Techniques for Utilizing Side-Looking Airborne Radar (SLAR) Imagery in Regional Highway Planning

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SLAR is a self-illuminating, imaging sensor capable of operating over a wide wavelength range in a side-scanning mode. Feasibility studies have demonstrated the potential value of SLAR in terrain analysis, geologic and planimetric mapping, vegetation classification, and a multitude of related earth science disciplines. This paper presents a procedure in which SLAR imagery strips or mosaics can be utilized as the primary presentation of terrain data for the regional planning of transportation systems. The SLAR image strip or mosaic can serve as a base map of existing major cultural features as well as a presentation from which regional classifications of engineering soil types, drainage, and topography can be made. Techniques for measuring and interpreting these factors from SLAR imagery are presented along with an evaluation of their reliability. Included are image texture and return analyses as well as interpretation keys. Advantages and disadvantages of SLAR imagery are compared with the conventional photography and topographic maps currently used for regional highway planning.

•SLAR (side-looking airborne radar) is a self-illuminating, imaging sensor capable of operating within a wide range of frequencies. Wavelengths in the radar band of the electromagnetic spectrum range from about one-half centimenter to several meters. The side-scan geometry of SLAR, illustrated in Figure 1, produces a small-scale image similar in appearance to a shaded relief presentation of the terrain. Contrasts in radar return (reflectivity) values are electronically processed to produce gray tones on film that can be related to a number of land surface conditions.

Although many studies have demonstrated the potential of SLAR for geologic and planimetric mapping, vegetative classification, and related earth science disciplines, few studies have been conducted utilizing SLAR imagery as a civil engineering tool. Moreover, very few reports exist in which a systematic approach toward the interpretation of SLAR has been the primary objective.

This paper presents an approach to the interpretation of regional engineering soil groups from SLAR imagery. SLAR imagery strips or mosaics are utilized as the primary presentation of terrain data for regional transportation system studies and regional mapping of engineering soil groups. An engineering soil group is defined for this purpose as an assemblage of similar soil types or parent materials, which constitute a unique landform and express a recognizable pattern on the radar image.

This paper represents only the opinions of the authors and does not reflect the official approval of the U. S. Army Engineering Topographic Laboratories, sponsor of this research, or of Purdue University.

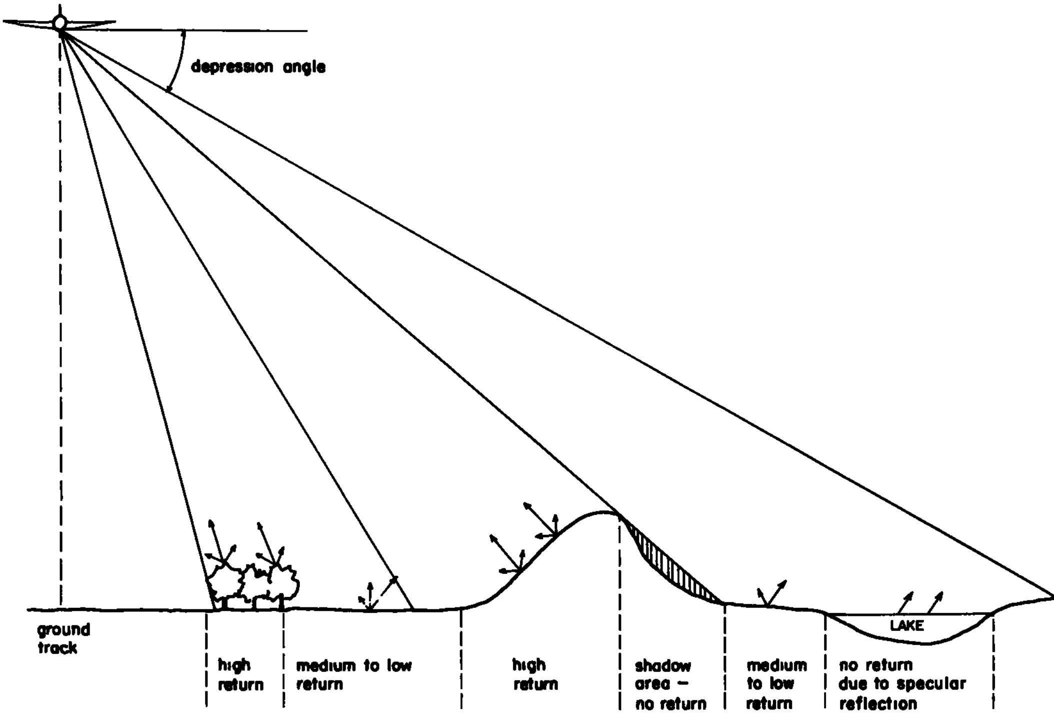


Figure 1. Basic radar geometry.

