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A CONTEXT-DEPENDENT CLASSIFICATION PARADIGM
FOR LAND MOBILITY PROBLEMS

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A CONTEXT-DEPENDENT TERRAIN CLASSIFICATION PARADIGM FOR LAND MOBILITY PROBLEMS*

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Abstract

Battlefield commanders, as well as autonomous vehicle systems, must have the ability to make near real-time mobility assessments of large terrain regions. A context-dependent terrain classification paradigm is proposed through a terrain mobility model that employs the notion of cooperating mission, agent and situation experts. The model attempts to produce a time-sensitive mobility view of the environment by classifying terrain into homogeneous regions, each with an associated traversal cost. The resulting classification of terrain regions can be used by object-based path planning algorithms to compute optimal paths to goals.

INTRODUCTION

"To win the next war, US forces must be able to move decisively, in all directions without loss of momentum... missions depend on knowledge of the terrain and cultural features as well as early detection and effective response to obstacles."

--US Army AirLand Battle Doctrine [5]

The topic of mobility has been an active area of research for many years, particularly in the area of land navigation and route planning. Recently, there has been renewed interest in a particular aspect of mobility research due to several initiatives within the Strategic Computing Program of the Defense Advanced Research Projects Agency (DARPA). Two of the more interesting initiatives involve the development of a mobile, autonomous land vehicle [2,8] and a battle management system for decision support applications [2]. These systems, when completed, will become an important part of the US military force structure for the next decade and beyond.

As described in [5,6], the battlefield of the future will be an extremely volatile environment, characterized by rapidly moving forces and a new generation of highly sophisticated, intelligent weapons systems. The employment of these forces and systems will have a significant impact on the conduct of future military operations in three areas. First, it will expand the *scope* or physical area of the battlefield where the combatants will operate. Second, it will greatly compress the *time* required to make critical strategic and tactical decisions. Third, it will place greater emphasis on the use of teleoperated and autonomous land vehicles. This extended-space, compressed-time, intelligent systems environment will render current battlefield information systems obsolete. It will also seriously challenge the traditional methods employed to create, maintain, and utilize intelligence information on enemy forces, weather, and terrain. This information is critical to the analysis of a military operation in terms of land mobility [6].

Land Mobility. One of the key factors in military operations is the concept of land mobility, or the ability to move quickly at will over any terrain on the battlefield [5]. The dynamic nature of the battlefield will necessitate anticipating situations which may impede movement and initiating appropriate actions in response. Friendly forces must be able to identify, describe, and understand the effects of natural and other restrictions to movement in order to maximize land mobility. Maximizing land mobility will ensure friendly forces maintain the necessary agility and momentum to win the engagement.

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Land Mobility Problems. Battlefield commanders, as well as autonomous vehicle systems, must have the ability to make rapid decisions based upon near real-time mobility assessments of large terrain regions. Many situations present uncertainty, perplexity, or difficulty with respect to movement from one terrain area to another on the battlefield. These situations are defined to be land mobility problems. The authors believe that land mobility problems involve three fundamental mobility questions:

- o What type of force is moving?
- o Where is the force going?
- o What factors affect force movement?

The solution to the land mobility problem is achieved by reducing the uncertainty of the force to the maximum extent possible. Uncertainty reduction can be accomplished by performing a detailed and comprehensive analysis of the battlefield area of operations in terms of mobility.

Mobility Analysis. Mobility analysis is a complex process that attempts to model the relationship between a force and its environment from the perspective of movement potential. The movement potential of a force depends on several mobility factors: mission, enemy, terrain, weather, and space/time restrictions [5]. Mobility factors are used during the process of mobility analysis to develop a composite picture of the battlefield. The composite picture, or *mobility view*, provides critical, time-sensitive information on movement costs associated with specific terrain areas.

Movement cost information is essential for the identification of hindering terrain and mobility corridors. Hindering terrain is defined in [5] to be those areas on the battlefield that physically restrict the movement of a force. Examples of hindering terrain are large, rugged mountains, lakes, steep hills, dense forest areas, and marshes. Mobility corridors, in contrast, are the areas where a force can successfully maneuver, given a specific mission. The development of mobility corridors, as described in [5], is accomplished by the identification of hindering terrain that will, in essence, isolate areas where the force can and cannot move.

