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The global-to-local search method: A systematic search procedure that uses the context of the textured layout to locate and detect low-contrast targets in aerial images

Keith Marron Park

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THE GLOBAL-TO-LOCAL SEARCH METHOD: A SYSTEMATIC SEARCH

PROCEDURE THAT USES THE CONTEXT OF THE TEXTURED

LAYOUT TO LOCATE AND DETECT LOW-CONTRAST

TARGETS IN AERIAL IMAGES

A Thesis

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

in

Interdisciplinary Studies

by

Keith Marron Park

June 1993

THE GLOBAL-TO-LOCAL SEARCH METHOD: A SYSTEMATIC SEARCH PROCEDURE THAT USES THE CONTEXT OF THE TEXTURED LAYOUT TO LOCATE AND DETECT LOW-CONTRAST TARGETS IN AERIAL IMAGES

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June 1993

Approved by:

Theodore R. McDowell, Chair, Geography	6/7/93 — Date
Diane F. Halpern, Psychology	6/2/93 — Date
David M. Riefer, Psychology	6/7/93 — Date

ABSTRACT

The Global-to-Local Search Method, as proposed in this thesis, is a systematic search procedure developed to assist military photo analysts in locating and detecting low-contrast targets. The method guides search from broad observations of a scene to narrow observations of a scene and uses the relief of the land to constrain search. Texture information is used during this narrowing of attention. Linear textures are found in broad upland and lowland textures, and local target textures are found in or near these linear textures. A zoom effect occurs when this broad-to-narrow (global-to-local) search approach is used. Consequently, targets are located quicker and more efficiently under this method than when no systematic search is used. Present findings support this proposal. During the present study, those that were instructed with the Global-to-Local Search Method performed significantly better than those who were not. Better performance consisted of a greater number of correctly detected targets and fewer false detections on aerial images of low-contrast targets (rectangular buildings) embedded in various locations throughout isolated desert terrain. The Global-to-Local Search Method is advocated for use in locating obscure targets such as illegal drug labs, bunkers, or mobile vehicles in isolated desert terrain.

ACKNOWLEDGMENTS

Finally, I wish to thank the 196th Tactical Reconnaissance Squadron at March Air Force Base for their hospitality during my research and internship there. Their expert guidance and assistance gave me many ideas to pursue for the thesis. In addition, as a result of their generosity, I was able to see how actual military photo analysts perform target analysis. I am sincerely grateful to them for allowing me to intern with their organization, an opportunity afforded very few civilians.

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CHAPTER ONE. INTRODUCTION

1.1 Overview of the Global-to-Local Search Method:

This thesis presents the Global-to-Local Search Method, a visual search procedure designed to assist the localization and detection of small, low-contrast targets (human-made objects) in airphotos of desert terrain. The method is based on the premise that context can be used to infer obscure targets through a global-to-local search of the environmental scene. 'Global' refers to broad, large-scale analysis. 'Local' refers to fine detailed analysis. It is proposed that search is fastest and targets are detected best when a global-to-local search sequence is used.

There is research support for this proposal. Field (1987) proposes that the visual system represents scenes at various scales, regardless of distance. In support, Campbell and Robson (1968) suggests that the human visual system has the neural capability to represent these various scales. They propose that neurons in the human visual system have receptive fields of various sizes. Each group of neurons that are tuned to a given receptive field record information about the scene at that respective scale. This is referred to as the "Multiple Spatial Channels Theory" (Sekuler & Blake, 1991).

An example of how environmental scenes are represented at various scales is presented in Figure 1. The oblique airphoto

SKYLINE

SLOPES

GULLIES

a

b

c
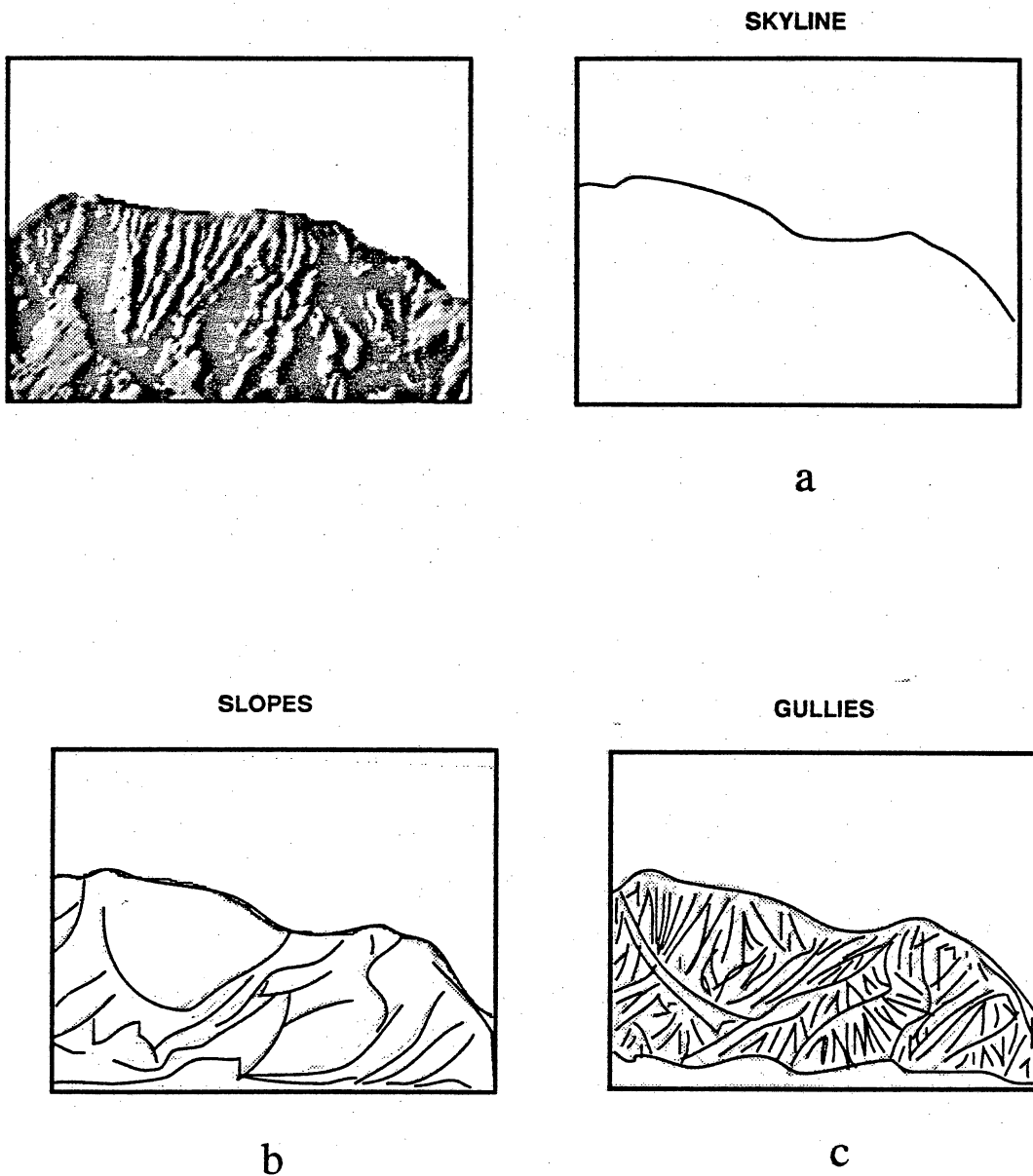
FIGURE 1.   VARIOUS SCALES ASSOCIATED WITH AN IMAGED
            ENVIRONMENTAL SCENE: (a) SKYLINE, (b) SLOPE
            FACES, AND (c) DETAILED EROSIONAL FEATURES.

of this mountain face can be represented at the global level of scale (Figure 1a) which affords information concerning the skyline. It can be represented at an intermediate scale (Figure 1b) which affords information about the individual slope faces of the mountain. Finally, it can be represented at the local level of scale (Figure 1c) which affords information about fine erosional detail such as the individual gullies.

