COMPUTROL COMPUTER GENERATED DAY/DUSK/NIGHT IMAGE DISPLAY

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INTRODUCTION

Advanced Technology Systems (ATS), welcomes this opportunity to describe our advanced computer generated, full-color, day/dusk/night Simulator Visual System which we call COMPUTROL*. We believe that the system represents a genuine breakthrough in the state of the art, in that the level of picture detail far exceeds that of currently available systems.

Among the noteworthy features of the ATS system are:

Its ability to produce a full-color, day/dusk/night picture including blue lights. A minimum of 10,000 colored point light sources can be generated and displayed.

Its ease of generating a new picture. A new airport can be programmed in one working day.

Its ability to display 30,000 edges. Expansion to 100K edges possible.

Its ability to drive additional, independently controlled displays.

Realistic special effects such as horizon glow, variable cloud cover, variable visibility, correct sun angle, moving traffic and lights whose intensity varies in slant range.

No blooming of lights at the end of runway.

As will be discussed later, the technology to produce a high-definition picture with full-color, smoothly rounded curves and infinite shading has been developed with illustrative photographs to prove the point. Color shading has also been developed for transition of one color to another without abrupt or noticeable effects.

BACKGROUND

For those not acquainted with ATS, please permit a slight digression. We are an operating division of The Austin Company, an organization of engineers, designers, and builders established in 1878 and operating coast-to-coast in the U.S. and 12 international offices.

ATS was organized as the Special Devices Division to handle classified research and development projects and has been devoted to the advancement of the state of the art of visual simulation since its founding in 1943.

Our credits include:

A torpedo and rocket attack trainer which features the first spherical-domed visual system of the simulated world environment in which the trainee maneuvered (12 units built).

Every Submarine Periscope Training System used by the U.S. Navy. Many now include our 40:1 diffraction limited zoom lens which revolutionized the Submarine Periscope View Simulator performance.

EARLY CGI DEVELOPMENTS

Our first Computer Image Generator was a nighttime system for the simulation of harbor navigation. ATS designed and developed a color, nighttime, dynamic CGI system which provided a 360^{0} view capability with simulated own ship speeds up to 60 knots. The system had 300 point lights, some of which were hooded to permit viewing to a restricted FOV. The simulated buoy lights blink at controllable rates which permits the maneuver into and out of a simulated harbor.

This early system also simulated aircraft flight providing maneuverability for takeoff, landing, and airborne maneuvers. Recognizing the inadequacies of current daytime CGI techniques, ATS embarked upon the development of the COMPUTROL Day/Dusk/Night Image Display and Control System.

The goal of this developemnt was increased capability for the real-time manipulation of perspective views of three-dimensional objects. The resulting system design will be capable of generating enhanced detail for terrain, cultural features, and moving target models while also displaying such special effects as contrails, weapon impacts, and transparencies.

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Upon becoming acquainted with the accomplishments of the Human Resources Research Organization's (HumRRO) CHARGE System, the two organizations decided to combine technical and financial resources for the fulfillment of common goals.

The CHARGE (Color Half-tone ARea Graphics Environment) System, part of a HumRRO study conducted in 1971 and 1972, addressed Computer Aided Instruction (CAI) techniques. The purpose was to develop specifications for a total CAI system with components that included hardware, software, lesson plans, and instructional decision models.

Image generation techniques were first modeled in software so that alternative algorithms and hardware architecture could be studied, simulated, and verified before committing image generation functions to hardware. The resultant hardware/software design exceeded expectations, rivaling in sophistication and performance any CGI system then on the market.

As a result of a continuing effort in the study of image generation techniques, ATS/HumRRO has evolved the basis for the current advanced design. While committing certain image generation functions to hardware to achieve an order of magnitude increase in processing capability, the system still retains immense versatility both in hardware and software flexibility. The main advantage is that it can handle more edges in real-time at less cost. Any additional or new image generation algorithms can be incorporated since algorithms are not completely frozen into special-purpose hardware.

APPLICATION SCENERIO

Although a CGI system can be tailored to match a variety of visual requirements, this paper relates to aircraft operations rather than other vehicles' use. We have, therefore, related our discussion to aircraft visual simulation.

The COMPUTROL visual system will present a CGI scene to the pilot which reproduces the outside world viewed through the windshield during ground handling, traffic pattern, and low-level maneuvers as well as high-altitude flight for both day and nighttime training.

With the exception of a flight data interface with the simulator host computer, the visual system is a self-contained digital image generator with bulk storage of specified geographical data bases. An off-line data base modeling capability is included.

