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Digital Sensor Simulation

Radar scenes were simulated utilizing digital culture and terrain data bases and specialized computer software.

ABSTRACT: *Project SENSE (Sensor Simulation Experiment) is designed to analyze the effectiveness of digital culture and terrain data bases generated at the Defense Mapping Agency Aerospace Center for the simulation of various types of sensor systems. Although most of the initial effort dealt with digital radar simulation, other sensors such as microwave radiation, forward looking infrared (FLIR), and low light level television (LLLTV) are being investigated.*

The simulation software to support this analysis consists of three general sections. The first segment searches the data bases to construct a perspective view of the area for removal of hidden objects. Studies are underway to determine optimal sampling steps. The next segment mathematically models the emission and interaction of the radiation with the data bases, the sensor receiving unit, and the sensor display response. This section is modular to accommodate any type of sensor. The third segment of the software improves the simulated display via image processing techniques and buffers the output image to the appropriate unit for display.

Parameters affecting radar simulations and comparisons of actual and simulated scenes are presented.

INTRODUCTION

THIS PAPER describes the physical models used and examples simulated with the digital radar simulation computer software developed at the Defense Mapping Agency Aerospace Center. Although the software was written to support the Digital Radar Landmass Simulator (DRLMS) program for the F-111A training simulators, the program is generalized for a wide variety of radar simulation problems. In addition, the program is modular to accept mathematical models for other types of sensors. The primary objective of the sensor simulation experiments is to establish an editing capability for the data bases prepared at DMAAC. The software, therefore, was written from the viewpoint of utilizing the sensor required information contained in the data bases, rather than as a real-time simulator.

The simulations require two input data bases, with both data bases registered in an array format. The first data base contains terrain height information at evenly spaced intervals. The second data base represents the culture, or radar reflectivity potential, over the corresponding terrain. Cultural heights may be added to the terrain height data base, and the reflectivity potential may be defined to be uni-, bi-, or omni- directional. A perspective view of the data base is generated wherein the brightness returns are a function of sensor parameters, reflectivity potential, and aspect angles to the terrain. This perspective view removes all hidden features. Atmospheric and receiver variation parameters are also applied. This image is then transformed into a range-azimuth display with additional radar effects added. Throughout the processing, special noise removal

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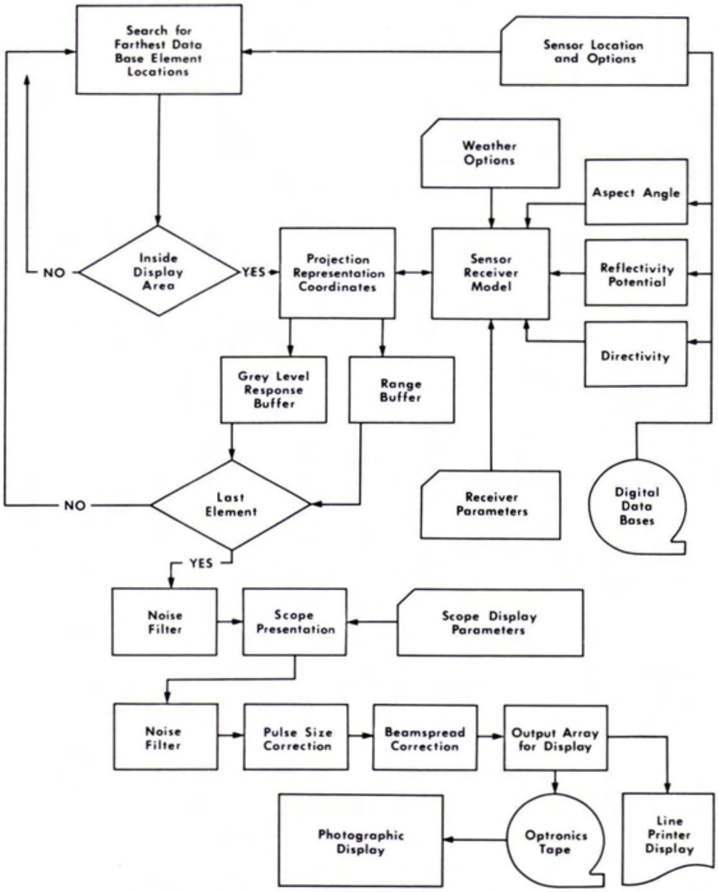

FIG. 1. Sensor simulation program flow chart.

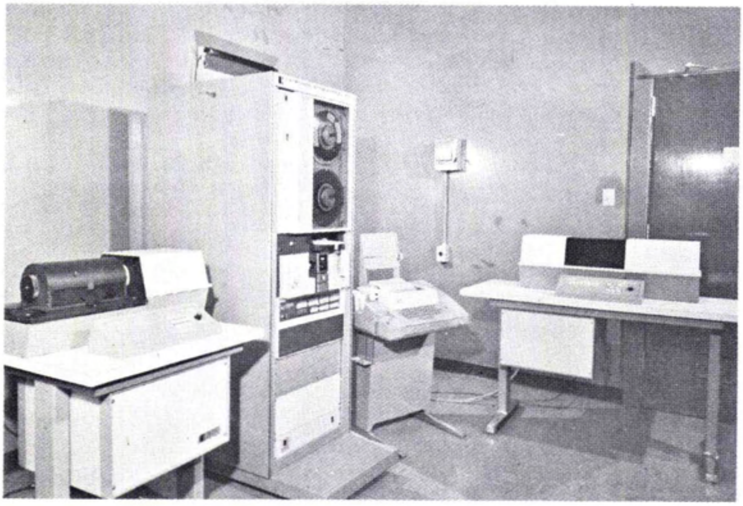

FIG. 2. Optronics SDR equipment.

