Computer Simulation of Electro-Optical Viewing Systems

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Electro-Optical Viewing Systems (EVS), including Forward-Looking Infrared and Low-Light-Level Television systems, are becoming increasingly important to the military for aerial navigation and targeting. Ground-based simulation of EVS displays is desirable for less costly training. This paper covers development of a software simulation model with adjustable computation parameters. This allows scenes to be made illustrating the effect of various sets of simulation system specifications. Feasibility of EVS simulation with current technology is demonstrated, and some results obtained from use of this model are discussed.

Introduction

PILOT training currently is accomplished using visual scene simulation provided by computer generation of images(CGI). Navigator training uses radar display simulation created by digital computation. Other sensor systems are used for flying, navigation, and target acquisition, primarily forward-looking infrared (FLIR) and low-light-level television (LLLTV) systems. Displays from these systems are in visual scene perspective but have transfer function and signal-to-noise considerations as encountered in radar displays. It is natural to consider applying to these systems the technologies used for visual and radar simulation.

In early 1974, the Human Resources Laboratory, Wright-Patterson Air Force Base, initiated a study program to investigate airborne electro-optical sensor simulation (AEOSS) and provide answers to many questions regarding such simulation.

Preliminary Considerations and Study Ground Rules

Electro-Optical Viewing Systems (EVS) simulation in a trainer must, of course, respond interactively in real time to the actions of the trainee. For this study, it was decided that the benefits of lower cost and far greater flexibility associated with a software model were more important than any benefits to be gained from real-time operation.

It is true that the dynamic effects of a given simulation frequently cannot be adequately evaluated from static scenes. However, a slow software model, in conjunction with time-lapse photography or time-lapse video recording, can generate sequences for viewing and evaluation in real time.

As an additional ground rule, it was specified that the programming, to the maximum extent possible, be in FORTRAN to enhance flexibility and facilitate the use of the resulting model on different computers.

Sensor System Characteristics

Figure 1 is a photograph of a FLIR sensor viewing one of the target areas to be simulated; an oil storage area near Eglin AFB. The combined optical and electronic transfer function is evidenced by the fuzzy nature of the boundaries separating features of different tones. The noise is apparent; this tends to be a function of the sensitivity setting of the system. The horizontal-stripe pattern which seems to overlay the scene is caused by the fact that this specific FLIR system scans with groups of infrared sensors, and when their sensitivities are not perfectly matched, such an effect results. A striking illustration of one difference between an infrared sensor system and visual or television systems is shown by the indication of oil level inside the tanks on this scene.

Figure 2 is an LLLTV display of the missile complex, another of the designated target areas for this study. It exhibits in varying degree the same general characteristics as the FLIR display, with the exception of the variable sensor sensitivity effect. There is no physical basis for this effect in the television system. Thus, a single software simulation model, with provision for varying transfer function, noise, atmospheric effects, etc., by inputting appropriate computational parameters, should validly simulate both types of sensor systems.

Figure 3 is a scene from a visual display CGI system. It is spatially equivalent to the AEOSS simulations required, but is sharp and noise free. Figure 4 is from a radar display simulation. It is not a perspective, but the effect of transfer function (pulse-width and beam-width effects) and of noise is seen to be similar to the AEOSS effects. This illustrates the technologies that, when combined, simulate the required sensor system characteristics.

Simulation Model Requirements

The fundamental requirements are quite simply stated. The software simulation model must work from a numerical description of all pertinent characteristics of the environment which the simulated sensor system is to be scanning. It must perform all computations necessary to result in a display reproducing the characteristics, to the degree possible with the level of detail in the defined environment, of the actual sensor

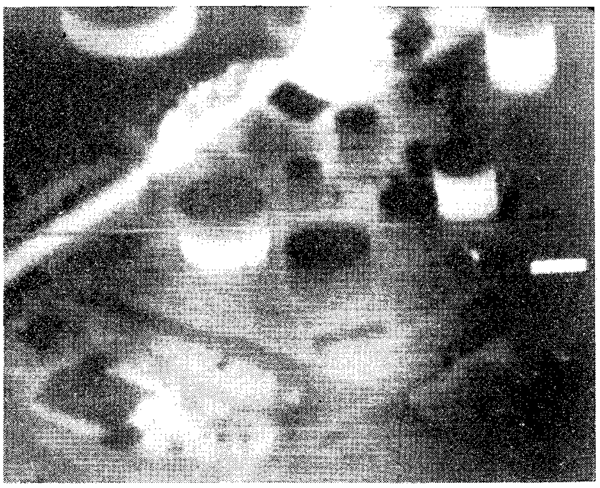

Fig. 1 FLIR display of oil storage area.

