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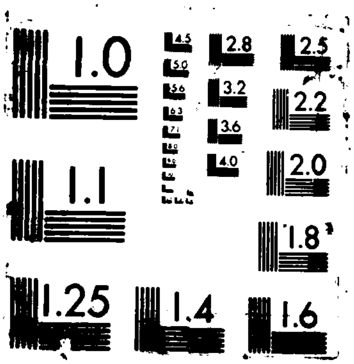
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TERRAIN DATA BASE GENERATION
FOR
AUTONOMOUS LAND VEHICLE NAVIGATION

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Abstract

The Defense Advanced Research Projects Agency (DARPA) Strategic Computing Program is a large, multi-year effort focused on developing the next generation of computers and machine intelligence. Within this program the Autonomous Land Vehicle (ALV) Project calls for the development and demonstration of increasingly sophisticated autonomous land navigation capabilities. As part of this effort, the U.S. Army Engineer Topographic Laboratories (USAETL) has the task of producing a high resolution, high accuracy experimental digital terrain data base of a 16 square kilometer test site. This data base will be used in conjunction with an inertial navigation system within the ALV. The data base will initially consist of six overlays including landforms, soils, surface drainage, land cover, roads, and a digital elevation model (DEM) at five meter spacing. Data on obstacles, control points, and mobility will be added later. ALV applications of the terrain data base include premission route planning, operational context, and a priori information for machine vision. It is expected that ALV experiments will lead to future data base revisions.

Compilation of this data base is being performed on the Computer-Assisted Photo Interpretation Research (CAPIR) system at USAETL. CAPIR is an ongoing research effort which addresses the issues of digital terrain data extraction, storage, and exploitation. This integrated system consists of an analytical plotter equipped with stereo-superposition graphics and a geographic information system to provide the mechanism for 3-dimensional data capture, verification and management. This paper will address data requirements and systems for building terrain data bases in support of experimental autonomous land vehicle navigation.

Background

The Strategic Computing Program is a large, multi-year Defense Advanced Research Projects Agency initiative devoted to developing the next generation of computers and machine intelligence. Within this program the Autonomous Land Vehicle (ALV) Project focuses on the development and demonstration of increasingly sophisticated autonomous land navigation capabilities. The vehicle has an eight-wheeled undercarriage covered by an air-tight fiberglass shell large enough to house on-board computers, sensors, power, and air conditioning. It's primary function is to provide a testbed for integration and demonstration of Strategic Computing Program technologies.

As part of this effort, the U.S. Army Engineer Topographic Laboratories has the task of producing a high resolution, high accuracy experimental digital terrain analysis data base of a 12 square kilometer test site. The compilation of this data base is being performed on the Computer-Assisted Photo Interpretatation Research (CAPIR) system. CAPIR is an ongoing research effort which addresses the issues of digital terrain data extraction, storage, and exploitation. This integrated system consists of an analytical plotter equipped with stereo-superposition graphics and a geographic information system (GIS) to provide the mechanism for 3-dimensional data capture, verification, and management.

Objectives for the five year ALV Project involve the development of road following capabilities, obstacle avoidance and off-road/cross country traversal. In order to achieve these project goals the vehicle will require the following capabilities:

1. Perception - the ability to handle and symbolically represent sensor images from a color video CCD TV camera and ERIM Multispectral laser scanner.

2. Reasoning - the ability to receive goal directed inputs, control subsystems, and derive navigation decisions necessary to achieve this goal.

3. Terrain Knowledge Base Maintenance - the ability to support and update both a-priori digital terrain information and extracted sensor data about the surrounding features.

4. Positional Knowledge - the ability to provide and update the 3-dimensional position of the vehicle over time and location.

This paper describes the construction of the experimental ALV terrain data base which will serve as the source of a-priori terrain information for the ALV.

Data Requirements

The ALV project brings a unique perspective to digital mapping. From this viewpoint, the digital terrain data must support and assist a dynamic autonomous robot to interpret and navigate the surrounding environment. Operationally, this increases emphasis on the following criteria. First, diverse knowledge is required about the encompassing terrain. Three-dimensional thematic data such as vegetation, cultural features, roads, soils, surface drainage, landforms, and topography are important due to their direct influence on mobility and navigation of the vehicle. Second, the relative horizontal and vertical accuracy of these data are very important because of the current limitations of robotics and computer vision/perception. Third, the project requires a high level of detail about terrain features or structures which might seriously impede vehicle navigation. This level of detail must not only be consistent within themes, but also between themes. Thus, individual terrain attributes within a thematic layer must support or coincide with attributes in other thematic layers.