The visual system will allow realistic training in all maneuvers, specifically:

Takeoff with critical engine failure.
ILS approach with engine failure.
Landing with engine failure.
Rejected landing.
Rejected takeoff.
Takeoff with crosswind.
Approach and landing with crosswind.
Instrument takeoff.
Nonprecision approach.

The visual scene will follow all motions computed by the simulator and, therefore, can visually reproduce any maneuver of which the simulator is capable.

DESIGN

The visual system covered by this paper consists of the following components:

Digital computer
Simulator interface
Image processing hardware
Cockpit displays
Gaming area/storage retrieval system
Support Equipment (SE) and Built-in Test
Gaming area modeling equipment

The visual computer consists of a special-purpose digital processor and related equipment. Insertion of a new gaming area into core requires less than ten seconds.

BASIC SYSTEM HARDWARE CONFIGURATION

The general configuration of the COMPUTROL system consists of essentially three components: Image Generator, Memory/Decoder Units, and Disc Storage Units.

The image generator performs in real-time all functions required to generate a perspective view from a compiled world whose unspecified parameters are derived from the user's input device or from another computer.

The memory/decoder units receive from the image generator the edges representing the selected two-dimensional projection of three-dimensional objects and buffers and decodes the edges for display on the monitor screen. One or more memory/decoders can be assigned to a color montior.

The disc storage units store the 3D definition of objects and surfaces comprising the data base gaming area. This representation of the real world is logically segmented into related object sets so that a "user" may roam through a world, not all of which can be held in the image generator's main memory at once.

The image generator consists of two parallel processors: the projection processor and the visible surface processor. Each processor consists of custom designed high-speed controllers and arithmetic units which communicate with a specially designed high-speed CPU and main memory.

CPU

Initially the architecture of the CPU was designed with the intent that image generation be accomplished utilizing a high-speed CPU in combination with a high-speed arithmetic unit. Further study, however, indicated, that by putting more of the image generation work into special-purpose subsystems, an enormous increase in speed could be realized. Thus, the major workload of image generation has been moved into the special-purpose subsystems and placed under the control of the CPU. Its high-speed architecture has been retained not only to provide the speed necessary to control the arithmetic and special circuitry, but also to provide the versatility for further system growth. This growth capability accommodates further research and development by permitting the simulation of additional features.

The ability to permit host computer functions to reside in the CPU may also be accomodated. This ability may be useful to permit stand-alone applications, to relieve the host computer of its workload, or even to provide look ahead computations to enhance image generator output.

The image generation capability of COMPUTROL will:

Display up to 30K edges in any single channel or throughout a wide angle FOV. Edges may be utilized to model point light sources, ellipsoidal surfaces, etc.

Provide up to 1,000 "X" intercepts/scanline. 2K, 3K, etc. intercepts may be handled by expansion of hardware buffer size.

Within the edge capability, provide for unlimited high resolution aircraft and/or ground vehicle images.

Display point light sources (10,000 min.)

Be limited only by the mass storage device for those portions of the world outside the FOV.

The COMPUTROL system is a special-purpose design and does not use general-purpose hardware other than standard peripheral equipment such as magnetic tape or disc units. The special design includes a CPU which may be utilized to facilitate implementation of new computational algorithms and to support further CGI development.

The attached data sheet illustrates COMPUTROL's image processing capability. These photographs have been taken from a standard 15" 525 line TV monitor that has been modified by increasing the bandwidth of the video amplifiers by a factor of five and the vertical