Watt (1988), Ericksen and Murphy (1987), Shulman and Wilson (1987), and Humphreys and Quinlan (1987) propose that the visual system not only represents scenes at various levels of scale, but that the visual system scans scenes from coarse-to-fine scales over time. Scenes are viewed wide at first. Broad outlines are resolved in parallel and then local areas of detail are cued from this initial global orientation. Broad outline information appears to be acquired first since it is relatively invariant over temporal and spatial displacements. That is, broad outlines are less disturbed by differing view angles and periods of observation than fine detail. These broad features give the initial gist of a scene and establish context for local areas.

The Global-to-Local Search Method is advocated because it allows search constraints to be placed on a scene. This is important for swiftly locating and detecting targets. For

example, Brown and Monk (1975) found that targets are found more easily when their backgrounds are constrained as in Figure 2a, as opposed to when they are randomly textured as shown in Figure 2b. As with Figure 2a, the Global-to-Local Search Method provides for selective search. That is, target areas are systematically selected from the orderly division of the terrain background.

Watt (1988) suggests that search constraints are best applied when scene elements are nested within clusters. Watt proposes that a zoom effect occurs when scene elements are clustered in this fashion. This zoom effect significantly reduces the time taken to locate the position of individual elements. For instance, Watt proposes that the positions of the individual dots in Figure 3a are acquired much faster when they are clustered within greater organizations (as within five circles) as shown in Figure 3b, than when alone as shown in Figure 3c by the sixteen individual view lines. Gibson's (1950, 1960, 1961, 1966, 1979) ecological perception theory supports this notion. Gibson proposes that the terrestrial layout is visually organized through nested visual angles. According to Gibson, terrestrial objects are referenced by super-ordinate layout structures. This theory coupled with Watt's proposal provide the major foundation for the Global-to-Local Search Method. Gibson's theory will be explained in detail in chapter 3.
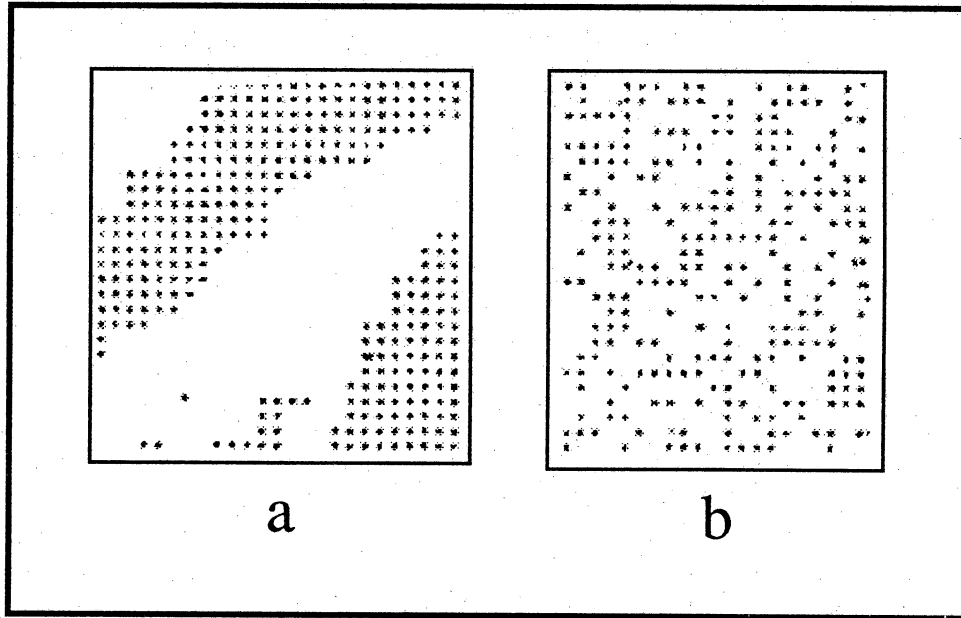
FIGURE 2. EXAMPLES OF (a) CONSTRAINED AND (b) UNCONSTRAINED
BACKGROUNDS IN BROWN AND MONK'S (1975) STUDY.

super-ordinate clusters

individual directions

a   b   c
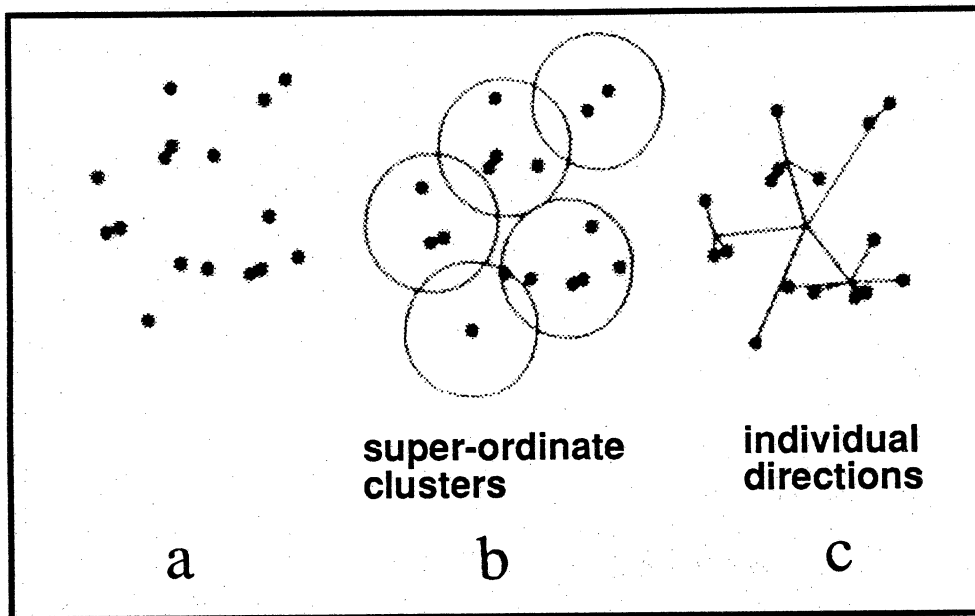
FIGURE 3. THE ADVANTAGE OF CLUSTERING OVER INDIVIDUAL
POSITIONING Of TEXTURE ELEMENTS. ELEMENT
INCLUSION WITHIN SUPER-ORDINATE STRUCTURES
IS SUPERIOR TO LOOKING IN INDIVIDUAL DIRECTIONS
(FROM WATT, 1990).

1.2 The Three Clustered Scales of Observation Associated with the Global-to-Local Search Method:

Since it is proposed that scenes should be clustered across broad-to-narrow scales when locating and detecting targets, it seems important to discuss what scales are best for this scene clustering. To find these scales, the spatial frequency range of the human visual system must be known. Spatial frequency refers to cyclic change in luminance per unit distance (Stroebel, Todd, & Zakia, 1980). Usually, it is expressed as the number of pairs of light and dark transitions (cycles) falling within one degree of visual angle subtended at the retina (Sekuler & Blake, 1990). The ability of the human visual system to sense various spatial frequencies (or modulations) is called the modulation transfer function of the human visual system. This function is shown in Figure 4. According to Figure 4, the range of spatial frequencies recorded (transferred) by the human visual system is from approximately 0.4 cycles/degree to 45 cycles/degree, with peak transfer around 6-12 cycles/degree.

