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Synthetic Vision for Enhancing Poor Visibility Flight Operations

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INTRODUCTION

Visibility is important for the pilot controlling an aircraft in flight conditions close to the ground, particularly when landing. Therefore, poor visibility yields a great restriction for aircraft operations. Restrictions exist for landing sites which are equipped with facilities providing a landing approach aid like ILS since a minimum is required for visibility. For landing sites providing no approach aids, restrictions are much more severe. This holds even if aircraft are equipped with modem instrumentation and navigation devices.

The natural view of the pilot is dependent on various meteorological conditions like darkness, dust, fog, rain etc. The degradation in view caused by these conditions can be compensated for partially or even completely by technical means providing artificial vision cues. Such technical means may be based on radar or optical sensor information. Concepts which employ these techniques are known as “Synthetic Visual Systems” or “Enhanced Visual Systems,” e.g. [1].

The present paper is concerned with computer generated vision as a further technique providing visual cues for the pilot. Computer generated vision may be used in combination with the aforementioned sensor based techniques. Thus, it is possible to compensate for limitations which sensor based visual systems have in providing sufficient visibility range or in generating a normal looking image. In addition, computer generated imagery has the potential providing additional information to the pilot for controlling the flight path or for warning purposes. This potential can yield improved and/or more information as compared with the natural view when looking out of the cockpit window.

SENSOR AIDED VISION

For visual information based on actual sensor measurement, two techniques may be used:
- Optical techniques
- Radar techniques

Optical sensors considered here are passive devices with the use of which an imagery can be generated without providing information on distances of objects. By contrast, radar-type sensors may be termed active devices which cannot provide a normal looking image (or to a small extent only). However, information on distances is available.

In regard to optical systems, infra-red sensors are very promising as a means for extending pilot vision. Recent tests in fog show that a head up display/infra-red combination can significantly improve the ability of the pilot to see the runway and its environment in low visibility conditions [1]. It is considered that the visibility range may be improved by a factor ranging from 2 to 6 (in the 8 to 14 mm wavelength range), depending on meteorological conditions.

The combination of database generated image and sensor image requires that both are congruent (Figure 1). Inaccuracies in navigation need to be corrected by comparing both images and deriving correction values. The quality of the sensor image determines the factor of transparency for the overlay of the sensor image onto the database generated image.