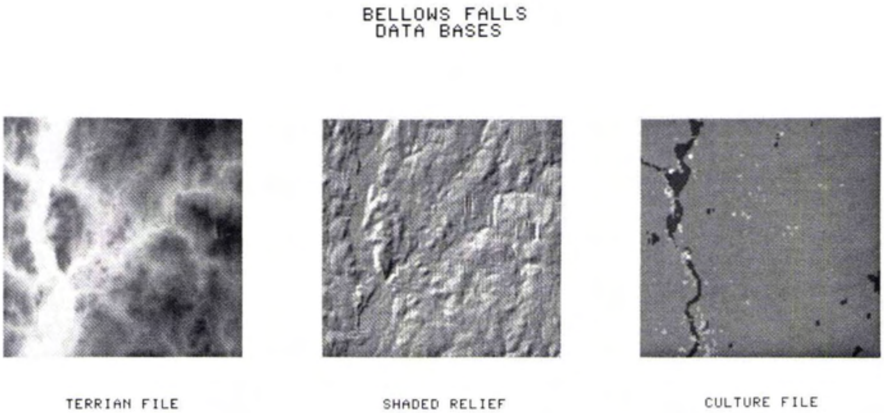

FIG. 3. Bellows Falls data bases.

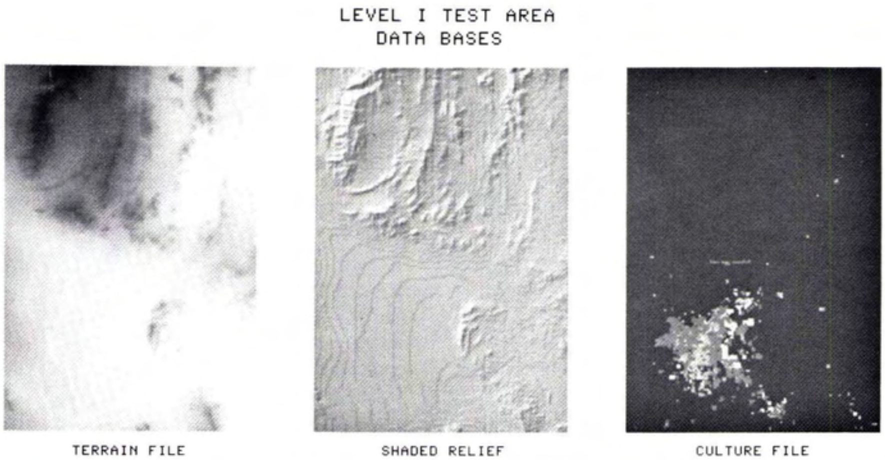

FIG. 4a. Las Vegas data bases.

FIG. 4b. Projection options.

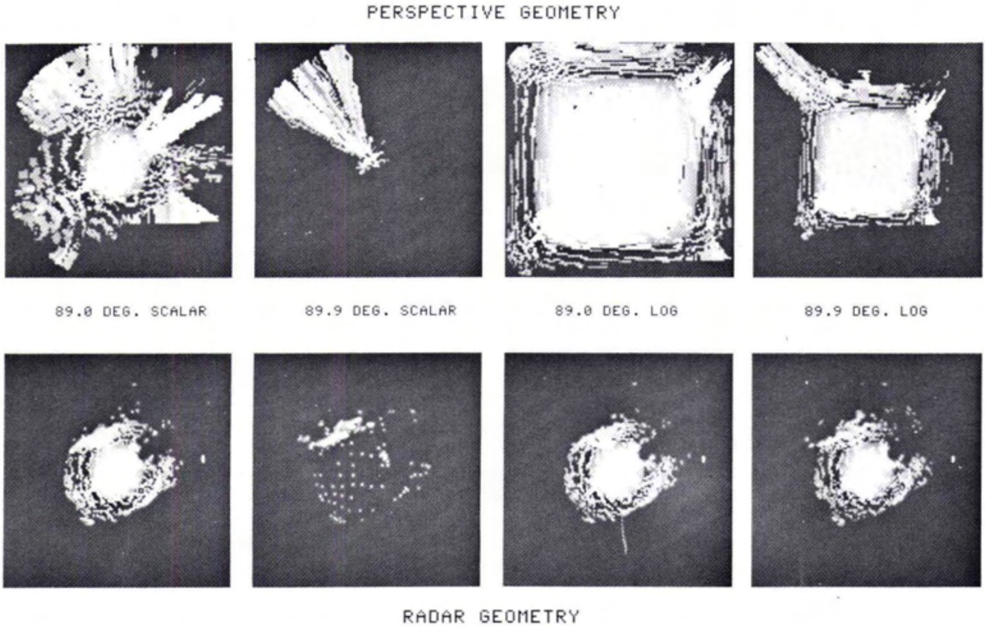

FIG. 5. Logarithmic versus scaler lens projection.

subroutines are used to improve the simulated imagery.

SIMULATION DISCUSSION

The general scenario in the scene simulation program is first to generate some type of projection of the scenes in order to remove hidden areas, and then to transform the projection to the geometry of the sensor display. Figure 1 gives a general flow diagram of the software. The program is written for the UNIVAC 1108 computer, and the photographic displays are generated on the OPTRONICS Scanning, Digitizing, and Reimaging System (see Figure 2).

Data bases of two geographic areas were used to prepare examples contained in this paper. The first is a 10 mile-by-10 mile area around Bellows Falls, Vermont. The elevation and cultural data bases for this area are matrix arrays of topographic heights and radar reflectivity potentials at 400 foot intervals with topographic heights quantized every 25 feet. Figure 3 is a density portrayal of these data bases where gray levels are coded such that the highest elevations are the darkest and the greatest reflectivity potentials are the brightest (a shaded relief presentation is also included in the figure). The second area surrounds Las Vegas, Nevada and is about 30 nautical miles by 40 nautical miles. The horizontal sampling interval for this data base is 200 metres with 35 foot height quantization. This data base is shown in Figure 4a.

Figure 4b shows the three types of projections used—planar perspective, spherical or "fish-eye", and logarithmic. The planar and spherical projections are common, but the logarithmic projection was developed to handle low altitude simulations. Consider Figure 5. This series of simulations is at low altitude over Las Vegas. The optical perspective shows the mountains slanting away from the observation point. The 89 degree field-of-view, however, is not wide enough to "see" over the top of one of the ranges. At 89°.9, another ridge appears, but the scale of the picture is reduced trigonometrically, and there is not sufficient data to transform the perspective view to a suitable radar scene. With a logarithmic projection, however, distances are broken into cycles. The 89°.9 view retains much of the 89 degree view data, and the radar scene contains most of the information obtained in both of the planar porjections. At higher altitudes, the logarithmic projection is disadvantageous. Limiting values for using this projection are currently being determined.