Individual mobility corridors can be further partitioned into homogeneous regions, each of which has an associated traversal cost [12]. To describe the process of creating and categorizing these regions according to selected mobility factors, the authors propose a *mobility model* that employs a context-dependent terrain classification paradigm. To fully understand the concept of context-dependent terrain classification, it is first necessary to examine the knowledge requirements for solving land mobility problems in general. The knowledge requirements can be expressed in terms of knowledge objectives and knowledge classes.

Knowledge Objectives and Classes. To provide a sufficiently powerful foundation of knowledge for solving land mobility problems, a set of knowledge objectives is proposed. As a minimum, a force must possess: (1) knowledge about its own physical attributes, (2) knowledge about the physical characteristics of the environment in which it is operating, (3) knowledge about its physical location within the environment, (4) an understanding of its capabilities and limitations with respect to the environment, (5) an understanding of the situation in which it is to perform, (6) the ability to sense or acquire new information, (7) the ability to dynamically change the state of its knowledge, and (8) the ability to generate plans.

In order to achieve each of the knowledge objectives, specific domain knowledge is required. This domain knowledge can be grouped into several general knowledge classes. These include:

- o Capability knowledge
- o Terrain knowledge
- o Mission knowledge
- o Situation knowledge
- o Position location knowledge
- o Route planning knowledge

It is the opinion of the authors that these six classes of knowledge form the nucleus of information needed to construct a mobility expert system for land locomotion capable of solving a wide variety of land mobility problems in the areas of terrain analysis, location analysis, and route planning.

Context-Dependent Terrain. The concept of context-dependent terrain is based on the notion of viewing a particular region of landmass from a mobility perspective according to three principle factors: (1) the agent, (2) the mission, and (3) the situation. An agent is defined in the most general sense to be any entity attempting to move across a specific terrain region. A mission provides critical information on goals and objectives as well as space and time constraints. The situation provides information on the current state of the world, i.e. weather conditions, enemy situation, and significant events. The assignment of traversal costs for a particular terrain region is dependent on the specific nature of the agent, mission, and situation at a given point in time. These entities define a *context* for mobility purposes. Subsequent to defining a mobility context, various search algorithms [10,12] can be employed to find an optimal path to the goal or objective. The following section presents a formal *terrain mobility model* that attempts to classify terrain in context and create a mobility view reflecting the relevant dependencies.

THE TERRAIN MOBILITY MODEL

The purpose of the *Terrain Mobility Model* (Figure 1) is to provide an appropriate framework of knowledge bases and reasoning mechanisms to produce time-sensitive, context-dependent *mobility maps*. At the highest level of abstraction, the model can be viewed as a system of cooperating experts as described in [7]. Each expert has specific domain knowledge to apply to the mobility problem. For a given terrain area, the *mission, agent, situation,* and *terrain* experts combine to produce a mobility mosaic of homogeneous regions, each with an associated traversal cost. The production of the context-dependent mobility maps is the result of the complex interaction of the domain experts within a well-defined environment.

Mobility Environment. The environment in which context-dependent terrain classification occurs is defined by the authors to be a mobility environment. A mobility environment consists of *objects* and *events*. An object is defined in the broadest sense to be either a physical entity or conceptual entity residing within a knowledge base. For example, physical objects consist of entities such as hills, roads, lakes, and vehicles. Conceptual objects consist of entities that describe an area based on the context of the mobility problem. Conceptual objects include entities such as threat area, obstacle area, and intervisibility area.

An event is defined to be any significant occurrence or happening that causes a change to an object. The four major categories of events within the terrain mobility model are mission, agent, terrain and situation. A specific type of event will alter only certain types of objects. When the event is completed, a new state of the world is created. Depending on the impact of the particular event and objects affected, the new state of the world may cause changes in the mobility map producing a different view of the area of interest. The process of modelling the interaction of the objects and events over time is called *mobility view generation.* To understand the process of view generation, an explanation of the specific roles of each of the cooperating experts is provided.

Mission Expert. The primary purpose of the mission expert is to develop a *mission profile* for the land mobility problem The mission profile provides the terrain expert with selected information pertaining to the designated mission. To accomplish this task, the mission expert performs the following functions: (1) identifies and selects a participating agent, (2) determines the area of interest for the problem, (3) identifies key terrain and cultural features, and (4) identifies mission constraints bearing on the problem.