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Fig. 2 LLLTV display of missile complex.

system. It is desirable that it do this for a wide range of processing parameters to simulate different control settings and completely different systems. Furthermore, with the real-time hardware in mind, it should demonstrate the capability of producing scenes, for any viewpoint, attitude, flight path, field-of-view settings, etc., with no glitches, blinking, or other effects that would detract from the illusion of realism in a training system.

Spatial

The spatial transformations involved in both FLIR and LLLTV are identical to those in earlier use of CGI for visual scene simulation. For each vertex in the environment, a translation and a rotation transform it to station point coordinates – a coordinate system with origin at the sensor location and with attitude aligned with the sensor system boresight and scan orientation.

Following this, determination of tangents of verical and horizontal components of the angle between the vertex vector and normal to the view window (the u axis of the u, v, w station point coordinate system) locates the image of the vertex on the display device.

In an operational system, there are many complicating factors. Some vertices are behind the viewer or sensor system. Some have infinite tangents. Edges and faces must be truncated at the boundary of the display – for faces, this requires generation of the new "pseudo" edges. Quantization effects represent spatial distortion and detract from realism unless properly handled. Transfer function involves the spatial relationship between the environment and the display.

Priority relationships, where one object partially or entirely obscures another, must be handled by the spatial transformation system.

With the exception of the transfer function area, all items above have been fully analyzed and effective algorithms developed previously for visual scene simulation. These were applied directly to AEOSS, along with transfer function implementation developed as part of this task.

Tonal

The tonal processing part of the system must accept an environment defined with any set of tonal values; it must process them based on any set of sensor system control settings, and it must produce a display such as would be produced by the actual system.

It is required that the simulation model produce scenes representative of both day and night operation. Each feature has associated with it in the data base both the night tonal value, and the day tonal value. As each is being made, a day/night factor can be specified, ranging from full day to full night. The simulation uses this as a proportionality factor in generating the scene, thus approximating tonal values that occur in actual day-to-night transition. In sequences with gradual change from day-to-night, many pairs of tonal values can be seen to blend and then reverse order of brightness.

Transfer Function and Noise

Transfer functions, not present in visual scene simulation, are associated with LLLTV and FLIR systems. For any system, the actual transfer function is a combination of the optical and the electronic transfer functions. The simulation must, of course, handle the combined transfer function.

Assume that a system is set to a 3×4-deg field of view, and the display is being computed by the simulation system as 480 scan lines of 640 elements each, as on this project. Thus, a single computed display element is approximately 0.37 arc-min square. Now assume the transfer function is two-dimensional Gaussian with dimensions of significant return of 2.5 arc-min by 1.85 arc-min. The brightness of this single element, in the actual sensor system, is thus a weighted sum of actual scene brightness corresponding to an array of seven elements by five elements surrounding it.

If the simulation model is programmed so that the tone of each element can be determined as a weighted sum of computed tones of it and surrounding elements, with no constraints on the setting of the weights, then any transfer function can be simulated. This technique also facilitates evaluation of the results of less exact simulation that might be considered if it promises to reduce hardware cost with imperceptible effect on the resulting simulated displays.

Noise is added, just as with radar simulation, by use of a pseudorandom noise generator. Noise can be varied from zero to any percent desired.

Atmospheric Effects

The effect of atmospheric fog and haze is to reduce contrast as a function of the distance through the fog between the observer or sensor system and the object. Furthermore, at great distances, the view contains only the color of the fog itself, and this may be variable.

The combination of the above effects is contained in the following statement. All tones change from their assigned tones toward the fog tone as a function of the distance through the fog between the sensor or observer and the object. Atmospheric effects for visual scene simulation have been implemented in this manner, with extremely realistic results.

The "function of distance" for visual effects is a negative exponential, $F = e^{-kd}$, where d is distance. The same physics and mathematics define the effect for LLLTV and FLIR as for visuals. The value of k for a given atmospheric configuration will differ for different systems.