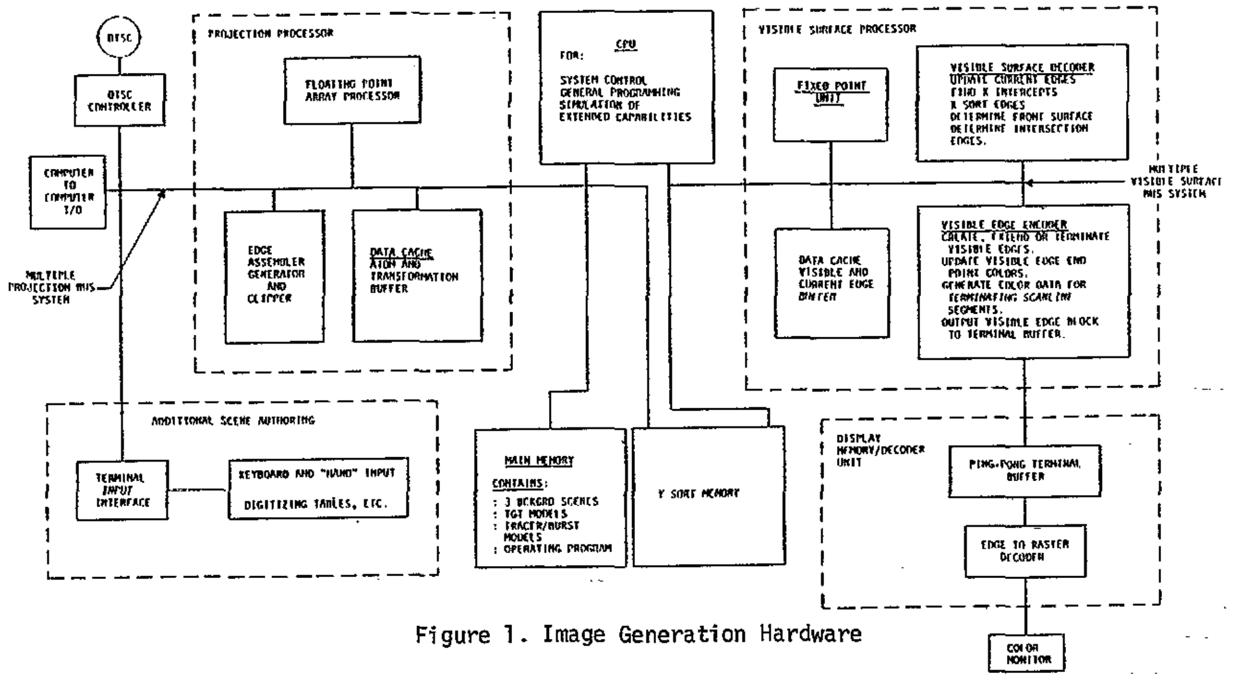

Figure 1. Image Generation Hardware

"resolution" to 1200 lines by a means of a 5:1 interlace.

Dulles terminal, as viewed from the cockpit window of a taxiing aircraft, consists of 2,162 edges.

The simulated view of a CONCORDE in the landing configuration consists of 910 edges. Color shading capability may be appreciated by a close examination of the fuselage. Motion of control surfaces (wheels, nose section, flaps, etc.) is updated in each new TV frame.

The dining room scene consists of 9,130 edges and is representative of the detail possible with the 16,000 edge early development system.

PHYSICAL CHARACTERISTICS

The CGI system, exclusive of displays and input terminal, is housed in a total of four vertical, joined cabinets suitably finished and covered. Cable access is from the rear and circuit board access is from the front.

One cabinet contains the wire-wrap logic boards for all CPU, processing, controller, cache, and interface functions required for the projection and visible surface image generators.

The second and third cabinet similar to the first houses main memory (MOS) mounted on PC cards, interconnected via edge connectors, mounted on a "mother board" chassis, and two dual-disc drives. Blowers and power displays are distributed in the fourth cabinet to support system requirements. A basic control panel is also included.

DISPLAY

The Cockpit Display System is mounted on the flight compartment/motion platform and produced a real-time, through the windshield color virtual image display. The system can include one or more high-resolution color monitors and associated infinity viewing optical systems.

The display monitor is a 1029 scan line RGB color monitor using a high-resolution shadow mask CRT such as the RCA 1908P22. The gun and phosphor design provides a brightness of 77 foot lamberts for 1 ma. of beam current. This is a high-resolution tube with 20 mils spacing between centers of adjacent triads. A very fine line width of 10 mils is obtained at a 40% amplitude level of the beam current density distribution curve for 200 micro amp per gun of anode current. It is the fine-beam spot capability of this CRT which permits full use to be made of the small triad spacing.

The selection of the RCA 1908P22 is based on its resolution, high brightness, availability, and the fact that this type has been successfully used on other beamsplitter, spherical mirror systems.

DETAILED DESIGN CAPABILITIES

COMPUTROL uses a numerically stored model and data of the real world to generate "out the window" visual scenes. All objects in the data base are modeled in three dimensions so that the observer can move about at will, throughout the playing area, with no restriction on movement, direction, altitude, or velocity.

Features of aircraft or other vehicles will be of sufficient detail to be visually identifiable at a range equal to the range in real life. As range decreases the motion of control surfaces will become visible. These surfaces will move as if they were actually controlling the motion of the aircraft.