The projected view is generated by computing the projected coordinates of each data base element in view by the sensor, and then storing the representation of that element in

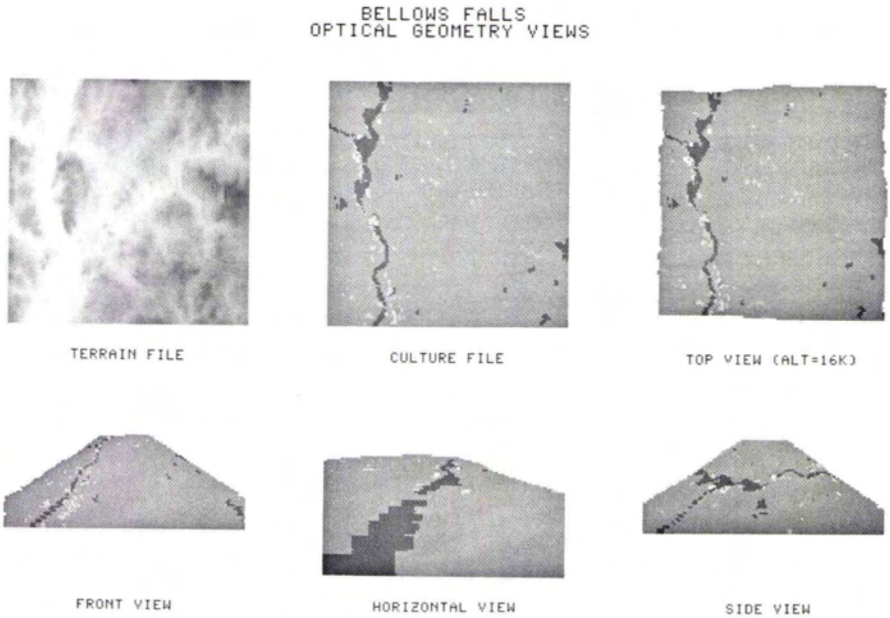

FIG. 6. Optical projections.

an output array buffer. The gray level stored for each element reflects the sensor response due to the element. The farthest elements from the nadir point of the sensor are investigated at first, and as closer elements are over-stored in the output array, all hidden areas are removed (Faintich, 1974). The software is capable of generating a scene given any sensor location, line-of-sight, focal length, or heading corresponding to values

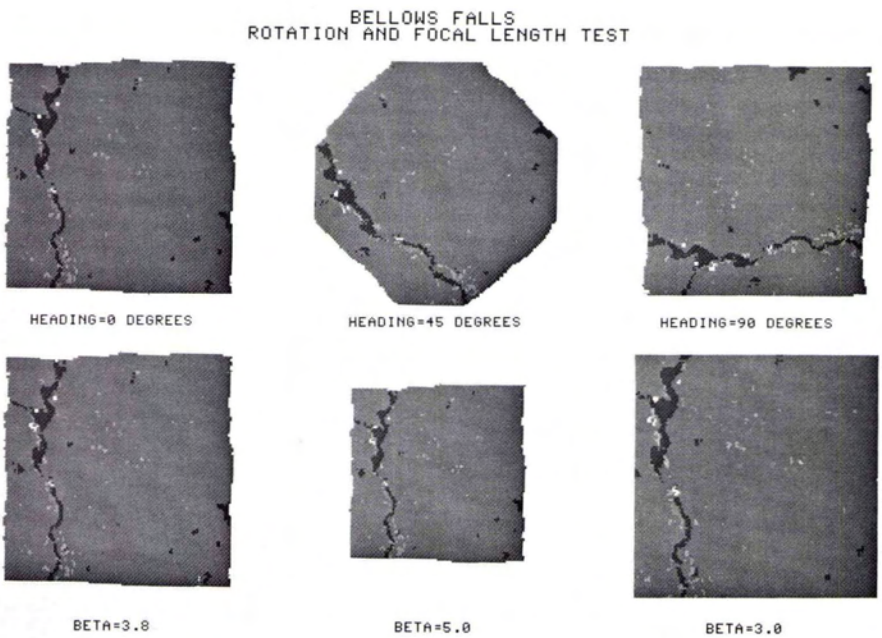

FIG. 7. Rotation and focal length options.

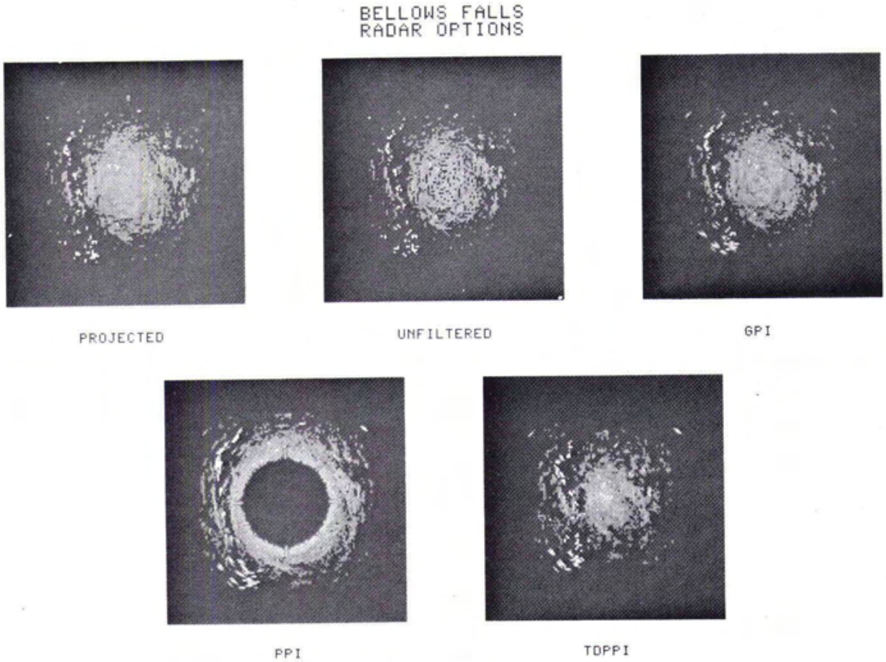

FIG. 8. Radar display options.

