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AIR FORCE

HUMAN RESOURCES

SIMULATION OF SYNTHETIC APERTURE RADAR II: SIMULATING SAR USING THE ADVANCED VISUAL TECHNOLOGY SYSTEM

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The Advanced Visual Technology System (AVTS) computer image generator was modified to produce highly accurate simulations of synthetic aperture radar (SAR) reflectivity and elevation effects that can be precisely correlated with corresponding visual and infrared imagery. The resulting SAR snapshot is a plan view of the selected patch area with the field-of-view corresponding to a selected scale of 0.65, 1.3, or 2.6 nm. The image generator is interrupted for only one frame time, during which the entire processing power of the AVTS, up to 4,000 polygons, is brought to bear on the SAR snapshot. Once the SAR patch is computed, the AVTS continues with visual and infrared processing. A post-processor then adds feature and terrain shadows, horizontal and vertical incidence effects, resolution fall-off in azimuth and range, and speckle.

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SUMMARY

The Advanced Visual Technology System (AVTS) is a computer image generator which produces high quality simulated visual and sensor imagery. This report describes a development effort to add Synthetic Aperture Radar (SAR) simulation capability to AVTS. The objective of this effort was to generate simulations of imagery produced by currently operational SAR systems with high-fidelity reflectivity, elevation, and incidence effects. SAR imagery was also to be correlated with corresponding visual and sensor scenes. Development efforts included: (a) modification to the feature and terrain grid data bases, (b) generation of SAR-only texture maps, and (c) use of the post-procesor to generate shadows, incidence effects, and image effects. SAR effects due to Doppler pheonomena are not modeled. The system can be configured to produce either high-density SAR images or precisely correlated SAR, visual, and sensor images. This system is being used at the Air Force Human Resources Laboratory to conduct research and development on training effectiveness requirements for imaging simulators.

PREFACE

This work was conducted by personnel from the Air Force Human Resources Laboratory, Operations Training Division (AFHRL/OT) under Work Unit 1123-33-01, Fidelity Requirements for Sensor Imagery, and General Electric Company's Simulation and Control Systems Department under Work Unit 1192-04-26, Contract F33615-84-C-0063, Program Element 62205F. The laboratory contract monitor was Mr. Steve Stephens. This effort was conducted in support of the Laboratory's technical planning objective: aircrew training technology. The goal of this effort is to develop cost-effective strategies and equipment for aircrew training. The authors thank Maj Manney Key and Maj Mike Seiverding for their cooperation and advice in the development of this simulation system.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

Modern weapon system trainers frequently need to provide high-resolution sensor imagery, as well as out-the-window visual imagery, to the aircrew in order to train weapon system employment. As part of its long-range aircrew training effectiveness research and development effort, the Air Force Human Resources Laboratory's Operations Training Division (AFHRL/OT) is conducting research to determine the scene content required for effective and efficient aircrew training. Part of this research involves determining the simulation requirements associated with visual, forward-looking infrared, and synthetic aperture radar (SAR) task performance.

In order to provide correlated high-resolution sensor and visual imagery for real-time simulation experiments, AFHRL/OT sponsored the development of a SAR capability for the Advanced Visual Technology System (AVTS) computer image generator. This development, accomplished by General Electric's Simulation and Control Systems Department, involved modifications to an AVTS infrared sensor channel and the addition of height and surface material information to the data base. The result is a highly accurate simulation of SAR elevation and reflectivity effects which can be precisely correlated with corresponding visual and infrared imagery. Some significant performance features include:

1. High-resolution ground patches with better than 10-foot ground resolution and ranges up to 40 nm;

2. Operator-selectable patch location as well as range and scale;

3. Accurate shadowing by terrain and three-dimensional features within the patch and by intervening terrain outside the patch;

4. Horizontal and vertical incidence effects, including surface transitions (e.g., far shore enhancement);

5. Azimuth resolution loss (blurring) as a function of squint angle;

6. Speckle or noise and receiver gain.

II. APPROACH

The AVTS image generator was modified to simulate SAR using high-resolution, plan view ground patches. These patches are retrieved from the AVTS data base as a function of the user-selected patch location (latitude, longitude) and the selected range/scale. A SAR-only pseudo viewpoint is then created directly over the selected patch with the appropriate field-of-view and altitude, thus creating the plan view representation.

