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Research Article

A Security Approach to a Military Autonomous Platform Path Planning

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ABSTRACT:

In this article, the authors consider the functional characteristics of autonomous platforms for various purposes and, in particular, ground autonomous platforms for military use with their specific requirements. At the forefront of the study is the ability to plan the platform's path without using the existing road network and with maximum use of the characteristics of the terrain for covert movement vis-à-vis the position of an enemy observer. A methodology for creating a test environment with the application of an open-source software tool and a system for developing functional extensions (plugins) is presented. The mathematical bases for data processing for the altitude of the earth's surface in determining the slope and the conditions for visibility are presented. A digital experiment for trajectory planning with the application of digital data for the height of the earth's surface was performed. The experiment clarifies the initial data structures and the applied algorithms for trajectory planning in the conditions of hidden movement. Finally, the authors evaluate the achieved results and outline directions for further research.

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Introduction

The development of autonomous vehicles is one of the priority areas for current scientific and practical research. Concerning the classification of autonomous platforms, factors such as purpose, working environment, and basic design and construction methods can be highlighted. Some of the best modern achievements are in terms of unmanned aerial vehicles, autonomous land vehicles, and underwater transport.

The term "autonomous mobile platform" refers to the need to focus research on two main requirements. The first and main requirement is to provide functionality related to the set conditions for performing specific tasks in various environments – land, air, or water/underwater. The second is the requirement to move within the technical capabilities of the autonomous platform without interactive human intervention. In the general case, the human operator sets the starting and final position for movement and observes the process of performing the tasks. The autonomous platform independently determines its route for moving between the set start and end position by applying digital data for the area and its computing capabilities.

Autonomous Platforms for Military Use

The military application of autonomous platforms is in the focus of attention of relevant specialists. The tactical and technical requirements for autonomous platforms for military use can be aimed at planning the route for traffic without using the existing road network, passability requirements based on the design data of the machine, combat radius and load capacity, the weight corresponding to the provided ballistic protection class and many others. In the available literature sources [1,2,3] some typical cases are considered, in which the information from the built-in sensors is actively used in practice for control of the movement of autonomous platforms for military purposes.

Regarding path planning, a digital model of the area is used, including data on the height of the earth's surface and natural obstacles. In this regard, suitable software products are part of the military command and control systems (C4I) put into operation. The developed graphical interface in C4I systems, based on a geographic information system, is a good information environment for route planning for autonomous battle platforms.

Avoiding unmapped objects is achievable with the application of 3D and lidar computer surveillance, simultaneous localization and mapping (SLAM), and other methods similar to artificial intelligence systems.

The full set of tactical and technical requirements for autonomous platforms for military purposes can be comprehensively defined by military specialists. When considering issues related to the route planning methodology, such as the use of a geographic information system and a digital surface elevation model [4,5] may be included.

In the present article, the authors focus on the study of an approach to planning a path hidden to a certain observation point and according to certain tactical and technical capabilities of the autonomous platform for overcoming the slope.

Methodology

The "hidden path planning" task defined above assumes specific output data, among which the minimum required are:

- Starting position of the autonomous platform marked as Start Point (SP);
- The end position of the autonomous platform marked as End Point (EP);
- Height of the autonomous platform above the ground, Platform Height (PH);
- Maximum Slope Angle (MSA);
- Observer position, Observer Point (OP);
- Maximum detection distance of a similar type of target, Maximum Observer Range (MOR);
- Observer Height (OH).

The required numerical data for the height of the earth's surface are presented in matrix form in the format Ascii / Binary Grid [6] and are available both from public sources [7] and from specialized departmental databases.

For the purposes of this study, the authors perform a three-dimensional analysis of the digital data on the height of the earth's surface in a given area of interest (Area of Interest, AoI) using algorithms for:

- Determining the slope of the earth's surface in the area of interest;
- Defining the zones of visibility relative to a known Observer Point;
- Defining a route in accordance with the Maximum Slope Angle of the autonomous platform and avoiding the defined areas of visibility.

In order to verify the achieved results, the product of digital analysis is converted to a standard vector file format (ShapeFile) and is reproduced on an electronic map with the use of specialized software.[8]

Mathematics Background

We assume that the numerical data on the height of the earth's surface is presented in the form of a rectangular matrix {M},[9] and Figure 1 shows one of its constituent elementary cells $\{M_1, M_2, M_3, M_4\}$. We also assume that for each of the nodes – nodes M_1, M_2, M_3, M_4 we know the height of the earth's surface with sufficient accuracy for practical purposes, and the matrix {M} is georeferenced in a known coordinate system. Let the total number of nodes in the height matrix be N = m x n, where m is the number of columns and n is the number of rows.

