision defines the GPS navigation integrity requirement. In addition, this model due to considering causal relation is closer to a naïve theory of motion [25].

In the relativistic physics [15] based on the postulate that the vacuum velocity of light $\boldsymbol{c}$ is constant and maximum velocity, the light cone can be defined as a portion of space-time containing all locations which light signals could reach from a particular location (Figure 1). With respect to a given event, its light cone separates space-time into three parts, inside and on the future light cone, inside and on the past light cone, and elsewhere. An event $\boldsymbol{A}$ can influence (influenced by) another event; $\boldsymbol{B}$; only when $\boldsymbol{B}$ ($\boldsymbol{A}$) lies in the light cone of $\boldsymbol{A}$ ($\boldsymbol{B}$). In a similar way, the aforementioned model can be applied for moving objects. Henceforth, a cone is describing an agent in mobile GIS environment for a fixed time interval. That means, a moving object is defined by a well-known acute cone model in space-time. This cone is formed of all possible locations that an individual could feasibly pass through or visit. The current location or apex vertex and speed of object is reported by navigational system or by prediction. The hyper surface of the cone becomes a base model for spatio-temporal relationships, and therefore enables analysis and further calculations in space-time. It also indicates fundamental topological and metric properties of space-time.

As described in Malek [21, 23], the movement modeling, are expressed in differential equation defined over a 4-dimensional space-time continuum. The assumption of a 4-dimensional continuum implies the existence of 4-dimensional spatio-temporal parts. It is assumable to consider a continuous movement on a differential manifold $\boldsymbol{M}$ which represents such parts in space and time. That means every point of it has a neighborhood homeomorphic to an open set in $\boldsymbol{R}^n$. A path through $\boldsymbol{M}$ is the image of a continuous map from a real interval into $\boldsymbol{M}$. The homeomorphism at each point of $\boldsymbol{M}$

determines a Cartesian coordinate system (x_0, x_1, x_2, x_3) over the neighborhood. The coordinate x_0 is called time. In addition, we assume that the manifold ***M*** can be covered by a finite union of neighborhoods. Generally speaking, this axiom gives ability to extend coordinate system to the larger area. This area shall interpret as one cell or portion of space-time. The partitioning method is application dependent. The partitioning method depends on application purposes [5] on the one hand, and limitation of the processor speed, storage capacity, bandwidth, and size of display screen on the other hand. It is important to note that the small portion of space and time in this idea is different from the geographical area covered by a Mobile Supported Station (MSS). This idea is similar to Helmert blocking in the least squares adjustment calculation [36].

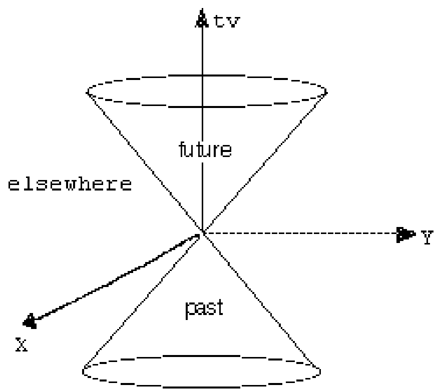

Fig. 1. A cone separates space-time into 3 zones, past, future, and elsewhere

Let us take influenceability as an order relation (symbolized by $\prec$) be primitive relation. It is natural to postulate that influenceability is irreflexive, antisymmetric, but transitive, i.e.,

$$(x \prec y) \wedge (y \prec z) \Rightarrow x \prec z \tag{1}$$

Thus, it can play the role of ‘after’.

Definition 1 (Temporal order): Let x and y be two moving objects with t_x and t_y corresponding temporal orders, respectively. Then,

$$(x \prec y) \Rightarrow (t_x < t_y) \tag{2}$$

Connection as a reflexive and symmetric relation [10]can be defined by influenceability as follows:

Definition 2 (Connect relation): Two moving objects x and y are connected if the following equation holds;

$$(\forall xy)C(x, y) := [(x \prec y) \vee (y \prec x)] \wedge \{\neg(\exists a)[(x \prec a \prec y) \vee (y \prec a \prec x)]\} \quad (3)$$

Consequently, all other exhaustive and pairwise disjoint relations in region connected calculus (RCC) [3], i.e., *disconnection* (DC), *proper part* (PP), *externally connection* (EC), *identity* (EQ), *partially overlap* (PO), *tangential proper part* (TPP), *nontangential proper part* (NTPP), and the inverses of the last two; TPPi and NTPPi; can be defined.