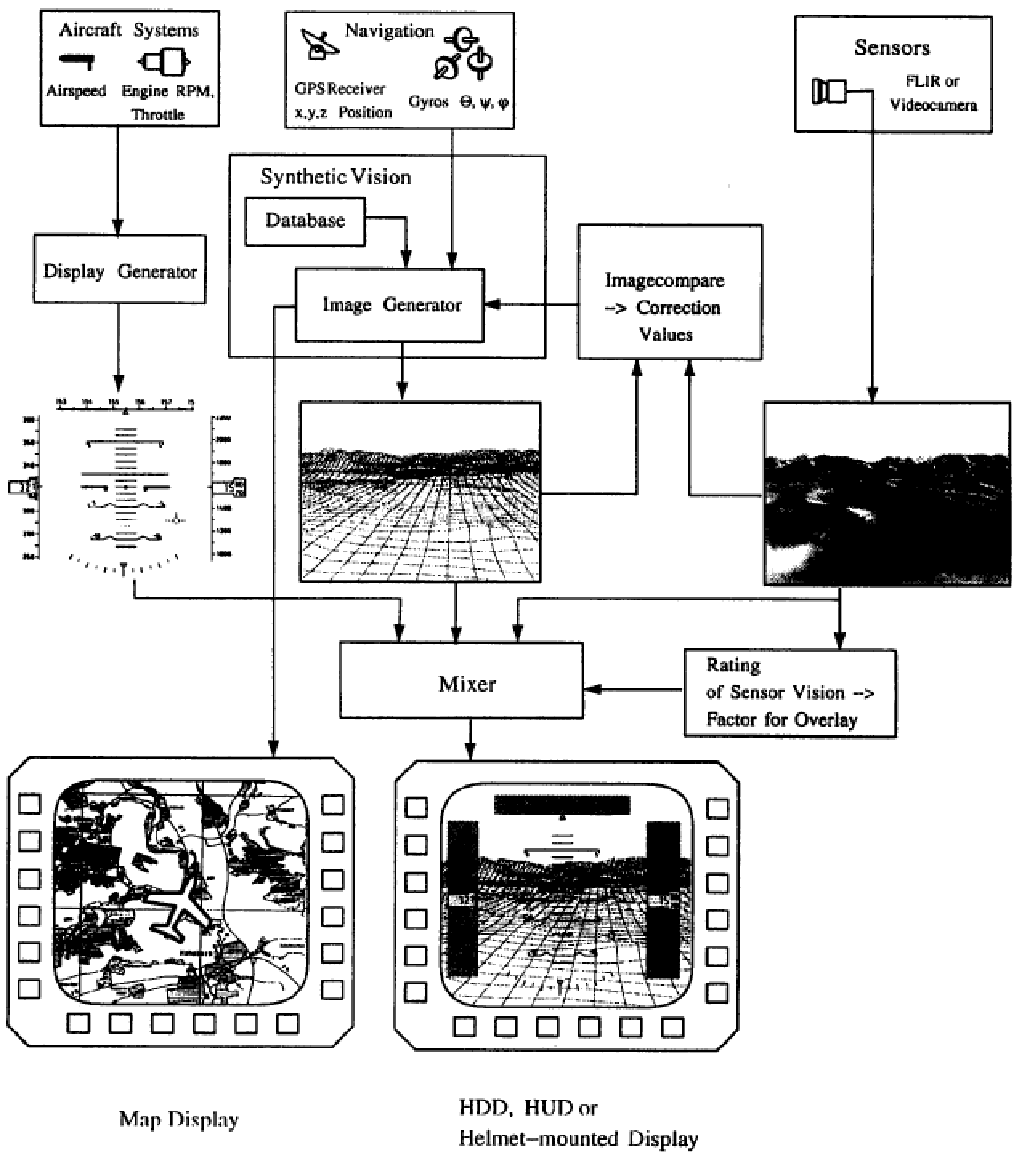

Fig. 1. System Components

DATABASE

The database contains terrain information of elevation and surface as well as object information related to aircraft operation like flight obstacles, airports or landing sites in order to generate a realistic 3D image [2]. Data from different sources is combined and stored in the database in an efficient way for little memory requirement and realtime image generation (Figure 2).

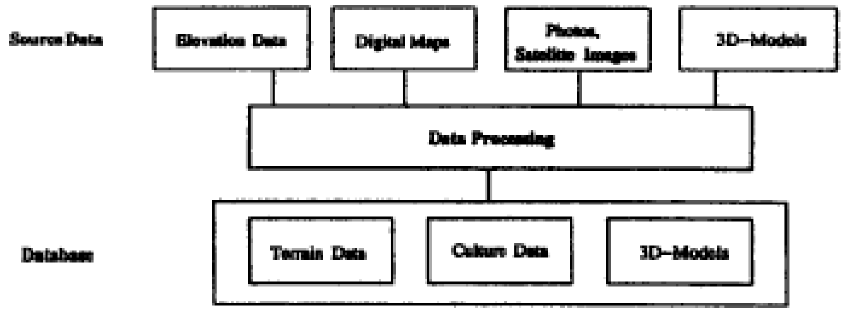

Fig. 2. Data Management

Source Data

Elevation Data and Digital Maps

Digital Terrain Elevation Data (DTED) is available from the Defense Mapping Agency (DMA) in WGS 72 or WGS 84 coordinates. The elevation points are arranged in a regular grid with a grid distance of 3 by 3 or 1 by 1 seconds. The grid distance corresponds to 60 by 90 m or 20 by 30 m for latitudes of 40 to 50 degrees. The best accuracy is about +/- 2 m.

In Germany, data is also available from civil surveyors' offices in cartesian coordinates with a grid distance of 50 m and an accuracy of 2 m. Digitized maps are available in several vector file formats from the same offices as the elevation data. File formats available from civil offices in Germany are **ATKIS**, **TOPIS** and **GEOGIS.** All of them contain polylines for streets, railroads, rivers, lakes, forests, and cities in cartesian coordinates.

Highly resoluted digital maps that contain single trees or groups of trees, ground plans, floor numbers and street boundaries are derived from maps at a scale of 1:1.000 and 1:5.000. These maps are stored in the **GRUBIS** file format.

The Digital Feature Analysis Data (DFAD) from military offices contain additional information characterizing each object. They are derived from maps at a scale of 1:50.000.

There are three basic types of feature objects:

- Point features (feature type 0)
  single buildings, bridges, high-tension poles

- Linear features (feature type 1)
  streets, railroads, rivers

- Areal features (feature type 2)
  Highly resoluted digital maps that contain single trees or lakes, forests, cities

The geometry of linear and areal features is represented by polylines. In main memory, every coordinate point needs 2 bytes for its elevation and 4 bytes for horizontal coordinates, so that 10 bytes are required. The data structure for additional object information is shown in Table 1.