If this range is divided by three, three visible scales associated with low, medium, and high spatial frequency result. These scales are correlated with known scene clusters in reconnaissance airphotos. For example, most reconnaissance airphotos are recorded from 500 to 10,000 feet above ground

MODULATION TRANSFER OF THE VISUAL SYSTEM

VISUAL SENSITIVITY

SPATIAL FREQUENCY IN CYCLES PER DEGREE

—•— Series 1
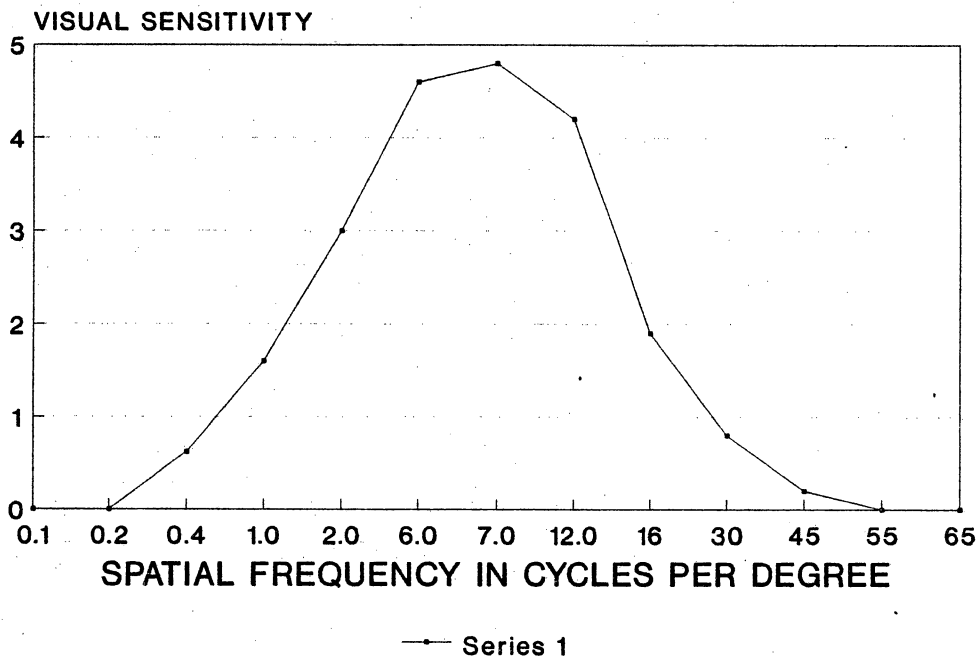
FIGURE 4. THE MODULATION TRANSFER FUNCTION OF THE HUMAN VISUAL SYSTEM (ADAPTED FROM CORNSWEET, 1970).

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level and at focal lengths of 3, 6, and 12 inches. Under these conditions, the scene clusters are upland/lowland differences (low spatial frequency clusters), linear features such as roads and rivers (medium spatial frequency clusters), and local target areas (high spatial frequency clusters).

High spatial frequency target areas are significantly affected by contrast. Contrast is the result of the amplitude of each frequency cycle. Figure 5 provides a visual example of the effects of contrast on high spatial frequency. As amplitude decreases in Figure 5 towards the bottom of the figure, high spatial frequencies become the least visible of all the frequencies. The area at which these frequencies become invisible is the detection threshold of the human visual system (Cornsweet, 1970). This percept is quantified in Figure 6. According to Figure 6, just detectable thresholds decrease drastically at spatial frequencies higher than 12 cycles/degree. For instance, a target with less than 0.05 contrast will be below the level of detection at frequencies greater than roughly 16 cycles/degree. It is proposed that a near threshold target may be inferred from scene context when it is referenced within medium and low spatial frequency clusters.

cycles per degree of visual angle
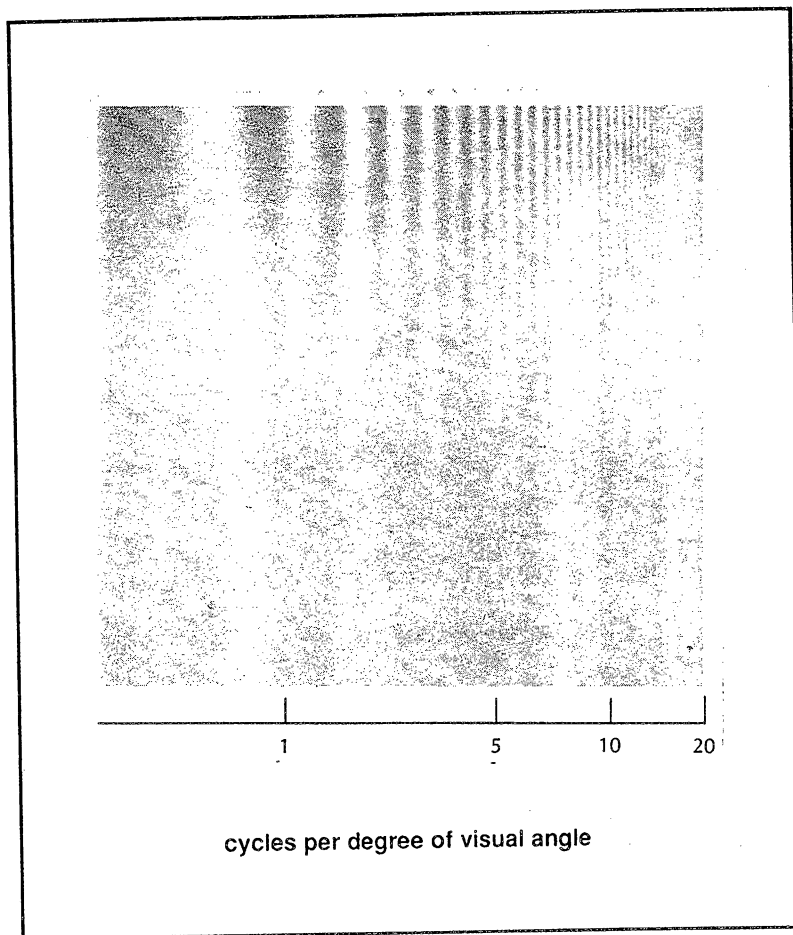
FIGURE 5. VISUAL EXAMPLE OF THE MODULATION TRANSFER FUNCTION. NOTE THAT HIGH SPATIAL FREQUENCIES NEAR THE RIGHT-SIDE OF THE FIGURE ARE THE LEAST VISIBLE TOWARDS THE BOTTOM OF THE FIGURE (FROM CORNSWEET, 1970).

10
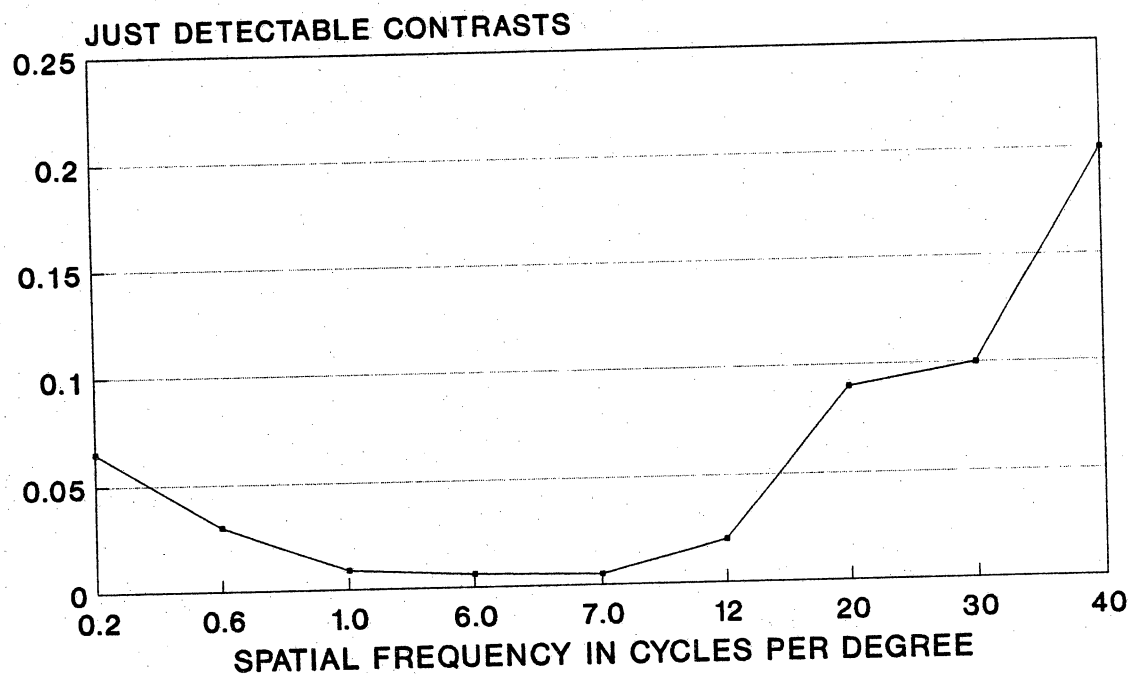
FIGURE 6. DETECTABLE SPATIAL FREQUENCIES AT VARYING CONTRASTS.
NOTE THAT SPATIAL FREQUENCIES OF GREATER THAN 12
CYCLES/DEGREE HAVE SIGNIFICANTLY HIGHER THRESHOLDS
(ADAPTED FROM SEKULER & BLAKE, 1991).