The COMPUTROL is designed to interface with multiple terminals. The terminal screen will act as a window into a three-dimensional world containing representations of:

physical objects	symbols
graphic images	surfaces
physical events	

The representations in this 3D world may:

- be solid, liquid, or gas
- have any color, brightness, sheen, transparency
- have any shape
- be point light sources
- have any location, orientation, scaling, and magnification

All parameters in the definition of the world and all parameters in the specification of the "window" into that world may be dynamic in real-time. Allowed functions of time or of user input include:

- Polynomial functions, i.e. constant velocity, constant acceleration, etc.
- Analytical functions such as sine (kt), square root (kt), e^{kt}, log (kt), 1/log (kt), etc.
- Numerical functions
- Arbitrary space/time trajectories

Object/Objects interactions include:

- Illumination shading of object surfaces
- Collision dynamics (i.e., collision detection and conservation of momentum and energy)
- Object lock-on (i.e., two objects colliding will stick together during and

following trajectory -- useful when one of the objects is under the control of a hand or joystick input device)

Planar scalpeling and "window" clipping (i.e., selective cross-sectioning of subsets of objects)

IMAGE GENERATION

Scenes, as displayed on the CRT, are described by the edges of surfaces. The system has the capability of displaying 30,000 edges. A minimum of 10,000 colored point light sources are available for use in the night scene.

The surfaces can be planar, cylindrical, or spherical because of the system's ability to "smooth shade" curved surfaces. The *30,000 edges is a limitation* on display detail and not on gaming area complexity. There is virtually no limit to the number of edges in the gaming area data base. The computer system discards edges not visible by virtue of being out of the field of view of the pilot or ones describing hidden surfaces. Another feature of the system is the ability to select the sun angle. This will be evidenced by different sides of buildings, hills, etc. being in shadow.

As the pilot nears touchdown, his landing lights will illuminate the runway ahead of him exactly as in real life. The area illuminated by each light is computed separately to produce the correct presentation for any combination of lights being used.

The visual system will accurately depict the simulator's computer flight space with sufficient realism and definition to induce proper psychological motivation and provide capability for rigorous pilot training. It will operate with accuracy and response so as to preclude the possibility of perceptible disagreement between the visual display and other parts of the simulation, including any motion cues and instrument indications, over the entire range of specified operation. The system will permit the aircrew to determine attitude, altitude, relative attitude rates, and relative velocity by reference to terrain and horizon features in the same manner as in an actual aircraft under visual flight conditions.

Real world six-dimensional changes will be simulated in size and perspective realistically and accurately in real-time with respect to aircraft under visual flight conditions. The system will provide realistic visual simulation of the taxi, landing, and takeoff phases of flight as well as all flight maneuvers. All maneuvers will be visually current. The visual system will properly display attitude and flight path characteristics that are associated with sideslip and crabbing maneuvers during crosswind landings and general maneuvering flight.

The visual system will portray all scene landing in the field of view in their proper perspective. The scene elements will be displayed with respect to their modeled coordinates to within three arc-minutes positional accuracy as seen from the crewmember's seated position.

The visual system will track the simulator's computer flight position to within one-half foot and its computer flight attitude to within three arc-minutes for the duration of the flight. Any modeled point will be locatable to within one inch in the data base.

FUNCTIONAL OPERATION OF THE CGI SYSTEM

The author language is divided into an atom language, and an object/world language. The atom language permits the creation of "primitive" objects out of xyz data, such primitive objects being termed atoms. The object/world language permits the modification or building of more complex objects/worlds out of other objects and atoms.

Worlds, objects, and atoms, portions thereof and operations thereupon, may be given symbolic names (labels) for their construction and manipulation.

The basic library contains standard two- and three-dimensional atoms such as cubes, spheres, cylinders, wedges, circles, squares, and triangles. Special atoms are created for such items as an airplane aileron when it cannot be adequately represented by combining standard shapes. Once created, the atom is added to the library and is available for use wherever needed. The atoms are created in one or more of the following ways:

By polygon input method
By contour input method
From other sets of points by interactive and/or analytical techniques
By modification of another atom, its points, contours, etc.

Additional capabilities are techniques to warp, bend, and cut. Logical functions between atoms (volume common to two atoms defines a third atom, etc.) along with parametric specifications of an atom are also included.

Objects or worlds may be created by assembling them out of transformations of one or more objects or atoms. Allowable transformations on objects are:

Translation (move in xyz) Size scaling

Surface or point recoloring (the color within a surface is a liner interpolation from the color at the edges defining the surface)
Rotation (about xyz)

IMAGE HANDLING

An image is encoded by a set of edges. An edge is a real or imaginary line to the right of which is displayed a color. The data word which defines an edge contains such characteristics as color, hue, saturation, brightness, and magnitude in xyz space. There are many atoms which could be described, but let us explore the cube as an example.