The mission expert receives its initial and follow-on information through the occurrence of *mission events.* A mission event contains all relevant *command guidance* for a specific mission. For example, a typical mission event may contain the following information:

> "From 1900 hours 23 Sep 1986 until 0200 hours 24 Sep 1986, B Company, 1st Battalion, 71st Infantry will conduct a reconaissance of Hill 432, grid coordinates FQ563808, and Nacimiento Road bridge, grid coordinates FQ552809. Avoid contact with enemy forces and use of primary roads."

Given this basic information, the mission expert is able to determine the type of agent that will be participating in the mission. From

TERRAIN MOBILITY MODEL

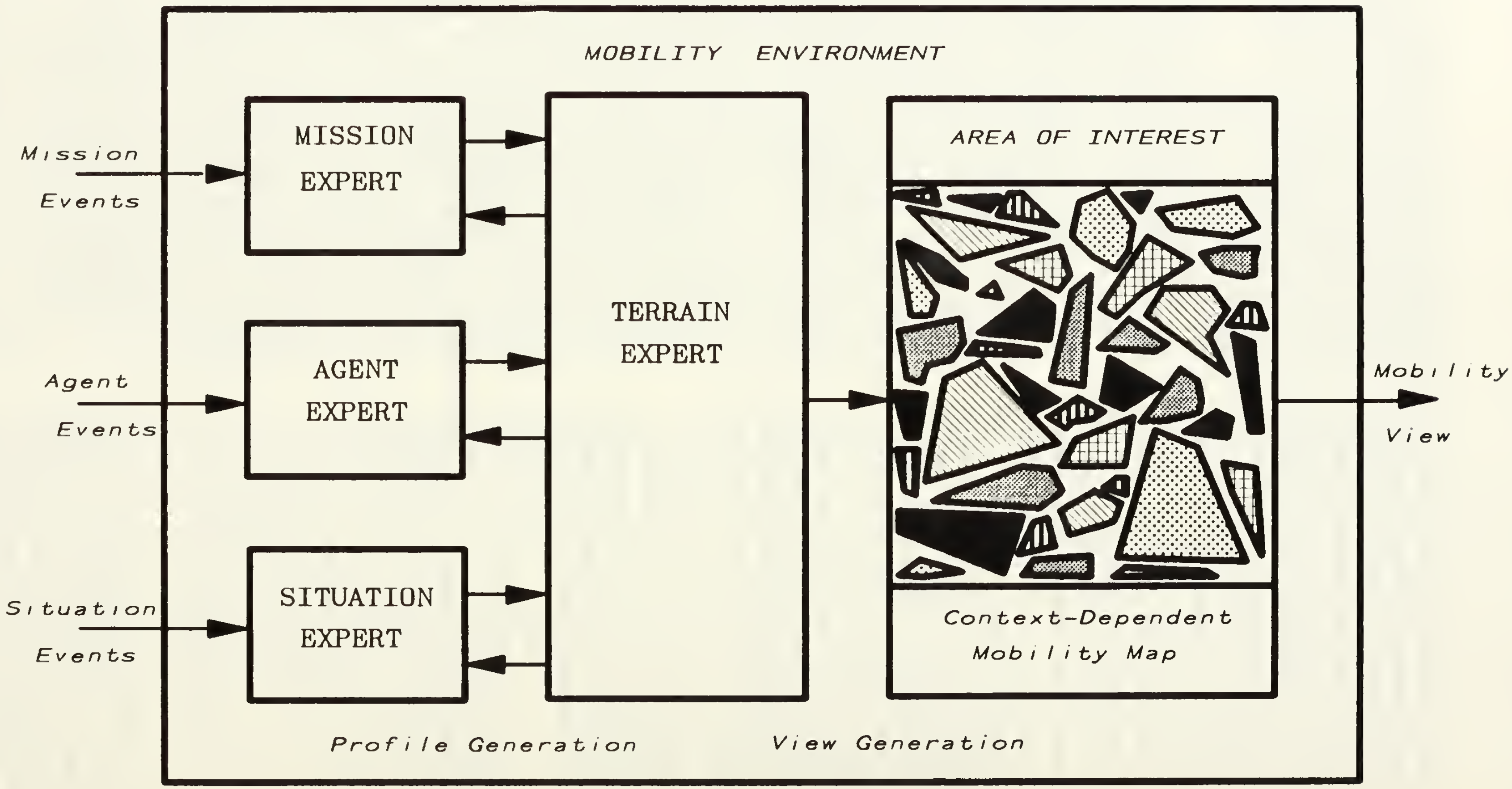

Figure 1

its *knowledge base* it discovers that the 71st Infantry is a mechanized unit and therefore must have type M113 armored personnel carriers. In addition, the mission expert uses the two grid locations. or objectives, to determine the appropriate area of interest for this operation. Since the current location of B Company was not provided in the initial mission event, the default area of interest includes the two primary 1000 meter grid squares containing the objectives and the 1000 meter grid squares adjacent to the primary grid squares. The mission expert also identifies the key terrain feature "Hill 432" and cultural feature "Nacimiento Road Bridge". This information, along with other related constraint information, is passed to the terrain expert for further processing.