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1.3 Texture as a Means to Describe the Spatial Frequency of Natural Surfaces:

It is practical to speak in terms of texture when referring to spatial frequency of natural surfaces. Texture is the cycle of change in reflected light intensity across surfaces and micro-surfaces (Gibson, 1950; Landwehr, 1990). It provides information about the structure and identity of natural surfaces (Estes, Hajic, & Tinney, 1983; Gibson, 1979; Lillesand & Kiefer, 1987; Sekuler & Blake, 1991). As an example, texture characterizes a surface's apparent 'coarseness' and/or 'smoothness', and provides clues to the composition, structure, and rigidity of that surface. Since the proposed Global-to-Local Search Method is designed for the detection of local targets in natural terrain, its discussion will be in terms of coarse-to-fine textures instead of low-to-high spatial frequencies. For example, it is considered that smooth textured mesas are located within coarse textured table lands (i.e., broad badlands topography).

1.4 The Purpose of the Global-to-Local Search Method:

The concept for the design of a visual search method based on texture arose after this author found that image detection errors occur in many applications of imagery analysis. For example, Swennson, Hessel, and Herman (1977) reported that as high as 40% of image detection errors occur

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in radiographic interpretation. Swennson et al. proposed that most of these errors fall under "potentially correctable mistakes." These errors occur primarily because of two factors: 1) faulty visual search and 2) decisions made under degrees of uncertainty. Faulty visual search occurs mostly from unsystematic and premature focusing of attention while uncertainty exists in any task with varying outcomes. Thus, this author decided to develop a method of visual search for those engaged in target detection in isolated terrain (such as for military, drug enforcement, and search-and-rescue purposes) that insured the systematic and relevant search of high probable areas within a reconnaissance airphoto. It is proposed that this type of search method results in a reduction of likely search areas and fewer errors. Ultimately, it gives an analyst more control over the search process and allows for greater confidence. The effectiveness of the search method will be experimentally tested in chapter 5.

1.5 The Steps in the Global-to-Local Search Method:

There are four steps to the proposed search method. Each step brings an analyst from the global level of analysis (i.e., from the observation of low spatial frequencies or broad textures) in an imaged layout to more local areas of analysis (i.e., high spatial frequencies or fine texture

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detail) observed at the target-terrain contrast area. This global-to-local analysis not only allows constraints to be placed on target search areas, but also allows local target areas to be found based on their inclusion within super-ordinate textures of the terrain.

The steps are presented as follows (see Appendix B for an example of an imaged environmental scene): 1) The entire scene layout is scanned. During this scan, the recession and expansion of the textured surface is observed. 2) Corrugated uplands are clustered from fine-textured lowlands. Step two divides the layout into broad areas of topographic highs and lows. 3) Linear textured features such as roads and rivers are observed in fine-textured lowlands. They are usually found in passage areas with reasonable slope. Their courses are followed. 4) Finally, local texture differences are noted in likely passage areas. Any fine and geometric texture dimensions that are suggested by these differences are noted. Very fine and highly geometric dimensions in local texture are classified as a target. Steps 3 and 4 are then repeated for other likely passage areas until the search is completed.

1.6 The Scope and Limitations of the Global-to-Local Search Method:

These steps represent a general approach to locating and detecting human-made targets in natural terrain. More complex

methods exist for locating and detecting targets (especially embedded or camouflaged targets). However, due to issues concerning national security, these factors have been omitted. The present method is intended only as an orientation tool to be used during the onset of target analysis. Further steps in target analysis such as target recognition (i.e., the mental matching of a target with a class in memory) and identification (i.e., categorization of the class) are beyond the scope of the search method.

In addition, the present method is limited in the fact that it is designed primarily for natural terrain. The method may be compounded in urban and highly vegetative areas. In particular, urban areas are geometric in texture just as human-made targets are geometric in texture. This common regularity may confuse target localization and detection. Similarly, vegetation obscures terrain features and distinctions, and may at times occlude a target from vertical view. However, the context afforded by a global-to-local perspective may overcome these limitations.

1.7 The Importance of the Global-to-Local Search Method:

The need exists for human factors research such as the proposed Global-to-Local Search Method. Very little research to date has delved into the perceptual and cognitive factors involved with image analysis. Recorded images are more than

a conjunction of pixels (picture elements) or grey values. They are objects and scenes. Thus, to understand them one must understand how they are visually organized. Visual methods such as the one presented in this thesis are backed by research that has considered these perceptual and cognitive factors. Kundel (1979) pointed out that in the past most research has focused on optical characteristics alone such as the modulation transfer function (MTF) of the imaging system. Kundel claims that changes in the imaging system's ability to record and display high and low spatial frequency does not always create corresponding perceptual changes. The MTF is a necessary factor, but not a sufficient one. It explains an image's ability to convey texture information, but provides no information concerning optimum ways to use this texture as information. The present method does. It is hoped that what is proposed in this thesis will act as a foundation for future research into the human factors of environmental image analysis.

1.8 Thesis Organization:

The organization of this thesis is as follows: Chapter 2 discusses texture and its role in the direct perception of environmental surfaces. Experimental support from previous and recent research is presented. Chapter 3 discusses J. J. Gibson's hierarchical approach to terrestrial textured layouts

and includes support from other researchers. This chapter explains theoretically why local targets can be found in an environmentally textured layout. Chapter 4 discusses the steps of the search method in detail. Illustrations are presented to highlight these steps. Chapter 5 discusses an experimental analysis of this search method. A study is presented that examines the performance of airphoto observers using the search method as opposed to those who do not. Chapter 6 summarizes the search method and the present findings, and discusses ways in which the search method can be enhanced by existing digital image programs. For example, software functions that zoom in on a scene and manipulate spatial frequency can in effect simulate and enhance the search method steps. Illustrations are presented to highlight these computer-assisted steps. Finally, limitations and avenues for future research are discussed.

CHAPTER TWO. THE IMPORTANCE OF TEXTURE FOR

THE PERCEPTION OF SURFACES

Gibson and others have shown that texture is important for the perception of surfaces. Gibson, Purdy, and Lawrence (1955) designed an experiment in which subjects saw an illusory tunnel when enough circles were used in the display shown in Figure 7a. They also produced the illusion that the tunnel was curving when the circles were moved off center as shown in Figure 7b. The key to this illusion exists with the change in spatial frequency of the circles. That is, the illusion is manifested when circle density increases from periphery to center of the display. Increasing the number of circles enhances the illusion by providing additional gradient density information. This produces greater apparent surface depth. Proximity of circles is important in producing this illusory surface density.