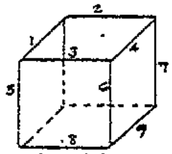

Figure 2.

A polygon of arbitrary shape and color is represented by these edges. Figure 2 depicts a perspective of a cube represented by nine edges. Because the color may vary lineraly along edges bounding the polygon and lineraly in x between edges, a polygon can also represent a portion of a curved surface. By means of these polygons, both flat and curved surfaces can be represented in any illumination environment.

When objects are occulted by other objects, new edges are created called "intersection edges." These intersection edges are created in real-time and do not reduce the basic 30K edge capability of the system. They are, therefore, not counted as additional visible edges.

We foresee that a later generation of COMPUTROL will provide the capability of computing 60K or 100K potentially visible object edges and displaying them in any single window or combination of windows throughout the FOV.

DATA INPUT

Data entry sequence is used by the modeler to create and manipulate descriptions of two- and three-dimensional objects and display real-time perspective views of these objects at his monitor. The major software components involved in managing the data are described below.

OPERATING SYSTEM

The monitor program handles all physical input/output requirements of the CGI software. These input/output devices include:

Visual display channels
Alphanumeric CGI and keyboard
Mass storage disc drives and controllers
Digitizing tablet
Card reader/punch
Operator's monitor
Printer Teletype
Link with the host computer

The mass storage discs are arranged into libraries and entries within libraries. A library is generally a logically related collection of entries such as object codes for programs, atom descriptions and compiler output listings to be printed or displayed via CRT, etc. Libraries and entries may be created, deleted, or modified either under program control or under user control via interactive commands. There is no restriction upon the number or size of libraries permitted other than the physical restriction of disc storage size. A library may contain either fixed-length data block entries for random access of variable length data.

Using the CGI system to advantage, the programmer may do such things as:

Delete an entry from a library
Delete an entire library from a disc
Copy an entry from one library to another
Copy a library of entries to another disc
Rename an entry or library
Merge two libraries together
Load a library from another medium, e.g. card reader
Copy an entry or entire library to another medium, e.g. card punch or printer
List the names of library entries, libraries on a disc or discs currently on the system.

TEXT EDITOR

The text editor allows a user to create, update and store text in a general form. Each collection of text is stored by name in a disc library and may be retrieved at any time for subsequent inspection or modification. While the text may be any arbitrary sequence of symbols in general, more specifically it will be used to contain the descriptions or atoms and objects created by a modeler. This text may be initially entered by using a keyboard and CRT terminal, by using a card reader as input or by using an interactive digitizing tablet program which generates text as its output. The modeler specified point coordinate locations and point linkages, with the program generating the modeling language statements as if the modeler had typed these statements directly. Thus, subsequent keyboard modifications to the data, such as the appending of comments of other features, are permitted, regardless of the original source of the input text.

ATOM COMPILER

The atom compiler processes a user's text description of the three-dimensional structure of an atom and generates an encoded description of the atom for subsequent processing by the image generator. The resultant compiler atom is stored by name in a disc library for later use in constructing objects. As delivered, the system library will contain a wide assortment of atoms reflecting geometric shapes and other special shapes encountered in modeling the data base. There is no limit imposed by the CGI hardware design on how many additional atoms and objects can be defined by the user. Optionally, a listing file is produced by the compiler containing the source input statements, a sorted cross-reference list of all mnemonic names used in the atom description text and error diagnostic messages if errors were encountered during compilation. This listing file may be examined on-line using the text editor, printed on a hard copy device, retained on disc for later reference or deleted from its listing library.

OBJECT COMPILER

The object compiler processes text describing a collection of previously defined atoms and objects and creates one or more new more complex objects from them. The input text identifies a set of atoms and objects by their names and specified such things as the color, size, and location of each with respect to the others. The resultant compiled object is stored by name in the specified disc library for subsequent viewing or use in constructing other objects. As with the atom compilation process, a listing may be produced by the object compiler.

WORLD COMPILER

The world compiler prepares a group of objects for processing by the image generator. A world consists of an object and a set of viewing parameters. The viewing parameters define such things as the color and brightness of the background area, the location and brightness of the sun and so forth. The world compiler is also responsible for segmenting large logically related sets of objects into "sub-worlds" and organizing linkages among these various sub-worlds so that a user may "roam" through the world, not all of which can be held in the image generator's main memory at once. The compilation process is in no way sensitive to the number of image generator channels to be used in displaying the world.

