REALSCAN - A CIG SYSTEM WITH GREATLY INCREASED IMAGE DETAIL

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ABSTRACT

Computer image generation (CIG) successfully provides images for a large proportion of visual simulation tasks, using polygon models of the environment. However, for close approach to terrain, e.g., for air/ground weapon delivery, confined area maneuvering and harbor navigation, the image detail is insufficient and the cost of generating the high detail data bases is becoming increasingly prohibitive.

The authors are developing a new form of CIG - the Real Environment Algorithm for Line Scanning (Realscan) System, using a uniform grid type digital data base of contoured, textured terrain semi-automatically generated from Defense Mapping Agency (DMA) and stereo photo data. The system will use video disc bulk storage, potentially visible data (for a given position and attitude of the simulated vehicle) being read into random access memory and then addressed in accordance with an algorithm giving correct perspective mapping into the display in real time with automatic elimination of hidden areas of terrain and without aliasing (sampling artifacts).

The image detail in a system of this type can be limited only by the display resolution, giving a very large increase in scene detail over what is likely to be available for many years with polygon modeled CIG. The application of the system to IR is being studied with the aim of producing coordinated visual/IR/radar displays generated from a common data base.

INTRODUCTION

One of the outstanding problems of visual simulation is the generation of a complex scene. Although satisfactory training can be achieved for many simulation tasks using current computer image generation (CIG) systems at their present stage of development, close approach to terrain in daylight reveals the severe limitations for tasks such as air/ground weapon delivery, confined area maneuvering, low level flight and harbor/channel navigation with both surface vessels and submarines.

With conventional CIG, the environment is modeled by defining the coordinates of points in space, grouping pairs of points to define "edges", connecting edges to form polygons, assigning color and reflectivity to the polygons and disposing them to form polyhedra which approximate the environment to a level limited by the processing power of the real time CIG hardware. The number of edges processed per displayed scene is the usual metric for such hardware with the state-of-the-art currently around 8,000.

For modeling regular objects such as a runway, polygon modeling is economical in terms of the size of data base and the amount of processing hardware. However, a complex environment such as an area of countryside consisting of contoured terrain having detailed surface texture and solid objects such as trees, building, etc. on it, is not realistically reproduced by present CIG systems for two reasons: modeling cost and processing hardware limitations of the polygon modeling technique. Further development in polygon model type CIG processing hardware is in progress by several manufacturers (the "edge war") but the limiting factor is not so much the real time processing hardware as the cost of generating the increasingly complex environment models or data bases required.

AUTOMATIC DATA BASE GENERATION PROBLEMS

Recent studies (1) at the Naval Training Equipment Center (NAVTRAEQUIPCEN) on the automatic generation of polygon type data bases from stereo photographs showed promise for individual objects but underlined the great difficulty of the problem for terrain. Automating the production of polygon models of real world environments is a task being addressed by the operational equipment community specifically with regard to Cruise Missile guidance systems, and success is not expected for many years.

The reason for the difficulty can be appreciated if one looks at almost any aerial photograph and mentally tries to break it down into separate objects that can be approximated by polygons. Much of what is visible can only be recognized by a skilled photo-reconnaisance technician. The difficulty, therefore, is fundamental: the process, to be automated, requires a degree of artificial intelligence greater (for this task) than that of the average human being. This basic difficulty emphasizes the need for considering the entire image generation system from data base modeling to image display when developing an advanced CIG concept, and for evaluating non-polygon type data bases as a way out of the automatic data base generation problem.

OUTLINE REQUIREMENTS FOR NEW SYSTEM

NAVTRAEQUIPCEN is currently pursuing an exploratory development program for an advanced CIG system. The aims of the development are:

a. Produce highly complex terrain scenes with detail approaching the limit of a unique scene element for each image display picture element.

b. Allow direct and automatic conversion of real world height, color and reflectivity information into the CIG data base.

c. Provide for large and variable gaming areas from which true perspective scenes can be computed and displayed in real time.

d. Provide compatibility of the new system with polygon model type CIG for optimum flexibility and economy in defining a total image generation and display system.