The consensus task as an acceptance of the unique framework in mobile network can not be solved in a completely asynchronous system, but as indicated by Malek [21] with the help of influenceability and partitioning concept, it can be solved. Another task in mobile network is leader election. The leader, say *a*, can be elected by the following conditions:

$$\forall x \in \{\textit{The set of moving objects}\} : a \prec x .$$

Furthermore, some other relations can be defined, such as which termed as *speed*-connection (SC) and time proper overlap (TPO) (see Figure 2):

$$SC(x, y) := \neg EQ(x, y) \wedge$$
$$\{[C(x, y) \wedge (\forall ab)(EC(x, a) \wedge (EC(x, b) \wedge EC(y, a) \wedge EC(y, b)] \Rightarrow C(a, b)\} \quad (4)$$

$$TPO(x, y) := \{(x \prec y) \wedge (PO(x, y) \wedge [\forall z\ (SC(x, z) \Rightarrow PO(y, z))]\}$$

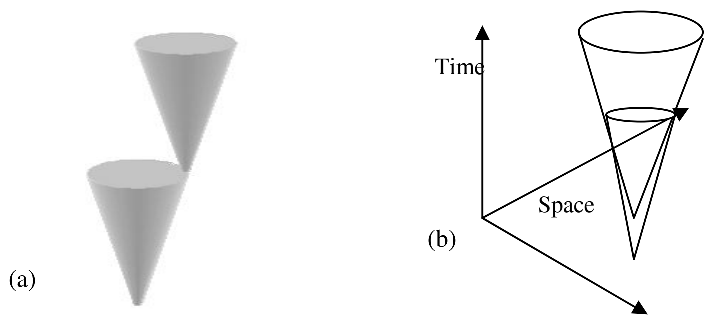

Fig. 2. a) Speed-connection relation and **b)** Time-proper relation between two objects

4 Collision-Free Path

An important task in navigation systems is to find a secure or collision-free path. A collision-free path is a route that a moving object does not have any collision or intersection with obstacles as well as other moving objects. It will be distinguished between two network architectures, centralized and co-operative. In the centralized architecture, a control center exists which receives and sends data to moving objects. In the co-operative architecture all moving objects exchange information between themselves [18]. In the former architecture, the control variables of all nodes associates in the optimization, but in the later only variables of the active node are considered. Finding a collision-free path requires four steps, dividing the space domain into small parts, finding connected cones, computing free space, and finally solving an optimization problem. The problem discussed in this section is using a mathematical programming technique to find the optimal or near optimal collision-free path between moving objects. The details of the other steps are left for future articles.

A mobile terminal in the mobile GIS environment exacerbates the tension between two extreme points. On the one hand, the resource poverty leads to the client-server architecture that the mobile host only supports a user interface but no application (dump terminal). On the other hand, frequent disconnections (see Figure 3), power saving, and scalability concerns of the server suggest a relatively high independent mobile host. Hence, the need to balance between these extreme roles of mobile host is necessary.

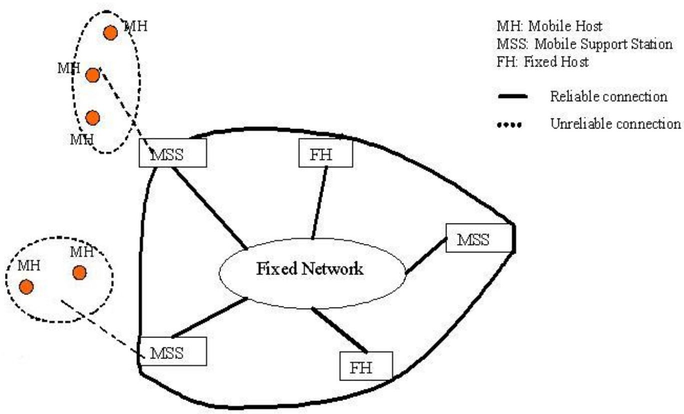

Fig. 3. In the mobile environment the fixed host communicates with a mobile host through a wireless interface that is provided by a mobile supported station

