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IMAGE SYNTHESIS FOR SAR SYSTEM, CALIBRATION
AND PROCESSOR DESIGN

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SUMMARY

The "Point Scattering Method" of simulating radar imagery is an efficient, cost-effective technique which rigorously models all aspects of the imaging radar phenomena. The model is valid for incoherently degraded SAR, PPI and real aperture systems. The target behavior, the radar antenna and signal processing equipment, and the storage of radar data on photographic film are incorporated although digital image storage can easily be accommodated. This method does not presuppose the existence of radar imagery; rather, its computational algorithms operate on a symbolic representation of the terrain test site to calculate such parameters as range, angle of incidence, resolution cell size, etc. Empirical backscatter data and elevation data are utilized to model the terrain. Additionally, the important geometrical/propagation effects such as shadow, foreshortening, layover, and local angle of incidence are rigorously treated.

Applications of radar image simulation to SAR system, calibration, and processor design problems are discussed. For example, data or images generated by the Point Scattering Method will display various degrees of interpretability depending upon the configuration of the imaging system being modeled. Therefore, the results can be used to establish optimum design parameters: frequencies, polarizations, angle of incidence, allowable fading, resolution, antenna pattern, and so on. Two tasks of a proposed calibrated SAR system are highlighted: soil moisture detection and vegetation discrimination. This simulation technique in conjunction with test sites containing these types of targets may be applied to establish baseline quality images. Subsequently, system error degradation studies can be performed using classification and detection algorithms to develop quantifiable performance criteria.

1.0 INTRODUCTION

The successful application of airborne imaging SAR and ground-based backscatter measurement systems to the tasks of soil moisture detection and crop discrimination has received considerable publicity. It has been proposed that a spaceborne SAR be designed to accomplish these same goals on a large scale. The proponents of the design cite as evidence that the proposed system will succeed, that the average σ^0 trends for the targets of interest exhibit considerable separation. SAR system designs have been proposed for orbital platforms capitalizing on the current state of knowledge. However, the degree to which these designs will accomplish the desired goals is not clear. Calibration problems, variability in system components, degradation due to navigational and structural problems (e.g., antenna performance) all must be considered as to their impact on the ultimate performance which can only be assessed in terms of the intended application. For instance, the problem of measuring soil moisture involves discriminating features within a narrow range (<6,7 dB) which clearly calls for a calibrated system having a measurement accuracy on the order of 1 dB. These and other conjectures can be investigated by rigorously modeling the imaging radar "closed-system" and by simulating imagery. The closed-system consists of the target terrain, atmosphere, antenna, signal processing equipment, and data storage medium. The interpretability or information content of the simulated images, as determined by either a human or automated classifier, would be useful in deciding whether the spaceborne SAR can perform the desired discriminations.

A cost-effective, efficient technique which has been developed for imaging radar simulation, and which is well-suited to the above SAR problems is the "Point Scattering Method" of Holtzman, et al. [1]. This method incorporates all aspects of the imaging phenomena, i.e., each component of the closed-system and its effects on the resulting image have been modeled. The present capabilities of digital implementations of the PSM allow simulation of SAR, PPI, and real aperture imagery. Both qualitative (visual) and quantitative (image cross-correlation measurements, real versus simulated imagery) validation tests have been performed for the PSM simulations, with excellent results [2]. The model accurately predicts the radar return by taking into account the propagation/geometrical effects and radar system parameters as well as the

image medium. The signal/target interaction is described in terms of σ^0 , the differential scattering cross-section; empirical or theoretical values of σ^0 are used in the simulation process.

2.0 THE POLAR SCATTERING METHOD: A BRIEF OVERVIEW

In order to produce imagery comparable to that which would be produced by a real radar traversing the atmosphere or space above the desired ground swath, it is necessary to obtain a representation of the terrain at microwave frequencies, and to sample its properties. These properties are electromagnetic and geometric; therefore, the microwave reflectivity and elevation of the site are sampled. Empirical backscatter data are utilized in combination with the relief data to model both the coarse and fine scale characteristics of the terrain. Backscatter data implicitly contain information about the texture and type of terrain, and its use complements elevation sampling which alone is insufficient for modeling the ground as a component of the imaging radar closed system. The digital data base which describes the ground site is in the form of a rectangular matrix, and each of the locations of this matrix contain x- and y-coordinate, elevation, and backscatter category (e.g., 15 cm green wheat over rough moist soil). A matrix of empirical σ^0 data, taken from the literature and from the Remote Sensing Laboratory agriculture/soil moisture data bank, is contained on tape for each distinct distributed target found to exist in the test site. Specular reflectors are either treated symbolically or by the optical technique of Holtzman, et al. [3].