Beck (1966) agreed that texture is important for the perception of surfaces. He showed that subjects use texture information to differentiate surfaces when surfaces do not differ in general luminance. Metzger (1930) also showed that texture information is important for surface perception. He reduced the lighting on a plastered wall to the point in which its texture was undetectable. Subjects reported seeing a fog or mist instead of the plastered surface of the wall. Thus, "surfaceness" depends on visible texture.
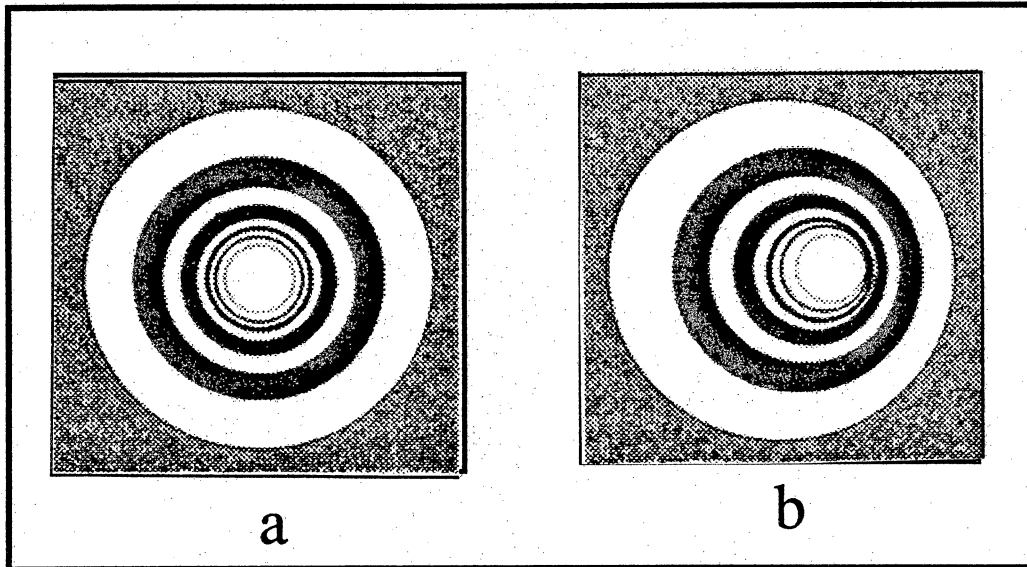
FIGURE 7.   EXAMPLES OF THE TUNNELS USED IN GIBSON ET. AL'S
(1955) STUDY.   FREQUENCY OF CIRCLES CREATED THE
PERCEPTION OF A TUNNEL SEEN IN (a). PROXIMITY OF
CIRCLES ON ONE SIDE AFFORDED THE PERCEPTION OF
A CURVING TUNNEL SEEN IN (b).

Moreover, texture gradients (i.e., changes in spatial frequencies over a surface) provide depth and coherence to a surface.

Recent researchers support the notion that texture information is used to perceive surfaces. Sedgwick (1983) updates discussion of Gibson's proposal that texture information provides direct perception of surface layout. In addition, Cowie and Clements (1989) refer to texture as an input variable that is "situation-specific." That is, texture provides direct information about a surface from any angle and/or orientation. Furthermore, Flucker and Baumberger (1988) support this view. However, instead of referring to texture as "situation-specific", they state that the optic flow of texture implies "ecological specificity." Both refer to the same concept that texture provides direct perception of surface layout and orientation. Flucker and Baumberger were interested in how the flow of texture provides continual expansion of the ground surface. More information about texture is presented in the next chapter, which explains how the nested arrangement of surface texture can be used to find local targets.

CHAPTER 3. THEORETICAL BACKGROUND FOR TEXTURED LAYOUT EFFECTS ON TARGET LOCALIZATION AND DETECTION

The surface layout can have a great influence on the detection of target objects that lie upon it. Apparently, a target object cannot be detected separately from its physical layout. They appear to be perceived together. Observers have trouble knowing "what" without "where" (Humphreys & Bruce, 1989). Biederman, Mezzanotte, Rabinowitz, Francolini, and Plude (1981), and Biederman, Mezzanotte, and Rabinowitz (1982) demonstrated this notion. One of the factors they investigated was the detectability of target objects that violated relations with their physical layout. They found that targets must be seen as supported by a ground surface, occluding some of that surface, and expected in certain areas along that surface. In order for a target to be accurately detected in a glimpse it must not violate these factors. Targets suffered significant miss rates when these violations existed. They claimed that these violations narrowed the encompassing visual field and increased detection errors. This research implies that awareness of the surrounding layout widens the visual field for the detection of targets.

In Biederman et. al's (1981, 1982) studies, subjects were presented with line drawings of real-world scenes. However, Snyder (1973) found that pilots in air-to-ground search use distinctive terrain textures to locate and detect targets. In

his study, subjects tended to fixate on those aspects of the terrain that were most apparent or broad at a distance such as linear road textures and bounded clearings when locating targets on the ground. Here again is support for the notion that the larger layout influences target location and detection (see also Greening, 1976; Overington, 1976; Scanlan, 1977). That is, Snyder's subjects used large terrain texture to hone in on local target texture. Gibson's (1950, 1960, 1961, 1966, 1979) ecological approach to visual perception provides an elaborate theory concerning the hierarchical nature of natural textured layouts. When examined in-depth, this theory explains specifically why the larger natural layout is so influential for target localization and detection.

3.1 Gibson's Concept of Layout Hierarchy:

Gibson (1979) proposes that the terrestrial surface is structured at various scales. The terrestrial surface is structured by mountains and hills on the order of kilometers. It is structured by boulders and cliffs on the order of meters. It is finely structured by pebbles and soil particles on the order or millimeters. Gibson refers to these as structural units of the terrestrial environment. He claims that the smaller units are nested in larger units; for example, "canyons are nested within mountains (1979, p. 9)."

This nesting occurs at all levels of surface scale and contains overlaps. The chosen unit to describe the environment depends on the chosen scale of the environment. Furthermore, these units repeat across the surface. Sand grains, pebbles, and rocks are stochastically (evenly) distributed.

According to Gibson (1979), the coarse macro-structure of the layout can be initially broken down into faces. Faces are component units of the total layout that face or do not face lighting. Note in Figure 8 how differential facing towards the source of light suggests surface undulations (topographic hills and valleys). This broad texture looks like wrinkles on the surface. This is the characteristic texture of a total layout.

At subordinate levels of scale, the individual faces within the layout have their own characteristic texture or micro-structure comprised of facets. Facets are also differentially inclined with respect to lighting and suggest the granularity of faces shown in Figure 8. Together, faces and facets of various scales produce nested textured layout information that is relayed to the point of observation. Textured layout information is relayed through a structured array of light that specifies the variegated conditions of the surface from which the light is reflected. Each edge of a face and facet corresponds to a projection in the array.
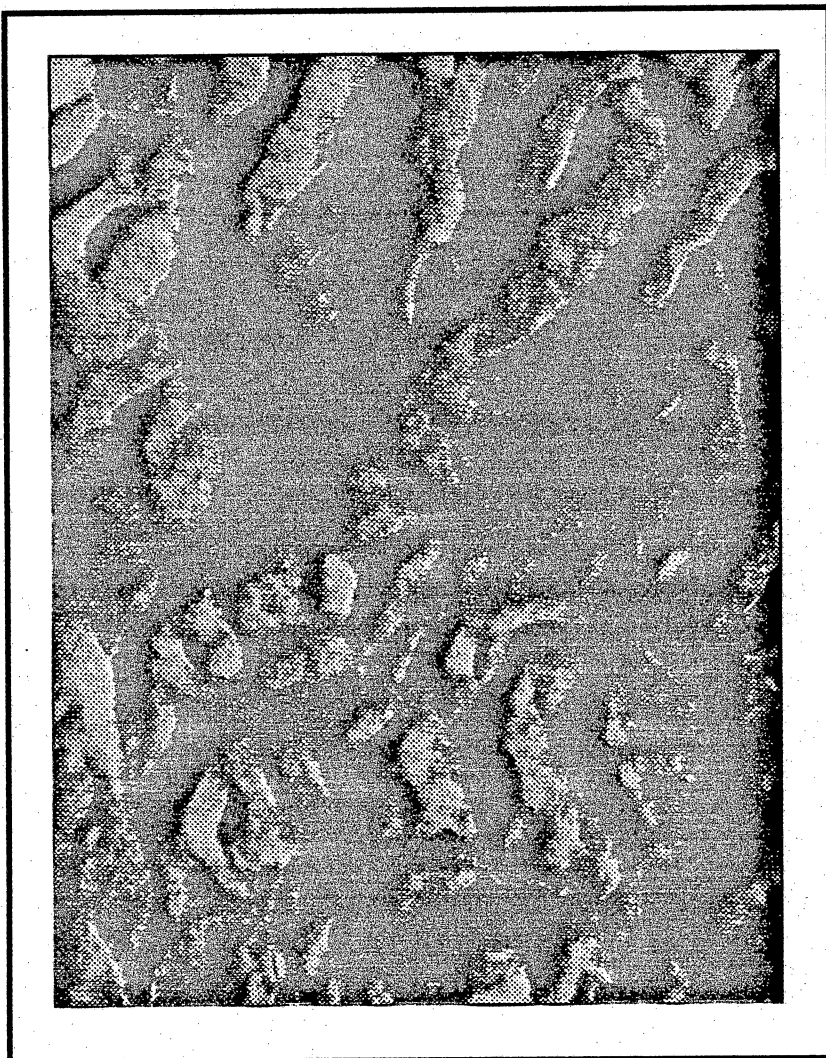
FIGURE 8. GLOBAL LAYOUT TEXTURES (FROM GIBSON, 1979).