The goal of complete flexibility and lack of constraints that guided this development effort requires that the operator be able to independently specify fog tone and the coefficient k. Fog tone is directly specified on the same 0 to 255 scale used for other tones. In visual work, it has been found more meaningful to allow the investigator to specify the distance of 50% contrast reduction, rather than k itself. The program then determines k. It is therefore handled in this manner in this simulation.

Function Categories

Implementation of the simulation model involves performing a sequence of functions. First are the off-line, or modeling, steps that involve the definition of the features to form the environment and its formating as required by the on-line functions. The on-line functions then use this environment data base to form scenes as required by the mission or exercise. The scenes may be from any number of different viewpoints and may involve variation in defined atmospheric effects, illumination conditions, day/night and processing parameters such as transfer function, noise, simulated gain, and brightness adjustment.

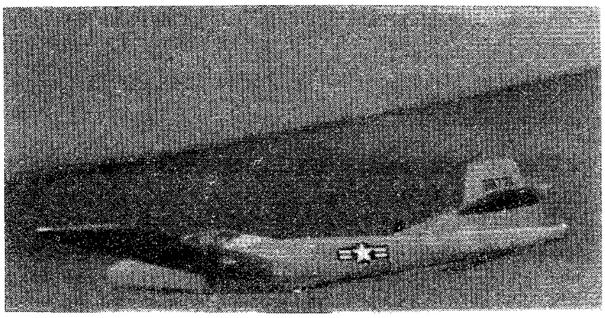

Fig. 3 CGI visual scene simulation.

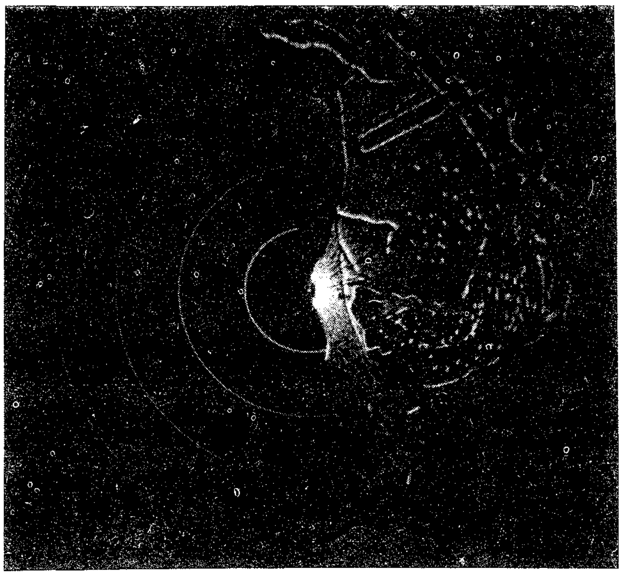

Fig. 4 Radar display simulation.

It is also useful to categorize functions as to whether they are performed once per scene update (30 to 60/sec in real-time systems), once per raster scan line (32 to 64 μsec), or once per picture element (25 to 100 nsec).

The following more detailed discussion will cover the functions as they are organized in the AEOSS software simulation model.

Environment Definition (Modeling)

The data base from which the on-line programs work in scene generation consists of the following information.

Spatial

This data defines the location of each vertex of the environment, and the topological information covering pairs of vertices which form edges, edges which form faces, and sets of faces which form objects. For objects that are to be shown as continuously curved rather than made of flat faces, vertex normals are also included. For each vertex, the vertex normal is a vector normal to the actual smooth continuous surface being approximated at that point.

Tonal

Four tones are defined for each face of the environment; day-bright, day-dark, night-bright, and night-dark. At the cost of very moderate increase in storage space and processing, this provides a very flexible capability. Day-bright is assigned to a face if full day is called for, with the illumination vector defined as full strength, and pointed directly toward the face. Day-dark applies if it is pointed directly away from the face. The dot product of the illumination direction vector with the normal to a face or vertex gives the angle cosine that is used to determine tones for other angles. Similar considerations apply regarding night illumination. For day-night factor other than "1" (full day) or "0" (full night), a proportional mix is assigned to the face.

The flexibility of the above scheme can be illustrated by considering its use to cover several cases. Assume there are two adjacent faces, one being quite hot by day and cold at night, the second being the same temperature day and night. A house with no insulation on the sides might approximate this. The sides will be essentially the interior temperature day and night, the roof will be heated by day and cooled by radiation to the sky at night. In actual system use, gain and brightness adjustments spread the actual temperature range across the display device brightness range. Thus, by day the roof would be white, and the walls black. By night, the walls will be white, and the roof black. The effect of the control adjustment can be incorporated in the simulation by giving the walls a brighter tone in their night definition, even though their actual temperature is the same.