DEVELOPMENT OF NEW SYSTEM CONCEPT

If one attacks the requirements individually the following system characteristics emerge. First of all, high scene detail requires a substantial data base; however, the storage requirements are less if two of the ground coordinates are addresses rather than data. Large areas of the world are mapped as uniform grid models, such as the Terrain File of the Digital Landmass System (DLMS) developed by the The Defense Mapping Agency and the ortho color photos produced by the U.S. Geological Survey (2). Models of this type are relatively easy to generate by low-skill processes (as compared with polygon models) and offer the greatest possibilities for use in a CIG system of the type we are considering.

To obtain constant angular resolution of visible details over the display, the corresponding ground resolution required decreases with range from the viewpoint. Since a change of viewpoint means all parts of the data base will at some time be viewed at close range, the data representing the gaming area must all be available at high resolution. However, for any given viewpoint, to avoid having to process, in real-time, high resolution data representing distant terrain, a lower-detail version of the data may be used for distant parts of the scene. This leads to the concept of a hierarchy of resolution levels in the data base, analagous to the levels of detail used in polygon model CIG.

However, whereas the levels of detail in a polygon model data base must all be created by the modeler, with a regular grid data base each level can be derived automatically off-line.

In current real-time CIG systems, following transfer of the polygons forming the scene into the display plane, sorting algorithms are used to produce the displayed image and the processing power required grows proportionally to the square of the detail processed. For systems dealing with a great amount of detail in real time, an architecture is needed in which processing power grows only linearly with detail, and this should be a feature of the new system. To process and display a great amount of displayed detail in real time a modular structure is indicated making use of basically independent parallel processors, each a pipeline.

The use of a ground coordinate grid allows incremental processing in a fixed data base. This feature eliminates the need for floating point operations and repeated need for divide operations. Hence, computationally efficient integer algorithms can be developed which incorporate a pseudo exponentiation upon crossing from one level of the data base to the next (using a step of 2:1 in linear detail between levels).

Finally, the generated image should be in one of the standard television formats, e.g. 1023 lines/frame, 30 frames/sec. This allows existing displays to be used and combined image generation systems to be developed using both polygon and grid data forms of CIG.

DESCRIPTION OF SYSTEM

REALSCAN (Real Environment Algorithm for Line Scanning) is a concept being developed at NAVTRAEQUIPCEN to produce highly detailed terrain displays directly from a uniform square grid data base in real time. This concept utilizes a hierarchy of resolution levels to model the environment and many parallel - pipelined processors to perform the required visibility determination followed by perspective transformation from world coordinates to display coordinates. The processing is based on computationally efficient integer algorithms.