The plan view image created by the AVTS image generator is captured via a 1/30-second snapshot. During this time, all the resources of the AVTS are applied to capturing the ground patch reflectivity and three-dimensional feature elevation data in the AVTS video memory. This causes AVTS to skip processing a single frame of visual imagery whenever a SAR patch is requested. The resulting visual effect is nearly imperceptible to the observer.

AVTS Components

Figure 1 illustrates the major components of this SAR simulation. Three major units within the AVTS image generator perform specialized functions during this 1/30-second SAR frame: the Vertex Processor, the Face Modulation Processor, and the Video Memory Combiner. The Vertex Processor substitutes feature reflectivities for the out-the-window red component of the red-green-blue video data and feature elevation data for the out-the-window blue component. This substitution allows simultaneous and correlated out-the-window and SAR processing. The Face Modulation Processor selects only the SAR-specific texture maps during the snapshot process. Of the 16 cell-textured maps AVTS provides, four are designated SAR only for those data bases with SAR capability. The Video Memory Combiner uses a ping/pong memory to hold the odd or even lines of video data. During the snapshot frame, the Video Memory Combiner places the odd lines of

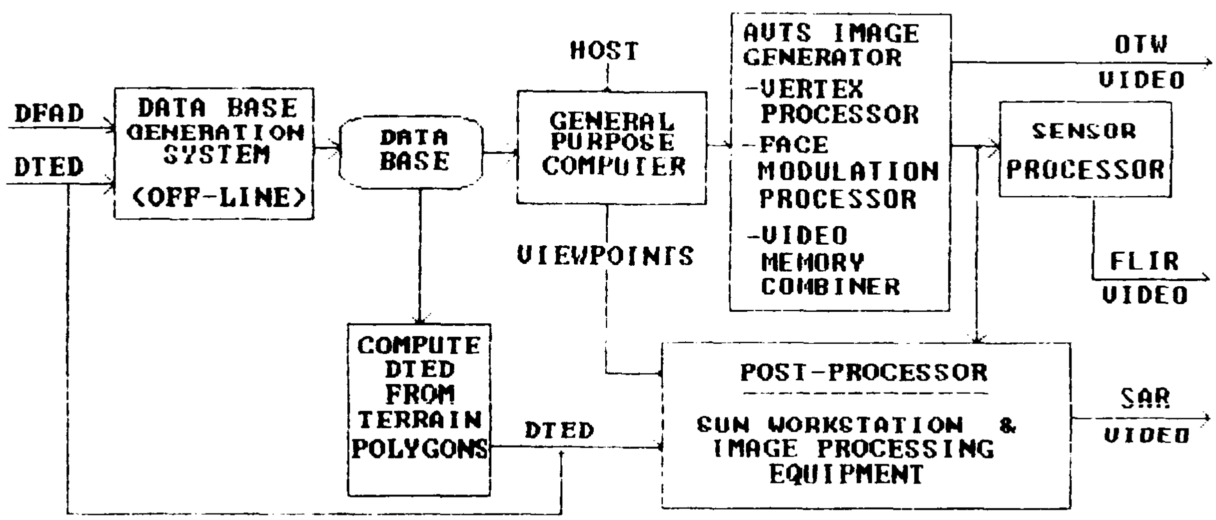
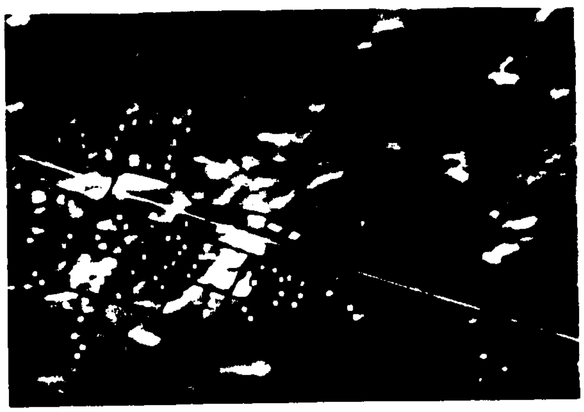