For further illustration, consider a structure with thermal characteristics such that its temperature is independent of illumination direction. By giving its faces the same tone for day-bright and day-dark, they are handled in the proper manner in scene generation.

Priority

This includes the centroids of groups and separation plane set definitions for objects and groups of objects which cannot be handled on a distance-to-centroid basis.

The environment is defined in two data bases, the Extended Data Base (EDB), containing the spatial and tonal definition, and Priority Information File (PRIF), containing the priority system definition.

Modeling

The Object Compiler consists of software that the modeler can think of as comprising a library of models from which he can form the desired environment. If a hip-roof building of a certain size is to be at a specified location, the proper page of the model book contains information on how to specify the desired characteristics; the software then takes this human-oriented input information and forms the machine-oriented definition of the building.

No matter how complete such a model book may be, there will arise cases in which structures are to be modeled that have not yet been covered. It would be burdensome for the modeler in such cases to have to compute and format the model in machine format. The software therefore includes provision for the modeler to provide minimum data defining the desired structure (necessarily more than for something covered in the model book, of course), and the software takes it from there.

When an environment is defined, it constitutes an artificial world in which any number of missions may be flown, with the on-line functions generating one scene at a time.

Scene Generation – On-Line Functions

The programs performing the on-line functions will now be discussed in general terms, concentrating on input and output and the flow of information, to give an overview of the entire sequence. For each program, a conceptual distinction will be made between the "data" used by the program, which may be unchanged for a number of runs or be received from prior processing, and the "directions," which are supplied by the operator to control the processing to meet the objectives of a given run or group of runs.

Figure 5 (on-line processing flow summary) shows the sequence of programs and the information flow that converts the environment definition to the simulated display.

Illumination Effects

Program DATBAS forms the Scene Data Base (SDB) from the complete environment definition and data-defining

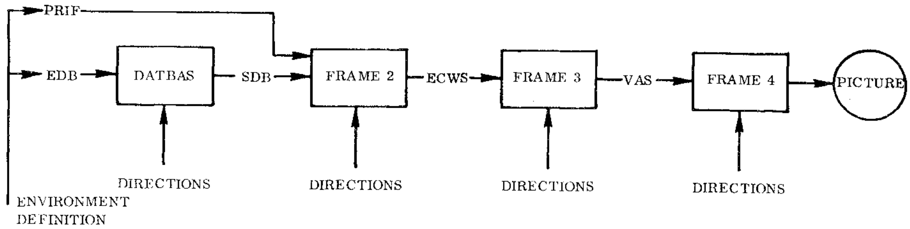

Fig. 5 On-line processing flow summary.

illumination conditions to be simulated. It is run only when these illumination conditions are to be changed, or if it is desired to evaluate the effect on a given scene of using or not using the curvature simulation.

In considering hardware, if illumination conditions are to be changed smoothly during the course of a mission, the functions of DATBAS would have to be designed as on-line functions. If, once illumination is set to the desired conditions for an exercise, it is left unchanged while the mission is flown, then the DATBAS functions will be handled as off-line functions. Hardware systems for CGI have been configured both ways. Although the cost of making the DATBAS functions on-line in hardware is not great, its justification is still dependent on the need for these functions in the intended use of the equipment.

Frame 2

The Frame 2 functions must be performed each time the viewpoint location changes or view window attitude changes; hence, they are without question on-line functions. Frame 2 processing is applied to each feature in the environment once for each scene to be generated. In the course of its processing, it transforms an unbounded three-dimensional definition of the environment, and a definition of the view window, to a bounded two-dimensional definition of the specific scene, in the form of a set of edge control words (ECW's). In addition, it performs part of the processing necessary for atmospheric effects simulation.

The processing following this point will in general be applied to each portion of the environment each scan-line time. It is thus important to reduce as much as possible the information that must be so processed. The number of bits of precision required by the hardware in the high-speed processing is minimized by the Frame 2 processing to truncate all edges and faces at the view window boundaries. Features behind the sensor or entirely outside the view window are deleted in Frame 2. Hidden faces, those completely obscured by other faces of their object, are eliminated by a simple test in Frame 2. The result at the Frame 2 output is the minimum information, in a highly preprocessed form, necssary to generate the display.