Let us continue with the following scenario: A private company in order to attract more tourists to the lake “Wörthersee” in Austria provides an autonomous navigation system for their motorized small boats. Each boat equipped with a palm-top computer; using GPS for positioning; that can communicate via a wireless network. Based upon this capability, the system can play the role of online tourist guide at each part of the lake. The server sends the necessary information like current position and velocity of the other boats those are relevant to the mobile host. That means, the only information of the agents that have accident possibility in the current cell will be sent. As an instance, only the information of the agent number 2 will be sent to the agent number 1 in the Figure 2. This rule can be formalized by spatial influenceability relation [20]. The mobile host will send its state information like its position and velocity once they have significant changes.

At call setup an optimal route is generated. This task can be done by the fixed host. In each cell, the preliminary route is ensured that no collision occurred. It is natural to define the target function by minimizing the distance between calculated route and the optimal one. It may be named as nearest to optimal path. The method described in this part provides a minimum distance formulation (1). It is combined with the linear collision avoidance constraints [33], turn and velocity constraints, and is extended to match with partition and conquer idea.

$$\begin{array}{l} \qquad \textit{Min.}\ \mathbf{d}^{\mathrm{T}}\,\boldsymbol{\Sigma}\ \ \mathbf{d} \\ \text{S.T.:} \\ \textit{Collision avoidance, turn, and velocity conditions} \end{array} \tag{1}$$

$\mathbf{d}$ is the vector of distances between optimal state parameters and the estimated control parameters in the space-time grid of interest. Finally, the linear constraint quadratic optimization problem should be solved. This part can be run in the clients and the procedure will repeat in other parts.

4.1 Collision Avoidance Condition

We shall consider for simplicity of exposition of two moving objects in a two-dimensional space. The position of agent p at time step i is given by (x_p^i, y_p^i) and its velocity by (v_{xp}^i, v_{yp}^i), forming the elements of the state vector $\mathbf{S}_{xp}^i$. The real value of the state parameter is represented by an asterisk. At every time interval the corresponding surfaces; i.e. cone; of both objects must lie outside each other. It is possible to consider one object as a point and similar to classical approach taken in robot motion planning, enlarge another object with the same size. In this case, the problem becomes easier where the point should be outside of a polygon. With this trick linear conditions introduced by Schouwenaars et al. [33] can be used:

$$\begin{array}{l} x_p^i - x_q^i \geq d_x - R.c_{pq1}^i \ \ \textit{and} \\ x_q^i - x_p^i \geq d_x - R.c_{pq2}^i \ \ \textit{and} \\ y_p^i - y_q^i \geq d_y - R.c_{pq3}^i \ \ \textit{and} \\ y_q^i - y_p^i \geq d_y - R.c_{pq4}^i \ \ \textit{and} \\ \sum_{k=1}^{4} c_{pqk}^i \leq 3 \end{array} \tag{2}$$

where d_l is the safety distance in direction l, c_{pqk}^i are a set of binary variables (0 or 1) and R is a positive number that is much larger than any position or velocity to be encountered in the problem.

4.2 Turn and Velocity Condition

It is possible to define other conditions to constrain the rate of turning ($\alpha_{\max}$) and changing velocity (Δ). Turn condition can be defined with the help of coordinates. Assuming space-time is small, linearization may apply. Other linear equations are suggested by Richards and How [30]. The velocity conditions can be derived easily as linear function from parameters.

$$\boxed{\begin{array}{l} \dfrac{x_p^j - x_p^i}{y_p^j - y_p^i} \le \alpha_{\max} \\ v - v^* \le \Delta \end{array}} \tag{3}$$

4.3 Example

This example demonstrates that the suggested method forms an acceptable collision-free path for two boats. Figure 2 shows current locations of the boats, destinations, and space grids. The time axis is perpendicular to the space. Minimum distance optimality condition results to straight line paths to the destinations which clearly lead to a collision. In this example, the control parameters of the left vehicle are optimized.