Each projection is a visual angle that subtends each face or facet. Slanted faces and facets project narrow visual angles. Adjacent visual angles convey borders or contours in the array as shown in Figure 9. The edges of faces in Figure 9 project overlapping, subtended visual angles to a point of observation. Only surface faces are shown. The visual angles associated with the micro-structure are not shown.

The light that is reflected to the point of observation contains information about the textured layout only when this variable information exists. This variegated light is called an ambient optic array, and it denotes the structural information associated with the reflected light. The concept of the ambient optic array is central to Gibson's proposal for the hierarchical nature of layout information. Namely, the optic array is comprised of nested visual angles that correspond to the hierarchical nature of the terrestrial layout.

Gibson states that "the structure of the environment at all levels of linear size is mapped into the structure of the array at all levels of angular size (Gibson, 1966, p. 192)." This nested hierarchy of visual angles has a common apex at the point of observation. The array is completely filled with overlapping visual angles. Every visual angle is composed of smaller visual angles which correspond to the hierarchical terrain as shown in Figure 9.
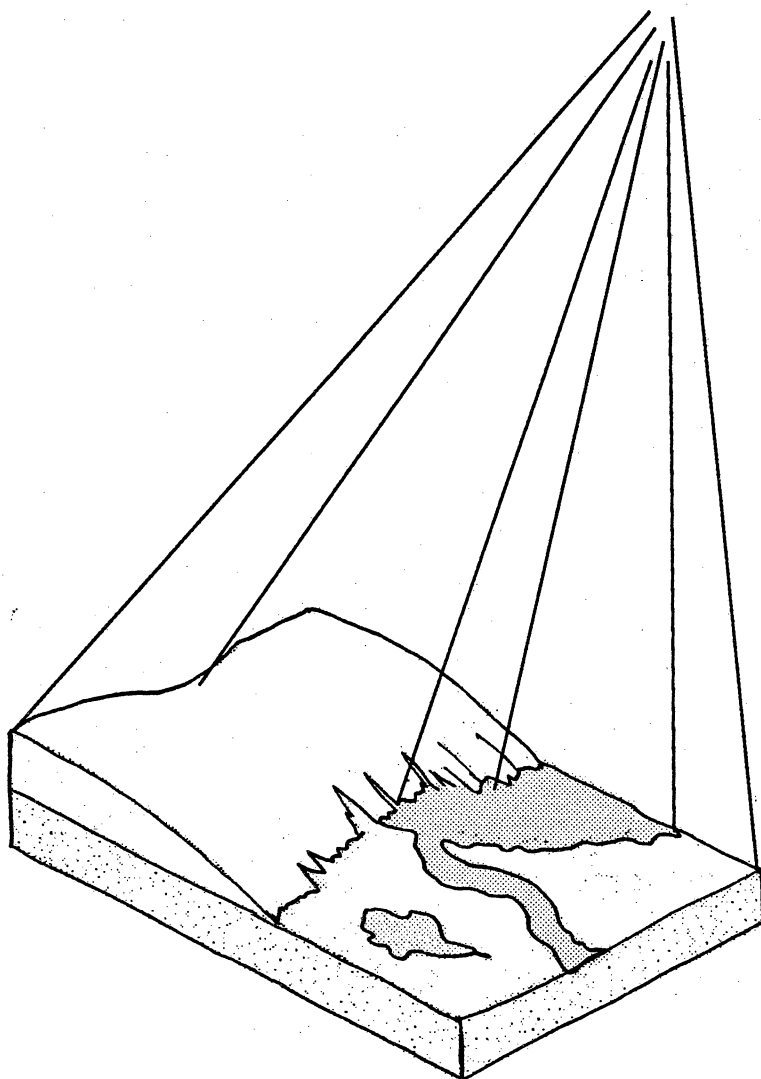
FIGURE 9. OVERLAPPING SUBTENDED VISUAL ANGLES ASSOCIATED WITH
THE MACRO-STRUCTURE OF A NATURAL SURFACE.

This means that objects are not found in the layout by a coordinate system but by their degree of inclusion within the hierarchical structure of the textured layout. Gibson provides a convincing example. A star in the sky can be found by its angular deviation from zenith, or better yet, by its inclusion within a constellation and "the super-ordinate pattern of the whole sky" (1979, p. 68). Likewise, surface facets can be seen within faces, faces within hills and valleys, and hills and valleys within mountain ranges. Each structure is found within the next super-ordinate structure. Apparently, the act of visual search over surface layout does not involve looking in different directions so much as it involves looking within structures.

3.2 Support for Gibson's Layout Hierarchy:

Recent research supports Gibson's notion about the hierarchical arrangement of terrestrial layouts and that information about the global layout is needed to understand local texture. For instance, several researchers support the notion of repeatable units within terrain hierarchies. Pentland (1986a) and Mandelbrot (1982) have shown that natural surfaces are comprised of fractal distributions. That is, surfaces are reducible and constrained to a few repeatable textural patterns. These patterns are repeatable over different levels of scale. Moreover, Mitchell (1991)

presented a terrain hierarchy composed of a fractal series. A partial list of this hierarchy is portrayed graphically in Figure 10. The terrain hierarchy is a nesting of the terrain surface based on the surface's internal variation of texture. The smallest terrain units in the hierarchy include the convex and concave faces of hillslopes and surfaces of uniform texture. Surface overlaps among nested units occur from recurring physical processes.

In addition, Katz (1935) found that the perception of global layout maintains perceptions of local texture. He proposed that a layout of definite orientation and reflectance appears indistinct and amorphous when restricted by a decrease in the angular size of the visual field. In fact, no surface perception exists. Katz showed this by narrowing the array of reflected surface light reaching the eye through an aperture. He found that a film-like field appears instead of the actual textured surface with extreme reductions in the optical field. Apparently, extreme reductions in the visual field eliminated the variable information of the global layout and resulted in a loss of local surface texture perception. Thus, these findings suggest that a global-to-local perspective is needed to accurately perceive local forms within a visual field. Scene context (as established in a scene hierarchy) appears to be a vital factor for observers to make inferences, associations, and conclusions as to what is being perceived.

SMALL-SCALE AERIAL VIEW

medium-scale aerial view

LARGE-SCALE AERIAL VIEW

LAND ELEMENT

LAND FACET
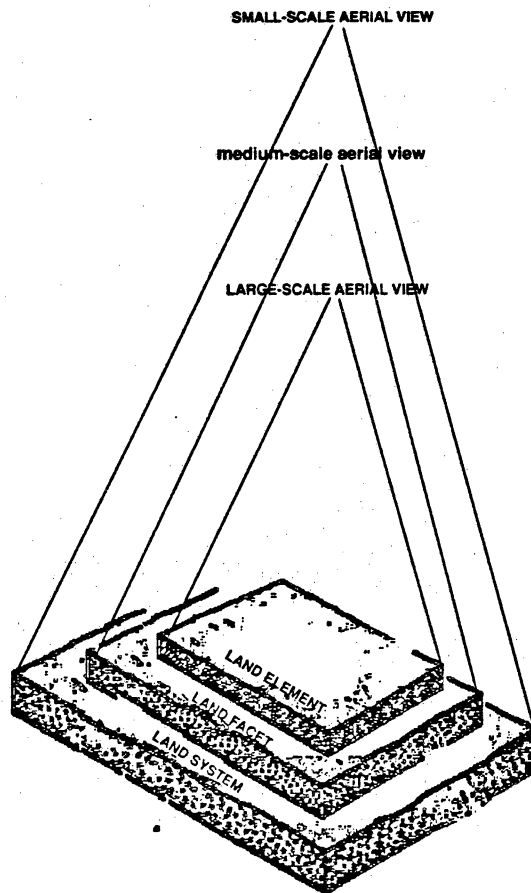
LAND SYSTEM

LAND SYSTEM: RECURRENT PATTERN OF GENETICALLY LINKED LANDS FACETS.