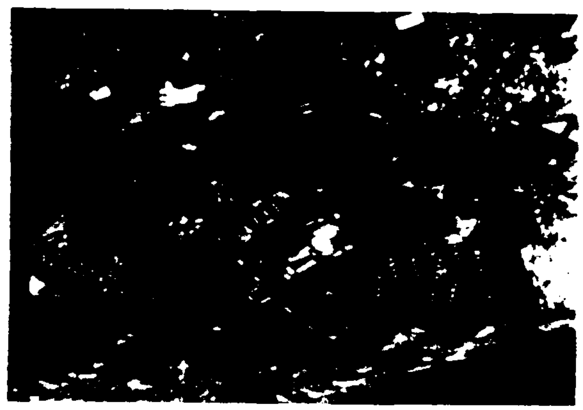
Figure 1. Synthetic Aperture Radar Block Diagram.

SAR data in the ping memory and the even lines in the pong memory to ensure that properly oriented data are sent to the SAR post-processor.

The AVTS real-time software monitors and controls the progress of capturing and shipping the SAR snapshot to the SAR post-processor. The AVTS General Purpose Computing Subsystem and the SAR post-processor are in constant communication during real-time operation across a high-speed data interface. When the operator enters the patch latitude, longitude, and size through the user interface, these data are transferred to AVTS and the radar position is returned from AVTS. Then, when the operator requests a SAR image of that area, the environmental data representing the patch area are loaded into the AVTS image generator. When this is complete, a frame of AVTS processing is taken for SAR processing. During this frame, the ownship is positioned at the pseudo viewpoint location directly above the patch, and SAR-specific parameters are sent to the AVTS image generator. There is no objectionable degradation to the visual imagery during this frame, and normal processing resumes with the following frame. The AVTS image generator captures the SAR image coded with reflectivity and elevation data in the AVTS video memories. The data from the video memories are transferred to the SAR post-processor. Subsequent snapshots can be taken as soon as the current snapshot has been completely processed. Figures 2a and 2b show examples of the resulting image.



2a. Dodge, ND.



2b. Eglin AFB, FL.

Figure 2. Simulated SAR Elevation and Reflectivity Effects For Two Scenes.

Once this single-frame plan view has been created, the SAR post-processor, consisting of a Sun Work Station equipped with image processing hardware and software, creates shadows and radar effects. This post-processor accepts the reflectivity and elevation data from the AVTS image generator and the current location of the aircraft (i.e., antenna position) from the AVTS general-purpose computer. These data are then combined with the intervening terrain elevation data which were previously compiled and stored in the Sun's memory to compute radar shadows. This post-processor also computes radar effects such as incidence effects, azimuth resolution loss as a function of squint angle, speckle, and receiver gain. Approximately 1 minute is required to complete all processing and display the resulting simulated SAR image.

Data Base

To construct a visual data base, the off-line AVTS Data Base Generation System creates polygons from Defense Mapping Agency Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD) or other user-supplied information.

Visual Data Base. Several attributes were added to features in the visual data base to be used for SAR. Each object that will be visible in the plan view snapshot is assigned a radar reflectivity and a SAR height. Features which are not visible in the visual data base are tagged with a SAR-only flag.

The radar reflectivity information is processed by the AVTS image generator in the red component of the video data. When the data base is generated, a 5-bit index is assigned to each feature from a look-up table based on the DFAD Feature Identification Code and Surface Material code. This index is stored in a table which contains the 8-bit reflectivity code for each feature. During snapshot processing, the image generator uses this index to access the red component of the color table.

