THE APPLICATION OF AERIAL PHOTOGRAPHY AND SATELLITE IMAGERY TO FLIGHT SIMULATION

Dr. Richard Economy, John R Ellis and Robert L Ferguson
General Electric Company
Simulation and Control Systems Department
Daytona Beach, Florida

ABSTRACT

Photographic texture has been a feature of Computer Image Generators for several years. When applied to models such as aircraft, trees, and buildings, photographic texture has produced extremely realistic results. Current methods of applying texture to the terrain surface of a simulator data base use either synthetic or *self-repeating* photographic texture patterns, neither of which produce the same degree of realism as that achieved with photo-textured models.

This paper describes techniques which have been developed to apply real imagery, either from aerial photographs or satellite data, to the terrain surface of a simulator data base. A data base, with extensive photo-texturing, has been built to demonstrate the results.

INTRODUCTION

Recent developments in Computer Image Generation have resulted in the ability to utilize texture maps derived from digitized photographs. The application of photographic texture to three dimensional models has produced extremely realistic aircraft, tanks, and trees in current flight simulator visual systems. However, many user applications demand more capability in applying geographically specific photographic texture to the terrain surface. These applications require a *photo-based* visual system.

GE Simulation and Control Systems Department is developing techniques which will produce unique real-world terrain texture over the entire data base. This *geographically specific* photographic texture will result in much improved scene realism.

A visual data base consists of a textured polygonal terrain model, and textured models and objects which lie on or move over the terrain. The terrain surface polygons are generated from Digital Terrain Elevation Data (DTED), which is available from a variety of sources. Texture for the terrain surface has usually been derived from a self-repeating synthetic pattern or from a digitized photograph which is representative of the local ground cover. Texture for the objects in the data base has usually been derived from a suitable photograph or scale model.

The geographically-specific photographic terrain texture, being developed by GE, is generated from satellite imagery and/or aerial photographs. The satellite imagery provides large area coverage at low cost, and can be used throughout the data base. Aerial photographs are more expensive to acquire and process and are therefore used in high interest areas of the data base.

A CIG Data Base Generation System is being enhanced with image processing techniques to produce continuous terrain texture from photographic source data. The new functions include radiometric and geometric correction, mosaicing and layering of dissimilar resolution imagery. Both man-made and natural cultural features are then extracted from the processed imagery and added to the data base as textured, polygonal models.

A data base has been constructed to demonstrate these new photographic texture techniques. Satellite images and aerial photographs were acquired and processed into terrain texture of different spatial resolutions. Ground level photographs were taken and used with the aerial photographs to construct geometric models of the significant 3D features.

Examples of the source data and the various processing steps are shown, as are simulated scenes using photo texture.

PHOTO-BASED VISUAL SYSTEMS

There are at least three approaches to Photo-Based Visual Systems which have been proposed or developed. One is known as image warping. Warping uses oblique photographs of the gaming area, or images synthesized from overhead photographs overlaid on a terrain model. In simulated flight, the photograph which best represents the pilot's current viewpoint is selected and warped to approximate the correct perspective.

Image warping has been used with photographic data in flight simulation. Image warpers do not use a three-dimensional polygon structure data base; imagery is essentially two-dimensional which leads to perspective and occulting inaccuracies, a lack of clearly defined edges, difficulty placing fixed or moving models in the data base, and constrained freedom of movement. They are typically utilized for *part-task* training applications.

Another method uses ray-tracing and a grid elevation data base to determine where each pixel in the image lies in the data base. Then the color of the surface at that point is determined from a texture map which has been derived from Digital Feature Analysis Data, an overhead photograph, or a satellite image. Sometimes the elevation value for each pixel is stored along with its color to give a volume element or *voxel*. These systems have limited capabilities for full mission flight simulation; fixed and moving models are difficult to handle without causing image artifacts, and extreme pitch and/or roll angles can cause distortions in the image

The third approach is to modify the texture capability of a polygon-based CIG system, to allow for the application of photographic texture patterns to all terrain surfaces and to the models and objects which lie on or move over the terrain.