IMAGE GENERATOR CONTROL

The image generator control software controls the operation of the various image generation hardware units. It first performs parameter substitution of all numeric parameters of a given world which were left unspecified at compilation time. These parameters are supplied by the modeler's control devices or by the digital computation system, whichever is controlling the image generator. After parameter substitution, the resultant compiler world is treated as a command list which causes the image generator control program to command the individual special-purpose hardware units to transform the data list portion of the compiler world into a set of projected edges in the user's CRT screen domain. Finally, the projected edges are transformed into visible edges by commanding the arithmetic units of the visible surface processor.

The modeler user creates his world from atoms and objects as detailed in the preceeding paragraphs. He combines objects and atoms to make other objects and scenes. This is done in the coordinates of a "scratch" world so that he can monitor his progress without the distraction of other objects which might occult the object being worked on. When complete, the objects are given real world coordinates and orientation to place them properly in the playing area data base. It is also possible to remove any object from the data base to the scratch world for making modifications or corrects.

ATOM LIBRARY

The library of standard faces, objects, and models which comprise the atoms and objects of the ATS author language has been illustrated in Figure 3. The ability to generate new atoms and objects is only limited by the modeler's imagination. The various methods of constructing the basic shapes have already been described with illustrations of the variations possible shown in Figure 4.

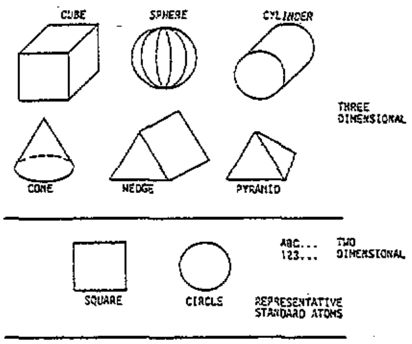

Figure 3.

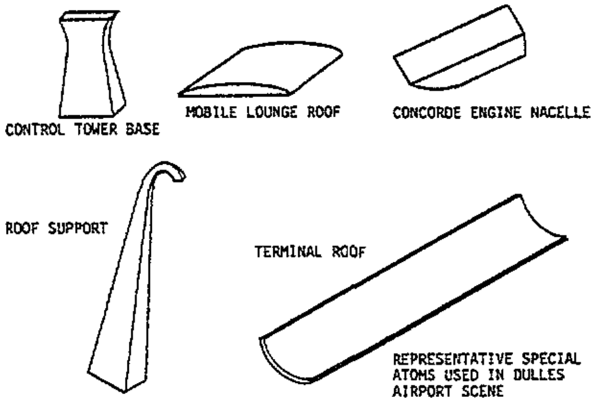

Figure 4.

These atoms were specially developed to conform to the real world atoms of the Dulles Airport complex.

In Figure 5 we model a car. A basic car "cube" atom has been extended and flattened to represent the car body. A similar atom is added to represent the top. Other modifications of the basic shape produces a car image with recognizable detail. The modifications may be refined until the car has the fidelity of an artist's rendering of a car.

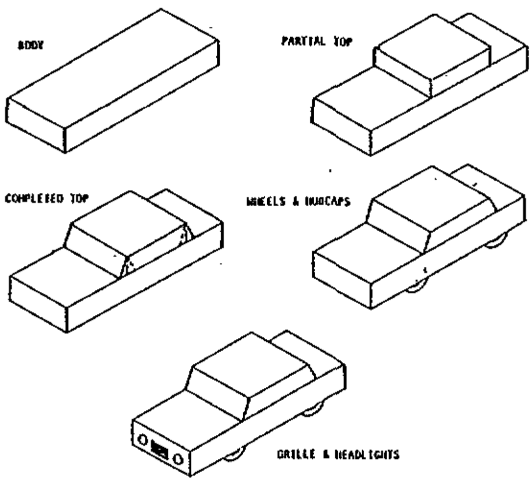

Figure 5.

TERRAIN GENERATION

We have discussed the users modeling of various objects. To place the objects into a "world" environment requires the modeling of terrain.

GENERAL TERRAIN

I/O equipment will be used to input raw data from constant elevation contours of topographical maps. Initial data reduction would be accomplished by techniques that monitor distances and radii of curvature between successive points along each contour. At this stage, color data can be introduced; a point that is not explicitly tagged with color data will be automatically assigned that color derived by interpolation as a function of its fractional distance between two points that are tagged with color information.