Table 1. Main Memory Requirements

	Main memory requirement
Feature type (0, 1 or 2)	1 byte
Feature identification code number (1 - 1023)	2 bytes
Surface material code number	1 byte
Orientation	2 bytes
Predominant height	1 byte
Length	2 bytes
Width	1 byte
Number of structures per km^2 (only areal feature)	1 byte
Percent of tree coverage	1 byte
Percent of roof coverage	1 byte
Total memory for one feature	**13 bytes**

The total memory requirement of DFAD for an area of 1 by 1 degree is 3.390.000 bytes when considering 30.000 different features and 300.000 coordinate points. Thus, a resolution can be achieved as shown in Fig. 5.

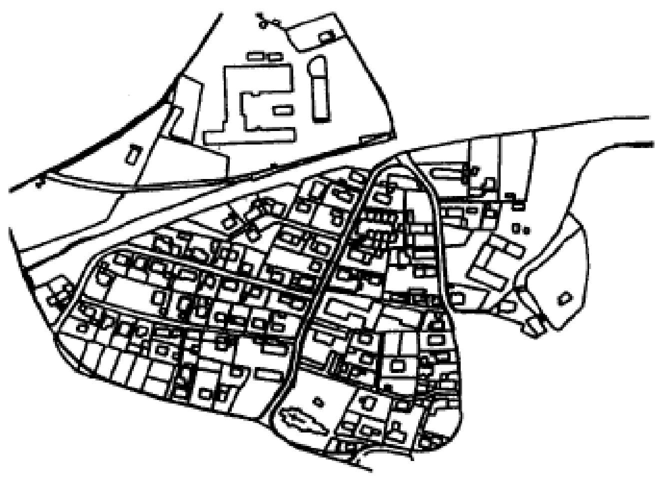

Fig. 5. Example of GRUBIS, from [4]

Photos and Satellite Images

Scanned photos are extensively used in high end visual simulation systems in order to achieve best realism. They offer advantages such as:
- Realistic image
- Easy availability
- Simple usage

However, there may also be disadvantages

- Much memory required
- Powerful hardware required
- No object information
- Not suited for application at low altitude

3D-Models

Present data sources do not contain 3D geometry information of single objects. In visual simulation, several models have been generated with the MultiGen database generation system [5].

To improve realtime performance by avoiding complicated data structures, 3D-models as shown in Fig. 7 are programmed as subroutines including the geometry data in the program code. The 3D-models have to be stored only once and are scaled, rotated and translated to their coordinate position according to the parameters from DFAD. A special treatment is considered necessary for objects the identification of which is important for the control task of the pilot. This concerns terminal areas like airports for landing and taxiing on the ground.

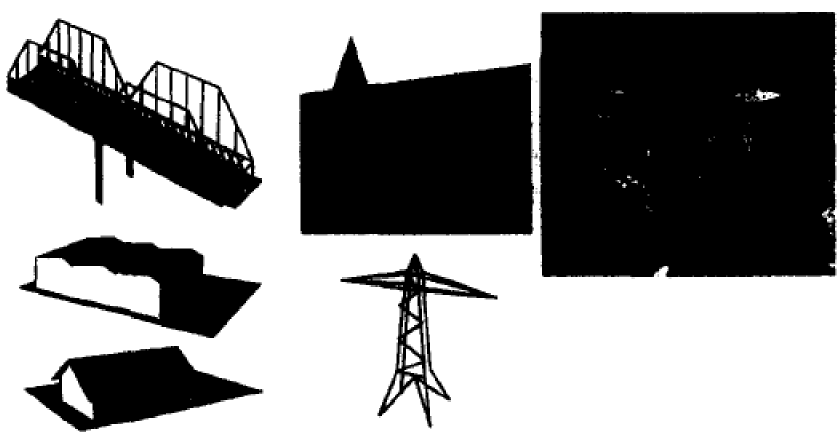

Fig. 7. 3D Models

Required Memory Capacity

The total main memory needed for storing the database of an area of 1 by 1 degree is shown in Table 2. This result means that a main memory of 64 Mbytes is sufficient for storing the data of an area of 3 by 3 degrees. For such a rather small memory requirement, single processor systems like an INDIGO™ can be used which do not have the ability to load data from a disk on-line.

Table 2. Required Memory for an Area of 1 by 1 Degree	
	Memory required
DTED	2.8 Mbytes
DFAD	3.4 Mbytes
3D-Models	0.5 Mbytes
Total	**6.7 Mbytes**

Rearrangement of Data for Combining Terrain and Feature Information

In a first step, the coordinate points which are given in longitude (λ) and latitude (δ) are transformed to a Cartesian coordinate system. The rectangled plane chart transformation used here may be expressed as

$$x = \lambda \cos(\delta_0) \qquad (1)$$
$$y = \delta$$

where δ_0 represents an average value.