This is the approach we have taken. It will provide the full mission simulation capabilities of CIG; complete freedom of movement, accurate collision detection and weapon impact calculations, and the ability to place static and moving models in the data base with correct occulting, along with the benefits of photographic realism.

CIG PHOTOGRAPHIC TEXTURE

Photographic texture has been a feature of CIG for several years [1]. Its primary application has been to increase the realism of objects such as trees, which previously required large numbers of polygons to model, and appeared cartoonish. By mapping a photograph of a tree on to a small number of polygons, and by controlling the translucency of each texture pixel, very realistic trees could be modeled.

Similar techniques were applied to buildings, airplanes, tanks and other models. However, the application of photo-texture to the terrain surface has been restricted by the relatively small size of texture memories in current CIG systems, and their inability to update terrain texture patterns as the ownship flies through the data base. Therefore, current approaches employ terrain texture patterns which can be reused. These are either *synthetic* or *self-repeating* texture patterns.

Synthetic Texture Patterns

Synthetic texture patterns are generated mathematically. They were first used in a real-time image generator to texture the terrain surface by GE/SCSD in the late 1970's. They can be made to give reasonable approximations of many types of terrain texture, and are adequate for data bases used in many training applications.

Self-Repeating Photo-Texture Patterns

Self-repeating photo-texture patterns are derived from digitized photographs of a type of ground cover such as grass, desert sage brush, forest, etc. The photograph is processed so that it may be repeated over the terrain surface without any visible seams between instances of the texture map. This processing is usually based on Peter Burt's pyramid processing algorithms.[2]

This approach is very economical; texture patterns can be reused many times, and a small number of patterns can be combined to produce textures of different scales.[3]

Limitations of Existing Methods

Self-repeating texture patterns produce texture which is typical of what exists in the gaming area, but it does not provide true photo texturing, which is imagery of the actual terrain surface mapped onto the CIG terrain surface.

True photo texturing of large data bases has not been possible before due to Image Generator limitations. Current and previous IGs could not store enough discrete texture maps and could not update them at high speed as the ownship moved through the data base. Other IG limitations include the lack of color texture with sufficient radiometric fidelity, and the lack of sufficient dynamic range to support extremes in altitude. Also, data base generation systems with the capability to transform digital imagery into large, continuous mosaics of texture patterns at many levels of detail, do not exist.

In anticipation of future image generator capabilities, we have been developing techniques to process photography and satellite data into discrete *non-repeating* terrain texture.

OBJECTIVES

When processing imagery for use in large area photo textured data bases our objectives include:

- The ability to use imagery from a variety of different sources and of different spatial resolutions.
- The ability to update any part of the data base quickly with new photography as it became available.
- The ability to extract the geometry and position of targets, and to insert them as models in the simulator data base.
- The ability to use this data base in an image generator which is capable of unrestricted movement of the ownship and of moving models, with high scene content and image quality, and in one that provides full mission simulation capabilities.

EVALUATION DATA BASE

We have constructed an evaluation photo textured data base to demonstrate the concept of large area photo texture. This is combined with a detailed simulation of the *image generator to produce static and* dynamic views of the data base.

Data Base Location

The evaluation data base is located in Nevada, between Las Vegas and Death Valley. It is a one degree square area *(approximately 2900 square nm),* centered at 116 degrees West, 36.5 degrees North. It includes the town of Pahrump, Nevada, the Springs mountains and the Indian Springs Airfield.

Source Data

Four satellite images were acquired from SPOT Image Corporation: two 20m resolution multispectral (green, red, and near-IR), and two 10m resolution monochrome scenes. Each scene covers a 60km x 60km area, which is approximately 1000 square nautical miles.

We contracted with an aerial survey company to acquire color overhead aerial photographs of the Pahrump Valley and the Indian Springs Airport.

35mm color slides of numerous buildings in Pahrump were taken at ground level, and used to produce color texture patterns for the sides of the building models.