Determining the slope of the earth's surface

Let the elementary surface from the digital model of the area's point of view be determined by the points:

$$P_1\ (x_i, y_j, z_{i,j}),$$
$$P_2\ (x_{i+1}, y_j, z_{i+1,j}),$$
$$P_3\ (x_{i+1}, y_{j+1}, z_{i+1,j+1}), \quad (1)$$
$$P_4\ (x_i, y_{j+1}, z_{i,j+1}).$$

It is necessary to determine the normal vector $\vec{n}$ of the approximating plane $S_o\{P_1, P_2, P_3, P_4\}$

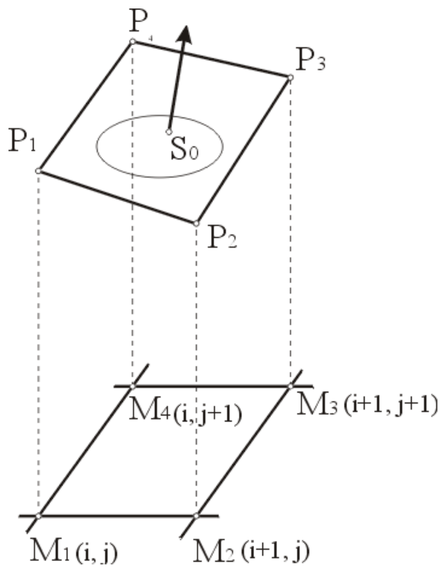


Figure 1: Digital terrain data and approximating surface S_o.

By the method of least squares, [10] we look for an approximating plane S_0 with the equation:

$$S_0 \equiv z = ax + by + c \quad (2)$$

and with coefficients *a, b*, at which the function *F* is minimized:

$$F \equiv \sum_{k=1}^{4} (aX_k + bY_k - Z_k)^2 \quad (3)$$

where:

$$X_1 = X_4 = x_i, \qquad X_2 = X_3 = x_{i+1},$$
$$Y_1 = Y_2 = y_j, \qquad Y_2 = Y_4 = y_{j+1},$$
$$Z_1 = y_{i,j}, \qquad Z_2 = z_{i+1,j}, \quad (4)$$
$$Z_3 = z_{i+1,j+1}, \qquad Z_4 = z_{i,j+1}$$

Finding a, b, and c for which F has a minimum is done by solving the system:

$$\left| \begin{array}{l} \frac{\partial F}{\partial a} \equiv 2\sum_{k=1}^{4}(aX_k - bY_k - Z_k)X_k = 0 \\ \frac{\partial F}{\partial b} \equiv 2\sum_{k=1}^{4}(aX_k - bY_k - Z_k)Y_k = 0 \\ \frac{\partial F}{\partial c} \equiv 2\sum_{k=1}^{4}(aX_k - bY_k - Z_k) = 0 \end{array} \right. \quad (5)$$

After determining the coefficients a and b by applying formulas (3), (4), and (5), we find that the approximating plane

$$S_0 \equiv z = ax + by + c$$

has a normal vector

$$\vec{N} = (-a, -b, 1) \quad (6)$$

As a result, the angle γ of the inclination of the plane S_0 with respect to the horizontal plane is determined by the equation:

$$cos\gamma = \frac{1}{\sqrt{a^2 + b^2 + 1}} \quad (7)$$

Therefore, the angle of the earth's surface for the cell in question in degrees, – degree, γ^{deg} is defined as:

$$\gamma^{\deg} = acos\left(\frac{1}{\sqrt{a^2+b^2+1}}\right)\frac{180}{\pi} \quad (8)$$

We mark the passability matrix with A. By performing (8) for each cell of {M} we get:

$$A \equiv \left\{\gamma_{i,j}^{deg}\right\},\ i = 1,2\ldots,m, j = 1,2\ldots,n \quad (9)$$

Defining a Zone of Visibility

Figure 2 schematically shows the definition of a line of sight for targets located on the earth's surface. Let the point p_0 be the location of the observer at a height h_0 above the earth's surface. The observer p_0 has an open line of sight between the points (p_0, p_1) и (p_2, p_3). Between p_1 и p_2, there is a closed line of sight.