In addition to the spatial and tonal processing functions discussed above, Frame 2 forms the priority list for the current viewpoint. In the event that two or more objects conflict at any portion of the display, the object with the lowest priority number has priority over, and obscures, the others.

The Frame 2 functions discussed above correspond exactly to the functions performed in this portion of hardware in the configuration providing minimum cost for real-time simulation.

Frame 3

In Visual Scene Simulation hardware, the output of Frame 3 is the video to form the display. Visual scenes involve no noise, no transfer function simulation, and no simulation of gain and brightness adjustments. These are additional requirements to validly simulate LLLTV and FLIR. In the AEOSS model, the Frame 3 functions programmed end just prior to actual video formation, with scene definition for each scan line reduced to a maximum compressed one-dimensional form, in an array called the Video Assembler (VAS). The

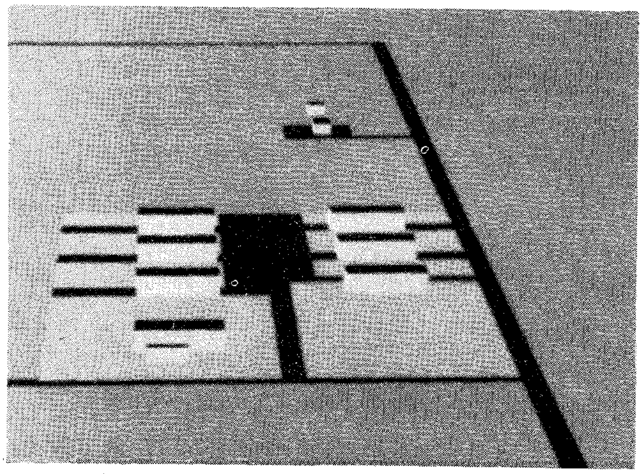

Fig. 6 Missile complex model – visual processing.

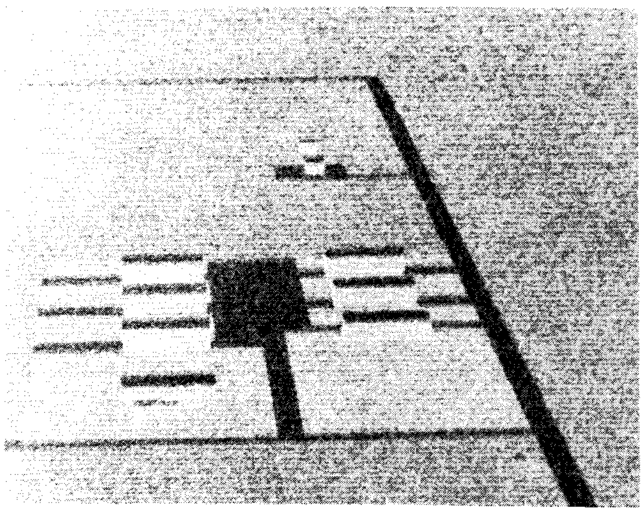

Fig. 7 Missile complex model, FLIR display simulation.

subsequent functions, to add the effects required for airborne electro-optical systems, are performed in Frame 4, which also forms the video.

The video assembler for a given scan line consists of an ordered listing, each entry consiting of an element number, a tone, and a tonal gradient. Video is generated by using the tone listed for the element listed, then incrementing the tone by the gradient for each subsequent element. When the video formed in this manner is used to generate a scene, it will be a valid simulation of a visual scene, with curvature effects and atmospheric effects included.

The programs are set up so that processing of a number of scenes through Frame 3 can be done, with the video assembler output for the sequence of scenes stored on tape. Frame 4 can then work solely from the contents of this tape and can produce displays of the sequence of scenes. In this manner, sequential scenes can be shown more rapidly.

Now, speaking generally, it can be said the Frame 2 converted from three dimensions to two, and Frame 3 converted from two dimensions to a set of one-dimensional scan lines.

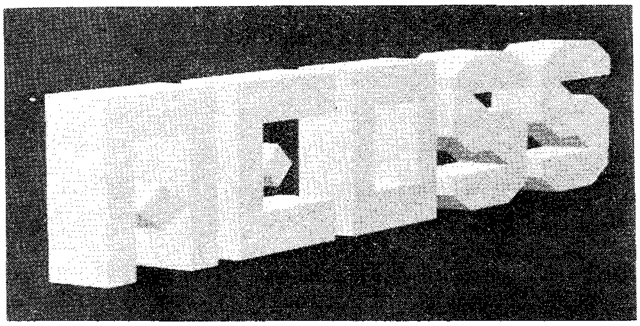

Fig. 8 AEOSS without noise.