CONCEPT

It is proposed that SLAR imagery affords the materials and transportation engineer a useful display of terrain data on which preliminary route locations and regional material boundaries can readily be delineated. Because of its imaging geometry and manner of recording reflected electromagnetic energy, the SLAR image can serve as the base map of existing cultural features as well as natural terrain information.

SLAR is indeed unique and useful for regional planning and engineering materials mapping. The following characteristics are exploited in the utilization of SLAR imagery for civil engineering purposes:

1. The SLAR system is operational in virtually all kinds of weather day or night. Imagery can be obtained from those portions of the earth that are perennially cloud covered.
2. SLAR imagery is generally produced at a relatively small scale. Typical scales range from 1:100,000 to 1:400,000 and afford a synoptic display of terrain data.
3. Relief of imaged terrain can be estimated in a relative sense from a SLAR image. The image geometry produces a display similar in appearance to a shaded relief topographic map.
4. Many objects that tend to be good reflectors of electromagnetic energy (including most cultural features) are emphasized on SLAR imagery. Objects or clusters of objects that would normally be lost on conventional small-scale mosaics of aerial photography appear as high returns (bright spots) on SLAR imagery.
5. Although highly reflective surfaces such as buildings are emphasized on SLAR imagery, SLAR characteristically tends to average returns from natural terrain, thus producing an image that is not confused by infinite detail. Thus, in comparison with a photographic mosaic at the same scale, the radar imagery strip will present a relatively unconfused display of regional terrain patterns and landforms.
6. The relatively small-scale SLAR image possesses characteristic regional patterns that can be analyzed by inference techniques for the interpretation of regional engineering soil types.

IMAGERY

Much of the SLAR imagery used for development of the interpretation approach has been from K-band radar (0.83-2.75 cm). A variety of SLAR imagery strips representative of many geographic regions has been analyzed. This imagery, originally obtained by the National Aeronautics and Space Administration in cooperation with the

TABLE 1

RADAR IMAGE CHARACTERISTICS OF CULTURAL FEATURES

Cultural Feature	General Radar Image Characteristics	
	Return	Pattern
Urban area	Very high	Linear and rectangular grid patterns produced by intersecting streets, clusters of high return spots from buildings
Suburban area	Medium to high	Linear and rectangular grid produced by intersecting streets, few high return clusters but dependent upon density
Highways—improved	Very low	Linear traces, generally smooth curves
Highways—unimproved	Very low	Linear traces, possibly sharp curves and poor alignment, similar to adjacent terrain
Railroad	Very high	Linear traces, very gentle curves
Power transmission lines	Very high	Beaded pattern resulting from individual towers
Bridge structures	Very high	Usually individual high return spot or short linear trace
Airport		
Runways	Very low	Linear traces, X-pattern
Structures	High to very high	Clusters of returns
Industrial area	Very high	Clusters of high returns in localized area
Agricultural area	Variable—high to low	Rectangular blocks with uniform return, variation in return from block to block

TABLE 2

DATA GUIDE FOR RADAR IMAGE ANALYSIS

Evaluate Relative Radar Returns

1 Overall return values
2 Special areas of high or low returns
3 Regional uniformity or variability of return
4 Extent and shape of radar shadow (no return) areas

Evaluate Image Texture and Local Pattern

1 Extent of smooth, rough, granular, etc , regional and local image textures
2 Effect of surface drainage and topography on regional and local image texture
3 Effect of surface drainage and topography on regional and local patterns
4 Effect of vegetation on regional and local image texture

Delineate Surface Drainage System

1 Evaluation of drainage patterns, i e , geomorphic types (dendritic, parallel, etc)
2 Areas showing evidence of lack of drainage or intense drainage
3 Estimation of drainage density