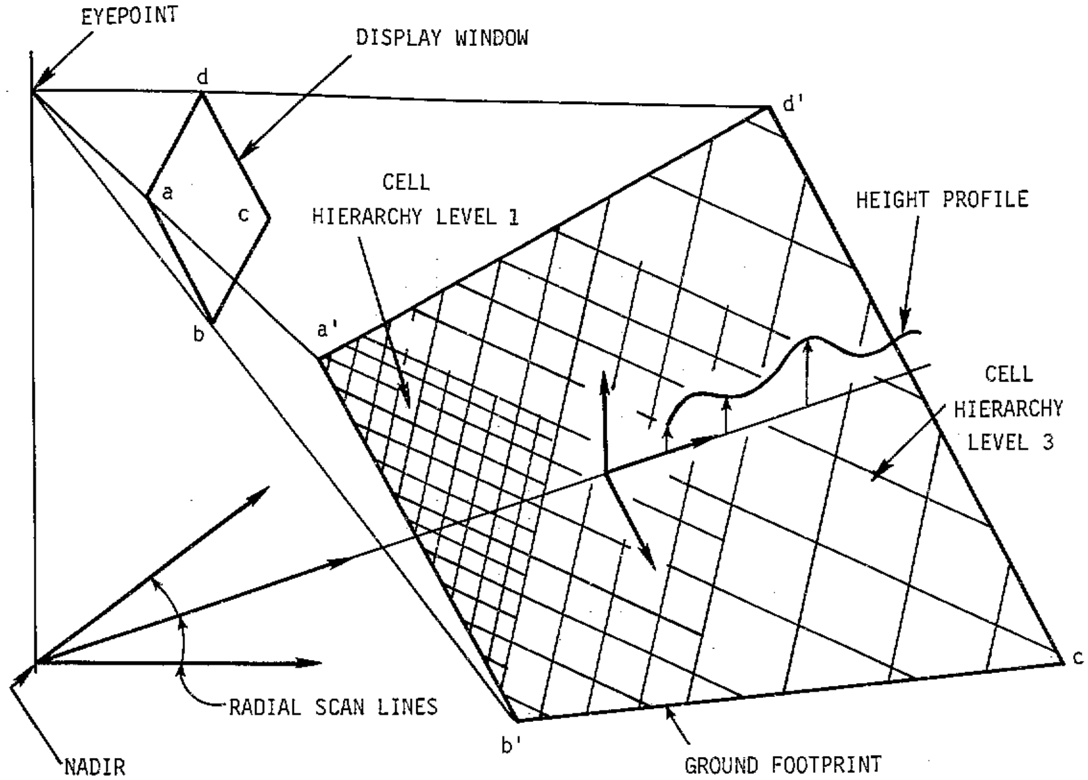

Figure 1. Display Window Projection

Figure 1 shows the projection of the display window on to the ground plane to give the "ground footprint" from which data must be transformed into the display window coordinates. Each level of the data base consists of a square array of "cells", each cell containing digital color and height data for that elementary area of the terrain modeled. Although all levels of the hierarchy are available over the whole gaming area, level 1 is used for parts of the terrain nearest to the eyepoint and levels 2, 3 etc., are used as the range increases. The determination of which points are visible is made by radially scanning the ground footprint in a manner similar to that used in radar landmass simulation. Each radial line drawn from the nadir point (the point directly below the eyepoint) through the ground footprint maps into a line across the display window. As explained later, a frame buffer is used to store the information to be displayed such that the information can be read out in accordance with any standard television scanning pattern for display (e.g. with horizontal scan lines).

New scan lines are initiated through the data base as the scanned distance from the nadir grows, such that the visible part of the data base is correctly sampled. It is necessary, for acceptable image quality, to avoid aliasing (interaction between the regular structure of the digital data base and the regular structure of the scanning pattern which generates spurious detail in the displayed image). The information in each displayed picture element (pixel) must be derived from the data stored in several adjacent cells, in accordance with a weighting algorithm that varies with the position of the pixel in the window. This requires averaging, in real time, of the processed data.

Real time averaging over many cells is impracticable, but the hierarchical data base concept, by providing pre-averaged information, reduces this problem to manageable proportions. Filtering is used to eliminate any remaining unwanted image components.

In transforming data from the ground plane into the viewing window, a perspective transformation has to take place. Each scan line through the data base is dealt with separately, the spacing between image details along the line being changed to allow for the oblique view of the terrain. Details which would be hidden by high ground, are of course omitted from the display.