The SAR height is assigned for objects which will cast shadows, and is processed by the image generator using the blue component of the color table. The color table contains 8-bit values, with the least significant bit representing 4 feet.

The texture patterns used during the SAR snapshot are different from the visual image texture patterns. This provides modulation to the reflectivity of the ground that more closely resembles radar returns.

Off-Line Terrain Grid Data Base. The data base containing the terrain elevations used by the post-processor for terrain shadow calculations is generated off-line and stored on the Sun Work Station disk. The terrain grid data base consists of grid posts representing elevation in feet, with 3 arc-second spacing. The grid posts are ordered in 1-minute square blocks to minimize disk seek time when the terrain is read in for shadow calculations.

The off-line terrain grid data base can be generated to precisely match the visual data base terrain or to use all elevation data provided by the DMA source. The latter can be desirable in order to obtain more shadow detail and thereby create the effect of higher-density terrain information when exact correlation with the visual data base is not required. Therefore, the user has the option of building a completely correlated terrain grid data base or a noncorrelated SAR-only data base with higher feature density. For a completely correlated data base, the terrain elevation data are reverse-transformed from the visual data base such that the resulting terrain surface exactly matches the visual (polygonal) terrain surface. For a SAR-only data base, the original Defense Mapping Agency DTED and DFAD can be used without the need to reverse-transform since correlation between the SAR and visual data base is no longer a requirement.

III. SHADOW GENERATION

The SAR post-processor receives the plan view, complete with radar reflectivities and the three-dimensional feature grid from the real-time AVTS image generator. The post-processor combines the three-dimensional feature grid with the off-line terrain data base stored in the Sun to compute a shadow mask which is merged with the final SAR picture to black out areas with no radar returns.

The radar shadows are computed using the ray-tracing algorithm illustrated in Figure 3. This algorithm includes both the intervening terrain (interpatch) and the terrain and other three-dimensional features within the patch (intrapatch). This algorithm is based on a front-to-back elevation grid scan, wherein grazing angles are computed and compared for each

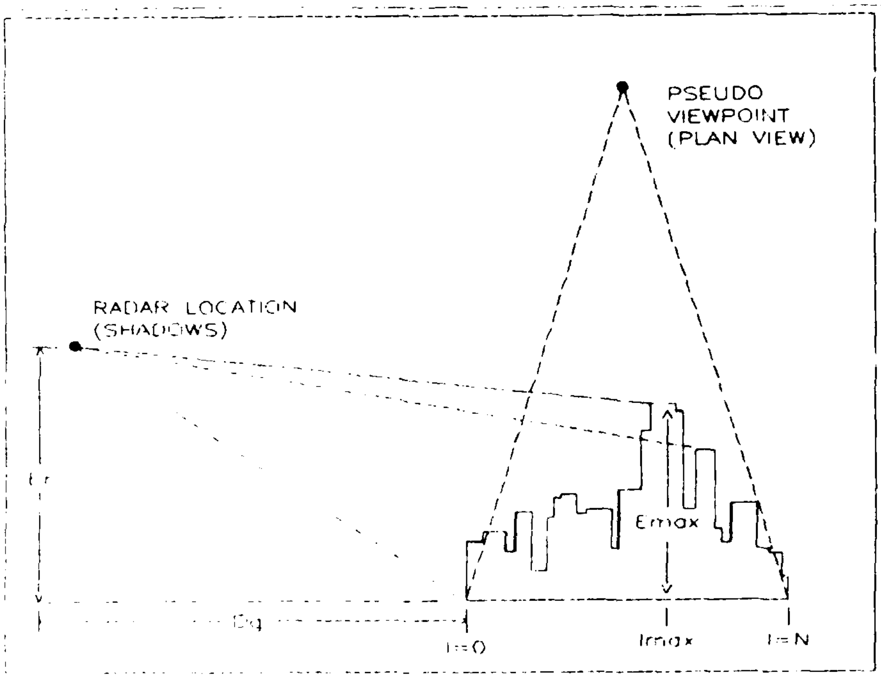


Figure 3. Synthetic Aperture Radar Simulation.

elevation grid value within each column. Each elevation grid value is the sum of the interpolated terrain elevation and the height of any objects on the terrain.