Analyze Topography

1 Degree of dissection
2 Estimate of relief based on size and shape of shadow as well as drainage density
3 Relation of topography to vegetation and culture
4 Effect of topography on radar return

Infer Vegetation, Culture, and Land Use

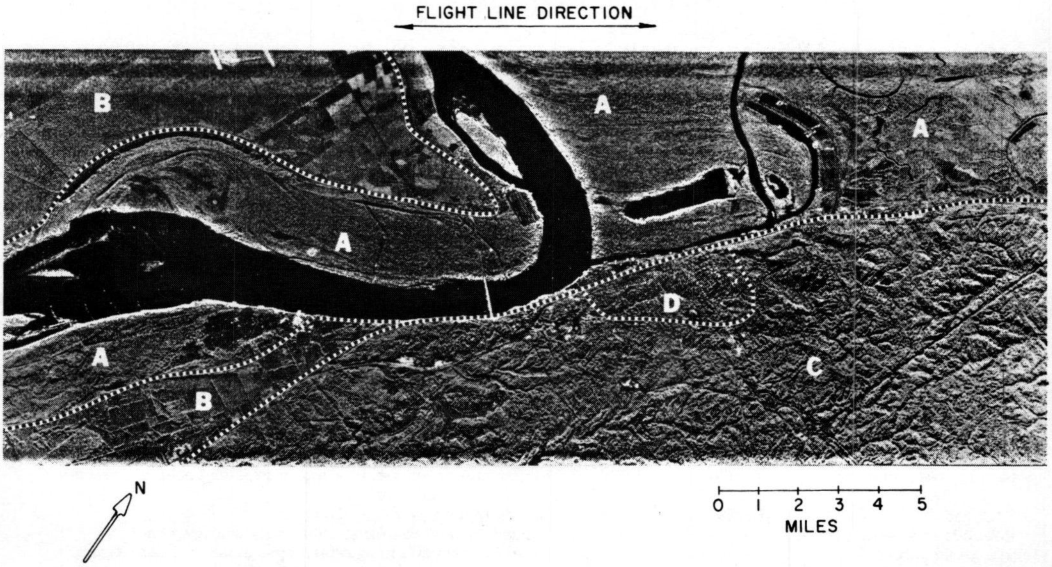
1 Types of crops and field patterns, i e , rectangular fields, contour farming, strip farming
2 Percent vegetation types
3 Location and extent of cities and surface transportation systems

Interpret Landforms

1 Landform types—genetic and morphological
2 Local association with other elements

Infer Parent Material

1 Consolidated material
2 Unconsolidated material



INTERPRETATION EXAMPLE

Area	Regional Drainage	Regional Topography	Land Use	Special Conditions	Landform and Inferred Engineering Soil Type
A	Oxbows meander scars prevalent	Relatively flat; curvilinear patterns indicative of low ridge and swale	Limited; predominantly forest with some grassy areas	Borrow pit for levee adjacent area; tonal contrasts indicative of selective growth of vegetation.	Flood plain, ridge and swale type; unconsolidated, fine-grained alluvium.
B	No evidence of surface drainage	Flat	Retangular field patterns, some trees along fencerows	Area protected by levee, fields not affected by topography.	Flood plain; unconsolidated, fine-grained alluvium
C	Dendritic with pinnate tributaries, high density of streams	Moderate relief, highly dissected steep valley walls	Limited activity, predominantly forested	Steep valley walls indicated by thin shadows and light tones.	Dissected loess surface; unconsolidated, fine-grained eolian material
D	None	Same as C	Light tonal elements and gridded pattern indicative of urban area		

Figure 2. SLAR image of Lower Mississippi Valley.

U. S. Army Electronics Command, was acquired from the U. S. Army Engineering Topographic Laboratories for use on a research project under contract with Purdue Research Foundation.

Although imagery from one system constituted the primary source of information for this paper, a comparative analysis has indicated that imagery from other radar systems is not significantly different in character for regional soils interpretation. Thus, the soils interpretation procedure is judged to be applicable to the use of imagery from several SLAR systems.