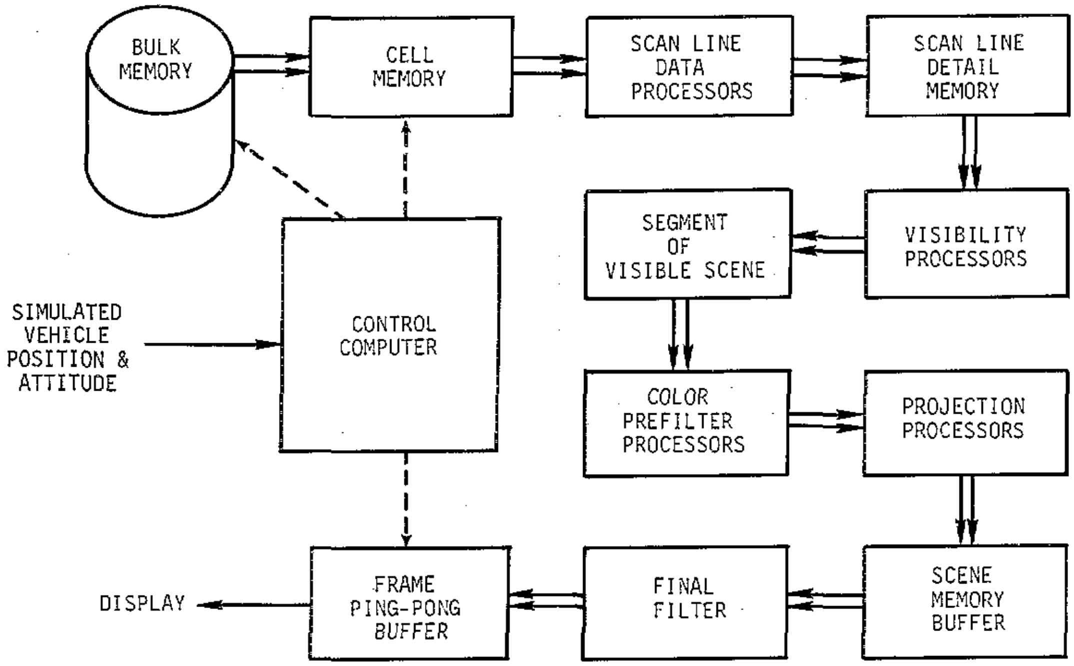

Figure 2. Functional Block Diagram of Realscan System

Figure 2 is a functional block diagram of the proposed system. The color and height data for the complete gaming area are stored in bulk memory; a videodisc is preferred in view of the large number of bits that can be stored in a compact space with reasonably rapid access (this will be considered in more detail later in relation to the generation of the data base). The cost of videodisc bulk memory storage is currently estimated to be $0.10/megabyte as compared to magnetic disc storage costs of $3/megabyte (3).

The control computer accepts simulated vehicle position and attitude data from the host computer and is used to control the flow of data to the Realscan system. For each television frame of picture information, the following processing steps need to be carried out:

a. Obtain observer view point location and viewing direction (simulated vehicle location and attitude) from the host computer.

b. Compute, in the control computer, the viewing pyramid intercepts with the ground reference plane.

c. Use linear and angular rates of the simulated vehicle to predict the potential field of view for future television frames.

d. Determine, using the control computer, which blocks of data representing hierarchical areas of terrain in the bulk memory are to be accessed for generating the required scene, given the nadir point location and field of view.

e. Using the control computer, transfer these blocks of data containing all the information necessary to compute a display of the current field of view plus additional information for future frames, to the "cell memory" (a high-speed, virtually addressed random access memory). After the cell memory has been initially loaded, there is always information available to generate the next frames. The cell memory is then the first stage of a pipeline computational process leading to a frame generation. After the current frame's information is read from the cell memory, those blocks which are no longer in the potential field of view are overwritten by new information.

f. Scan the cell memory using a group of identical scan line data processors. Each processor calculates the elevation and reflectivity information along its scan line using the regular grid data in the cell memory. The radial lines are scanned in parallel groups to minimize the time taken for this process. The data is assembled in the scan line detail memory, data for each scan line being separately stored.

g. Transfer the data, in parallel as needed, from the scan line detail memory to the visibility processor and carry out visibility processing on each line of data. This process determines which parts of the data from the cell memory are to contribute to the displayed scene and which are hidden from view. The algorithm used to determine visibility is similar to that used to determine radar shadows in digital radar landmass simulation systems (4, 5), suitably modified for the hierarchical data structure.

At this stage only the elevations of cell data enter the computation; cell reflectivity/color information is carried with no modification.

h. Accumulate, in the segment of visible scene buffer, reflectivity/color data from the visibility processor in first-in first-out format, to allow for timing variability in the pipeline up to this point.

i. Pass the data from the segment of visible scene buffer to the color pre-filter processor and perform initial filtering along the lines to avoid aliasing while correctly passing sudden luminance changes corresponding to non-aliased edges in the scene.

j. Pass the data from the color prefilter processor to the projection processor where the reflectivity/color data is perspectively transformed from ground coordinates to display coordinates.

k. Pass the output from the projection processor to the scene memory buffer.

l. Perform final filtering using a weighted average processing filter to generate display pixels.

m. Pass the data into a random write/serial read ping-pong frame buffer.

n. Read the frame buffer continuously into the display.