Digital Terrain Elevation Data (DTED) for this area was acquired from the Defense Mapping Agency (DMA) and used for terrain generation.

Image Processing

Image processing converts the source imagery into texture patterns which can be applied to the surface of the terrain and to the faces of the models.

Data Input

The first task is to digitize the photography. The 9" x 9" aerial photographs were digitized on an Optronics 4100HS scanner at several pixel sizes from 25 to 200 microns. The pixel size was chosen to produce imagery of the required spatial resolution. For example the 1:24000 scale photography was digitized to produce 16 foot resolution pixels. At this scale one inch on the film represents 2000 feet on the ground, thus 125 pixels/inch would produce 16 foot resolution pixels. 125 pixels/inch requires scanning at 200 microns.

The 1:12000 and 1:6000 scale photographs were digitized to produce imagery with one and four foot pixels. The satellite imagery is supplied on Computer Compatible Tape, which was read directly into our image processing system.

The next task is to convert the digital imagery into a number of mosaics at different spatial resolutions. This involves color balancing the various images followed by a geometric correction, and then a mosaic process. Each step is described below.

Color Balancing

Color balancing is a two stage process. It involves first adjusting the pixel values of adjacent images of the same resolution, so that when several of them are joined together in a mosaic, the boundaries of the images are not visible due to a color shift. Then the pixel values of mosaics of different resolution images are adjusted so that color shifts between them are minimized.

Color balancing of adjacent images is fairly simple in most cases. One image is selected as a reference. An adjacent image is color balanced with the reference image by histogram matching the overlap region, and the look up table thus produced is saved. Then this look up table is applied to the entire adjacent image thus balancing the color with the reference image.

Color balancing is done before geometric correction because histogram matching sometimes produces some contouring in the processed image. This contouring is removed during geometric correction by the cubic convolution resampling which computes an output pixel value from a 4x4 neighborhood of input pixels.

Geometric Correction

Geometric correction resamples the imagery to a specified resolution such that the resulting pixels represent the color of the Earth's surface at points on a predefined grid. This grid may represent an orthographic projection where each pixel size is a specified number of feet, or a Lat/Lon grid where each pixel is a specified fraction of an arc second.

We used control point warping for the geometric correction of imagery for this data base.

Control Point Warping

Control points are features which are recognizable in the image and on a map or in another image, for example road intersections, or the ends of runways. There are two steps to this process: picking the control points, and then warping the image.

A map, such as a USGS 1:24000 quad sheet, is place on the digitizing table and the four corners digitized. The coordinates in UTM are entered at the terminal. Control points are then selected from the map and the corresponding points selected from the image. The coordinates in Lat/Lon, UTM and image x,y are written to a control point file. A transform is fitted to the points, the order of which can be changed interactively. The error at each point, that is the difference between the measured pixel address and the computed pixel address using the transform, is displayed, and control points with large errors are deleted from the file.

One image can be registered to another using control point warping. Control points in both images are written to a file. The image processing system displays both images in split-screen, the reference image on the left and the image to be warped on the right. A control point is selected from the reference image, and then the same point is selected from the other image.

Mosaicing and Feathering Images

After color balancing and geometric correction of images of the same spatial resolution, they can be joined together into a mosaic. There will usually be residual errors in color balancing and geometric correction which could lead to a visible seam between two images in a mosaic. By defining a small

Figure 1a

Figure 1b

Figure 1a shows the join region between two satellite images before the image on the left has been color matched to the image on the right. Figure 1b shows the same two images after color matching.

blend region in the overlap area between adjacent images, these errors are hidden in the final mosaic.

The one foot resolution imagery was low pass filtered using a 5x5 convolution kernel. The result was then subsampled by writing every other pixel from every other line to a new file. This gave an image of two foot resolution. The process was repeated with the four foot resolution imagery to produce an eight foot resolution image.

The 32 foot resolution imagery was produced from the multispectral and panchromatic satellite data. An area of about 60 sq nm around the town of Pahrump was extracted from the corrected multispectral and the panchromatic data.