Data Compilation

Initially, the compiled terrain data base will consist of six themes or layers of information. To date, the land cover, road network, and surface drainage layers have been compiled (Figure 1). These three files contain more than four megabytes of data (Table 1).

File Name	Size in kbytes	Compilation Time in Man-Hours
Road Network	352	64
Surface Drainage	524	80
Land Cover	3,185	108
DEM	5,784	TBD
Soils	TBD	TBD
Landforms	TBD	TBD

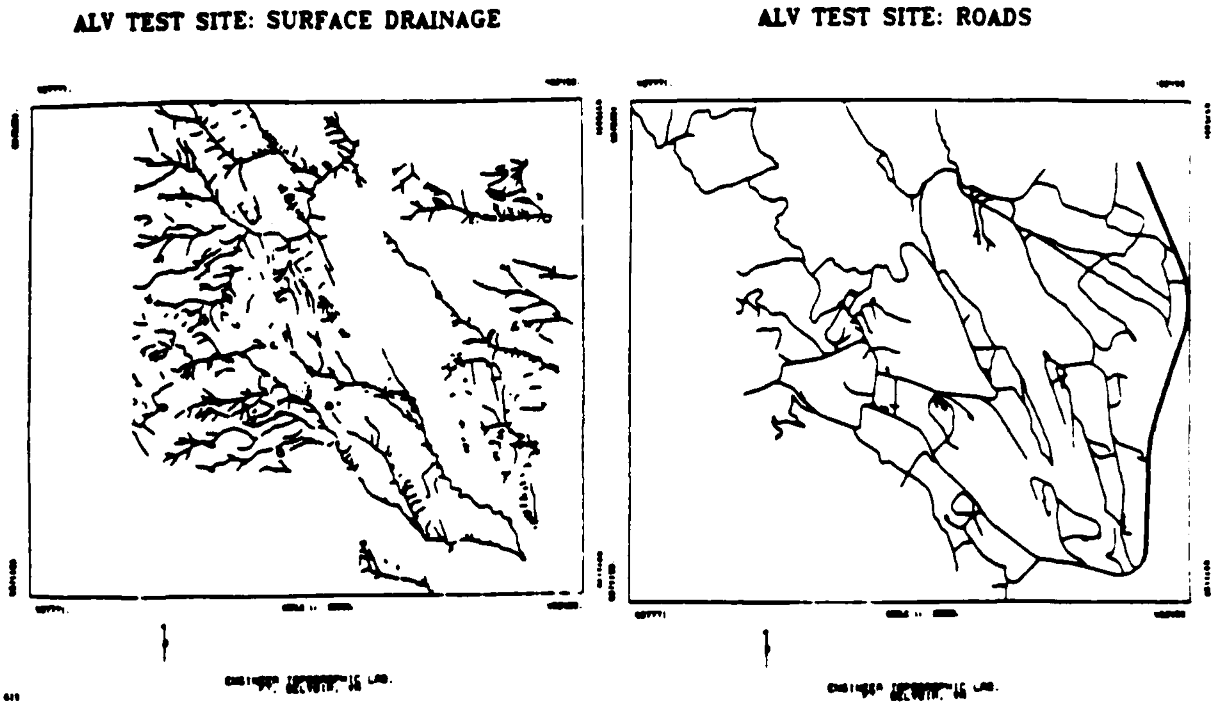
* TBD: To be determined

TABLE 1. Information on terrain data base files.

Soils and landforms, as well as elevation data with a 5 meter resolution, are presently being compiled. Data on obstacles, control points, and mobility will be added later.