After the ground truth data base (terrain feature model) of the desired site has been specified, the reflectivity (σ^0) data for the various categories included in the data base have been obtained, and the complex geometry relating the radar platform to the scene has been determined, then the imaging model, i.e. the final computational algorithm of the PSM is used to calculate the signal reradiated from the ground back to the radar for each resolution element in the scene. It calculates the ground-return signal exiting the receiver, and then converts this into the appropriate density of silver grains in the exposed and developed image. This algorithm determines the shade of gray of each pixel in the image, and hence, is called the gray-tone equation. The graytone equation produces the final result, drawing upon all preceding data and calculations. It relates the ground to the radar and

to the image. When the desired storage medium of the SAR is not photographic film but magnetic tape, the PSM can be adapted to reflect this change. The final computational algorithms of the Point Scattering Model can reflect a linear, log, or other signal receiver and signal quantizer. The input to the quantizer is most often the output of a phase detector, that is, the bipolar video data of a coherent radar receiver. The PSM algorithms can be modified to this chain of events for further digital processing.

As an example of the most recent results of the Point Scattering Model, an image was simulated for a site ($35^{\circ} 04' N$ by $88^{\circ} 15' W$) through which the Tennessee River flows. Goodyear 3 m resolution SAR imagery was purchased for comparison purposes. The actual radar data were not employed in the construction of the ground truth data base, nor in decisions about the terrain reflectivity model. Thus, some misidentification of the scattering categories can occur since the source intelligence material for delineating categories was high resolution aerial photography. Because radar and optical imagery differ so much with respect to each other in the response to terrain features, and especially moisture content and ground roughness, 100% accurate microwave response categorization would require more kinds of source intelligence data than just optical imagery in future studies. Some minor differences between the real and simulated imagery were caused by misidentification of categories because only optical intelligence data were used. Figure 1 is a side by side comparison of 3 m SAR imagery and 18 m resolution PSM simulated imagery (lower swath). The simulation parameters were set to match as closely as possible those for the actual radar system and flight path. Table 1 lists several of the system and flight parameter for the situations.

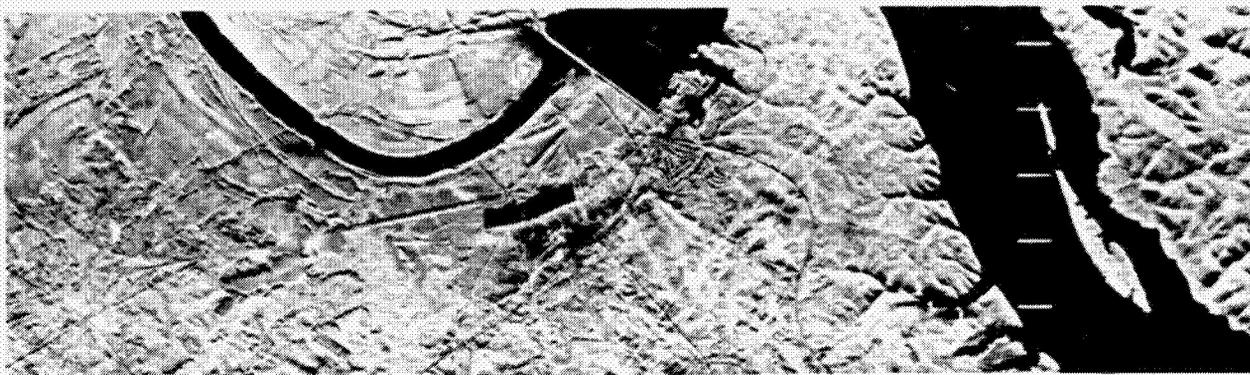
TABLE 1
FLIGHT AND RADAR PARAMETERS

Parameter	APD - 10	Simulated
Altitude	8900 m	8900m
Near Range Angle of Incidence	66.7°	66.7°
Far Range Angle of Incidence	71.3°	71.3°
Heading	116.4° Magnetic	116.4° Magnetic
Look Direction	Southwest	Southwest
Frequency/Polarization	X Band HH	X Band HH