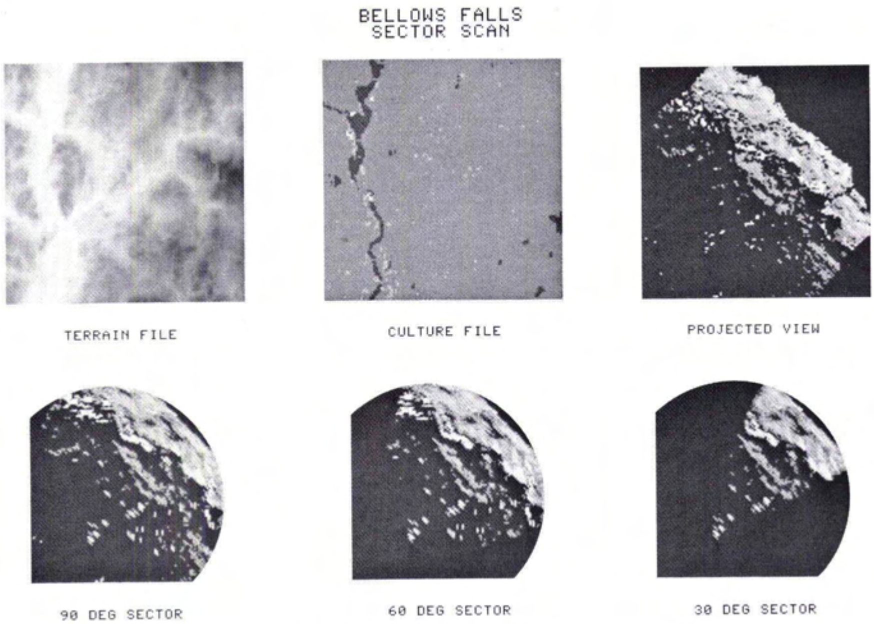

FIG. 9. Sector scan capability.

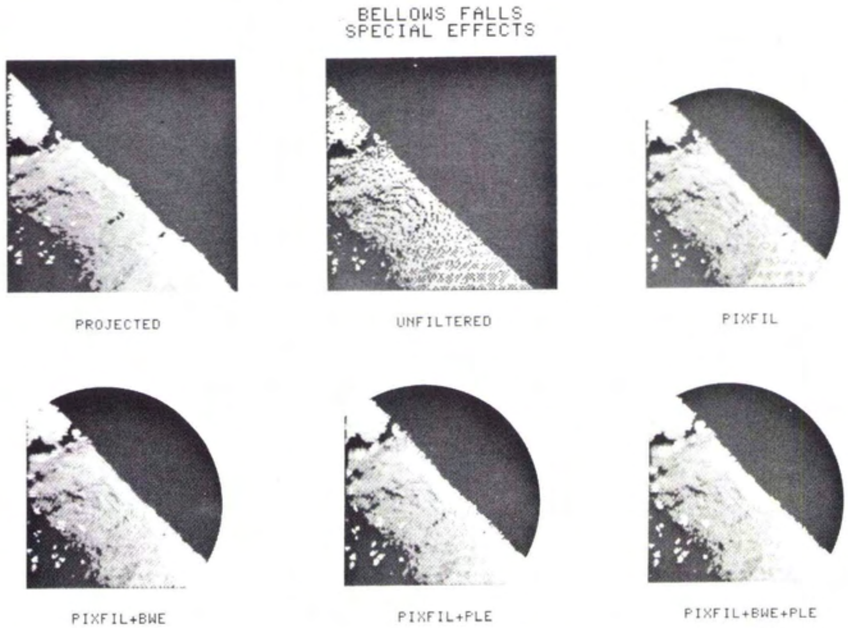

FIG. 10. Special radar effects.

input to the program. Examples of these variable parameter changes are shown in Figures 6 and 7.

RADAR DISPLAY MODULE

The sensor module is designed to model the electronics of the actual sensor receiver and controls. Both the sensor decibel response for, and range to each element in the data base are stored in arrays. Once the project view has been generated, the view may be transformed to the desired radar geometry. The program offers these options of display: ground position indicator model (GPI—computed ground range versus azimuth), plan position indicator model (PPI—slant range versus azimuth), and time-delayed PPI model (TDPI—time delayed slant range versus azimuth). The GPI mode gives a fairly good ground map appearance, whereas the latter two modes present anywhere from a barrel to a pincushion distortion. Because the transformation is not one-to-one, some noise or "holes" result. Therefore, the image is passed through a high frequency noise filter. This image is

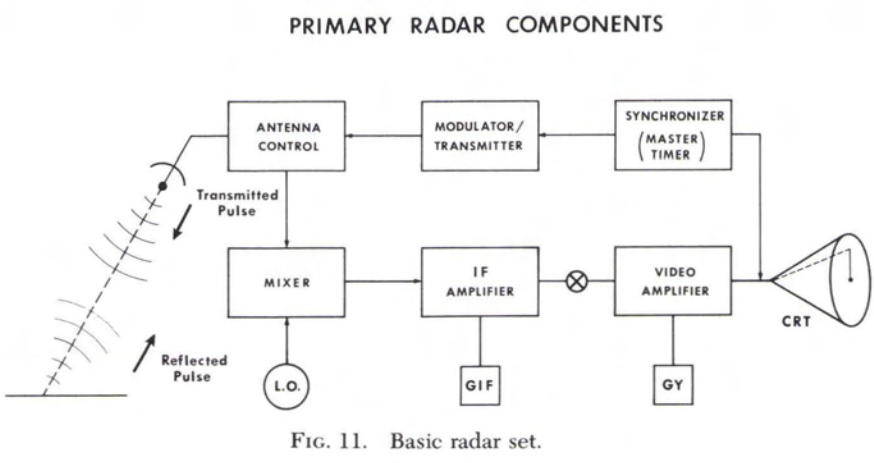

FIG. 11. Basic radar set.

