

Volume Modeling and Seeding Parameters Calculation for Hail Suppression Purposes

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Abstract – Different techniques are used for volume modeling, based on advantages they provide in the particular domain. The most popular models are surface and volume based ones. Choosing the most appropriate model for cloud representation is essential for hail suppression purposes. The voxel based model is chosen for modeling of clouds. The choice is made to satisfy the request for precise and efficient calculation of rocket launching parameters for seeding the hail-threatening cloud. The developed algorithm is based on computation of number of voxels in the seeding area, affected by the part of rocket trajectory during reagent seeding. The presented solution is designed to replace the existing algorithm for rocket launching parameters calculation implemented in Hail Suppression Information System (HASIS 3D). The new solution uses 3D mode for seeding area extraction and 3D criteria for rocket launching parameters calculation, thus making it much more precise than the previous one.

Keywords – Volume modeling, Voxel, Hail, HASIS.

I. INTRODUCTION

The importance of information systems in meteorology domain cannot be overemphasized [1]. In this paper, we focus on specific type of information systems involved in weather modification domain – information systems for hail suppression. Main purpose of these systems is to predict the occurrence of hail hazard in the near future and manage hail suppression activities. HASIS (Hail Suppression Information System) is an information system for hail suppression, developed at the Faculty of Electronic Engineering in Niš, to satisfy requirements of Republic Hydrometeorological Service of Serbia (RHMS) [2]. HASIS is a complete system that uses methodology based on cloud seeding using rockets and stationary radars for monitoring weather conditions. HASIS obtains radar data of cloud reflectivity in polar coordinate system, with center at radar location. To efficiently use this data, the conversion to Cartesian coordinate system is performed. The result is the 3D matrix of cloud reflectivity data that can be visualized and analyzed in 2D or 3D view [3]. HASIS provides measurement of hail-threatening cloud

parameters, calculation of cloud seeding area, selection of rocket launching stations (RLSs) and calculation of rocket launching ballistic parameters [4].

Previous version of HASIS system was only able to analyze atmosphere situation using 2D radar data products. Consequently, 2D mode of cloud seeding area extraction produces seeding area with equal horizontal 2D cross sections on all altitudes. This approximation of the seeding area can be considerably different from the real 3D area that should be seeded. This deficiency is resolved in the new version of HASIS system, HASIS 3D, which is able to process data in 3D space. The new quality provides possibility for improving the system for seeding parameters calculation. The system for seeding parameter calculation, implemented in the previous version of HASIS system, is conformed to the methodology of cloud seeding area extraction in 2D mode, and cannot exploit the advantages of new methodology. In this paper, we present a new approach for seeding parameters calculation that exploits all the advantages of new methodology of cloud seeding area extraction in 3D mode. The voxel based model is chosen for modeling of hail-threatening clouds, mainly because it is the most suitable for representation of input radar data set and efficient examination of spatial relationship between rocket trajectories and seeding area. The new algorithm for seeding parameters calculation is designed to efficiently use voxel based model and rocket trajectories in 3D space. The new system achieves higher level of accuracy of calculated parameters than the old one, while retaining the satisfactory processing performance.

The paper is organized in six sections. The section 2 describes methodology for automatic selection of RLSs and calculation of ballistic parameters for hail suppression rocket launching that is supported by HASIS system. The section 3 gives a brief theoretical insight in volume modeling problem, essential for proper selection of cloud modeling technique. Section 4 presents the selected cloud modeling technique and the reasons for given selection. Section 5 describes the new system for automatic selection of RLSs and calculation of ballistic parameters for rocket launching. The ending section summarizes the advantages of the proposed system and specifies the interests for further research.

II. EXISTING METHODOLOGY

As previously mentioned, cloud analysis can be performed in 2D or 3D view of cloud reflectivity data [3]. Based on meteorological knowledge and experience, radar operator can determine whether the observed cloud is hail-threatening. If the cloud is classified as hail-threatening, operator proceeds to

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the 2D view, where he analyzes horizontal cloud cross sections on desired altitudes and specifies the type of the cloud (one of six types). Then, HASIS system automatically calculates horizontal cross section of the area to be seeded. The third dimension of the seeding area is calculated knowing the fact that the aim of cloud seeding is to inject the chemical reagent as much as possible in the volume limited by the -4°C and -10°C isotherm (Fig. 1a). It should be noticed that the described methodology [4] calculates the seeding area that has equal horizontal cross sections on all altitudes. This clearly doesn't correspond to the actual cloud area that should be seeded.