Other transformations such as the Gaussian Transformation have smaller angle and distance errors, but they do not produce a terrain grid with parallel lines. The accuracy achievable with the transformation according to Eq. (1) for a range of 1 by 1 degree is sufficient for the application under consideration.

When drawing DFAD lines over the terrain surface formed by filled polygons, they may be partially covered by the surface.

To avoid this effect, interpolated points have to be inserted into the DFAD lines at the intersections with grid lines.

In order to avoid a double rendering of the region inside the areal feature, the nearby elevation points are moved onto the feature boundaries. The polygons inside the feature boundary get the color of the areal feature.

The x,y coordinates of the moved points have now to be stored. A moved point is indicated by a negative elevation. The points with positive elevation remain in the regular grid position.

REALTIME GENERATION OF DATABASE VISION

Field of View

For determining the field of view, reference is made to Fig. 10. The equation for the pyramide edge lines may be expressed as

$$X = Z + t\,[B + hd\,(e_l + e_2] \qquad (2)$$

where the following quantities are used

Z:	viewer position vector (Z_x, Z_y, Z_z)
B:	line of sight vector (Bx, By, Bz)
X:	3D-vector (x, y, z)
h:	height of screen
el, e2:	normalized vectors of screen coordinate system (el_x, $e1_y$, $e1_z$), ($e2_x$, $e2_y$, $e2_z$)
t:	parameter for line equations
d:	distance from screen to viewer position

With the use of

$$z = Z_Z + t\,[B_Z + hd\,(el_Z + e2_Z)] = 0 \qquad (3)$$

the parameter t can be eliminated in Eq. (2) so that x and y coordinates values can be computed.

As an approximation for the intersection points of the lines of sight with the real terrain surface, a maximum elevation in a nearby area is used. This maximum elevation is considered predetermined. The start and end points of the grid lines have to be calculated to draw the polygons inside the trapezoid. The polygons between two grid lines can now be rendered as quadrilateral strips (qmeshes). This method allows to draw only the meshes inside the viewing frustum. The calculation time is independent of the database size.

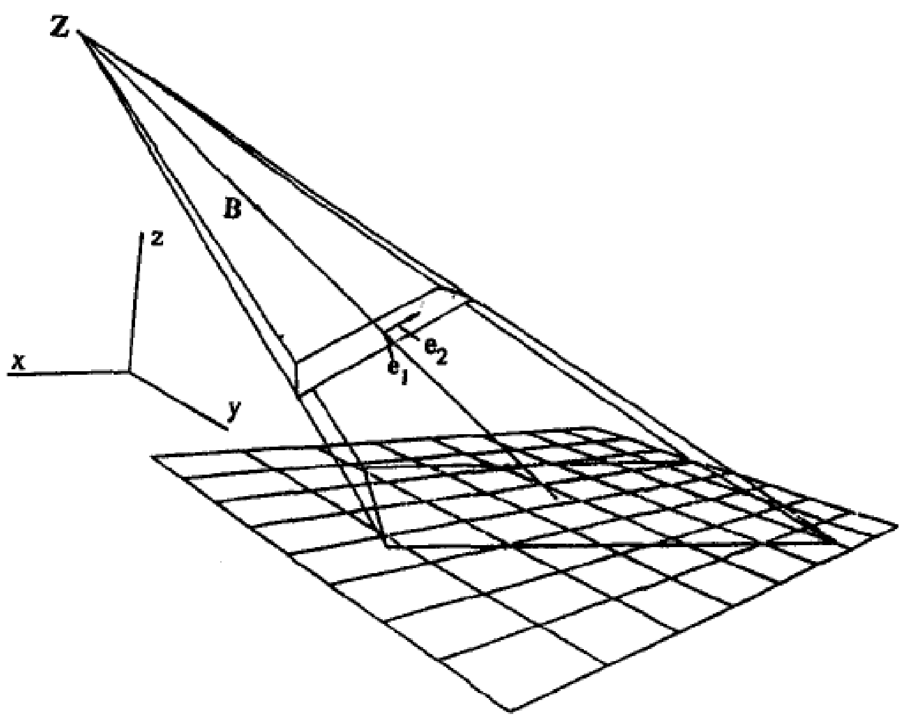

Fig. 10. Intersection of Viewing Pyramid with Ground Plane

Distance Dependent Resolution

The number of meshes in the field of view increases with the square of the visibility range. A realtime drawing of the polygons may not be possible for a large visibility range. Therefore, the field of view is divided into several areas with different Levels Of Details (LOD). Due to the regular elevation grid, the grid distance can be doubled from one LOD area to the next one. The areas for different LODs are calculated in the same way as the field of view with Eqs. (2) and (3), but using different distance restricted t-parameters. The points of the last grid line with a higher LOD have to be moved to the first grid line of the adjacent lower LOD to avoid gaps in the terrain at the boundaries of areas with different LODs. This linear interpolation can be done on-line.