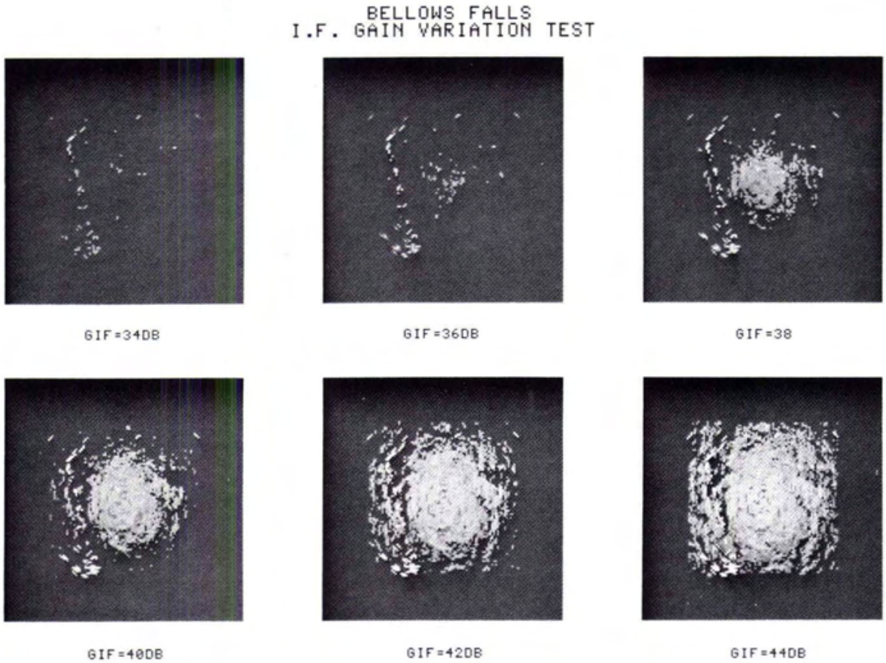

FIG. 12. I. F. gain variation.

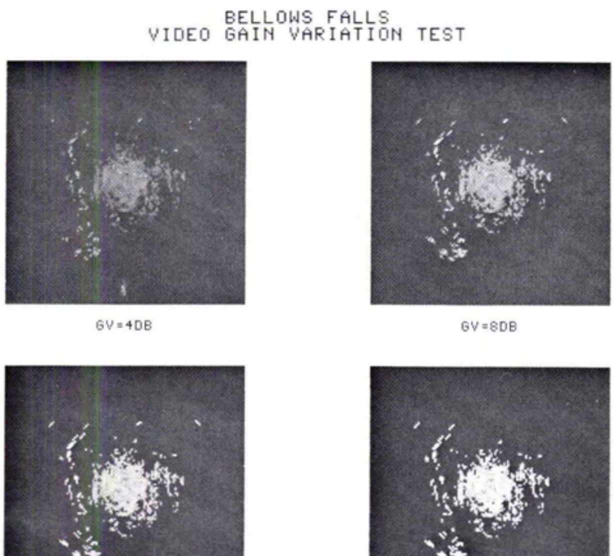

FIG. 13. Video gain variation.

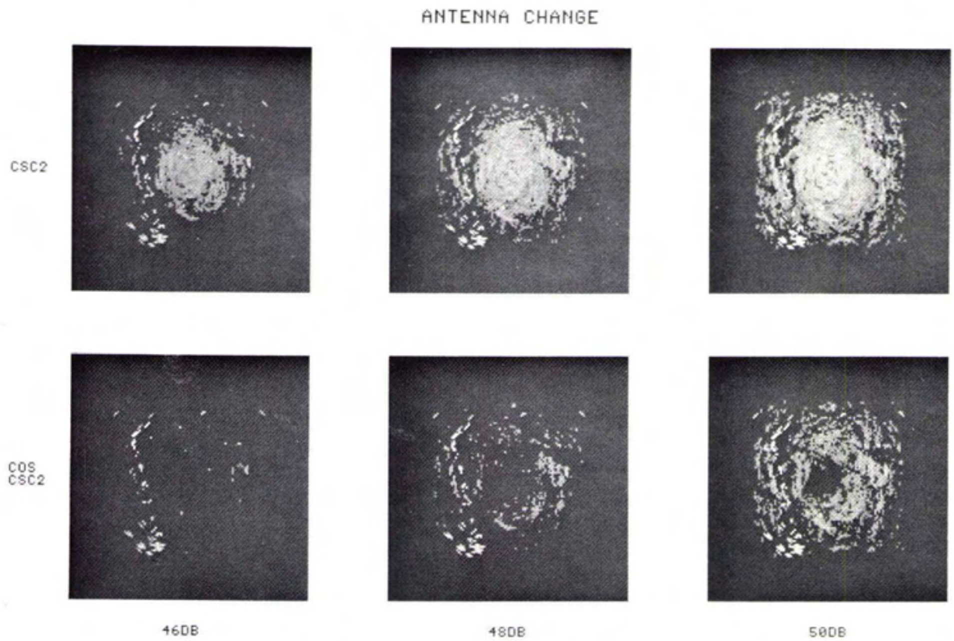

FIG. 14. Antenna power pattern change.