Let minimum speed, maximum speed, fixed time interval, and maximum deviation angle (off-route angle) be 12 m/s, 30 m/s, 20 sec., and 5 degrees, respectively. It can be easily seen that the approximate envelope of cones with that deviation angle is a rectangle in 2-dimensional and a cylinder in 3-dimensional space. Figure 3 shows the result of optimization with equal weight for all parameters. As can be seen, only velocity of the left boat at collision time is reduced without any significant change in direction. In order to reach a minimum time trajectory or maximum traveling with a

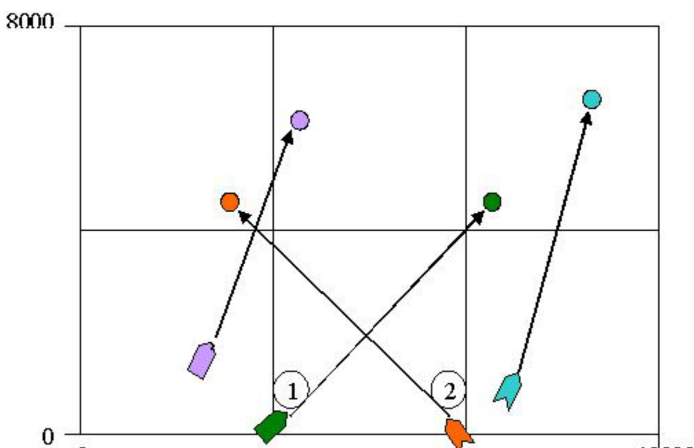

Fig. 4. The trajectories of two intersecting boats. Accident will occur at fifth time interval.

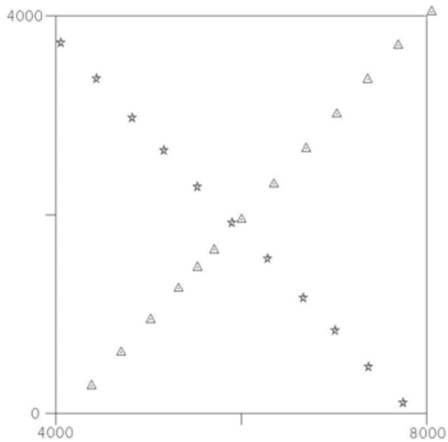

Fig. 5. The designed trajectory for the left boat when all parameters are considered with equal weights

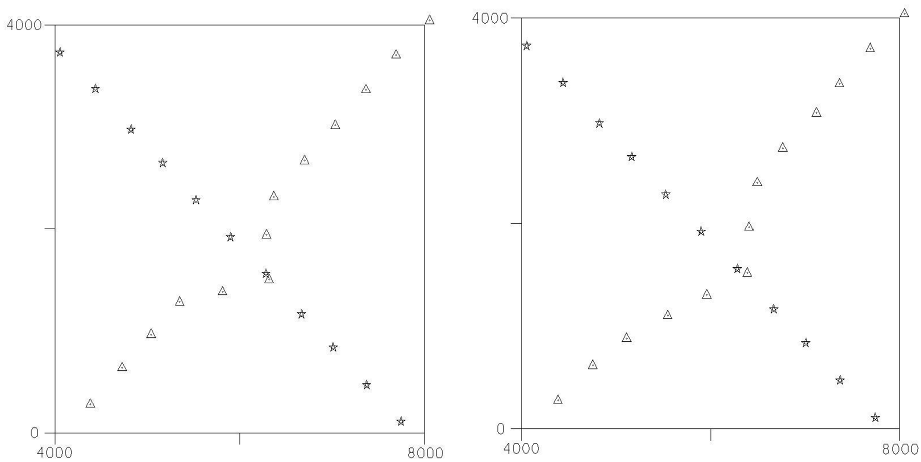

Fig. 6. The designed trajectories with different turn conditions and priority of the velocity

fixed amount of money in our scenario, high weights for velocity are defined and the results are shown in the Figure 4.

By this method it is not necessary to assume that target point and the altitude are fixed. In each space-time cell some new object can appear. Due to linear formulation, this approach may be used in real or fast-time systems.