Intervening Terrain Shadows

Shadows from the intervening terrain are computed for the area between the ownship and the SAR patch. The 1-minute square blocks of the off-line grid data base are read in starting at the ownship and continuing to the front of the SAR patch. The terrain in each of nine equally spaced view rays is sampled using a line-of-sight occulting algorithm. All of the terrain data for the nine view ray tangents in a single 1-minute square block are recorded when a block is read in. This eliminates any excess processing time which would result from reading in the same block multiple times.

These intervening terrain shadows are calculated by tracing nine equally spaced rays from the radar to the near edge of the patch. The points are sampled at a spacing equal to the off-line terrain point spacing. The tangent of the depression angle at each point is computed for each scan and the minimum tangent for each sweep is saved. The minimum tangents for the nine sweeps are interpolated to get 256 values that are used in computing intrapatch shadows.

Intrapatch Shadows

The intrapatch shadows are calculated based on the terrain elevations within the patch and three-dimensional feature heights. The intervening terrain shadows are generated using terrain elevations between the radar and the patch. The intrapatch terrain is generated using the off-line terrain grid data base. A 32 by 32 intrapatch grid is constructed by reading the data point from the grid data base that is the closest to each of the patch sample points. The intrapatch grid is expanded to 256 by 256 points via interpolation and added to the three-dimensional feature heights. Shadows inside the patch are computed using 256 parallel sweeps from front to back, with 256 points in each sweep. The tangent of the depression angle at each point is computed and compared with the previous minimum tangent for each scan. The first point on each scan is compared with the result of intervening terrain calculations. If the tangent is less than the previous minimum, the point is visible and this value becomes the new minimum. Otherwise, the point is in shadow and the old minimum is retained. The calculation of these intrapatch shadows is shown below:

```
FOR j   = 1, grid_size

    TAN_MIN = int_terrain_tangent (j)

    Dp      = Dg

    FOR i   = grid_size, 1

         TAN_HERE = (Er - E (i, j) ) / Dp

         Dp       = Dp + F

         If TAN_HERE > TAN_MIN THEN

         S (i, j) = SHADOW

         ELSE

         TAN_MIN  = TAN_HERE

         S (i, j) = NO_SHADOW
```

WHERE:

```
j           = column number
i           = row number
Er          = elevation of radar
E (j, i)    = elevation at this (i,j) location
Dg          = ground distance from radar to beginning of
              patch (feet)
DP          = ground distance to current (i,j) elevation
              point
F           = scale factor in i direction (feet/line)
grid_size   = number of rows and columns in SAR image=256
S(j,i)      = shadow mask memory value written into the
              frame buffer
TAN_MIN     = TAN of angle from radar to max elevation in
              column so far
TAN_HERE    = TAN of angle from radar to current (i,j)
              elevation
TAN_INIT    = Er/Dg = initial value for TAN_MIN at start
              of each column
SHADOW      = 0
NO_SHADOW   = 'FF' hex
int_terrain_tangent (j) = interpolated minimum tangent
                          value for intervening terrain
                          between the ownship and this
                          column
```

The shadow mask is then filtered to decrease its square, cellular structure and is oriented line of sight up.

Shadow Merge

A low-pass convolution filter is applied to smooth the edges of the shadows after the shadow mask is generated. This smoothing reduces the stark contrast between shadows and adjacent features. The mask is logically AND'ed with the plan view image; i.e., all pixels within shadowed areas are set to zero to black out the shadowed areas.

IV. RADAR EFFECTS

The post-processor adds both incidence and image effects to the shadowed image.