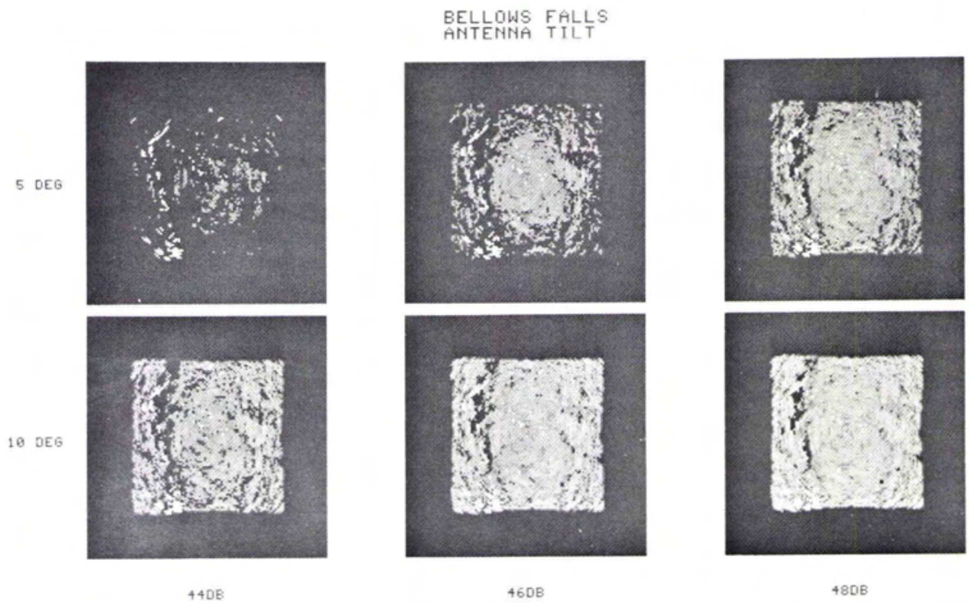

FIG. 15. Antenna tilt effects.

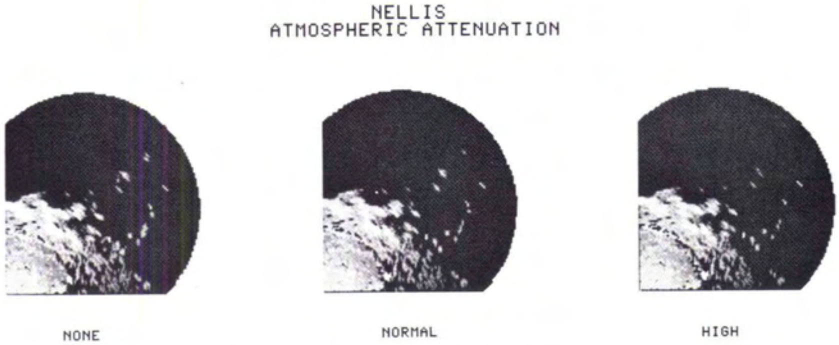

FIG. 16. Atmospheric attenuation.

then corrected to show the proper amount of pulse length error (PLE) and beam width error (BWE).

The F-111A radar set has the capability of displaying a 90 degree sector or a 20 degree sector. In addition to the simulation of the three previously mentioned 360 degree modes, any sector between 0 and 90 degrees may be displayed. Only those data elements within the displayed sector are processed. Figure 8 shows examples of the three options of display. Figure 9 gives an example of the variable sector scan capability of the program. Figure 10 shows the special radar effects (with exaggerated PLE).

The gray level response of each data base element is a function of its radar reflectivity potential, aspect angle to the terrain, weather conditions, and radar set parameters. Basically, the radar set modulates a pulse through the tilted antenna pattern at some carrier frequency and power (see Figure 11). This energy is backscattered by the terrain and culture, is attenuated by weather conditions, and finally, some of the returned energy is captured by the antenna if its strength is above some minimum detectable signal. These signals are then passed through the intermediate frequency (I.F.) amplifier and then boosted by the video gain

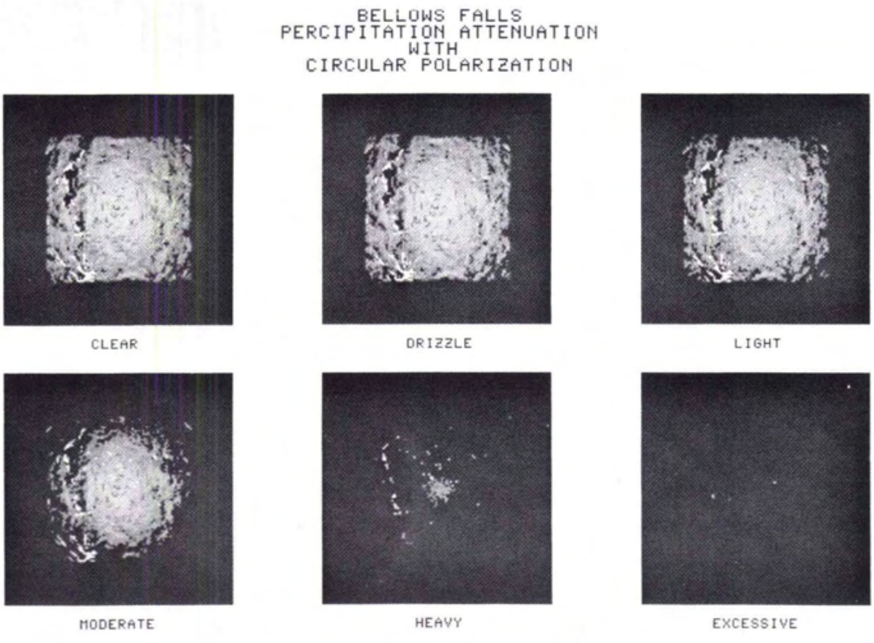

FIG. 17. Precipitation attenuation.

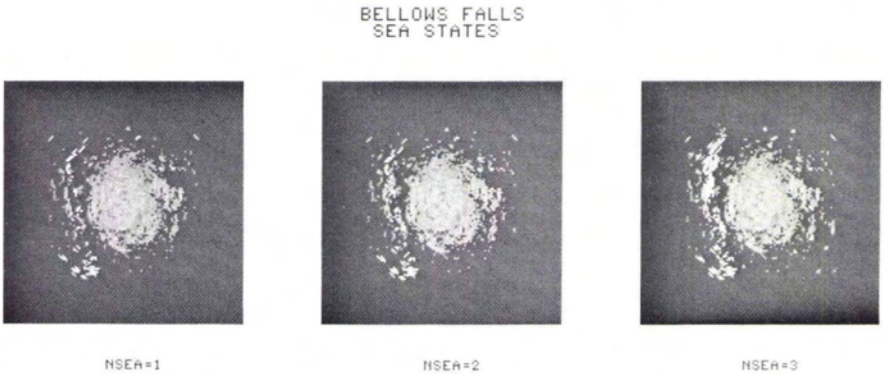

FIG. 18. Wind-wave effects.

amplifier to be displayed on the radar screen. The signals lose some energy in the electronics and are limited by the dynamic range of the display screen. All of the mentioned variables are parameters to the simulation program. (This module of the software is replaced for other types of sensors.)