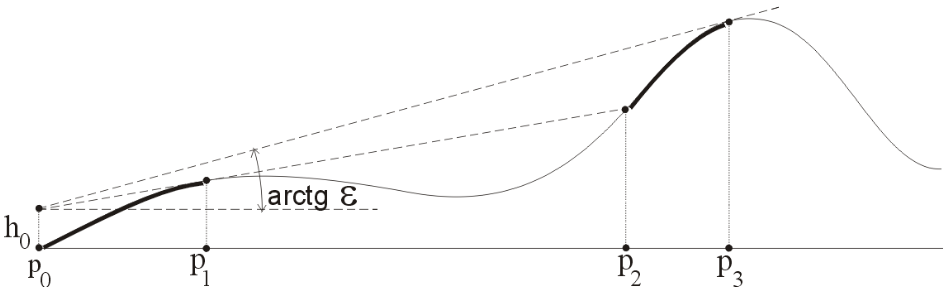


Figure 2: Defining a Line of Sight

To determine the line of sight, we will introduce the term angle of closure between the observer and the points on the earth's surface. We represent the angle of closure by its tangent and denote it by ε.

We will denote by p_k a target representing a point on the earth's surface.

Control angle of closure ε^k_{contr} concerning to the target $\boldsymbol{p_k}$ will be called the maximum angle of closure between the observer $\boldsymbol{p_0}$ and the target $\boldsymbol{p_k}$ as follows:

$$\varepsilon^k_{contr} = max\ (\varepsilon_i),\ 0 < i \leq k \qquad (10)$$

The line of sight between the observer $\boldsymbol{p_0}$ and the target $\boldsymbol{p_k}$ is open, when:

$$\varepsilon_k \geq \varepsilon^{\kappa}_{contr} \qquad (11)$$

The line of sight between the observer $\boldsymbol{p_0}$ and the target $\boldsymbol{p_k}$ is closed, when:

$$\varepsilon_k < \varepsilon^{\kappa}_{contr} \qquad (12)$$

When determining the conditions (11, 12) for all possible lines of visibility in a circular sector with center OP and radius MOR we obtain a matrix of visibility B, where:

$$B \equiv \begin{cases} 1, & \varepsilon_k \geq \varepsilon^{k}_{contr} \\ 0, & \varepsilon_k < \varepsilon^{k}_{contr} \end{cases} \qquad (13)$$

Path Planning Data Flow

Figure 3 presents the sequence of processing the output data to achieve path planning of an autonomous platform with hidden movement – Secure Path Planning.

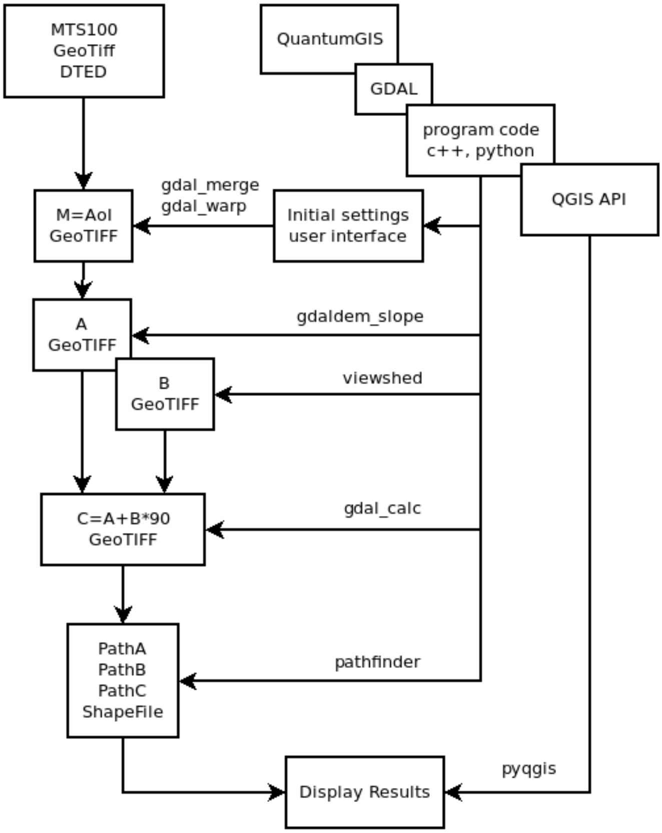


Figure 3: Path planning data flow diagram.

The data required for further processing are contained in the digital terrain model used, marked as MTS100 in Figure 3. The model includes an electronic map base in the form of georeferenced raster files GeoTIFF and a model of the height of the earth's surface DTED (Digital Terrain Elevation Data) in the form of Ascii Grid. The Initial settings necessary to achieve a certain solution are submitted by a specially designed for the purpose user interface. The software solution is implemented in the form of a functional extension – plugin to the specialized product QuantumGIS [11] and using Python programming languages with C ++. Standard geographic data processing is assigned to modules fromGDAL (Geographic Data Abstraction Layer) software library,[12] which is an approved product of OSGeo, Open Source Geospatial Foundation.[13]

The processing sequence goes through:

- Selection of an area of interest determined by the initial data – AoI and its presentation in a suitable for processing digital form – matrix of heights M in file format GeoTIFF. The processing is performed by applying the modules gdal_merge.py and gdal_warp.py from the GDAL library.