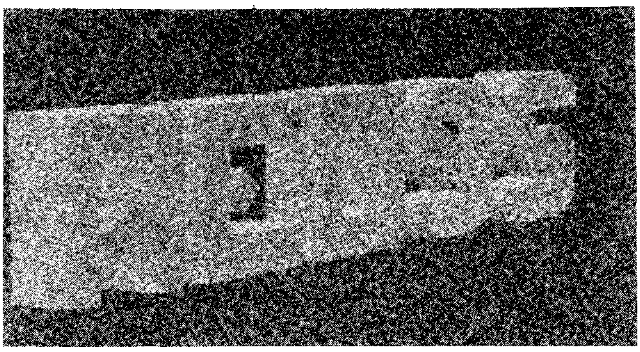

Fig. 9 AEOSS with 70% noise.

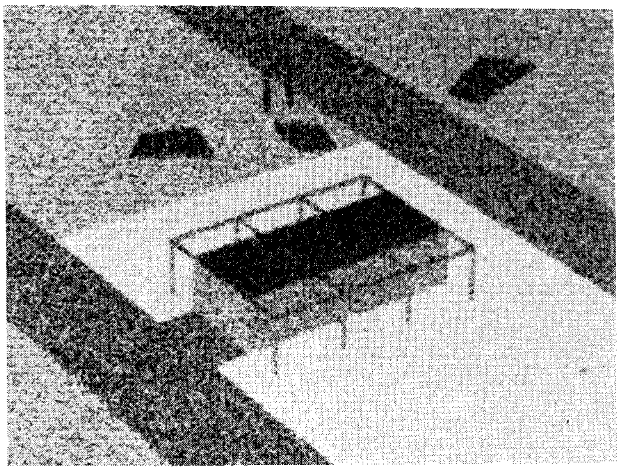

Fig. 10 Gaussian transfer function.

Frame 4

The operator-supplied directions to the Frame 4 functions "tune" the model to the specific system to be simulated and to the control settings for that system. Transfer Function Definition allows the operator to specify the array, and the weight of each member of the array, for use in simulating system optical and electronic transfer function. This can range from visual scene simulation, to very blurred scenes.

Sensor Sensitivity Pattern allows simulation of the effect sometimes noted on FLIR simulation, where a group of sensors scan a group of lines of the scene, and they do not have matched sensitivity. Here, again, the operator can provide an arbitrary set of sensor sensitivity number. Scene noise characteristics can be set by the operator as a percentage of noise to be added to the computed signal level. Noise is added following transfer function computation to most closely simulate the situation in actual systems.

Gain and brightness simulation also allows complete flexibility. They could readily be set, for example, so that the upper half of the scene brightness range all becomes full white with the lower half spread over the display brightness range. Display quantization simulation allows the video, after full computation including noise, to be truncated to a desired number of bits. It is computed to 8-bit precision, corresponding to the 256 shade-of-gray Image Recorder on which scenes are made. Truncating to fewer bits prior to sending video to the Image Recorder simulates the results of using display systems with coarser quantization.

Results – Illustration and Discussion

Transfer Function, Noise, and Sensor Sensitivity

Figure 6 shows some roads, buildings, and pads of the missile complex. It is a simplified model – no scaffolding or ground texture is included. It is shown as the scene would be produced for visual simulation. Figure 7 shows the same scene, but with parameters adjusted to simulate a FLIR display. A two-dimensional Gaussian transfer function is simulated. The tone of each element is determined as the weighted sum of a group of 25 elements with it in the center. The pattern of weights is as follows:

3	3	3	3	3
3	4	7	4	3
3	7	8	7	3
3	4	7	4	3
3	3	3	3	3

Random noise is set at 25%, and a sensor sensitivity pattern, eight sensors deep, is simulated. The sensitivity pattern producing the figure is 70%, 75%, 100%, 85%, 70%, 95%, 100%, 95%. Although the threshholding effect, producing the pure blacks and pure whites, is not included on this scene, it is instructive to compare the transition from the top to the front of a building with the similar transition on an actual scene (Fig. 1).