FEASIBILITY OF PROPOSED SYSTEM

None of the components required for the proposed system is particularly unusual; however, like any CIG system it is complex and will take considerable effort to implement.

The use of a videodisc as the bulk memory has already been referred to. The control computer can be an off the shelf item. The cell memory size is a function of the access time of the bulk memory; for example, an access time of 500 msec. (a design goal for the videodisc system) would require the storage of sufficient data to produce the current television frame plus 29 future frames (assuming a position update of 60Hz). The amount of new information required per frame is a function of the rate of change of position and look direction. With the above access time; a horizontal field of view of 50^o; a velocity of 100m/second (200 knots); a heading change rate of 50^o/sec; a high resolution cell size of 0.1m (with appropriate blocks from other resolution levels); the cell memory size requirement is approximately 1 megabyte (assuming 6 bytes/cell). This does not present any special problem.

The scan line data processors need special attention. At this stage of the processing the desired display resolution becomes a consideration in determining how many radial scan lines must interrogate the cell memory. In order to carry out a feasibility analysis, a display having the usual 50^o horizontal by 36^o vertical format is assumed, with one million pixels. The angular subtense of the diagonal defines the worst case width of the current field of view in world coordinates; in this case 60^o.

From sampling and anti-aliasing considerations, it is desirable to have approximately twice as many radial scanned lines computed as there are displayed pixels across the display for the worst case condition. In this example approximately 3,000 radial scans should suffice.

In principle, 3000 identical processors could be used, all operating in parallel to scan the radial lines. However, the overall throughput delay of the complete CIG system can be kept smaller than that of polygon-type CIG systems with approximately 300 processors each scanning 10 lines. Study is needed to determine the optimum number.

The plan being followed is to develop the processing algorithms for computational efficiency and ease of implementation in modular hardware as a prime consideration. The algorithms have been coded into software and tested in non-real time using the VAX/11/780 at the NAVTRAEQUIPCEN Computer Laboratory. The data base used for initial testing consisted of analytic function generators which simulated a uniform grid of elevation and reflectance values. The extension to operation on a real world uniform grid terrain model for elevation and a digitized ortho-photo of the same terrain area for the reflectivity is the next step. After an evaluation of the non-real time imagery and iterations of the algorithm formulation, a feasibility analysis of a hardware design will be carried out for potential real time implementation.

THE REALSCAN DATA BASE

The last section presented, in outline, a likely architecture for the system. However, to judge the value of the system it is necessary to relate it to the data base and to quantify some key parameters.

The desired data base form is a hierarchy of two-dimensional arrays of elevation and reflectivity/color. Each array corresponds to the entire gaming area at a specific ground resolution. The size of the data base is a function of the desired ground detail size, the size of the gaming area, and the amount of information stored at each array location.

For example, consider a gaming area of 100 km^2, a desired ground detail size of 0.1m, and 48 bits of information stored at each array location. The largest array, corresponding to the highest resolution, would contain 10^{10} grid positions or cells and $5x10^{11}$ bits of information. If the cell size in each array is doubled or the resolution is half that of the adjacent array in the hierarchy then the total data base required for the entire hierarchy is (1 + 1/4 + 1/16 + 1/64 ...) times the information stored in the highest resolution array, or approximately $7x10^{11}$ bits for the total data base. Although this is a large number, the optical disc digital storage technology has progressed to the point where such large data bases are feasible. In fact, optical disc storage configurations have been proposed for systems having a capacity of 10^{14} bits (6). The next question is: What is the value of a regular grid data base with 0.1m ground resolution? For close approach to the ground, as with a helicopter maneuvering in a confined area landing site, a minimum range from the pilot's eye to ground could be taken as 5m.

Considering a television display with 1000 horizontal scanning lines and 50^0 wide field of view (a typical CIG "viewing window"), the ground resolution (detail size) should be of the order of $\frac{5}{1000}$m or ½ cm. This is smaller than the figure of 0.1m chosen above by a factor of 20. To provide the desired fine detail in the display, the basic concept is to interpolate special functions.