HIGH-RESOLUTION TERRAIN

For high-resolution (close up) modeling, the data would be passed through a software package that connects successive contours with triangular facets. The technique attempts to optimize the selection of the triangular facets by minimizing the volume of the resultant general polyhedron that is thus formed. There is no restriction that contour lines be convex.

MEDIUM-RESOLUTION TERRAIN

The same process can be used at lower resolution by further reducing the number of redundant data points along a contour and by considering fewer, more widely separated (in elevations) contours.

LOW-RESOLUTION TERRAIN

An alternative technique that could be used for relatively distant terrain would be to pass the initially reduced contour data through a software package that would perform a Fourier analysis of the surface; that is, a set of parameters would be generated that would permit the generation of a continuous analytical surface that approximates the original terrain surface. For lower resolutions, the higher Fourier coefficients would be excluded from the computation of the analytical surface.

HIGH-RESOLUTION DETAIL

The occurence of a significant geographical feature, such as an isolated mountain surrounded by relatively flat field, will be handled by creating them separately from the general terrain and placing them as objects in the gaming region.

LAKES

Lakes (regions of constant elevation) lend themselves nicely to the constant elevation contour technique since the shape of the lake should be independent of the surrounding higher elevation terrain.

PLACEMENTS OF OBJECTS ON TERRAIN

Software will permit the modeler automatically to place objects at (x.y.) positions on the terrain. This is particularly important, for example, for the automatic placement of a 2-D type of object such as a road or a river, on top of the faces of the terrain contour.

DESIRABLE FEATURES

OCCULTATION

For any given viewpoint, the CGI system will generate the appropriate perspective between overlapping surfaces. As conflicts between overlapping surfaces are resolved, intersection edges are created for display of proper occultation relationships.

COLOR

The CGI system generates image coded in nine bits for each of the red, green, and blue channels of the TV display. This corresponds to 512 intensity levels for any color. The data base is stored by specifying for each object its color in the visible spectrum.

CURVED OBJECT SIMULATIONS

The CGI system provides realistic curved object simulation by assigning color to vertices and lineraly varying the color between the vertices and along the scanline between edge intersection. Color interpolation solutions are performed in parallel with the decoding of edges and do not affect the linear geometric processing or display capability of the image generator.

PROGRAMMABLE FIELD OF VIEW

The field of view for each of the windows is completely programmable. Thus, for any given window the FOV need not be defined as that required to completely fill the window but instead can be that FOV defined by any portion of the window. This is possible since the window/clipping parameters are programmable and can be altered or varied as described.

SYSTEM OVERLOAD

Overloads, caused by excessive edge capacity in a computed scene, is eliminated by employing frame-to-frame coherence monitoring. This type of monitoring senses the number of visible edges in a scene and utilizes this number to cause logical simplifications of the world when overload conditions are approached. Thus, if the number of visible edges in the FOV approaches the limit during a frame solution, certain objects will be simplified to assure maintaining the edge count below the maximum capable of display by the system.

If, despite the logical detection and subsequent object simplification an overload does occur, the system design is such that the solution is completed while the last solution is used to refresh the display. With this approach, an overload will not cause picture disintegration, but will merely cause a momentary and slight delay. The frame-to-frame coherence will prevent this overload condition from persisting and of course will minimize the probability of its occurrence.

POINT LIGHTS

The CGI system permits the display of a minimum of 10,000 colored point light sources. Lights can be modeled whose intensity is constant or varies in accordance with slant range and time (blinking). There are no restrictions on placement.

PERSPECTIVE LIGHTS

Perspective lights are modeled individually by the author language. Several different types of perspective lights are possible including omnidirectional, such as taxiway lights and directional, such as VASI lights. In addition, a certain number of the perspective lights can be designated as light emitting. These will emit colored light with appropriate color mixing and surface absorption as observed in a real physical environment (a blue object illumined by a red light will appear black). The directional lights are modeled with hoods such that the cone of visibility may be specified.

AERIAL PERSPECTIVE

"Aerial perspective" is an important ingredient in any visual presentation. A certain amount of visibility limited haze or fog almost always exists, so that a scene without it lack realism. It provides an additional altitude cue by causing the horizon to seem lower as the point goes higher, and is a factor in his ability to judge the range of targets within the blanket of haze. *The fog blanket also provides a hiding place* for ground, or low-flying targets and so is essential in combat simulation situations.

The visibility restriction is simulated as a low-lying layer of haze, fog, or smoke. It is densest at ground level and thins out with height. The operator selects thickness of the layer as well as the density at ground level. The CGI system computes the visibility and observed color of each component of the data base as a function of the altitudes of the object and the observer, and the slant distance between them.