INTERPRETATION

Cultural Detail

The correct identification of cultural detail that may influence location decisions on SLAR imagery is affected primarily by an interpreter's ability to recognize typical returns. Although not all individual objects (houses, etc.) will be identifiable on the imagery, all urban areas and concentrations of cultural objects are interpretable. Table 1 lists some of the cultural features pertinent to route location studies along with their radar image characteristics.

The mapping of cultural features is based on the identification of radar returns from objects and is somewhat less involved than the interpretation of regional soils. Point return spots are the major clues.

It must be stressed again that all cultural features are not interpretable from the SLAR image. Some of the cultural information needed for determining preliminary route locations is not directly available from the SLAR imagery. However, the imagery can form an excellent base map, if corrected for geometric distortion, upon which collateral data can be displayed. It is important that major features are recorded on the imagery, for in some cases these are the first items of interest.

Regional Engineering Soils (Parent Materials)

The interpretation of regional engineering soil groups is accomplished by analyzing radar imagery in a systematic manner. The technique is based on the correlation of radar patterns of terrain from which engineering soils information is inferred. Basically, the only information to be gained directly from the radar image includes return value (brightness of each resolution element on the image) and the spatial arrangement of resolution elements. In other words, the image tones and image textures are the only data directly obtainable from the radar. From this, however, one can interpret relief, drainage, and landforms as well as infer general vegetative cover, engineering soil groups, and general physical condition of the land surface. The more one can relate "ground truth" data to the radar image, however, the more accurate will be the inference of engineering information.

The radar interpretation technique presented, being patterned after conventional photo-interpretation techniques, requires a step-by-step evaluation of radar returns and radar image textures as well as a systematic analysis of the local and regional patterns formed by the radar returns. In practice, the technique is most efficient when gross features and patterns are evaluated first, followed by the delineation of areas of apparent homogeneity on the SLAR imagery. Once these boundaries have been established on the basis of regional radar patterns, a closer look at radar returns and textures helps in the inference of engineering soil group and land surface condition.

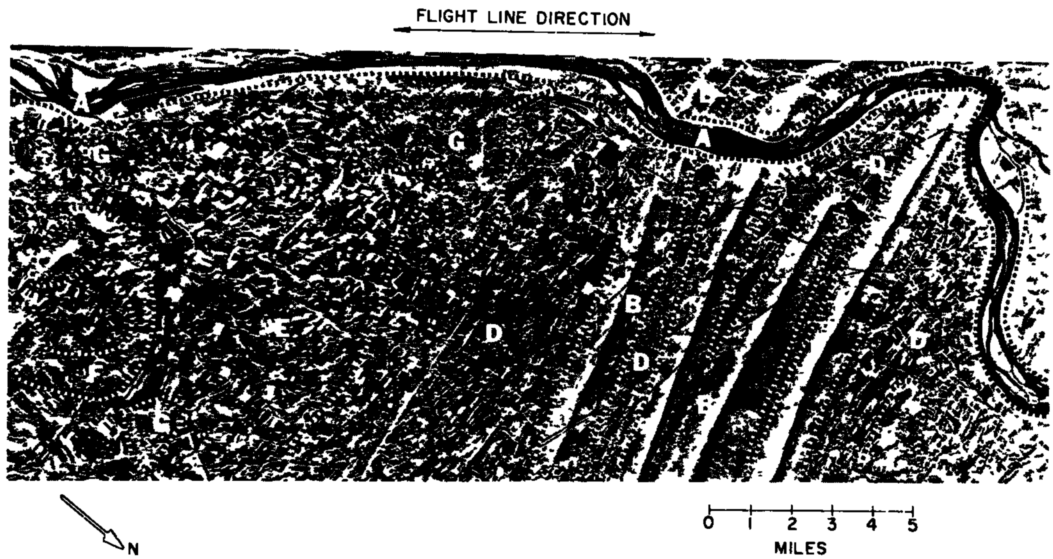
Table 2 outlines a basic data guide used for organizing a process of information extraction from SLAR imagery. As the topics in the data guide are evaluated, an interpreter can delineate those areas on the imagery that appear to exhibit uniform radar characteristics. As previously mentioned, relative radar return and textures are the basic radar data presented in the photographic format, whereas drainage system, topography, vegetation, culture, land use, landform associations, and regional parent materials are inferred from the basic radar information. All of the elements that combine to form a radar pattern are interrelated. However, the arbitrary subdivisions in the data guide tend to force the organization of radar interpretation information into an efficient format.