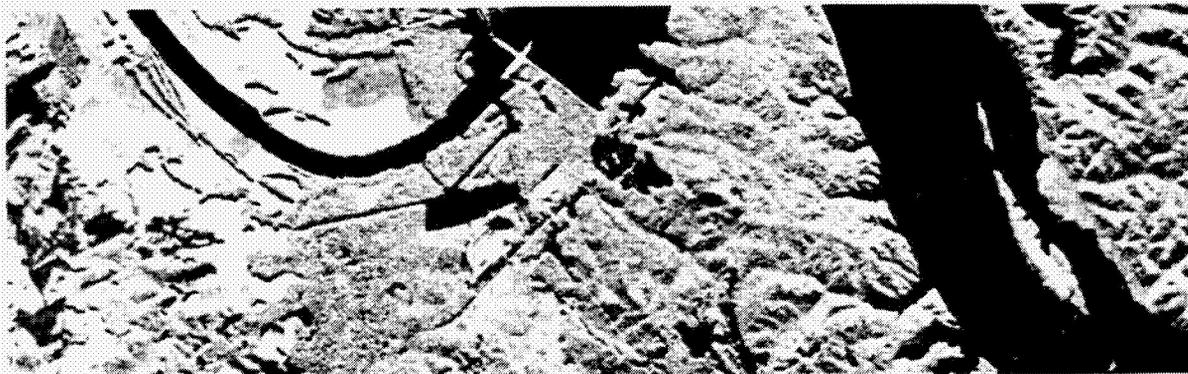


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APD - 10 IMAGERY



SIMULATED IMAGERY

FIGURE 1. COMPARISON OF APD - 10 SAR IMAGERY
AND PSM SIMULATED IMAGERY.

Note that because identical flight paths with respect to the ground were employed, there should be a direct correspondence between feature locations in the two images. Shadows should be of the same lengths, and oriented similarly. Fidelity in the ground truth data base in addition to correct simulation methods account for the favorable similarities in these respects. As secondary points of comparison, the relative gray shades and texture may be employed, but with caution. The deciduous trees in the test region were modeled as having a mean height of 21 meters, and a standard deviation of 3 m. The resulting texture adds to the resemblance between the imagery.

Gray tone comparisons can be made in a relative manner. When the tone of a field "A" with respect to field "B" is lighter in the real radar image, then such a relationship should exist in the simulated version. There are few instances in the swaths of Figure 1 that fail to meet this criteria. These discrepancies are explained by one of two possibilities; either a mislabeling of radar scattering category has occurred, or else the terrain reflectivity model at that particular angle of incidence does not suitably describe the region's behavior. We cannot attach a number to depict the accuracy of the simulated radar image shown, for such a comparison cannot be construed as absolute or quantitative, but the overall visual effect, in the opinion of trained radar interpreters is very good [4].

3.0 SAR SYSTEM, CALIBRATION, AND PROCESSOR DESIGN

Radar image simulation (especially the PSM) has already been shown to be invaluable in assessing and solving defense department problems [2]. In this section we propose extensions of proven technology (PSM) to a different class of problems. Consider two of the potential applications of a spaceborne SAR: soil moisture detection, and vegetation discrimination. Radar image simulation can serve as an important research tool in the implementation of a calibrated SAR for these two (and other) particular objectives. Simulation offers a way to evaluate all aspects of a spaceborne SAR program from preliminary design through mission planning via the most graphic method possible; the final image product and resultant discrimination analyses. Perturbations of recorded data, created by processor design trade-offs, operating parameters trade-offs, antenna design and degradations, calibration requirements and degradations, etc., can be predicted and the effects analyzed through the use

of radar simulation.

A well-designed candidate program utilizing radar simulation would require developing a data base for a suitable site, surveying the soil moisture and vegetation properties of the site, and collecting supportive scatterometry data and airborne radar images of the site. Before the radar simulation model would be used to evaluate the SAR questions, it would be validated by producing simulations of the airborne images and comparing them to the actual images. This would lend credence to the use of the simulation model to evaluate the SAR. After completion of these preliminary activities the PSM would be applied to evaluate the potential problems (both design and calibration) of a spaceborne SAR.

For instance, the PSM could be employed to confirm the design of the candidate SAR system. One way this could be accomplished is through confirmation of the optimum frequencies, polarizations, and angles of incidence for either soil moisture detection or vegetation monitoring. Another way this could be accomplished is through verifying the design parameters of the hardware. Design variants and their impacts on ultimate data, interpretability, and discriminations could be assayed easily. Candidate receiver/processor models could be implemented in the PSM, statistical degradations introduced, and resultant images formed. These images could be interpreted and the effects measured.

In addition, the PSM could be applied to answer questions about the design of the SAR system through the easily implemented resolution versus averaging (to reduce fading, data rates, etc.) trade-off studies. With a very fine resolution ground truth data base the effects of sacrificing resolution for speckle reduction could be appraised by human interpreters or automated classification schemes. The significance of the savings in terms of data processing expense could be large, yet the loss of information content of the imagery could be strictly monitored through such a systematic study.