The 64 foot resolution multispectral data was resampled to 32 foot pixel size. Then it was converted from red, green, blue to hue, intensity and saturation (HIS). The panchromatic data was then warped to register it with the resampled multispectral HIS pixels.

The panchromatic data was then histogram matched to the intensity band of the multispectral HIS values, and then the two intensity bands were swapped. The resulting image was converted back to RGB from HIS giving an effective spatial resolution of 32 feet.

<u>Terrain Tile Generation</u>

Terrain tiles are small squares of color texture which can be updated from disk to the image generator memory as the ownship moves through the data base. They are cut out of the mosaiced imagery. A terrain tile layout map was produced which outlined the coverage of the different spatial resolution tiles in the data base.

The terrain tiles are produced in layers such that there is a binary increment in spatial resolution between layers, and coarser resolution layers surround the finer resolution layers.

At the boundaries between tiles of different spatial resolution, the tile of finer resolution was spatially filtered over the last 128 pixels from its original resolution to the next lower resolution. This avoids hard edges at resolution boundaries in the terrain texture.

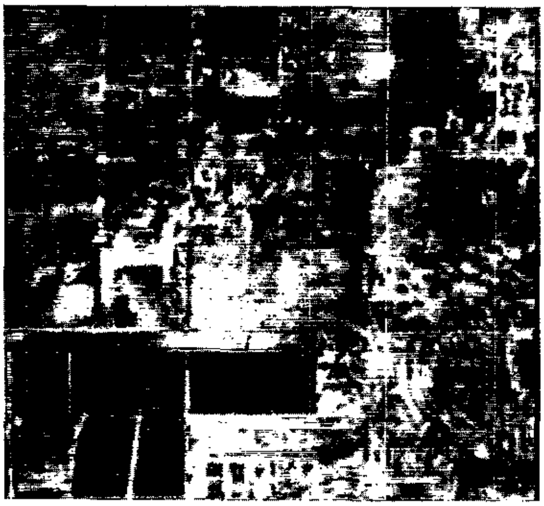

Figure 2a

Figure 2b

Figure 2a shows the terrain texture around the target area at a spatial resolution of 64 feet. Figure 2b shows the same area at one foot resolution

Terrain Triangulation

Variable density terrain triangles were generated from the DTED using the data base generation system software. The one degree square region was triangulated at an average of five triangles/square nautical mile.

3D Model Generation and Placement

Several 3D models were constructed for this data base. These were buildings in the target area. The footprints were extracted from the geometrically corrected one foot resolution imagery. This data gave us the size and the position of the buildings in the data base. The building height values were derived from ground level photographs. The texture for the roofs was taken from the overhead imagery, and the sides of the buildings were textured from the ground level imagery.

RESULTS

Perspective scenes were generated along a flight path from 8000 feet AGL to 200 feet AGL. A software simulation of an Image Generator with large area photo-texturing capabilities was used to generate these scenes. The resulting images were copied to video tape for evaluation of image quality in simulated flight.

This video tape showed the gradual transitions between the different layers of texture, and finally the appearance in the scene of 3D building models. The activation of the different texture layers and the transitions between them were not noticeable.

The construction of this data base showed that realistic photo-derived terrain texture, and photo-textured models can be generated from satellite images and aerial photographs.

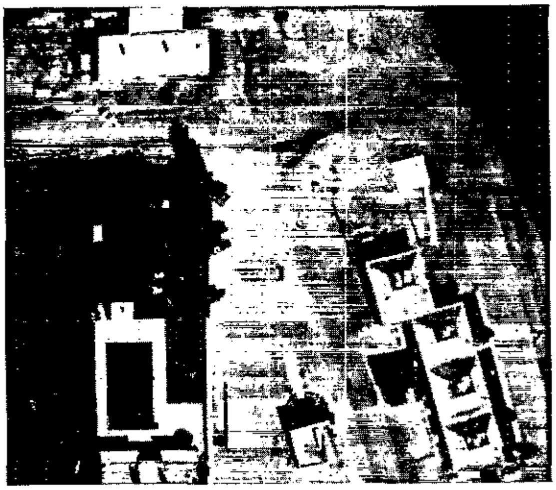

Figure 3

Figure 3 shows the footprints of buildings in the target area outlined in the processed overhead imagery.