Problems with popping up hills at the boundaries of the LODs are still a remaining task when considering a rough terrain and using a graphic system the drawing speed of which is not fast enough.

Requirements Concerning Pilots Orientation

One point concerns the number of displayable objects. This number is confined because of limitations in graphic hardware performance and memory capacity. Another point is related to texturing. Present computer hardware which is suited for use onboard of an aircraft has also no real-time texture capabilities. The lack of texturing may cause difficulties for the pilot in estimating the height above ground when the terrain surface is rather smooth. This is illustrated in Fig. 12 which shows a rather flat terrain in the foreground. A feature for overcoming the described difficulty is the addition of a grid which provides a height information by showing altitude contours. Fig. 13 shows an overlayed grid and single objects to improve the pilots orientation as well as his judgment of distances and heights.

Fig. 12. Terrain Surface without DFAD

Fig. 13. Terrain with DFAD and Overlaid Grid

GUIDANCE AIDS

All necessary information may be displayed on a central screen, thus forming an integrated flight display [3]. In this case, the synthetic vision is overlaid by information of the primary flight display (Fig. 14). Further display elements like ILS bars are no longer necessary and may be replaced. New display forms of flight path indication may be possible. This is illustrated in Fig. 15 which shows a curved flight path in the form of a tunnel. Further information like the nameplate of a city may also be added. Anti collision warnings, 3D-clouds instead of a simple weather radar display or restricted flight areas presented in three dimensions are additional possibilities in order to improve cockpit displays.