The importance of antenna design and performance for a spaceborne SAR is significant. Radar image simulation as performed by implementation of the PSM can be applied to determine the effect of antenna configuration (e.g., flatness) under orbital conditions upon the final image and ultimately the effects on interpretability of the data.

In order to accomplish the goals in soil moisture detection the SAR will have to be a calibrated instrument. While conventional statistical techniques can be used to estimate the effect of component variations, orbital trajectory errors etc., on the return video signal it is only through simulation of the final data products that an assessment can be made as to the effect on the ability to interpret the images. It is suggested, therefore, that simulated imagery be produced for typical soil moisture (and agricultural) targets to test different calibration techniques, as well as to evaluate the variability. The simulated images would be compared to baseline simulations and the resulting classification would establish the expected success under the tested conditions.

Simulation can also play a vital role in "real-time" calibration of the orbital sensor. It is anticipated that calibrated ground-based measurements taken simultaneously with orbital overflights will be performed to "calibrate" the SAR. Rather than calibrate on a few fields, simulated imagery could be produced to mimic the conditions at the time of the overflight incorporating the ground measurements and then could be used to calibrate the identical imagery produced by the spaceborne SAR. This experiment is analogous to the S193 exercise of comparing pre-flight antenna patterns with antenna patterns measured from space (APEX Experiment [5]) to validate system performance and to obtain the final calibration of the S193 data.

Calibration has many ramifications as to the final success of an orbital SAR. Conjectures as to the performance, precision, and accuracy of the SAR must be answered at an early date. Simulation, especially using the PSM as a vehicle, can play an important role in ending the conjectures, leading to definitive results.

Assuming a design is finalized for the proposed SAR, the value of image combinations, for example, spaceborne SAR with LANDSAT could be evaluated. Human interpreter studies and/or automated multivariate classification analyses could be performed on the superposition to determine the usefulness of such a combination. In the event that a multifrequency/multipolarization SAR design is proposed or later chosen, then corresponding simulated images could be digitally processed, optically filtered, superimposed, etc., before the SAR becomes operational.

Needless to say, there are many techniques which will be employed in the design and operation of a spaceborne SAR assigned to accomplish the tasks of soil moisture detection and vegetation analysis. Simulation of radar imagery is one feasible, cost-effective and efficient method. It should be combined with others, e.g., observation of existing SAR imagery and empirical σ^0 data. There may be glaring objections to the use of a single method when such an enormous number of factors contribute to the success or failure of the mission. Choosing design parameters from radar imagery alone is probably insufficient because (1) the lack of space radar imagery of natural terrain surfaces, (2) the absence of numerous data collected by a single, calibrated system, and (3) the "individuality" of resultant images produced by existing commercial and government radars.

4.0 CONCLUSIONS

The Point Scattering Method for radar image simulation has been briefly reviewed and some strip-image format results were shown as a means to assess quality of the products generated. Space does not permit either a full theoretical development of the PSM or a complete analysis of the results. The interested reader can find such details in the referenced documents [1,2].

Simulation traditionally has been an important research tool in all engineering and scientific disciplines but has not been available to the radar designer to the extent being discussed here. Certainly simulations of systems and components have been employed but not the complete imaging simulation represented by the PSM. This newly emerging area, radar image simulation, has been successfully applied to defense-related problems [2] and now offers its capabilities to evaluate problems and answer questions regarding a spaceborne SAR designed to measure soil moisture or to monitor vegetation.

Sample studies of a well-designed program employing radar simulation for evaluation of SAR system, processor design, and calibration are proposed. Space prohibits a definitive statement about the application of radar simulation to address specific system problems, so only the major goals and objectives, and potential rewards are discussed.

REFERENCES

1. Holtzman, J.C., V.H. Kaupp, R.L. Martin, E.E. Komp, and V.S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," ETL TR-0047, U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, February, 1976.
2. Holtzman, J.C., V.H. Kaupp, J.L. Abbott, V.S. Frost, E.E. Komp, and E.C. Davison, "Radar Image Simulation: Validation of the Point Scattering Model," Volume 1, ETL TR-0117, U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, June, 1977.
3. Holtzman, J.C., V.S. Frost, J. L. Abbott, and V.H. Kaupp, " A Mathematical Model for a Terrain-Imaging Radar and its Potential Application to Radar Image Simulation," Remote Sensing Laboratory Technical Report 319-6, University of Kansas, Lawrence, Kansas, November, 1976.
4. L. F. Dellwig, personal communication.
5. Kaupp, V.H., J.C. Holtzman, "Skylab Program Earth Resources Experiment Package, Sensor Performance Report, S193 RAD/SCAT Final Report," Remote Sensing Laboratory Technical Report 236-4, University of Kansas, Lawrence, Kansas, July, 1975.