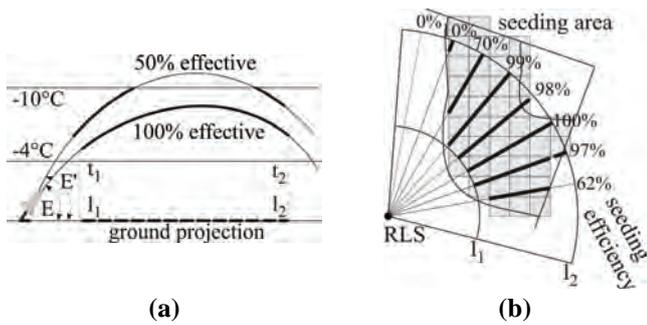


Fig. 1. a – elevation calculation, b – azimuth calculation

After seeding area calculation, automatic selection of RLSs and calculation of rocket launching parameters is performed. This must be completed very quickly, because the whole process, from detecting the hail-threatening cloud to rocket launching, is limited to 2 minutes. This is the reason the calculation is performed in two steps [4]. Rocket launching parameters are: azimuth, elevation and type of rocket. Type of rocket uniquely determines seeding time delay (the time between launching and start of seeding) and seeding duration.

First step – elevation calculation: For every type of rocket from every RLS calculate the elevation with maximum seeding efficiency, ignoring the cloud existence (Fig. 1a). The seeding efficiency criteria for given elevation represents the amount of seeding material injected in the volume between the -4°C and -10°C isotherm. For the chosen elevation the horizontal projection of the seeded track is calculated (l_1 and l_2) and memorized for further usage by the azimuth calculation step. Elevation calculation is usually done only once a day with the arrival of a new synoptic report with the new values for -4°C and -10°C level altitudes.

Second step – azimuth calculation: For every type of rocket from every RLS (with previously calculated elevation) calculate the azimuth with maximum seeding efficiency (Fig. 1b). This is a 2D problem. Previously determined horizontal cross section of the seeding area is represented by a collection of radar cells shown as gray rectangles in Fig. 1b. The rocket seeding trajectory is represented by a straight line from l_1 to l_2 away from the RLS, for particular azimuth.

Given approach is suitable for the existing methodology of seeding area extraction, performed in 2D mode. It cannot exploit the advantages of new methodology of seeding area extraction, performed in 3D mode. In this paper, we present a new approach for automatic selection of RLSs and calculation of rocket launching parameters that resolves the emphasized

drawbacks and increases accuracy of the result, while retaining nearly the same processing efficiency.

III. VOLUME MODELING

In computer graphics, the term volume modeling [5] is used to denote a set of techniques for creating a logical entity (model) of 3D object, using a computer. Model is a 3D object description, made using strictly defined language or data structure. Model represents some of the 3D object characteristics, important for the specific appliance. Appliances of models are diverse: visualization, various types of analysis, simulations etc. Selection of the volume modeling technique depends on the domain of appliance and posed requirements (memory and processing requirements for visualization, for various calculations etc.). There are three main types of models: *wireframe*, *surface based* and *volume based* model. In this paper we will focus on surface and volume models, suitable for modeling complex 3D objects.

Surface based model [6] represents a 3D object as a set of vertices, boundary edges and boundary surfaces. The volume of a 3D object is modeled by defining a boundary that separates 3D object from the rest of the world. Boundary of complex 3D objects can be approximated by *polygonal mesh* or by *surface patches*. Polygonal mesh is the most commonly used form, as any object can be approximated by polygonal mesh, to arbitrary accuracy (Fig. 2). However, as the desired accuracy increases, i.e. level of details (LOD), so does the number of polygons in the mesh, and also processing time and memory requirements. On the other hand, small number of polygons in the mesh results in a poor approximation of the boundary, and limited use in domains where high level of precision is requested. Surface patch is a part of some surface, surrounded by 3 or 4 curves (Bezier curves, B-splines etc.). Compared to polygonal approximation, approximation by surface patches is more economical, as far less surface patches than polygons is needed for achieving the desired accuracy.