The elements of terrain that include topography, drainage, and landforms can be inferred from SLAR imagery. It requires only a little instruction in basic radar imaging principles to recognize and evaluate these elements. The evaluation of local terrain surface roughness and land surface condition by means of relative image tones and textures, however, is unique to the radar system. A partial list of the radar characteristics of these terrain elements is given in Table 3.

The effects of the various terrain elements on radar reflection and the resulting radar image are interrelated, with topographic effects being dominant. The unique effect of one particular element cannot always be ascertained. Thus, the interpretation of engineering soils from the image requires considerable judgment based on the best evidence available on the imagery and from collateral information.

Examples of Engineering Soils Interpretation

SLAR imagery of Mississippi Valley and Pennsylvania study sites has been selected to illustrate the interpretation technique. Figure 2 is an unretouched SLAR positive image of a portion of the Lower Mississippi Valley. The image was evaluated with respect to the items shown in Tables 2 and 3. The annotation of Figure 2 summarizes the analysis of regional drainage, regional topography, land use, and special conditions, and presents an interpreted landform and inferred engineering soil type for each delineated area.



INTERPRETATION EXAMPLE

Area	Regional Drainage	Regional Topography	Land Use	Special Conditions	Landform and Inferred Engineering Soil Type
A	Meandering stream and tributary	Relatively flat, terraces and flood plain exist, several islands	Agricultural activity along flood plain and terraces	Strong control exerted on the stream in several areas	Flood plain and terrace, unconsolidated fluvial drift
B	Trellis	Linear ridges with high relief	Predominantly forest	Ridges parallel and separated by linear valleys	Sedimentary mountains, resistant sedimentary rock
C	Dendritic	Hills with moderate relief	Predominantly forest	Associated with linear ridges of area B but does not express linearity	Sedimentroy hills, relatively resistant bedrock
D	Dendritic with locally rectangular	Low-relief valleys associated with adjacent linear ridges	Agricultural activity, limited riparian vegetation	Many cultural features scattered throughout area	Sedimentary valley, non-resistant sedimentary rock
E	Dendritic, tributary streams bifurcate between areas E and D, major stream exhibits marked pattern of retangularity	Relatively low relief, valley	Agricultural activity, field size larger and more regularly shaped		Sedimentary valley, non-resistant sedimentary rock
F	Drainage part of dendritic pattern of area E, but annular in form	Hills in circular shape	Predominantly forest	Topographic expression suggests igneous intrusive activity	Ring dike, resistant bedrock consisting of metamorphosed or igneous instrusive rock
G	None	Same as E	Light tones and gridded pattern indicative of urban areas	Grid	

Figure 3. SLAR image of Pennsylvania site.

With respect to regional terrain analysis, it can be seen in Figure 2 that the high-relief areas are represented on the image as containing a high density of drainage and radar shadow produced by topography. The determination of high-relief areas along with the ability to define and locate major cultural features allows preliminary regional transportation corridors to be established on image overlays. These corridors can be selected on the basis of regional topographic and cultural influences, thus eliminating the need for detailed examination of the entire region in question. Conventional photo-interpretation techniques can be utilized in establishing possible highway routes within the previously defined corridors.

A SLAR image of an area in Pennsylvania is illustrated in Figure 3. It is inferred that each of the delineated areas of the image contains similar parent materials and regional engineering soil types. The annotation summarizes the evaluation of factors used in the deductive process.