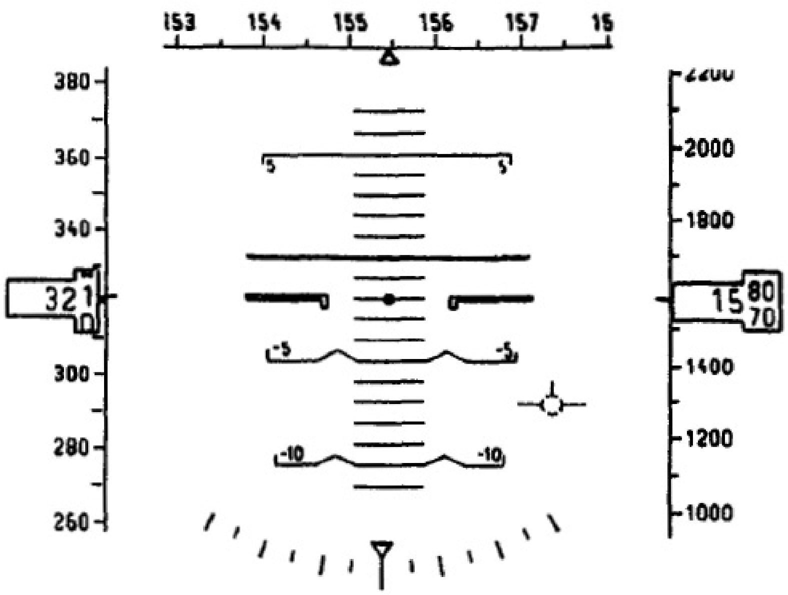

Fig. 14. Conventional Primary Flight Display

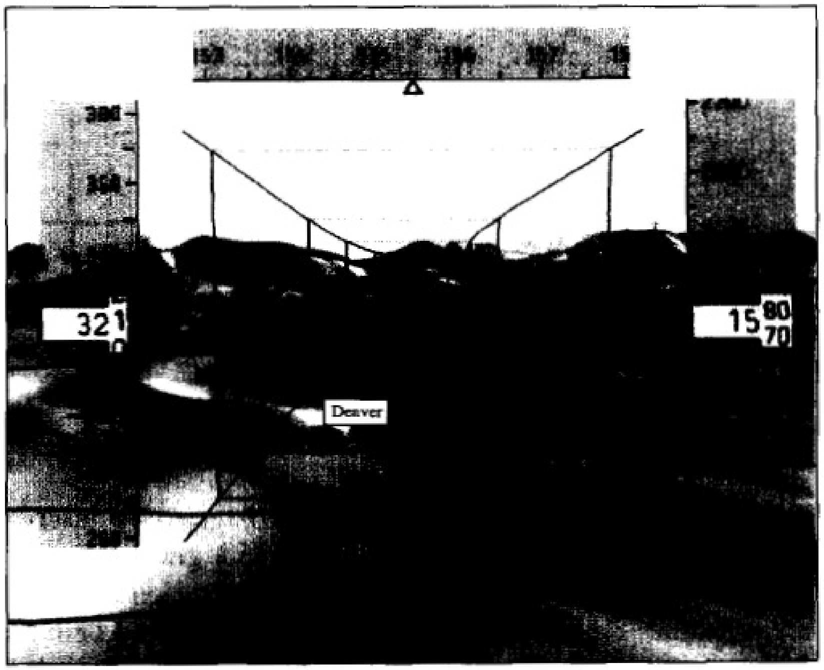

Fig. 15. Integrated Flight Display

GROUND MOVEMENT AIDS

Synthetic vision information provides also a means for enhancing poor visibility operations of aircraft when moving on the ground. At poor visibility conditions, control of aircraft during taxiing is a demanding task for the pilot because there are only simple or marginal optical aids for surface movement. For example, such aids concern lighting of center lines of taxiways, stop and cle3arance bars or signs.

With use of synthetic vision, the information of the pilot for controlling the aircraft on the ground can be significantly enhanced. This goal may be achieved by providing guidance information based on a map representing the airport area (Fig. 16). 3D geometry information provided by synthetic vision may be a means for further enhancing the capability of a pilot for controlling an aircraft on the ground (Fig. 17).

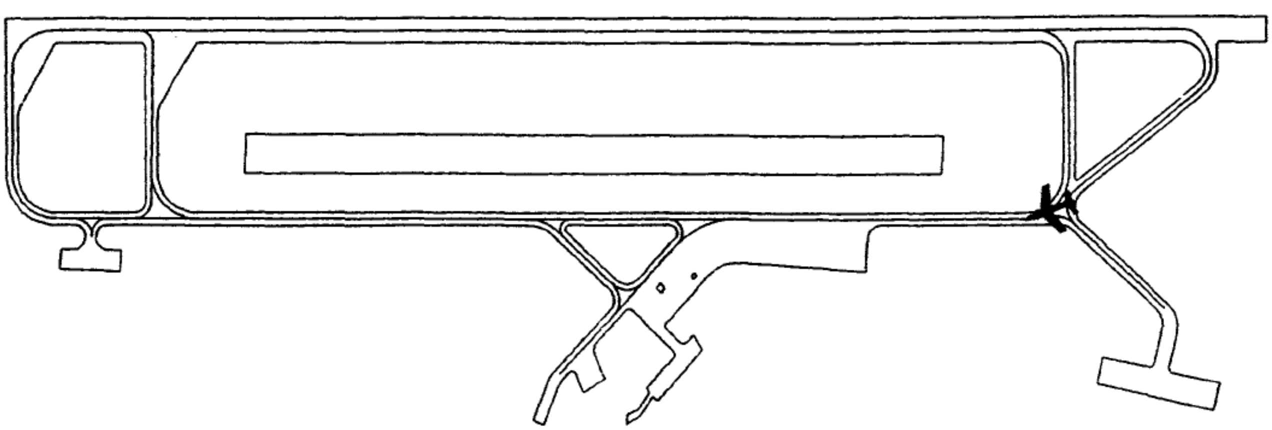

Fig. 16. Airport Chart Representation

Fig. 17. Synthetic Vision for Controlling Aircraft on the Ground

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Figures Not Referenced in the Paper