Agent Expert. The purpose of the agent expert is to produce an *agent profile*. An agent profile consists of all of the attributes associated with a particular type of agent. The attributes describe the form, size, weight, and power characteristics of the agent and is used to develop the appropriate thresholding information for the land mobility problem [1]. For example, the size and weight attributes of the armored personnel carrier limit the types of bridges it can cross as well as the forest areas it can operate in. The form and power characteristics of the vehicle also restrict the types of terrain configurations it can successfully traverse. The agent expert is queried by the terrain expert for the profile of a specific type of agent, previously identified by the mission expert. After the profile is completed, it is passed back to the terrain expert for further processing.

An agent object can be modified by the occurrence of an *agent event*. An agent event is any occurrence or happening that changes the physical attributes of a particular agent. An example of an agent event is the occurrence of a flat tire or a thrown track on a vehicle. An agent event can also be occurrences of fuel consumption or other factors that influence potential movement speed.

Situation Expert. The situation expert is responsible for developing a *situation profile* for the land mobility problem. The situation profile represents the current state of the mobility environment. It contains the following critical, time-sensitive information: (1) location of friendly forces, (2) location of enemy forces, (3) direction of force movement, (4) weather conditions, and (5) other similar items.

The situation expert receives its input via *situation events*. A situation event contains time-sensitive information that has a potential impact on the mobility of an agent within a given terrain region. For example, a typical situation event may appear as follows:

> "Heavy rainfall, grid coordinates FQ58, from 0600 hours 23 Sep 1986 until 0100 hours 24 Sep 1986."

From this information, the situation expert consults its *knowledge base* to determine if there is a potential impact on the terrain within the area of interest for this particular problem. The situation expert is aware of the fact that the current mission is of type reconaissance with a restriction on the use of primary roads. It also has knowledge of the location and extent of the current area of interest. Thus, the situation expert is able to infer that the rainfall event is significant, not only because it occurs within the area of interest, but also because of the restriction on the use of primary roads. This restriction implies that the agent must travel off-road and therefore, the effect of the rainfall on the soil types is an important factor in the computation of traversal costs for selected regions. Other situation events, such as enemy force location and direction of movement, allow the terrain expert to create a progressive series of threat regions at different points in time. This information may be useful in modelling what the mobility view of the terrain may be at some future point in time.

Terrain Expert. The terrain expert is the focal point of the land mobility model. It is responsible for developing the *mobility view* for the land mobility problem. The terrain expert uses information from the mission, agent and situation experts to create homogeneous regions that are either part of the hindering terrain or mobility corridor. A second partitioning is accomplished within the mobility corridors to assign traversibility cost factors to the various regions within the area of interest.

The terrain expert consists of a large terrain knowledge base and associated inferencing mechanisms that are essential to the process of view generation. The knowledge base contains both *functional* and *spatial* terrain map information as described in [9]. Functional information describes the functional properties of both physical and conceptual terrain features, i.e. hills, lakes, forests, rivers, threat areas, obstacle areas. Spatial information describes the geometric properties of the individual terrain features and the spatial relationships among the features.

The terrain map knowledge base stores preprocessed information on key static *terrain mobility factors*. The terrain mobility factors include surface configuration, surface composition, surface covering, surface drainage, and transportation [3,4].

The process of view generation proceeds in a systematic manner as outlined by the following sequence of events. The terrain expert first obtains the agent type and area of interest from the mission expert. It then obtains the characteristics of the participating agent from the agent expert. The terrain expert uses the agent characteristics to compute a thresholding factor that serves as an index into a series of preprocessed terrain mobility factor overlays. The factor overlays for the area of interest are extracted from the knowledge base and combined to produce a composite overlay for the same area. Information from the situation expert is also used to create additional overlays that are integrated into the final composite overlay.