LAND FACET: REASONABLY HOMOGENEOUS TRACT OF LANDSCAPE DISTINCT FROM SURROUNDING AREAS AND CONTAINING A PRACTICAL GROUPING OF LAND ELEMENTS.

LAND ELEMENT: SIMPLEST HOMOGENEOUS PART OF THE LANDSCAPE, INDIVISIBLE IN FORM.

FIGURE 10. A PARTIAL LIST OF UNITS FOUND IN A TERRAIN HIERARCHY. THREE NESTED EXAMPLES ARE SHOWN. EACH ARE OBSERVABLE FROM A RESPECTIVE ALTITUDE (ADAPTED FROM MITCHELL, 1991).

CHAPTER FOUR. A DETAILED DISCUSSION OF THE SEARCH METHOD

The Global-to-Local Search Method has been synthesized from ideas reviewed in the previous chapters. Each step in the method centers attention on one of the three scales-of-view mentioned in chapter 1, section 1.2 (i.e., upland/lowland differences, linear features, and target areas). Together, they produce the nesting effect mentioned by Watt (1988) and Gibson (1979). That is, search is from a broad to a narrow focus and within terrain structures. Thus, search narrows from the layout, to upland/lowland areas, to linear passages, to local target areas. This sequence places the most logical constraint on human-made targets, by confining them to the structure of the land.

An overview of this step sequence is shown in Figures 11, 12, 13, and 14. In particular, Figure 11 is the first step. It is a visualization of the entire terrain layout. Figure 12 is a visualization of the upland and lowland differentiation step. This step is the second largest level of scale, next to scanning the entire scene layout. Figure 13 is a visualization of the lowland area focus. This step involves attention to medium-scaled texture information such as linear features and likely slopes. Finally, Figure 14 is a visualization of target-pinpointing. This last step is the most local level of scale which involves noting fine detail on or near these linear features and likely sloped areas.
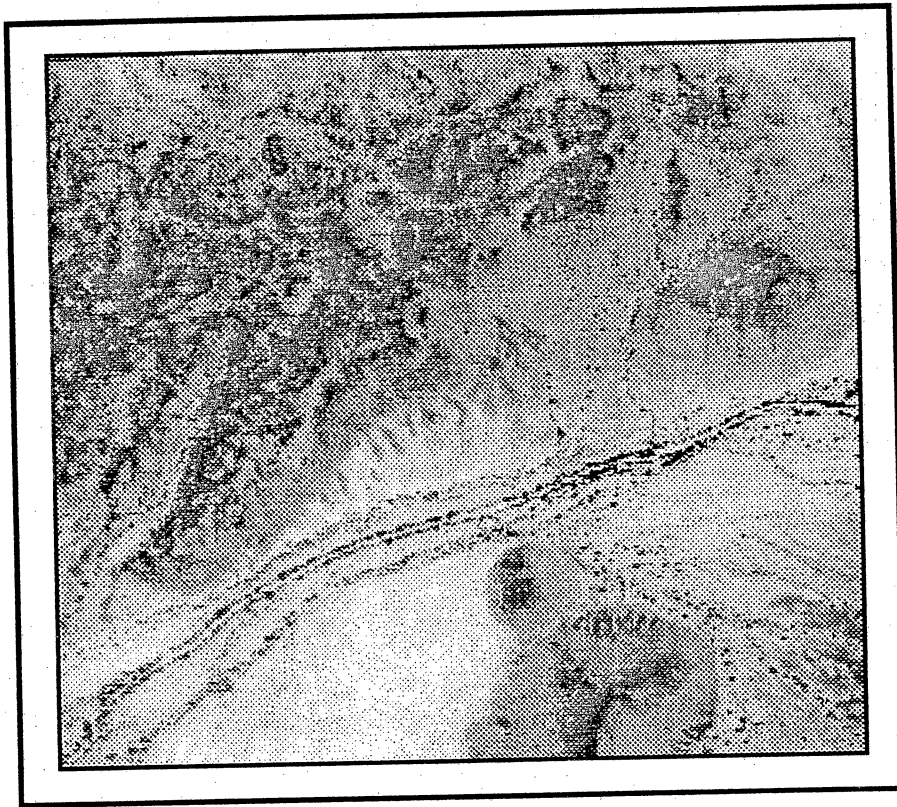
FIGURE 11. LAYOUT VISUALIZATION STEP.
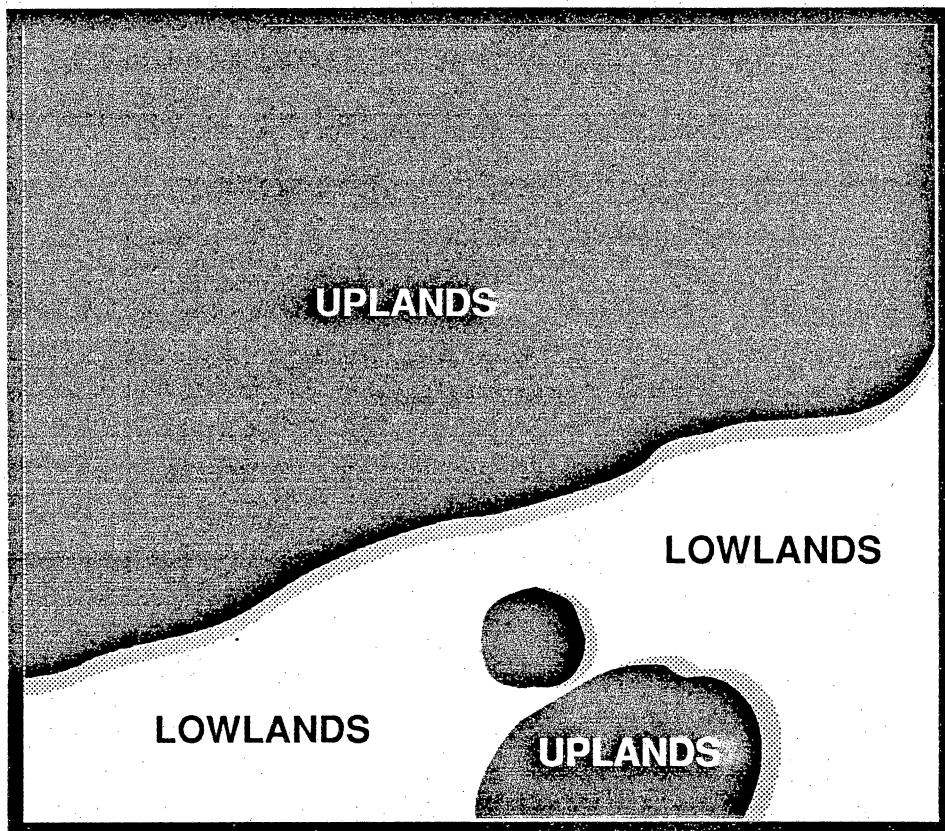
FIGURE 12.   UPLAND/LOWLAND DIFFERENTIATION STEP.
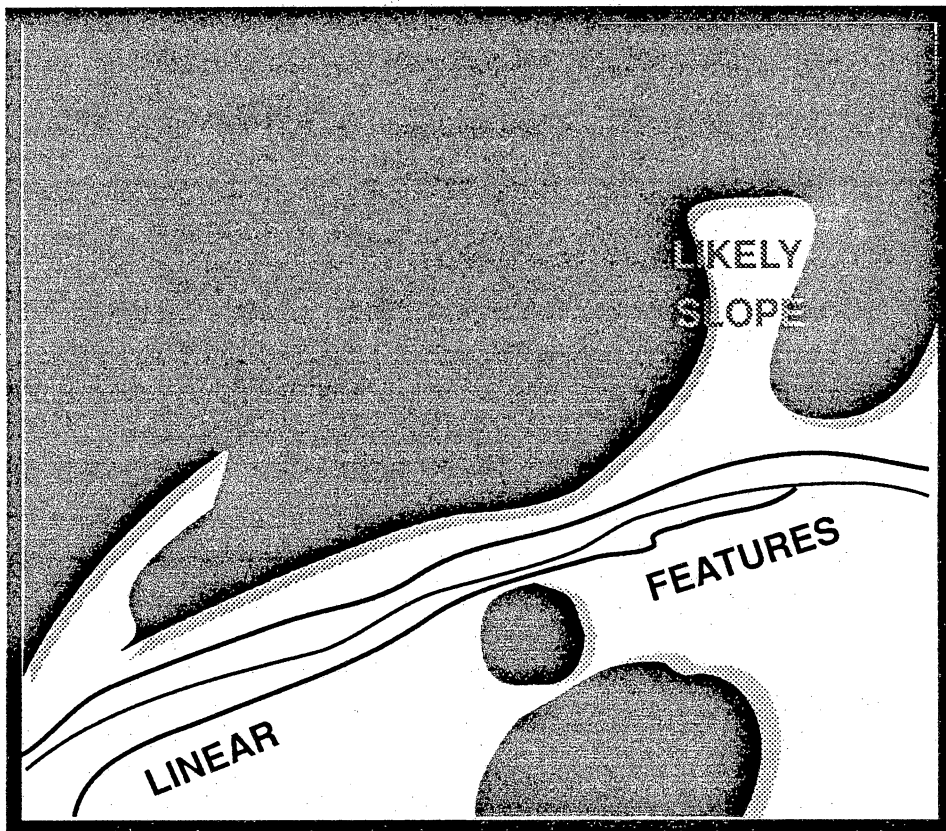
FIGURE 13. PASSAGE AREA FOCUS STEP.
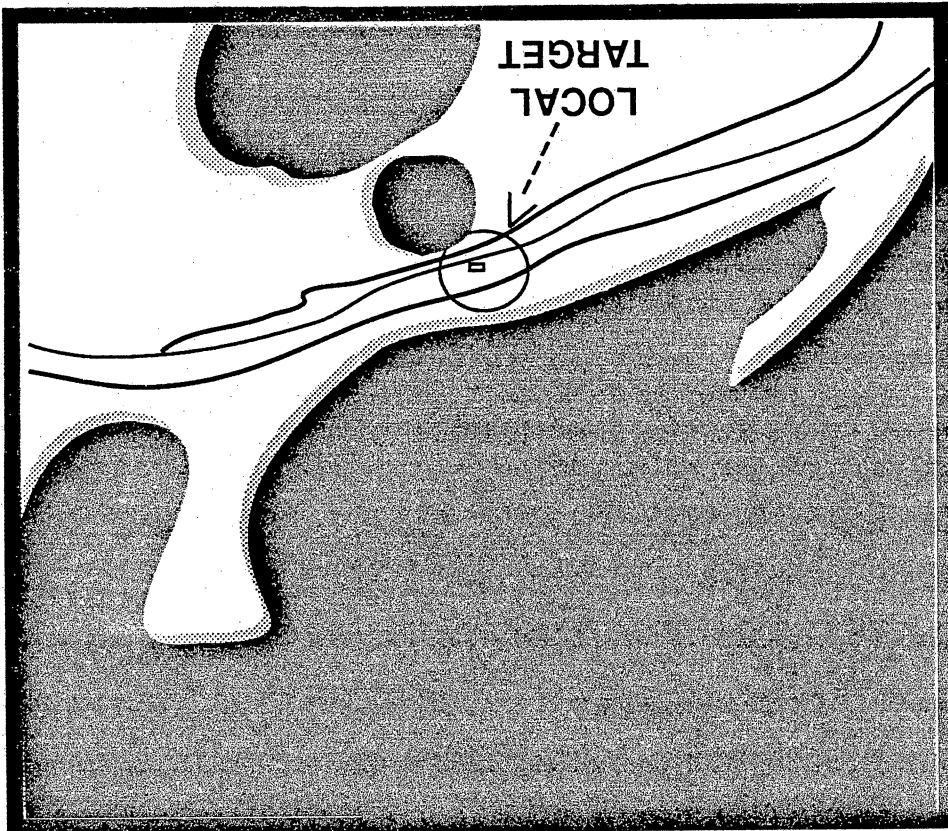
This visualization process illustrated by Figures 11, 12, 13, and 14 provides the simplest and quickest way to efficient clustering of the scene layout. The following sections in chapter 4 discuss in detail these steps and their importance in locating and detecting human-made targets. Rationale for their inclusion in the Global-to-Local Search Method is provided by further experimental or theoretical support where required.