Transfer function simulation involves significant computing time in the software simulation and can be expected to involve significant hardware in a real-time simulation. The question might arise: Suppose noise alone is used, without transfer function simulation – might the results be sufficiently valid for training? The whole purpose of this versatile software simulation model is to provide evaluation scenes to help in answering such questions. The following is an example of such use.

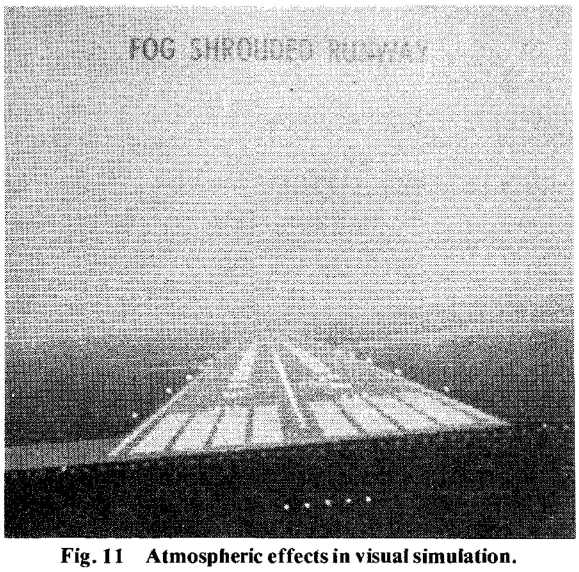

Fig. 11 Atmospheric effects in visual simulation.

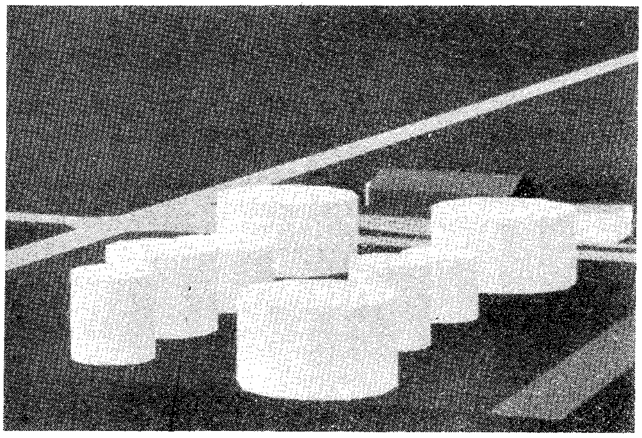

Fig. 12 Oil storage tanks without curvature.

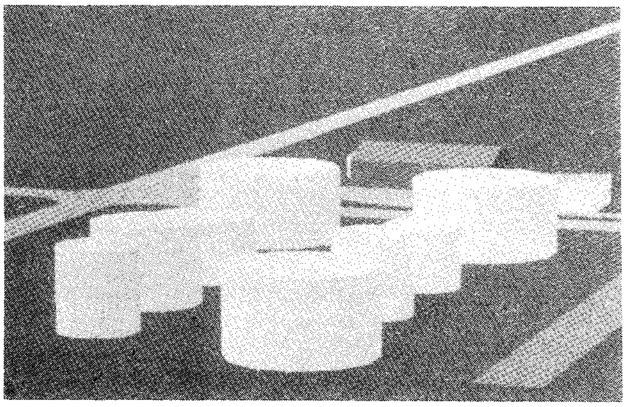

Fig. 13 Oil storage tanks with curvature.

Figure 8 shows "AEOSS" modeled with solid objects. The tones are handled as for LLLTV with illumination from the upper left. Figure 9 shows the same scene with 70% noise. Even with this amount of noise, the fuzziness characteristic of the transfer function is not present.

One might next consider using a less exact approximation of transfer function to reduce hardware cost. Suppose that instead of the weights giving the Gaussian approximation, we use uniform weighting of elements in the 5×5 array. This could be expected to simplify hardware. How would it affect the simulation results? We have the tool to answer this question.

Figure 10 shows a single building in the missile complex, with roads, a sign, and limited ground texture. The transfer function parameters are the same as for Fig. 7. The same scene was made using the uniform distribution. There is no discernible difference, even when large photographs of the two are viewed side by side. It might be noted that this result was not unexpected, since very similar investigations have been made in connection with simulation of radar transfer function.