5 Conclusion and Further Work

This paper addressed the collision-free path problem in the context of a limited resources mobile GIS environment. We have demonstrated that concerns to mobile

GIS theory can be addressed profitably in terms of the partition and conquer idea. It is based on partitioning space-time into small parts, solving the problem in those small cells and connecting the results with each other to find the final result. The reasons behind are clear. The problems can be solved easier and many things are predictable at a small part of space-time. Then, a logic-based framework for representing and reasoning about qualitative spatial relations over moving agents in space and time was derived. We provide convincing evidence of the usability of our suggested method by demonstrating how it can provide model for routing and navigation. A mathematical programming formulation has been proposed and simulated by an example to express optimal or near optimal collision-free path under the framework of such partitioning paradigm.

One important possible application of suggested methodology as our further work is mobile wayfinding services. It is based on the suggested method because wayfinding is an ordered presentation of the needed information to access an environment. It can be done in small parts as far as reaching to the desired point. A detailed uncertainty modeling for partitioning method and solving inverse problem, i.e., to determine the size and other characteristics of small parts based on the given information about needed precision, resource constraints, etc. are also among our future work.

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References

1. Born, M.: "Natural Philosophy of Cause and Chance", Dover Publications, New York, 1949.
2. Caduff, D. : "Sketch-Based Queries In Mobile GIS Environments", Spatial Information Science and Engineering, Maine, University of Main**:** 114, 2002.
3. Cohn, A. G. and Hazarika, S. M.: "Qualitative Spatial Representation and Reasoning:an Overview", Fundamenta Informaticae, 43, pp. 2-32, 2001.
4. Chon, H., Agrawal, D. and Abbadi, A. E.:" Query Processing for Moving Objects with Space-Time Grid Storage Model", Dept. of Computer Science, University of California, No: 2001-15, 2001a.
5. Chon, H., Agrawal, D. and Abbadi, A. E.:"Storage and Retrieval of Moving Objects". Proceeding of *International Conference on Mobile Data Management.,* 2001b.
6. Chon, H., Agrawal, D. and Abbadi, A. E.:"Using Space-Time Grid for Efficient Management of Moving Objects". Proceeding of *MobiDE*, 2001c.
7. De Berg, M., Van Kreveld, M., Overmars, M. and Schwarzkopf, O.:"*Computational Geometry-Algorithms and Application",*(Berlin, Springer-Verlag, 1997.
8. Erwig, M. and Schneider, M., 1999, The Honeycomb Model of Spatio-temporal partitions. In *Spatio-Temporal database management*, (Edinburgh, Scotland, Springer), PP. 39-59.