The terrain expert uses the cost information in its knowledge base to compute the traversibility costs for each of the homogeneous regions developed as a result of the overlay procedure. At the completion of the view generation process, the terrain expert has created a mobility view of the area of interest at an instant in time. Subsequent events may cause a change to a particular object within the mobility environment necessitating a regeneration of the mobility view.

The terrain knowledge base can be changed as a result of mission, agent, or situation events. For example, a new mission event creates an entirely different scenario that triggers a complete regeneration of the mobility view producing a new mobility map. The regeneration occurs as a result of a new participating agent, new area of interest, and new situation. It is also possible to have a regeneration of the mobility view due to a partial change in scenario or the occurrence of a less significant event. The rainfall event, previously mentioned, is an example of a situation event that causes a change to only one of the terrain mobility factor overlays. In this case, the only factor overlay to change is the one for surface composition. This change is due to the heavy rainfall and results in a higher traversibility cost for selected soil regions.

CONCLUSIONS

A context dependent terrain classification paradigm for land mobility problems has been presented. To support the paradigm, a terrain mobility model has been developed based on a series of cooperating experts attempting to create a time-sensitive mobility view of the environment. The mobility view provides associated traversal costs for the terrain regions in a particular area of interest according to the mission, agent, and situation components of the model.

A prototype mobility expert system employing the terrain mobility model and classification paradigm is currently under development at the Naval Postgraduate School. Progress on the prototype development and experimental results will be reported in future publications.

As a result of the initial investigation, the authors have identified several related areas for future research. A key component within the terrain expert portion of the mobility model is the terrain knowledge base. Currently, terrain information is obtained from digital databases that contain raw point elevation data and cultural information [4]. The ability to automatically classify individual terrain cells with respect to the nearest neighbors has been demonstrated in [11]. The next logical step will be to use artificial intelligence techniques to perform a more refined terrain analysis by aggregating individual terrain cells into larger objects such as relief features. Such aggregation resulting in symbolic features with associated attributes will be necessary for the objected-based path planning algorithm described in [12].

Another potential area of research relates to the caching of terrain information within the terrain knowledge base. Once the initial classification is accomplished and an optimal path has been computed, this information can be stored in the knowledge base for future use. Subsequent path planners can check the historic database and possibly use all or part of previously computed optimal paths in generating new optimal paths relevant to the current mission, agent and situation.

REFERENCES

[1] Bekker, M., *Introduction to Terrain-Vehicle Systems,* The University of Michigan Press, Ann Arbor, 1969.

[2] Defense Advanced Research Projects Agency (DARPA), *Strategic Computer New Generation Computing Technology: Strategic Plan for Its Development and Application to Critical Problems in Defense,* October, 1983.

[3] Defense Mapping Agency, Product Specification, *Hard Copy Tactical Terrain Analysis Data Base (TTADB),* Hydrographic/Topographic Center, Washington, D.C., 1982.

[4] Defense Mapping Agency, Product Specification, *Digital Land Mass System (DLMS) Data Base,* Hydrographic/Topographic Center, Washington, D.C., 1984.

[5] Department of the Army, Field Manual FM 5-101, *Mobility,* US Government Printing Office, 1985.

[6] Department of the Army, Field Manual FM 34-1, *Intelligence and Electronic Warfare Operations,* US Government Printing Office, 1984.

[7] Hayes-Roth, F. and Waterman, D., "An Investigation of Tools for Building Expert Systems", *Building Expert Systems,* F. Hayes-Roth, D. Waterman, and D. Lenat (eds.), Addison-Wesley Publishing Co., Reading, 1983.

[8] Horgan, J. "Roboticists Aim to Ape Nature", *IEEE Spectrum.* Vol. 23, No. 2, February, 1986.

[9] Kuan, D., "Terrain Map Knowledge Representation for Spatial Planning", *IEEE Computer Society Conference on Artificial Intelligence Applications,* 1984.

[10] Nilsson, N., *Problem-Solving Methods in Artificial Intelligence,* McGraw-Hill, 1971.

[11] Poulos, D., "Range Image Processing for Local Navigation of an Autonomous Land Vehicle", MS Thesis, US Naval Postgraduate School, 1986.

[12] Richbourg, R., Rowe, N., and Zyda, M., "Exploiting Capability Constraints to Solve Global Two-Dimensional Path Planning Problems", *IEEE Conference on Robotics and Automation,* 1986.

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