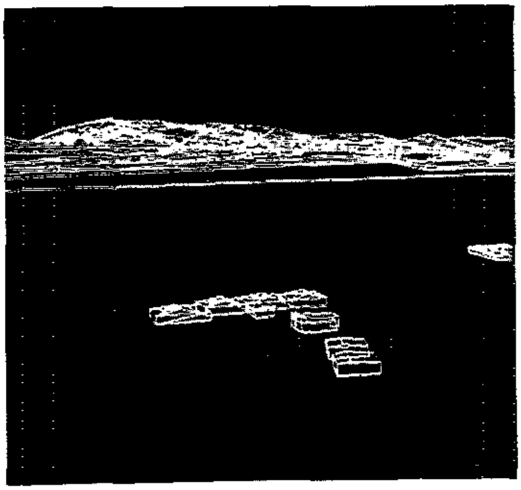

Figure 4

Figure 4 shows wire frame models constructed from the footprint data in Figure 3, and placed in the data base.

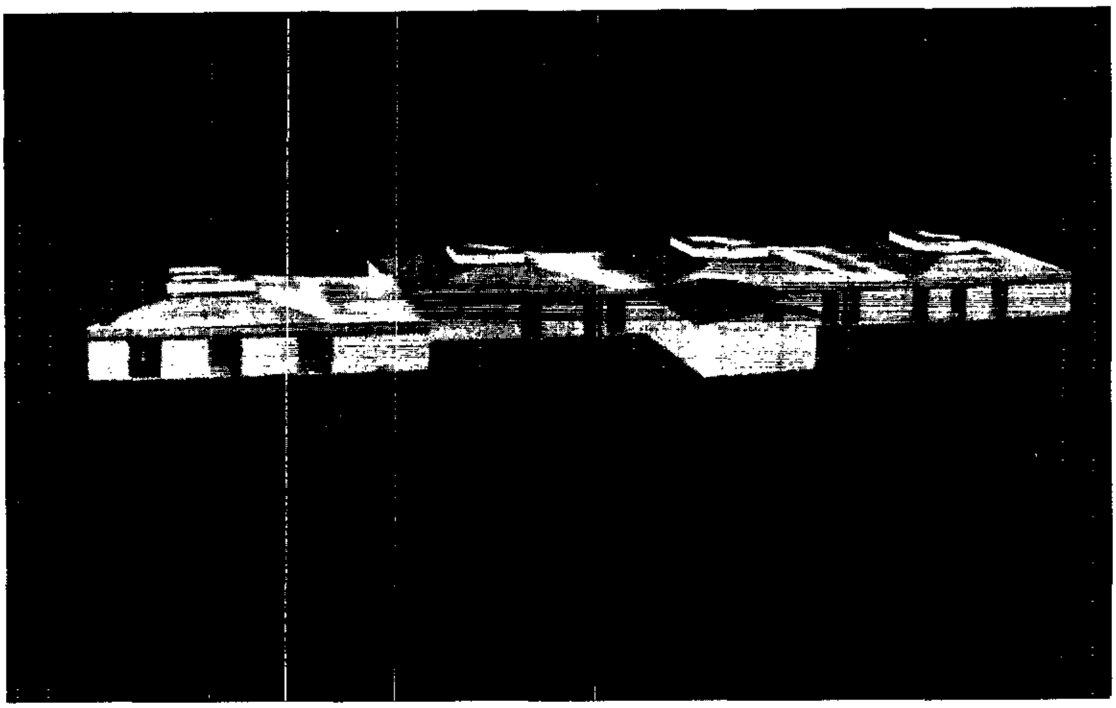

Figure 5

Figure 5 shows a photo-textured 3D model from the target area.