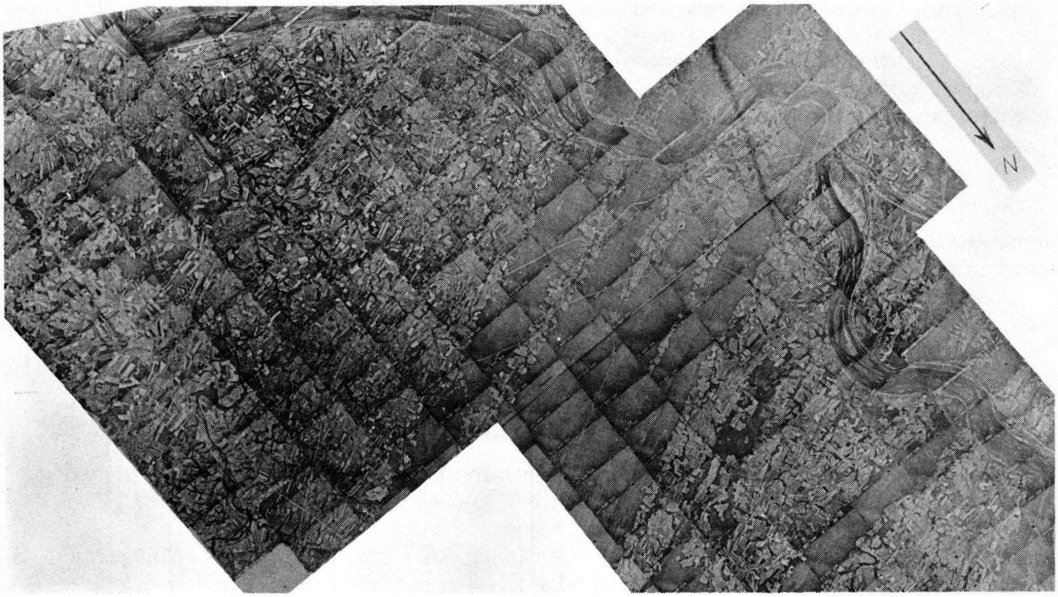


Figure 4. Index photo mosaic of Pennsylvania site.

TABLE 3

TERRAIN FACTORS AND REPRESENTATIVE TONAL RANGES
(Factors are not mutually exclusive)

Factor	Reflection Characteristic	Tonal Range
Topographic		
Flat surface	Specular reflection if surface is smooth; no return	Dark tones
Sloping surface facing antenna	Relatively high return due to orientation effects	Medium to light tones
Sloping surface facing away from antenna	Relatively low return due to orientation effects	Medium to dark tones
High relief	No return from shadow areas	Dark tone
Geologic		
Rough surfaces (> 1 wavelength)	Diffuse reflection; medium to high returns	Medium to light tones
Smooth surfaces (< 1 wavelength)	Specular reflection if surface is flat; no return; reflection influenced by topographic effects	Dark tones; lighter tones produced by orientation effects
Natural corner reflectors produced in bedrock by weathering	Maximum reflection; high return	Very light tones
Vegetation		
Trees Woods and forests	Diffuse reflection High returns	Light tones
Brush	Higher returns with increasing density of occurrence	Light tones in humid to subhumid areas; medium to dark tones in arid environment
Natural grass	Diffuse reflections; medium to low returns; dry sparse vegetation produces less scatter than lush moisture-rich vegetation	Medium tones in humid to subhumid areas; dark tones in arid environment
Broad-leaf crops with naturally high moisture content	Diffuse reflection; high returns	Light tones
Small-leaf crops	Diffuse reflection; medium returns	Medium tones

The value of this image for preliminary regional transportation corridor evaluation can be seen when comparing it with the photo index of the same area illustrated in Figure 4. Although the resolution of the SLAR image is poorer, land-water contacts and topography are accentuated on the monoscopic imagery. In addition, major cultural features stand out in contrast to the natural terrain.

SUMMARY

SLAR imagery, because of its relatively low resolution, is useful for presenting a synoptic display of terrain information. It can be utilized for maximum benefit when used in concert with aerial photography.

A systematic procedure for SLAR image interpretation can be used to advantage in regional terrain and engineering soils studies, which in turn can aid in highway planning of regional scope. The technique provides the potential for the preliminary selection of routes as well as the mapping of construction material sources.

REFERENCES

1. Beatty, F. D., et al. Geoscience Potentials of Side-Looking Radar. Raytheon/Autometric Corporation, Contract No. DA-44-009-AMC-1040 (X) with U. S. Army Corps of Engineers, 1965.
2. Thompson, M. M. (Editor-in-Chief). Manual of Photogrammetry. American Society of Photogrammetry, 1966.
3. Barr, D. J. Use of Side-Looking Airborne Radar Imagery for Engineering Soils Studies. PhD thesis, School of Civil Engineering, Purdue University, 1968.