Example of data base construction

a. DLMS terrain file (Level I) consists of an elevation array with a grid spacing of approximately 100m. This array would be interpolated using bicubic functions to form the initial hierarchy arrays. In the case of a desired 0.1m ground detail the number of arrays generated would be 10 corresponding to cell sizes of 0.1, 0.2, 0.4 ..... 25.6, 51.2m.

b. The enhancement of the elevation models can be carried out in a variety of ways. By making use of the DLMS cultural file, generic cultural features which have been stored in a feature library in the gridded elevation format at the various resolution levels can be added to (or subtracted from) the initial elevation data. The generic models can be obtained by photogrammetric techniques using stereo photos of representative real world cultural features.

c. Reflectivity/co information can also be generic or specific. .nis information can be derived from digitized/quantized color ortho photos. (An ortho photo is a product of automatic analytic stereo photogrammetric equipment in which the image displacement due to relief is corrected). If the reflectivity/color model for a specific $100km^2$ area is desired, approximately fifty color aerial photographs would be required to obtain the raw reflectivity photographic data to 0.1m cell size. If the generic route is chosen, appropriate color orthos photos of representative cultural features are utilized to form a library which corresponds to the generic elevation library.

d. The high resolution reflectivity information is interpolated to form the reflectivity data for succeeding lower levels in the hierarchy. In this way scene compatibility across hierarchical levels is ensured.

e. In addition, elevation and reflectivity/color function codes can be assigned to each cell. These codes describe the fine detail referred to in b. above and provide for blending of reflectivity/color and terrain height between cells so as to avoid discontinuities. This scheme enables the aim of making the system generate as much detail as can be displayed to be achieved without excessive memory, although individual objects cannot be dealt with in this way. Further elaboration to the system shown in Figure 2 is, of course, required.

The net result is a highly automated data base modeling system which is not dependent on subjective decisions by the modeler and can be implemented using available data and technologies in the photogrammetric community.

The concept of essentially overlaying a digital elevation model with photographically derived reflectivity data to form an environment model is not new (7) (8) (9), but the use of such a model in a real time CIG system has not been attempted to our knowledge.

The reasons for pursuing this approach to environment modeling are summarized as:

a. The need for efficiently produced low cost, highly detailed environment models.

b. The availability of equipments and technologies which can produce highly detailed environment models in a uniform grid format.

c. The availability of technology to store and access large amounts of data.

d. The feasibility of an automatically generated level of detail hierarchy which greatly reduces computational processing load, since simulated long ranges utilize coarser levels of the hierarchy.

The environment model described has been initially restricted to terrain surfaces which are single valued in elevation, and the acceptability for training using such a model has not been evaluated. However, the potential for extension to multivalued elevation and vertical surfaces has been considered and various algorithms for implementation are being evaluated to represent multi-valued elevation features such as clouds (10).

THE USE OF THE REALSCAN CONCEPT IN SIMULATION

As already indicated, the proposed system can generate a perspective scene in any television format and so is compatible with polygon model CIG. In fact, its likely eventual use would be in a visual system having a Realscan-generated contoured textured terrain with polygon-modeled target vehicles and buildings.

The generation of irregular objects such as trees remains a problem for polygon CIG although various approaches are being investigated. An adaptation of Realscan may be of value here, using automatic generators of a digital model from a physical model.

Just as polygon CIG image generators are built in channels, each channel feeding a display window, so can Realscan be built in a similar way. Wide angle displays of multiple windows are equally feasible.

Particularly interesting are the possibilities for the Realscan concept in association with current display systems under development in which the pilot is presented with a display over a limited field of view in the direction in which he is looking, using head and eye tracking to control the image generator. Such a combination of image generator and display would give very high effective detail to the pilot for any position of his head and eyes.

Finally, the increasing use of infrared sensors must be mentioned. The simulation of an IR system requires a data base even more demanding for some systems, than visual simulation and the IR and visual data bases must possess the same correlated geometry as the radar data base. A Realscan type system may in the long run unify the simulation of all these sensors.

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