Atmospheric Effects

Figure 11 shows atmospheric effects in a visual scene simulation. The AEOSS incorporated exactly the same algorithm. Since past work has demonstrated the full validity of the concept, no extensive investigation was made of the results.

Curvature Simulation

Figure 12 shows the planar-segment approximation of the cylindrical tanks in the oil storage target area. Figure 13 is made from the same spatial definition but with the curvature algorithm applied. As in the case of atmospheric effects, the results of this technique were known in advance due to its application to visual scene simulation.

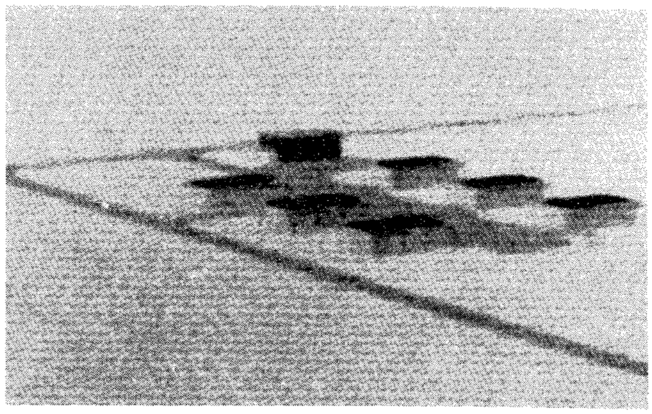

Fig. 14 Start of fly-in toward missile complex.

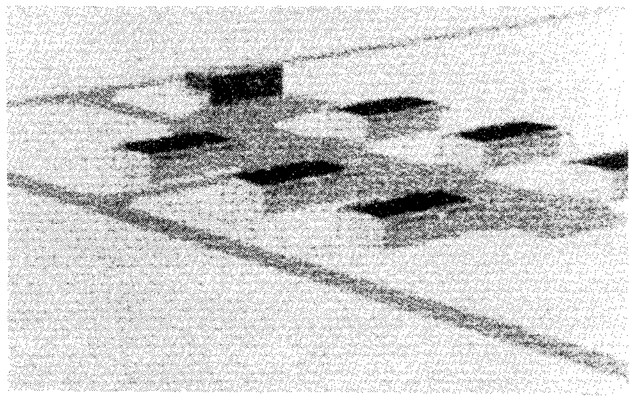

Fig. 15 Mid-range on fly-in.

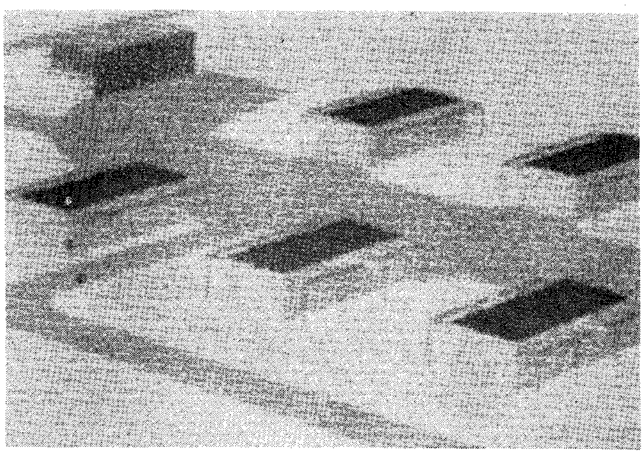

Fig. 16 Close range on fly-in.

Fly-In

Figures 14-16 show three views of a flight toward the missile complex. Of particular interest is the manner in which the scaffolding detail gradually becomes clear with decreasing distance.

Summary

The goal of this simulation was to produce a software model that would validly simulate the effects associated with airborne electro-optical systems and that would have variable parameters to simulate any of a number of such systems with a variety of operating conditions and control settings. Since the effort is directed toward eventual real-time simulation hardware for training, it was important that the simulation produce results that could be duplicated with feasible hardware and that it be possible to vary results to match prospective hardware specification variation to produce scenes for evaluation. The discussions and sample scenes of this section demonstrate that this goal has been met.

Current Status

The software simulation model covered above is currently in use performing its intended function as a research tool at the WPAFB Human Resources Laboratory. The HRL personnel are preparing data bases representing portions of Las Vegas, Nevada, as digitized on the Air Force 1183 program. Operational parameters are selected, a flight path is determined, and scenes are produced for evaluation.

Acknowledgment

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