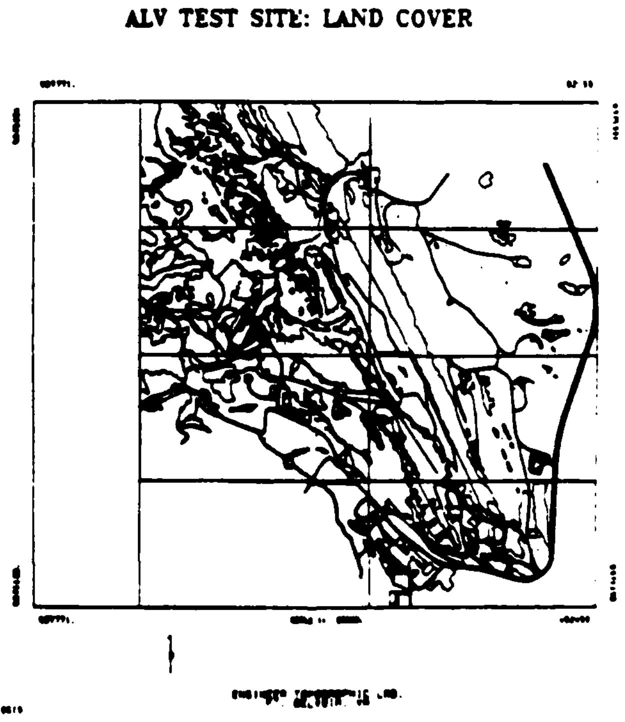
The requirement for high accuracy weighed heavily in deciding what data sources should be selected for use in data capture. As a result, aerial photographs were the only source considered. The basic concerns in selection of photography were large scale, recent date, and image quality. Immediate availability of imagery and camera calibration data also were considered. Photos used for digitizing were stereo black and white, dated 9-29-76, at a scale of 1:12,000. At this scale eleven stereo models cover the test site. Also acquired were stereo natural color photography dated 7-8-78, at a scale of 1:28,000, and color infrared photos, dated 10-5-83, at a scale of 1:58,000. These photos are used for updating information in areas where changes may have taken place.

The CAPIR system employs the use of a GIS and a photogrammetric analytical plotter equipped with stereo superposition displays for data capture. The spatial data are in an arc/node format with left-center-right type attribute entry when digitizing. In addition to digitizing, the GIS also provides for aerotriangulation, editing, topological verification, and data base operations.



ALV TEST SITE: SURFACE DRAINAGE

ALV TEST SITE: ROADS



ALV TEST SITE: LAND COVER

Figure 1. Compiled ALV Terrain Data Base

Once geodetic control data were obtained from previous surveys of the area, a field check was conducted to locate and photo identify the available survey markers. A block triangulation and error propogation was then performed on the complete fourteen model block of temporal images. The unit variance of the final block adjustment was .791 with 661 degrees of freedom.

The project area boundaries were defined and geounits (project sub-areas) were calculated to coincide with the actual areas contained in each of the stereo models. The geounits could then be completely digitized without constantly changing photos on the analytical plotter and unnecessarily performing rigorous set-up and registration procedures. Classification files were also created to contain the specific attribute information.

Data collection began through on-line photo interpretation and manual digitization using the CAPIR system. Three-dimensional terrain information was collected theme-by-theme and geounit-by-geounit. The road network layer was collected first by digitizing the road center and assigning surface material and road width attributes. Surface drainage was delineated in the same manner by digitizing the center of streams and gullies. These two layers consist solely of linear features. Therefore, only the center attribute was entered leaving the left and right attributes of the line being digitized empty or null. Land.cover was defined as the terrain surface covered by both natural vegetation and man-made polygonal features. Areal information of this type were entered with attributes for each of the left, center, right portions of the line being digitized for defining polygons.

The digital elevation data (DEM) are being collected with the CAPIR/DEM profiling system on the analytical plotter. This is a collection system which uses an adaptive spacing grid to optimize profiling in areas which exhibit significant topographic disparity (Edwards et. al., 1986). For instance, areas of different sizes, corresponding to individual geomorphic features or other regions, may be sampled at a wide range of posting densities. The horizontal resolution of the data has a 5 meter spacing in those areas which may be traversed by the ALV. Elevation data for rugged areas will be collected at a higher spacing, interpolated to 5 meters, and flagged within the DEM file. The soil theme consists of photo-interpreted soil materials. Emphasis will be placed on mapping materials that would hinder mobility when wet. The landform layer will consist of photo-interpreted geomorphologic structures. This information will be useful as a qualitative check on other thematic layers and could be used in resolving uncertainty.

Once data capture was completed, topological verification was performed for each geounit in every layer. When verification was accomplished the data was reformatted from an arc/node structure into a polygonal structure to be compatible with other system components.

Data Implementation

The terrain data base will be fulfilling several operational roles. Besides providing a-priori terrain information for road following and pre-mission route planning, it will be supporting the perception, or visual, subsystem for obstacle recognition/ avoidance and landmark recognition. A simplified version of the system architecture is depicted in Figure 2.