Fig. 2. Polygonal approximation of a sphere, with different LODs

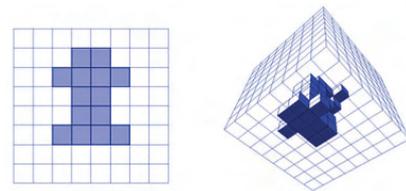


Fig. 3. Comparison between pixel formation in 2D space (left) and voxel formation in 3D space (right)

Volume based model [6], [7] contains information about vertices of a 3D object, its boundary edges, boundary surfaces and enclosed volume. Due to the large amount of information about a 3D object that this type of model contains, it is widely used for visualization, various calculations, simulations etc. State of the art volume based model is *voxel based model*.

Volume that contains a 3D object being modeled, is broken down to small volumetric elements of equal size – *voxels* (volumetric pixels). Voxel is the smallest volumetric element on the regular rectangular grid in 3D space. Voxels in 3D space are analogue to pixels in 2D space (Fig. 3). Every voxel is associated with a numerical value that represents some measurable feature of 3D space (color, density, type of material, hardness etc.). These values are stored in 3D matrix, called *3D volume buffer*, that represents a portion of space being modeled.

Differences between surface and volume graphics capabilities are the result of fundamentally different mediums for representation (i.e. modeling) and manipulation of 3D scenes. For this purpose surface graphics uses a list of geometry objects, while volume graphics employs a 3D volume buffer. Table I shows the comparison between surface and volume graphics, given for most important capabilities regarding the problem discussed in this paper [7].

Volume graphics is beginning to supersede surface graphics for modeling, handling and visualizing volumes as well as for modeling and rendering synthetic scenes composed of surfaces. This is particularly the case when it comes to volume modeling and visualization of some specific complex 3D objects (clouds, smoke, fire etc.).

TABLE I
COMPARISON BETWEEN SURFACE AND VOLUME GRAPHICS

| Capability | Surface graphics | Volume graphics |
|--|--|---|
| 1. Memory and processing requirement | Variable - depends on scene and object complexity | Large but constant |
| 2. Rendering of interior and amorphous phenomena | No, surface only | Yes, rendering of inner structures as well as surfaces |
| 3. Adequacy for sampled data and intermixing with geometric data | Partially and indirectly (fitting followed by surface rendering) | Directly (supports representation and direct rendering) |
| 4. Measurements (e.g., distance, area, volume) | Analytical, but often complex | Discrete approximation, but simple |

IV. SELECTION OF CLOUD VOLUME MODELING TECHNIQUE

For volume modeling of hail-threatening cloud (that contains calculated seeding area) the best choice is **voxel based modeling technique**. There are several important reasons that support this choice.

Voxel based model is extremely suitable for modeling of sampled data. In HASIS system, data acquisition is done by data sampling, i.e. radar scanning of environment. To efficiently use the obtained data, the conversion to Cartesian coordinate system is performed. The result is 3D matrix of cloud reflectivity data. This matrix is transformed, using new methodology of seeding area extraction. The result is a 3D matrix equivalent to the 3D volume buffer for voxel based

model of scanned portion of space (voxels that reside in the seeding area are marked with 1, and voxels outside the seeding area with 0). Use of voxel based model for calculation of rocket launching parameters eliminates the need for additional transformation of data, as this 3D matrix is an input for the new algorithm for automatic selection of RLSs and calculation of rocket launching parameters. This would not be the case if surface based model was used.

Because of an amorphous nature of the cloud structure, geometric definition of boundaries of the extracted seeding area can be very complex. As a consequence, all calculations that include seeding area, done on surface based model, are potentially time consuming. On the other hand, voxel based model offers the possibilities for very simple calculation of different measurements (distance, volume etc.). This is an essential feature, because, as mentioned before, the calculation of launching parameters must be done very quickly. Precision of calculations is not a bottle neck, due to the fine resolution of 3D volume buffer (in the typical case, the 3D volume not larger than 20km x 20km x 2km is represented using 3D volume buffer of size 400 x 400 x 40).

V. CALCULATION OF LAUNCHING PARAMETERS

Input parameters of the new system for automatic selection of RLSs and calculation of ballistic rocket launching parameters are: seeding area, location of RLSs and hail suppression rocket parameters.

Input seeding area parameters are: 3D volume buffer, referent point of scanned volume and voxel size. 3D volume buffer determines the location of the seeding area inside the scanned volume (voxels that reside in the seeding area are marked with 1, and voxels outside the seeding area with 0). It is important to point out that all clippings of the seeding area, due to the position of -4°C and -10°C isotherm and forbidden areas marked by the flight control, are done before creating 3D volume buffer. Position of the scanned volume in 3D space is fully determined via coordinates of referent point and voxel size. Based on this information it is possible to determine whether specific point in 3D space belongs to the modeled volume or not. In the case it does, it is possible to calculate the indexes of the voxel that contains particular point.