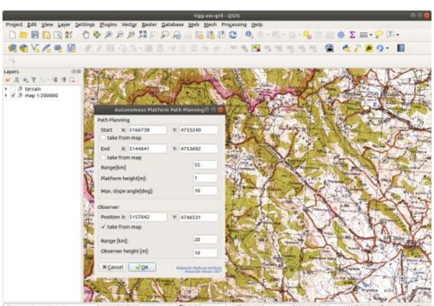
- Determining a passability matrix A by applying the module gdal-slope.py
- Determining a visibility matrix B by applying the code viewshed.c as modified by the authors
- Determining a matrix of complex path planningC, for this purpose mathematical processing of the data from matrix A and matrix B is performed using the modulegdal_calc.py.
- Execution of a path planning algorithm by applyingpathfinder.py, the results are stored in the form of a vector graphic file ShapeFile
- Visualization of the results – the vector layers PathA, PathB, and PathC are presented on an electronic geographical basis. In these layers the defined routes are presented, taking into account the passability matrix A, taking into account the visibility matrix B, and taking into account the complex path planning, matrix C. In a text-content window are shown the results for the processing time for achieving the result and the estimated length of the route for each of the options.

Experiment Details and Results

A software experiment was conducted to determine the route for hidden movement of an autonomous combat platform using QuantumGIS v.3.6 software and an MTS100 digital model of the area, a product of the Military Geographic Service (part of the Bulgarian Armed Forces).

Digital raster geographic maps in GeoTiff format, equivalent to a scale of 1 : 200K, and data on the height of the earth's surface DTED in Binary Grid format are used from the MTS100 product. The DTED data is converted (and verified) by the authors in the Ascii Grid format, which is suitable for processing using modules from the GDAL software library. The elementary cell of the height matrix is a square with a side of 150 m. All geographic data are presented in the Coordinate Reference System (CRS) EPSG: 28405.[14]

The experimental path planning was carried out in the vicinity of the town of Breznik, in the western part of the Republic of Bulgaria, characterized by various terrain conditions.



(a)

(b)

(c) (d)

Figure 4: Graphical results of the path planning decision.

By applying the user interface developed by the authors and shown in Figure 4 (a), StartPoint and EndPoint are specified in the units of the CRS used, MaxSlopeAngle of 10^0 and PlatformHeight of 1 m. The position of the opposing observer ObserverPoint, against which the hidden path planning is to be performed, is specified in the same CRS; for the height of the observer of the earth's surface ObserverHeightis selected the value of 10 m. The maximum detection distance of the moving autonomous platform, Maximum Observer Range is limited to 20 km.

The data processing procedure is according to the diagram in Figure 3. For the selected test site in the passability matrix, slope values from 0^0 to 43^0 are obtained. The areas with impossible passing when set at a given MaxSlopeAngle of 10^o are shown in dark in Figure 4 (b).

The visibility matrix showing the visible areas to be avoided is shown in Figure 4 (c) in dark color. A basic form of a raster data path planning algorithm, known in specialized sources as Deterministic Eight (D8), has been applied.[15] The graphical results for path planning according to the MaxSlopeAngle set point according to the visibility conditions relative to the specified Observer Point position and the combined passability variant while avoiding the areas visible to the opponent are shown in Figure 4 (b, c, d).

Table 1. Experimental path planning results.

Path planning Indicators	**According to the slope**	**According to the visibility**	**According to the complexity**
Processing time	0.073s	0.046s	0.115s
Expected path length	34439.3 m	38475.7m	38818.3 m

Conclusion

In the article, the authors propose an approach for path planning of an autonomous combat platform with a requirement for hidden movement in relation to a known enemy observation post. The prerequisites as necessary data structures and algorithms are clarified, the application of which leads to the achievement of a result with known output data. An essential part of the mathematical apparatus is presented, which forms the basis of the numerical processing of the georeferenced data for the height of the earth's surface in determining passability and visibility.

A workplace has been configured with specialized software installed and a special functional extension created by the authors with the application of Python and C++ programming languages. At the present stage of the research, satisfactory graphical results have been obtained.

In the course of conducting the experiments described here, the authors identify several possible scenarios in which the graphical solution may not be accepted. These are the cases in which it is not possible to plan a path at set traffic parameters, or in the case when the specified route is longer than the resource for movement of the autonomous platform. One solution could then be to adaptively modify the output data and set stricter requirements for the characteristics of the autonomous platform.

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