Incidence Effects

Horizontal and vertical incidence effects are simulated in both the AVTS and the post-processor. The AVTS image generator computes incidence effects by utilizing the solar illumination hardware as a radar illumination simulation, with the source located at the radar antenna. The calculation is:

Ro = Ri (k1 + TLU (k2 * [I dot Nf]))

WHERE:

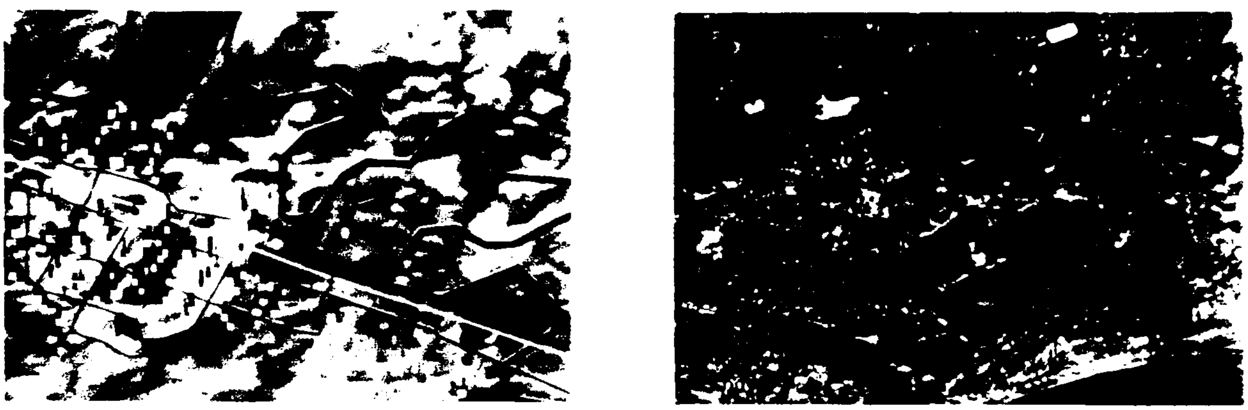
Ro = Ouput reflectivity
Ri = Input reflectivity (assigned in the Visual Data Base)
k1 = Ambient illumination
k2 = Multiplicative illumination
I = Illumination Unit Vector (points to antenna)
Nf = Face Normal Unit Vector
dot = Vector Dot Product
TLU = Table Look Up (values stored in PROM)

and where k1 and k2 are controllable uniquely for the SAR channel. The TLU function can be adjusted to accentuate small angles--when the face normal is nearly aligned with the illumination vector--thereby providing low-altitude/small grazing angle effects.

The post-processor computes vertical incidence effects to simulate brighter returns along vertical surfaces and shorelines. These two situations are detected and handled by separate algorithms.

The brighter returns resulting from the radar beam reflecting off of a surface normal to its path are simulated by increasing the intensity of several pixels, which follow a positive change in the height of three-dimensional features. The leading edges are detected using a horizontal edge detection convolution on the three-dimensional feature heights received from AVTS. Several pixels above each pixel in a leading edge are marked for further processing. The intensities of the pixels in the plan view image corresponding to the marked pixels are multiplied by a power of 2 using a binary shift, and limited to 255 to simulate the brighter returns.

The brighter radar returns from shorelines perpendicular to a radar beam path are simulated by increasing the intensity of several pixels behind a water-to-land transition. A water-to-land transition is detected by searching for water pixels adjacent to land pixels. A water pixel is represented by an intensity value ranging from zero to 3, and a land pixel is represented by an intensity value greater than 3. The transition line pixels are emphasized by multiplying their intensities by a power of 2 using a binary shift. The intensity factor and the number of pixels affected at each detected transition can be varied to fine-tune the far shore enhancement. Figures 4a and 4b show reflectivity and elevation effects combined with shadows and incidence effects.



4a. Dodge, ND.　　4b. Eglin AFB, FL.

Figure 4. Simulated SAR Elevation, Reflectivity, Shadows and Incidence.