Now, consider the radar program module capability to accept variable input descriptors of intermediate frequency and video

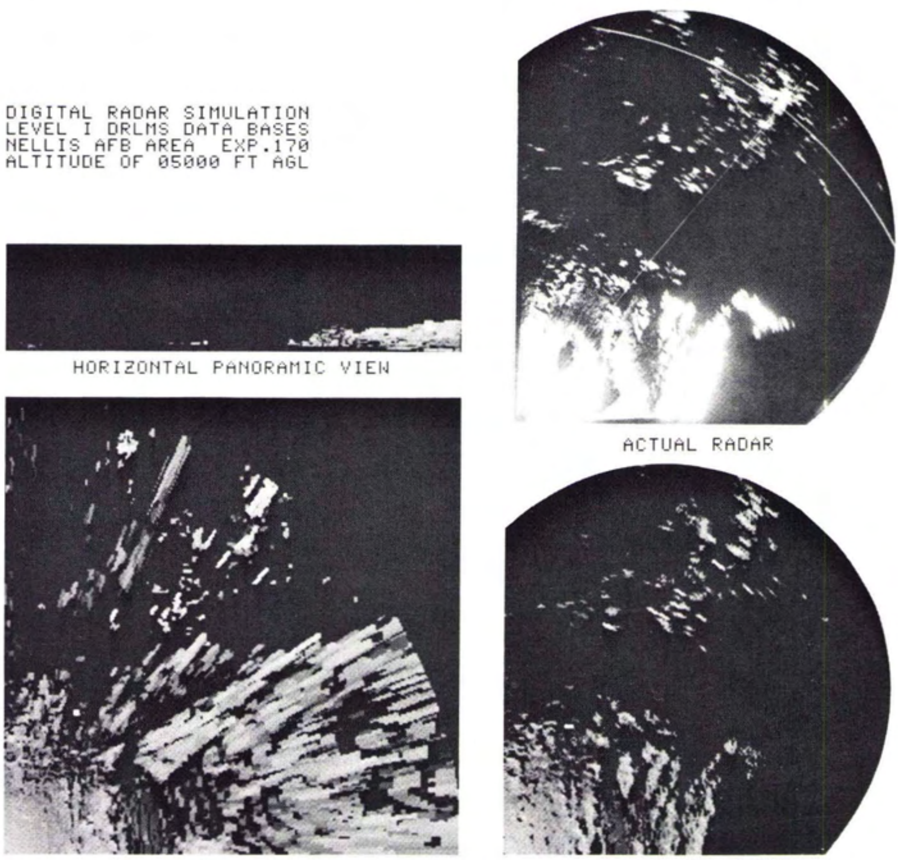

FIG. 19. Las Vegas data base from northeast corner at 7000 feet (MSL).

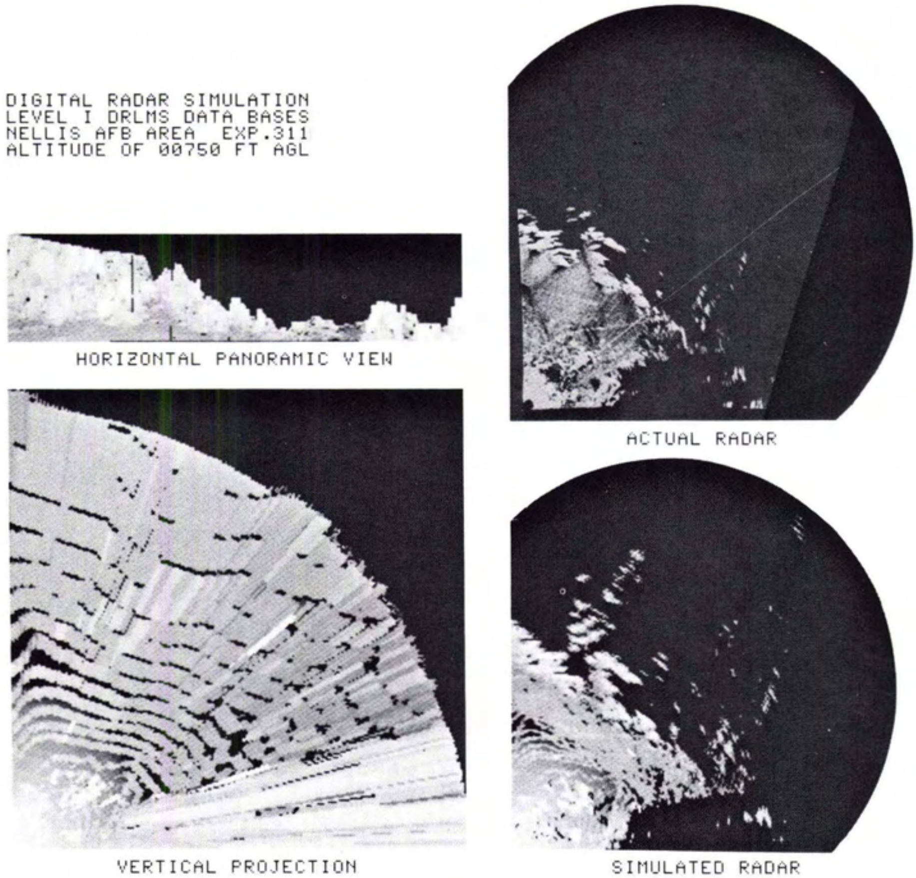

FIG. 20. Las Vegas data base from above Nellis AFB at 2750 feet (MSL).

gain amplifier settings, antenna pattern and tilt, and weather conditions. Figures 12 and 13 show the effect of changes in the I.F. and video gain settings on the resulting radar simulation. For low I.F. gain settings, only the bright reflectors are displayed. In contrast to this variable, the changes in video gain affect only the signals from the I.F. amplifier. With higher video gain settings, the display brightens until the various gray levels saturate (exceed the dynamic range) the display and are of the same brightness.