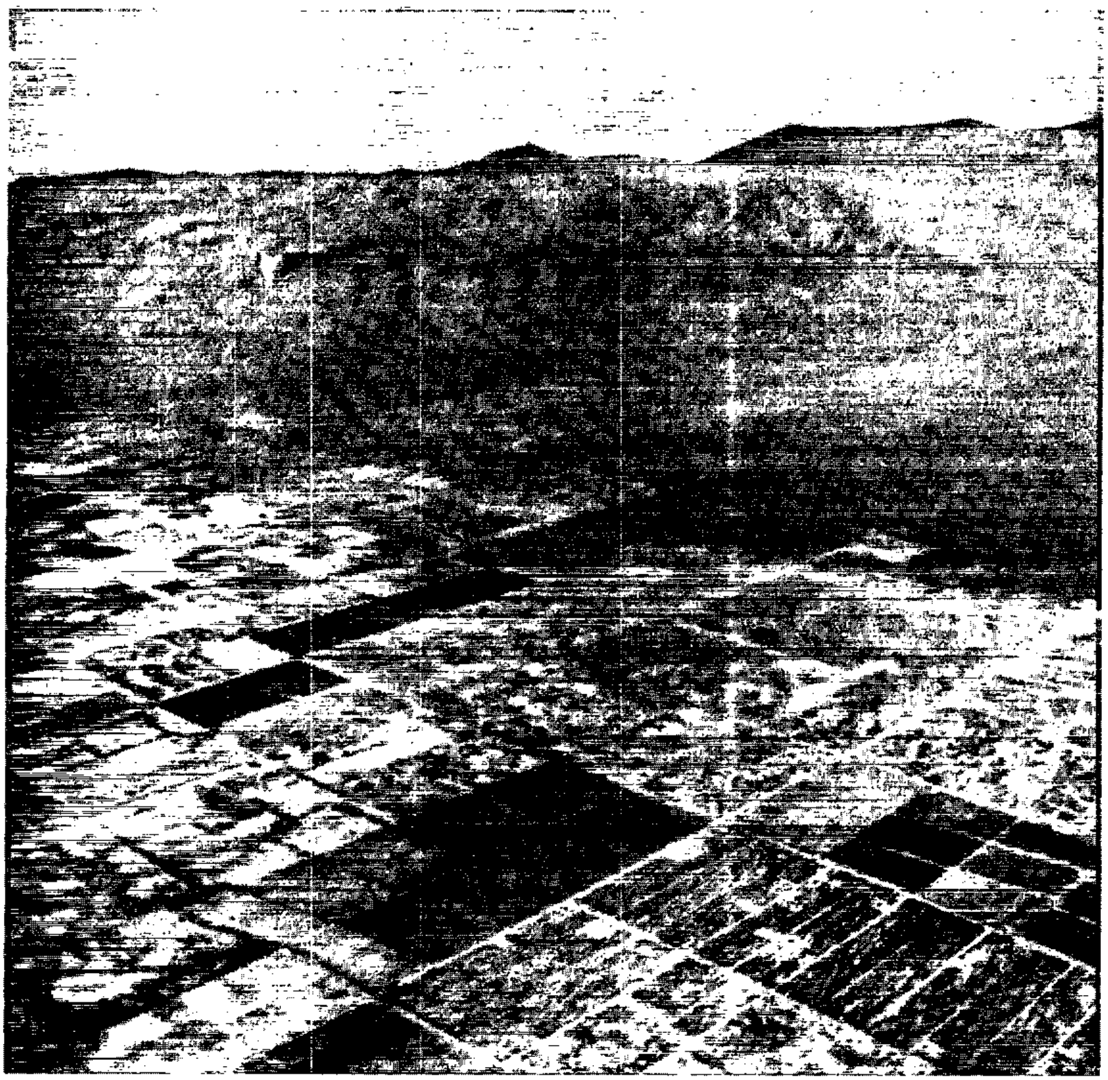

Figure 6

Figure 6 shows a high altitude view of the Nevada data base

Some example images from various viewpoints along the flight path are reproduced here.