MOVING MODEL SIMULATION

The CGI system puts no limit on the number of items in the data base that can be dynamic. Likewise, there is no restriction on the degress of freedom of this motion. Any part of an object can be addressed separately so that incremental movements are also simple, that is, an aileron will move with the airplane but also rotates about its hinge line.

TEXTURE

To provide surfaces with a realistic textured appearance, it is necessary to display the texture pattern with the same perspective processing applied to object or polygon edges. There is, therefore, a need to obtain a perspective of each discernable "characteristic" of a texture pattern. It is appropriate that each "characteristic" be represented and processed so as to contain all the features inherent in edge representation (perspective, size, brightness, occultation, etc.)

CLOUDS

The CGI system provides for operator selection of cloud condition ranging from overcast to clear skies. The bottom of clouds can be placed at any height above ground level while cloud tops can be at any altitude above the bottoms.

Clouds are treated as objects and are able to be placed where needed and given appropriate motions, with appropriate shape and size functions of time. Solid cloud covers and scud clouds are, therefore, modeled in the data base.

SUN SIMULATION

The sun's glare and horizon glow is modeled by two-dimensional model at infinity. Since shading of all objects is computed at execution time, the location of the sun can be dynamic. It can thus be updated every "frame" along with its effects upon the shading of the world.

When the sun is masked by clouds, it results in a diffuse illumination of the world. This kind of light source, which is not truly directional, is handled by altering the brightness of fall-off function from an angle defining the direction of the light source and the direction of the surface. The fall-off function is a slower fall-off function than normally encountered with a point light source at infinity.

SUMMARY

In recent years, we have come to realize that physiological motion cues are but one part of a total simulation experience. It must be augmented by the "visual" cue which appears to have become accepted as the more important aspect of the two. In the past, we have seen a transition of Visual System techniques from Film Projection to Terrain Model Boards with current enthusiasm for Computer Generated Image Systems. In the competitive struggle for increased realism, the COMPUTROL Computer Generated Image System has come of age due to its ability to dynamically change scene content in real-time. Not only is there freedom of eye movement around a particular CGI model, but also the capability to effect a "complete" change of gaming area in reasonable time. The goal of our research and development efforts has been to incorporate current "chip" technology, resulting in a new computer design capable of high-speed data handling. The objective was to create a full-color raster scan simulation of a three-dimensional real world. We recognize that the product of our research and development efforts should match the following criteria.

- Resolution and fidelity of the final scene should closely equate to that of optical or high-quality film systems.
- Minimal power requirements for economical operation.
- Inherent capability to quickly change entire gaming areas.
- Gaming data size sufficient to permit extended flight simulation without reaching the limit of stored data.
- High-speed computation to permit dynamic movement of objects within the displayed scene, e.g. moving vehicle (land, sea, or airborne).
- System design sophistication to permit miniaturization of the entire system.
- Reasonable purchase price and cost of ownership. Affordable by a majority of customers.

We feel confident that our research efforts have met these seven basic criteria. A 16,000 edge full-color static demonstrator has been developed. Capability to generate high-definition pictures with variable sun angle, smooth shading, and the occultation of hidden surfaces has been proven. Occulting of objects through the visible edge solution guarantees nonbleed through of hidden lines. Another feature of the COMPUTROL,windows look like windows rather than holes in buildings. The transition to and from clouds is also much more convincing.

System architecture and special algorithms are used to permit the incorporation of texturing with respect to trees, grass, clouds, and water. The key ingredient of the system design is the "atom" philosophy of geometric forms used as building blocks for the total scene model. The basic forms are stretched, squashed, lengthened and/or added to other geometric forms to develop a particular scene. The modeling and use of atoms is performed in the off-line mode where there is the ability to generate and modify scenes as well as to edit and assemble programs. With the exception of flight data or any other vehicle interface which is resident within a simulator "host computer," the visual system is a self-contained digital image generator with bulk storage of specific geographic areas. The current design has the capability of displaying 30,000 edges. The surfaces can be planer or spherical due to the systems' ability to smooth-shade curved surfaces. There is virtually no limit to the number of edges that can be contained within the gaming area data base. The special-purpose CPU used with the image generation system has been especially developed to provide the computational speed necessary within the total system. Risk normally associated with a specially designed computer system has been substantially reduced due to the use of standard MOS chips and straight-forward computer architecture. The resulting CGI technology promises to set the standard for visual simulators for many years to come.

ABOUT THE AUTHORS

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