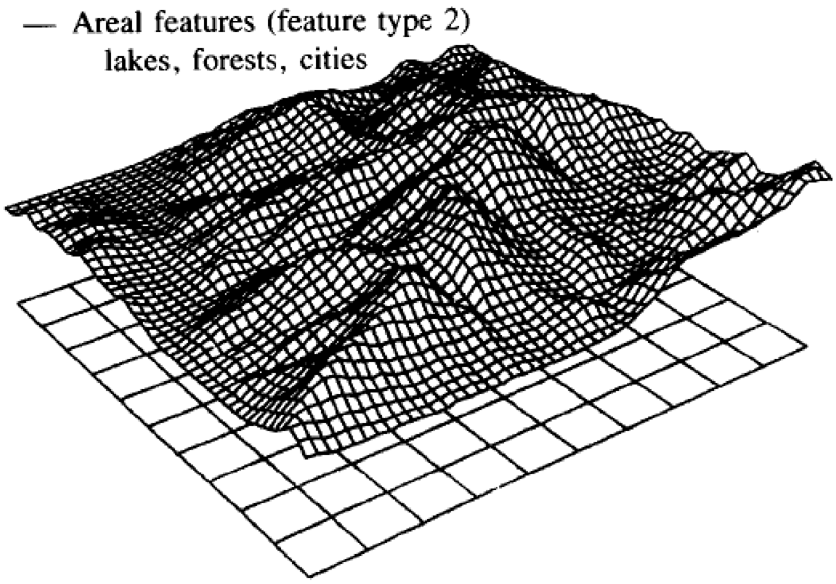


Fig. 3. DTED Grid

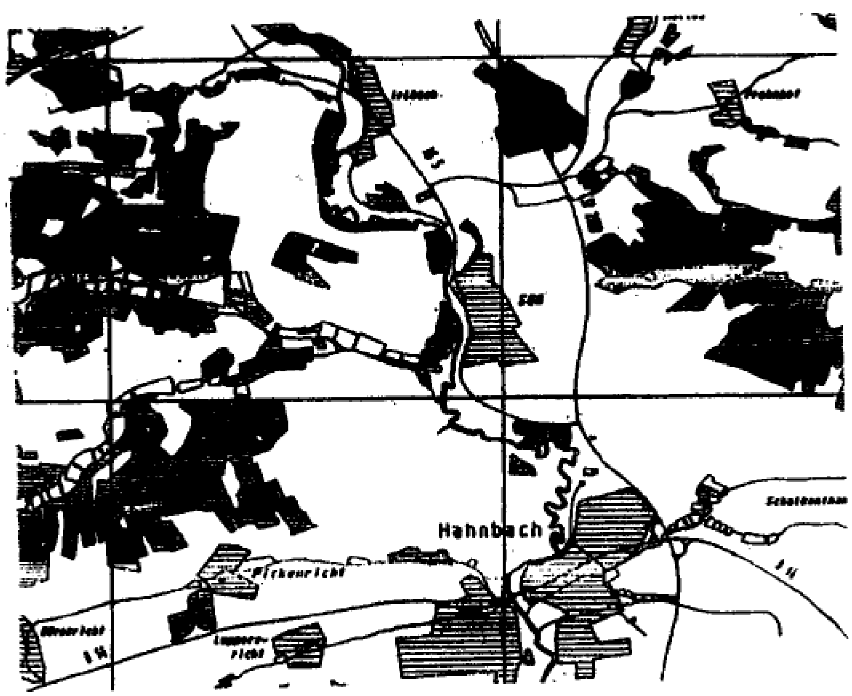


Fig. 4. Example of GEOGIS 25
(Corresponding to a Map at a Scale of 1:25000), From [4]

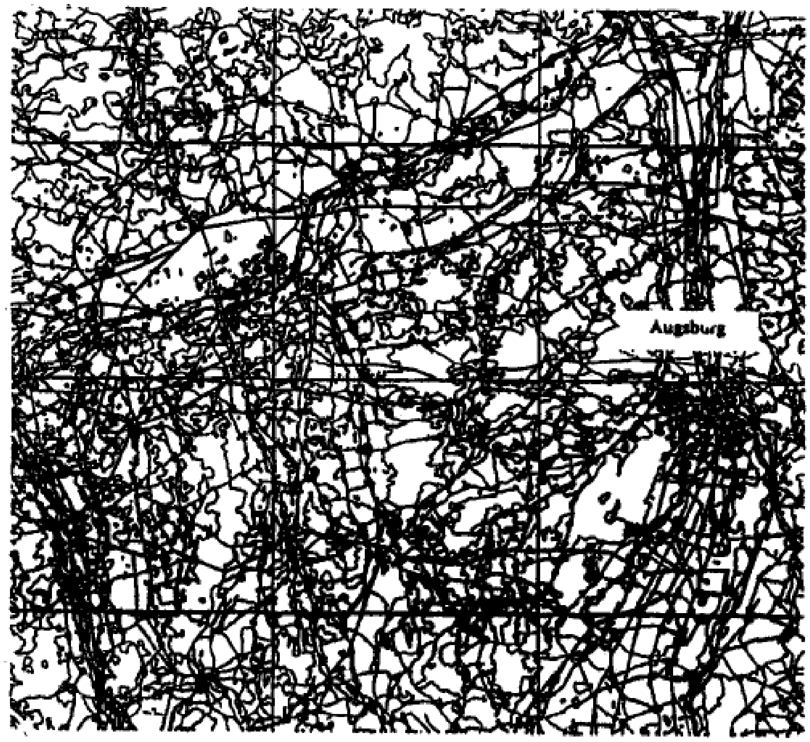


Fig. 6. Example fo DFAD (Areal Features Not Filled)