Figure 6 shows a view from 8000 feet above the terrain surface. The mountains in the distance are about 15 miles from the view point. This view shows the *macro texture* which is derived from the use of satellite imagery.

Figure 7 is a view from about 2000 feet above the terrain surface. This view shows the mountain texture in the distance and the coarser resolution photographic texture in the foreground. Notice the smooth blending between the different layers of texture. Each layer is composed of a different spatial resolution texture.

Figure 8 is a view from about 200 feet above the terrain surface. Here the individual buildings on the ground are visible, as are all the different resolutions of terrain texture.

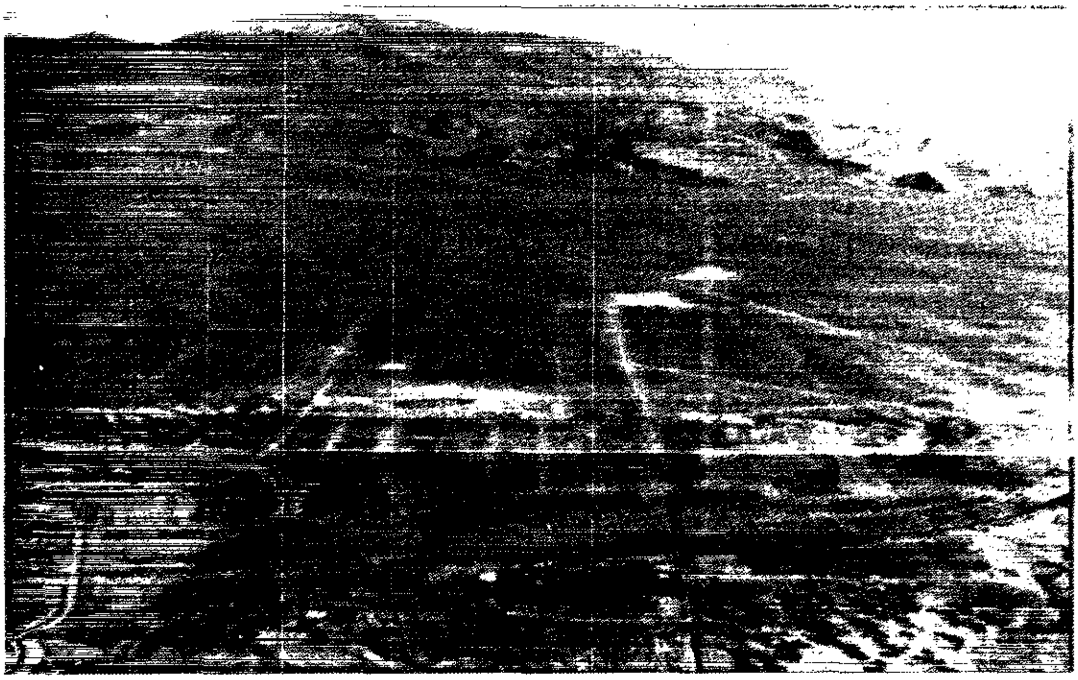

Figure 7

Figure 8

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ABOUT THE AUTHORS

Dr. Richard Economy is manager of Advanced Products and Technologies Engineering at GE SCSD in Daytona Beach, Florida. He received a BSEE, MSEE, and Ph.D. from the University of Texas. He is responsible for the Department's IR&D Program. In addition, he has made numerous contributions to CIG in the areas of cell texture, system design, and architecture.

Robert Ferguson is a Consulting Engineer for Advanced Products and Technologies Engineering at GE SCSD in Daytona Beach, Florida. He received a BSME from Rensselaer Polytechnic Institute and an MS from the University of Florida. Currently he is serving as the Principal Investigator for the Photo-Based Visual System IR&D Program.

John Ellis is a Systems Engineer in Advanced System Technologies Engineering at GE SCSD in Daytona Beach, Florida. He received a BS in Computer Science from Embry-Riddle Aeronautical University. He has been involved in the development of photographic texture for Compuscene IV and Advanced Compuscene systems.