Image Effects

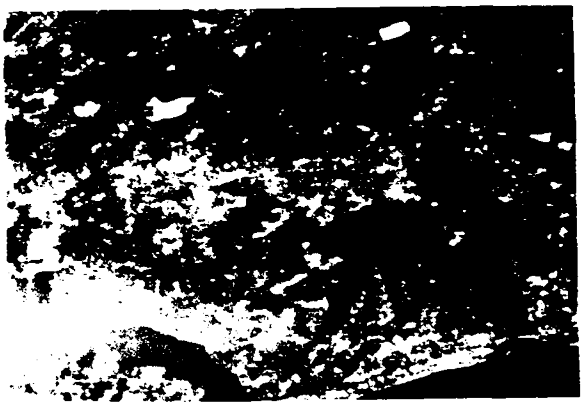
The radar image effects simulated in the post-processor include loss of azimuth and range resolution as a function of squint angle, the addition of noise, and a receiver gain function.

Resolution Blur. The resolution blur is used to simulate the loss in resolution as the radar antenna is moved toward the nose of the airplane. For snapshots taken at squint angles from 15 to 60 degrees, a convolution is performed using a one-row by four-column low-pass filter kernel. For snapshots taken with squint angles less than 15 degrees, a larger kernel with four rows and eight columns is used to produce more blurring. These kernels can be easily changed to provide a wide range of blurring effects.

Rayleigh Noise. After image blurring, noise is randomly assigned for each pixel, using a Rayleigh distribution to simulate the noise present in actual SAR images. The standard deviation of the noise values is chosen based on the radar operating mode. The noise values are selectively added to the image using the image processing hardware. Noise is not added to those pixels which represent regions with low radar returns (shadows, water, and roads) by identifying and not modifying features having an intensity below a given threshold.

Receiver Gain. A receiver gain function is simulated through the user interface on the Sun Work Station after the snapshot processing is completed. It provides a variable brightness control that can be used for isolating target areas. The function is implemented with a look-up table which controls the intensity of the displayed image. The look-up table consists of a function with a constant slope, but varying x-intercept. The intensities are clipped to a range of 0 to 255. Figures 5a and 5b show the final, simulated SAR images.

5a. Dodge, ND.



5b. Eglin AFB, FL.

Figure 5. SAR Simulation Including Image Effects.

V. APPLICATIONS

Data Base Evaluation

AFHRL/OT conducted a test of data base requirements for simulating SAR in support of other Air Force and Department of Defense agencies. DTED was combined with different prototype DAFD products and imaged using the AVTS SAR simulator. Air Force

SAR subject-matter experts then performed a navigation update task using these images and evaluated the adequacy of the images for use in a weapons system trainer.[1] For this application, correlation with a visual or infrared image was not required, thus allowing very high terrain and feature densities.

Multisensor Image Correlation

AVTS SAR simulation is being combined with visual, forward-looking infrared sensors for navigation, and targeting infrared imagery to allow evaluation of integrated, multisensor simulation. For this evaluation, all images can be perfectly correlated so that the pilot will see the same features plus sensor-specific effects in each image. Alternatively, feature density can be increased for SAR and targeting IR compared to visual and navigation FLIR. AFHRL/OT will be conducting studies to evaluate the utility of correlated versus maximum detail multisensor imagery using the capabilities of AVTS.

VI. CONCLUSIONS

Modifications to the AVTS computer image generator have produced accurate simulations of SAR elevation and reflectivity effects. SAR effects which result from Doppler phenomena are not simulated using this approach. The AVTS SAR simulation can produce high-density SAR images or correlated visual, infrared, and SAR images. This modification to AVTS is allowing AFHRL/OT to conduct further research on SAR simulation requirements and on integrated, multisensor simulation-based training.

[1] Crane, P. M., & Bell, H. H. (in press). Simulation of Synthetic Aperature Radar III: Evaluation of Defense Mapping Agency Level 3-C Digital Feature Analysis Data (AFHRL-TR-89-04). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory

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