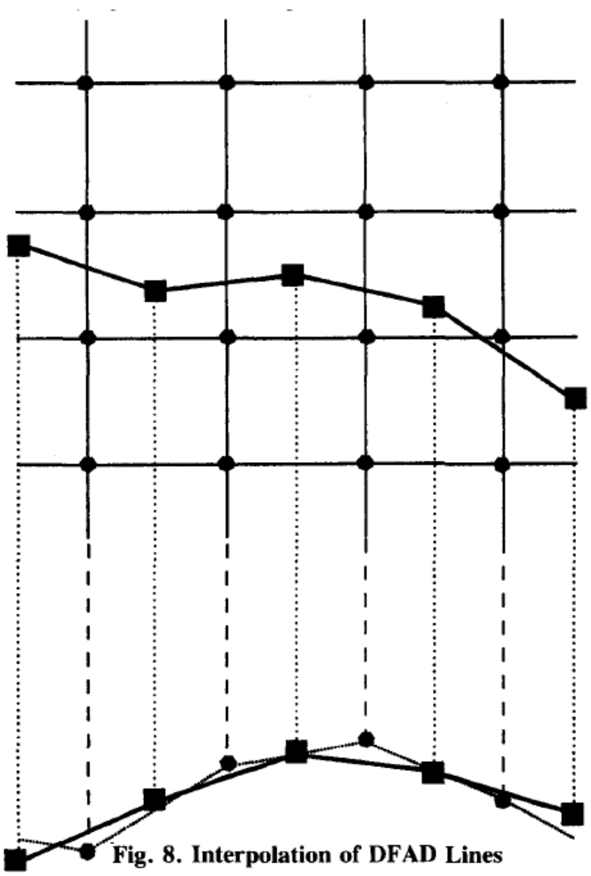
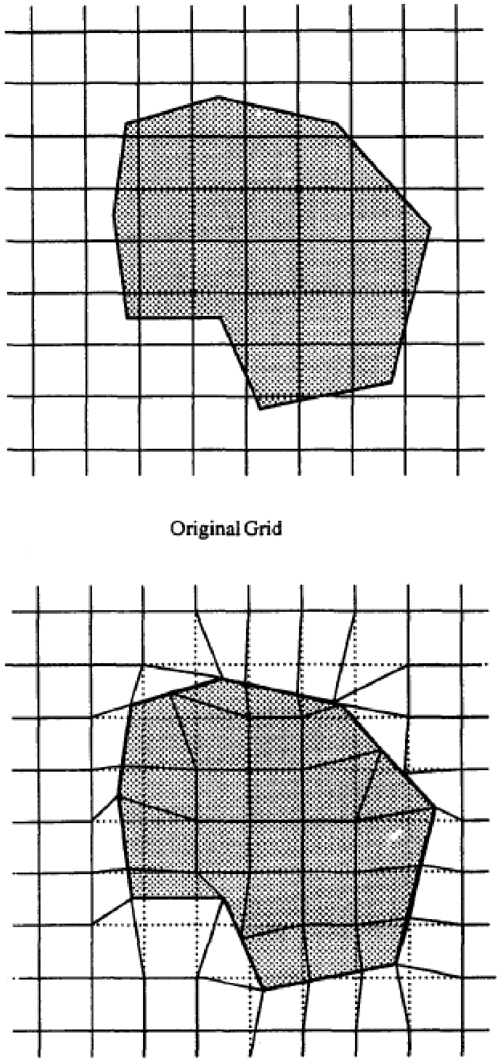


Fig. 8. Interpolation of DFAD Lines



Original Grid

Rearranged Grid

Fig. 9. Grid Representation

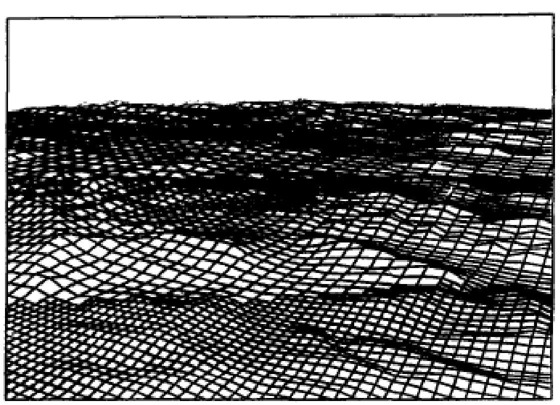


Fig. 11. Synthetic Vision with Three LODs