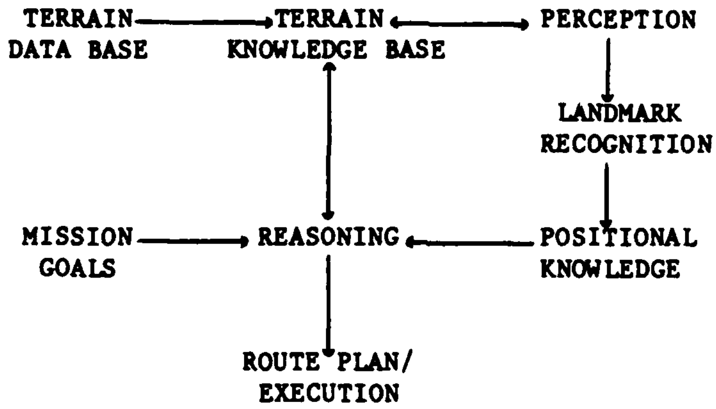


FIGURE 2. General system architecture.

The terrain data base is incorporated into a terrain knowledge base subsystem as the a-priori information source. During pre-mission route planning, the terrain knowledge base is queried by the reasoning subsystem which functions to determine the most cost-effective route to get from point A to point B. Several researchers have proposed using an optimization factor referred to as a figure-of-merit (FOM) which is calculated by estimating the probable cost of traversing small unit areas within the terrain (Linden, 1986). Starting at point A, rules are used to determine the traversability of various terrain features along a potential route to point B. If an impassable feature is encountered, the reasoning subsystem will determine a route around the feature while keeping the ultimate mission goal, arrival at point B, as the main objective. It should be stressed that information from all terrain themes will be considered in the route planning process. As a result, it may find an obstacle in one overlay while not in the others. Thus, it is crucial that the reasoning system identify and evaluate such conflicts in the terrain knowledge base in order to arrive at the most efficable decision.

Once the pre-mission route plan has been determined, the vehicle will proceed from point A to point B. At this stage, the perception subsystem will be activated. This will acquire scene information about environmental conditions along the route. As each scene is collected, a corresponding perspective view of what the perception subsystem should be detecting is generated from the terrain knowledge base. This "predicted" scene is then used to constrain the segmentation of the perceived scene in order to remove extraneous edges (Lawton et al, 1986). The result is a high-level symbolic image of the environment at that specific location along the route (Leighty and Lane, 1986). Obstacle detection is accomplished by identifying inconsistencies between the predicted scene and the symbolic image. If an object is delineated in the symbolic image which is not present in the predicted scene, the terrain knowledge base will be updated with this new information. If this object appears on the route itself, the reasoning system is queried to determined a route to circumnavigate around it and back to the original route plan. If no acceptable route is found, the vehicle automatically requests assistance from the operator. Thus, the reasoning system must function to resolve conflicts between what perception detects and the information in the terrain knowledge base in order to provide for safe traversal of the ALV.

The perception subsystem and terrain knowledge base also function to perform landmark recognition and positional update. Data from an onboard land navigation system enables the vehicle to coordinate it's position and attitude within the terrain data base. At various points along the route, the perception system will attempt to train on selected landmarks which are also defined in the data base. When a landmark is positively identified, the ALV will be able to update the land navigation system as to it's position in the data base. This capability is necessary to keep the vehicle positioned on the route plan and for accurate route re-planning.

Issues

Our experience brings several issues to light. The most immediate is the time and effort required to compile a comprehensive data base (Table 1).

Unless several dedicated workstations are available, compilation of even the smallest area can translate into several months of effort. Unfortunately, this reality is not compatible with the rapid response nature of future ALV applications. This addresses the need for automated feature extraction research which, in an interactive environment, could assume many redundant tasks now performed manually by an interpreter. However, until this technique becomes more feasible, emphasis must be placed on both limiting data capture to factors which are most crucial and development of comprehensive, interactive mapping systems based on robust hardware and software.

Another issue is the size of the data set. For a digital terrain data base which requires a high level of detail there are the problems of data storage and retrieval. The ALV data base is in an experimental phase and requirements are expected to relax as other capabilities are improved. Nonetheless, the data base is only partially complete and presently exceeds four megabytes, a figure which is expected to more than triple (Table 1). Even if further developments reduce the emphasis on level of detail, spatial data base technologies will need to improve in order to complement them.

An issue which is concerned primarily with the data base is conflict resolution between data sets. Digitization of features common in multiple layers will not be identical due to successive interpretation. Thus, a discrepancy arises in the actual ground position of these features. Likewise, elevation values within the digital elevation model will differ from spatially corresponding feature coordinate elevations in other themes. For instance, most surface drainage will not be detectable within the 5 meter DEM. Finally, misclassifications of features lead to conflicts between themes and tend to break down the coherency of the data set. These need to be resolved as efficiently as possible.

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