Figure 14 shows the effect of changing the antenna power pattern. For various I.F. gain settings, the displays are shown for CSC^2 and COS-CSC^2 antenna power patterns. In addition, the effects of tilting the antenna down on the data base by 5 degrees and 10 degrees below the horizontal are shown in Figure 15. Notice that it is possible to get nearly the same simulation for different combinations of gain and antenna tilt.

Figures 16, 17, and 18 demonstrate changes in weather conditions. Atmospheric attenuation is noticeable only at longer ranges and is influenced primarily by humidity. On the other hand, rainfall is a very major concern and may greatly affect the radar returns. Finally, high winds will cause large waves in water. Normally, water will not show a return (except for far-shore brightening), but the high waves can give a strong return. This is shown for the river in the Bellows Falls example.

COMPARISON WITH ACTUAL RADAR SCOPE PHOTOGRAPHY

Obviously, the real test of any simulation is the comparison with actual radar scope photographs. To date, only preliminary results are available due mainly to the absence of actual radar scope photographs with defined supporting information (i.e., aircraft position, antenna tilt, I.F. gain settings, weather, etc.). In the following examples,

FIG. 21. Las Vegas data base from southeast corner at 7000 feet (MSL).

the only known fact about the actual scenes were ground range mode and 30 nautical mile scope display range. The simulations, therefore, were made with position and control settings which were assumed to nearly match the actual displays. Future test and evaluation procedures will include more known information. The actual scope display camera system does not match the range of the scope, and this causes some loss in gray levels. In areas outside of the input data bases, the actual scope displays are masked. Figures 19, 20, 21, and 22 each show a comparison between a photograph of the radar scope and the corresponding simulation produced from DMAAC software and the Las Vegas data base. These scenes were taken at altitudes near the same level as some of the terrain heights in the scene. In consideration of the many unknown parameters, the simulations yield a fairly close likeness to the actual displays. Simulations at much higher and much lower altitudes compare with a similar degree of accuracy.

COMPUTER USAGE

All of the sensor simulations were generated on a UNIVAC 1108 computer. The logic of the software is independent of data base size and resolution, and in areas where the matrix size of the data base is too large for core memory, the software processes the data by dividing the scene into angular wedges from the observation point and storing out-of-wedge data on disk. Data bases used cover areas from 15 minute squares to a 1 degree by 2 degree area. The horizontal spacing interval between data base values is, of course, as important as the physical area coverage. Data base matrices have ranged from 100 by 100 to 1000 by 2000 in the various simulations. The software is currently undergoing program optimization to increase data handling efficiency. In addition, run times are dependent upon topography

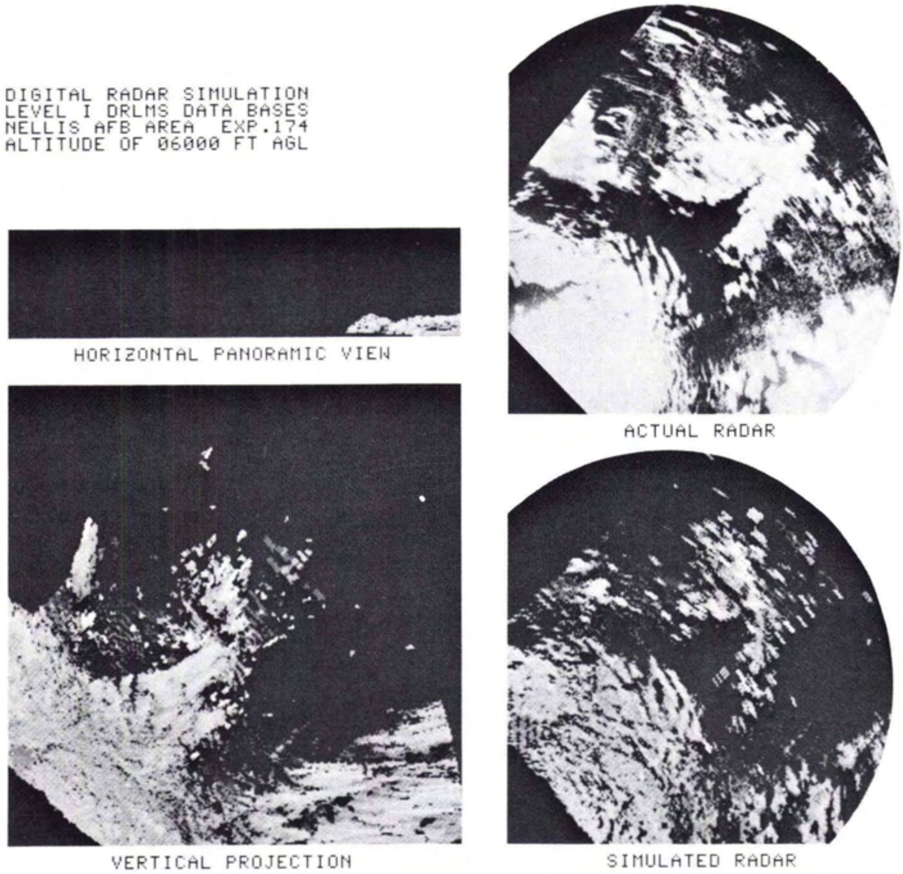

FIG. 22. Las Vegas data base from east at 8000 feet (MSL).

and sensor location. In general, however, scene simulation CPU, I/O, and system run times range from two to twenty minutes per scene.

CONCLUSIONS

It has been shown that digital data bases can be used to effectively simulate radar scenes. The program has been shown to be a valuable editing and analysis tool for the production of digital data bases. In addition, it is anticipated that as experience is gained with the program, it will prove to be capable of refining data base production specifications. The addition of software modules to handle other types of sensors requires a comparable effort, but should yield similar results. The application of the simulation concepts to a real-time simulator would require modifications and approximations. This would be beneficial in a training device, but detrimental to data base editing and analysis. Further testing and evaluation is planned to better calibrate the simulated sensor responses.

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ACKNOWLEDGMENTS

Dr. Bernard Kolo is responsible for the mathematical development of the radar return portions of the model. Mr. James Simpson assisted with the examples, and Mr. Ronald Updegrave managed the OPTRONICS processing. Dr. Raymond J. Helmering reviewed this paper.

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