9. Ferscha, A. and Hoertner, H. and Kotsis, G.: "Advances in Pervasive Computing", Austrian Computer Society, 2004.
10. Forman, G. H. and Zahorjan, J.," The Challenges of Mobile Computing". *IEEE Computer*, **27** (4), 38-47, 1994.
11. GAMMA, http://www.cs.unc.edu/, Accessed: June 2006.
12. Garg, V. K. and Mittal, N., "Computation Slicing: Techniques and Theory". Proceeding of *DISC 2001*, Lisbon, Portugal, PP. 29-78, 2001.
13. GIS-LOUNGE, http://gislounge.com/ll/mobilegis.shtml, Accessed: June 2006.
14. Lewis, D.: "Causation", Journal of Philosophy, 70, pp. 556-567, 1973.Khatib, O., "Real-time obstacle avoidance for manipulators and mobile robots". *International Journal of Robotics Research*, **1** (5), 90-98, 1986.
15. Kaufmann, W. J.: "Relativity and Cosmology", 1966.
16. Kuchar, J. K. and Yang, L. C., "A Review of Conflict detection and Resolution Modeling Methods", *IEEE Transactions On Intelligent Transportation Systems* (December), 2000.
17. Latombe, J.-C., "*Robot Motion Planning"*, Kluwer academic Publishers, 1991.
18. Laurini. R., ”An Introduction to TeleGeoMonitoring: Problems and Potentialities”, In Atkinson P. and Martin D.:”Innovations in GIS“, Taylor & Francis, 2000
19. Li, L., Li, C. and Lin, Z., " Investigation On the Concept Model Of Mobile GIS". Proceeding of *Symposium on Geospatial theory, Processing and Applications*, Ottawa, 2002.
20. Malek, M. R., " Motion Modeling in GIS". Proceeding of *GEOMATIC 82*, Tehran, Iran, National Cartographic Center, 2003.
21. Malek, M. R.,"A Logic-based Framework for Qualitative Spatial Reasoning in Mobile GIS Environment", Lecture Note in Artificial Intelligence, Vol. 3066, pp. 418- 426, 2004.
22. Malek, M. R., Delavar, M. R. and Aliabady, S., "A Mobile Computing Approach for Rescue", proceeding of the 1st International Conference on Integrated Disaster Management, Tehran, January 2006, (in Persian).
23. Malek, M. R., Delavar, M. R. and Frank A.U., "A Logic-Based Foundation for Spatial Relationships in Mobile GIS Environment", Proceeding of 2nd Intenational symposium on LBS & Telecartography, Austria, Vienna, 2006.
24. McClosky, M.: "Naive theories of motion" In: Gentner D. and Stevens S. (Editors): "Mental Models", Hillsdale, New Jersey, Lawrence Erlbaum, 1983.
25. Mittal, N., "Techniques for Analysing Distributed Computations", Department of Computer Science, Austin, USA, The university of Texas, 2002.
26. Nivala, A. M. and Sarjakoski, L. T.: "Need for Context-Aware Topographic Maps in Mobile Devices", In: Virrantaus, K. and Tveite, H.: *ScanGIS'2003*, Espoo, Finland, 2003.
27. Pallottino, L., Feron, E. and Bichini, A., "Mixed Integer Programming for Aircraft Conflict Resolution". Proceeding of *Guidance, Navigation and Control Conference*, 2001.
28. Pallottino, L., Feron, E. and Bichini, A., "Conflict Resolution Problems for Air Traffic Management systems Solved with Mixed integer Programming". *IEEE Transactions On Intelligent Transportation Systems*, **3(1)** (March), 3-11, 2002.
29. Richards, A., How, J., Schouwenaars, T. and Feron, E., "Plume Avoidance Maneuver Planning Using Mixed Integer Linear Programming". Proceeding of *AIAA 2001*, 2001.
30. Richards, A. and How, J. P.,"Aircraft Trajectory Planning with Collision avoidance Using mixed Integer Linear Programming". Proceeding of *American Control Conference 2002*, 2002.
31. Sang, J.: "Theory and Development of GPS Integrity Monitoring System", PhD Thesis, Queensland University of Technology, 1996.
32. Satyanarayanan, M., "Fundamental Challenges in Mobile Computing". Proceeding of *ACM Symposium on Principles of Distributed Computing*, 1995.

33. Schouwenaars, T., Moor, B. D., Feron, E. and How, J., "Mixed Integer Programming For Multi-Vehicle Path Planning". Proceeding of *European Control Conference 2001*, 2001.
34. Verma, T. S.: "Causal Networks: Semantics and expressiveness", In: Sacher R. and Levitt T.S. and Kanal L.N. (ed.s):"Uncertainty in Artificial Intelligence", Elsevier Science, 4, 1990.
35. Van den Bergen, G., "*Collision Detection in Interactive 3D Computer Animation",* Eindhoven, Eindhoven University of Technology, 1999.
36. Wolf, H.,"The Helmert block method, its origin and development", Proceeding of *Second International Symposium on Problems Related to the Redefinition of North American Geodetic Networks*, Arlington, PP. 319-326, 1978.
37. Wolfson, O., Jiang, L., et al., "Databases for Tracking Mobile Units in Real Time", Proceeding of *Database Theory- ICDT'99, 7th International Conference, LNCS 1540*, PP. 169-186, 1999.
38. Zaslavsky, A. and Tari, Z., " Mobile Computing: Overview and Current Status", *Australian Computer Journal*, **30,** 1998.
39. Zhao, Y., "*Vehicle Location and Navigation Systems",* Boston, Artech House, 1997.