RLSs (hail suppression stations) are defined with their world coordinates, stored in the database of HASIS system. New system for launching parameters calculation takes into account that some launching directions on particular RLSs are forbidden, that different rocket launchers have different rotation steps and that every RLS does not necessarily have all types of hail suppression rockets.

Hail suppression rockets are classified by their type that determines seeding time delay (the time between the rocket launching and the beginning of seeding) and seeding duration. Rocket launching parameters that the new system should determine are: rocket type, elevation and azimuth. These parameters uniquely define rocket trajectory. The database of HASIS system contains definition of rocket trajectory for every rocket type and every significant elevation. Rocket trajectories are defined using parameter functions $x=x(t)$ and

$z=z(t)$ that represent the correlation between distance (x-coordinate and z-coordinate, respectively) and time. Given parameter functions stand for azimuth equal 0° , in which case the y-coordinate is constant. When azimuth differs from 0° , x-coordinate and y-coordinate are computed using simple trigonometry. So, rocket trajectory is uniquely defined by parameter functions $x=x(t)$ and $z=z(t)$ and azimuth. Using this information, rocket trajectory coordinates can be calculated in arbitrary moment of time

Based on the previous discussion, we conclude that index of voxel affected by the rocket trajectory can be calculated for arbitrary moment of time. In the new system for launching parameters calculation, the efficiency of a rocket trajectory is measured by the *number of voxels* of the seeding area affected by the part of rocket trajectory during reagent seeding. By inspecting all possible rocket trajectories from a specific RLS, launching parameters for that RLS are determined. Pseudo code of this algorithm is shown in Fig. 4.

```

Read information about RLS from database.
foreach permitted rocket trajectory RT of RLS
begin
    Read information about rocket trajectory from database.
    foreach permitted azimuth A of RLS
    begin
        Move along the rocket trajectory, from the beginning of
        seeding to the first voxel of modeled volume.
        Continue moving along the rocket trajectory while the
        rocket trajectory is in the modeled volume and seeding is
        in progress; count voxels of the seeding area affected by
        the rocket trajectory.
        If calculated voxel count is the biggest calculated so far,
        memorize parameters of the rocket trajectory (including
        azimuth).
    end foreach.
end foreach.
Write memorized parameters of the rocket trajectory in the
database.

```

Fig. 4. Launching parameters calculation for the specific RLS

As the pseudo code shows, all discussed restrictions are considered. In order to determine which voxels are affected by the rocket trajectory, time sampling of the rocket trajectory is needed. Choosing appropriate time step is very important. Short time steps can lead to very bad processing performance. On the other hand, long time steps can cause many voxels to be skipped. Implemented algorithm uses *variable time step*. Longer time step is used while the rocket trajectory has not yet reached the modeled volume. Near and in the modeled volume time step is chosen so the distance between two consecutive points on the rocket trajectory is less than tenth of the length of the shortest voxel edge. This way, probability of skipping a voxel is very small.

Described algorithm is repeated for all RLSs. RLS is declared inactive if no rocket trajectory from this station is able to seed the required minimal number of voxels. Algorithm uses spatial data coherence to achieve higher efficiency [8]. Although using 3D seeding area, processing performance of the presented method is at the same level as

processing performance of the existing method. In typical cases, the time needed for launching parameter calculation is less than 5 *seconds*.

VI. CONCLUSION

Unlike the old system, the new system for automatic selection of RLSs and calculation of ballistic parameters for hail suppression rocket launching is able to exploit all the advantages of new methodology for seeding area extraction in 3D mode. In the new system the real volume of seeding area is used, which makes calculated parameters for hail suppression rocket launching much closer to the optimal ones. Due to the chosen volume modeling technique (voxel based modeling technique) and an adequate algorithm for launching parameters calculation, efficiency of the process is retained at the same level, despite much higher calculation complexity. Integration of the new method in the hail suppression system HASIS 3D is in progress.

New approach provides possibilities for future research and improvement. Instead by the number of voxels of the seeding area affected by the rocket trajectory, the efficiency of the rocket path can be measured by the amount of time rocket spends in the seeding area, during reagent seeding. In proposed method, every rocket launching station is inspected separately. The next step will be to consider spatial relationship between trajectories of rockets launched from numerous stations. In this case, efficiency of the configuration of rocket trajectories would be an issue.

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