2.1 STEP ONE: Layout Visualization:

Layout visualization is the first step in the Global-to-Local Search Method. This step entails the scanning of the scene layout in its entirety. Much information can be afforded from this initial scan. For one, observers may note the recession and expansion of the surface. This recession and expansion is suggested by the stochastically (evenly) distributed textures comprising gradients that span the surface (Gibson, 1979). Texture gradients afford surface depth information (in oblique airphotos) through the observation that there are fewer texture elements present in the closest visual angle than in the farthest visual angle. Yet, it is assumed that the actual distribution of texture elements remains invariant throughout the observed layout (Gibson, 1979). Consequently, observations of steep (dense and small) texture gradients suggest recession in space.

Observations of loose (elongated and enlarged) gradients suggest expansion in space. This is illustrated in Figures 15 and 16.

This layout distribution of texture gradients acts as a reference plane in which sub-ordinate areas in the layout are localized. That is, the characteristic density of textures at each and every location in the layout specifies that location. Consequently, local objects are referenced and judged in depth and in relation to each other by the correlation of texture elements they rest upon. Objects at different depths appear the same size when they appear as covering the same amount of texture elements. This point is illustrated in Figure 16. It is important to remember this texture-size-depth relationship when referencing local target areas in oblique airphotos.
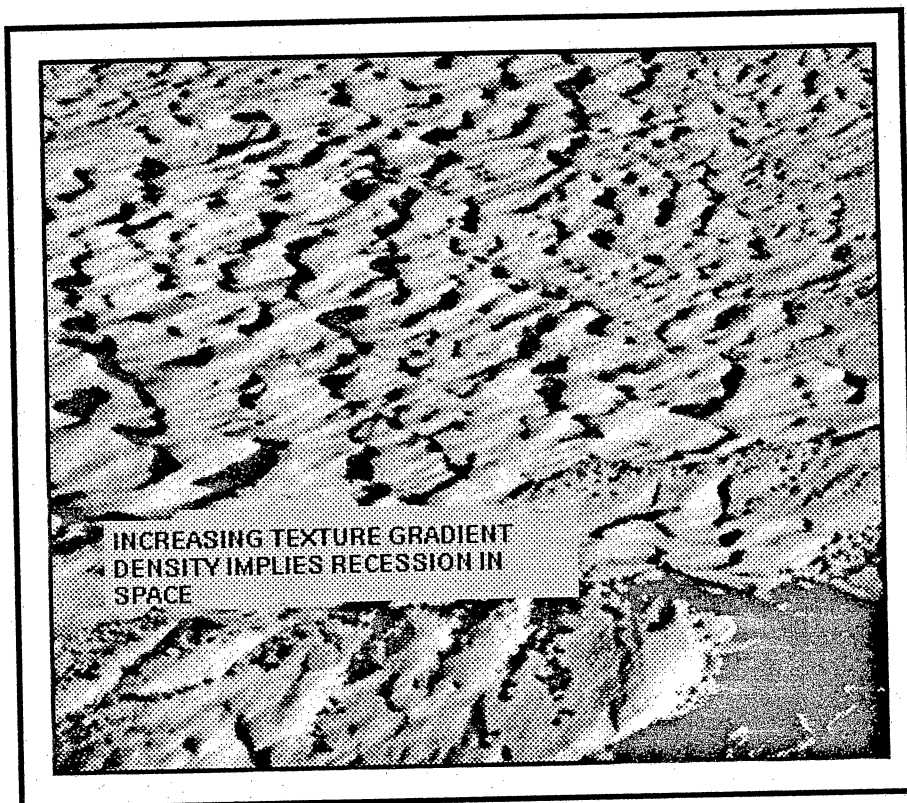
FIGURE 15. LAYOUT IS SPECIFIED BY INCREASING TEXTURE DENSITY
WITH DISTANCE (ADAPTED FROM MONKHOUSE, 1960).

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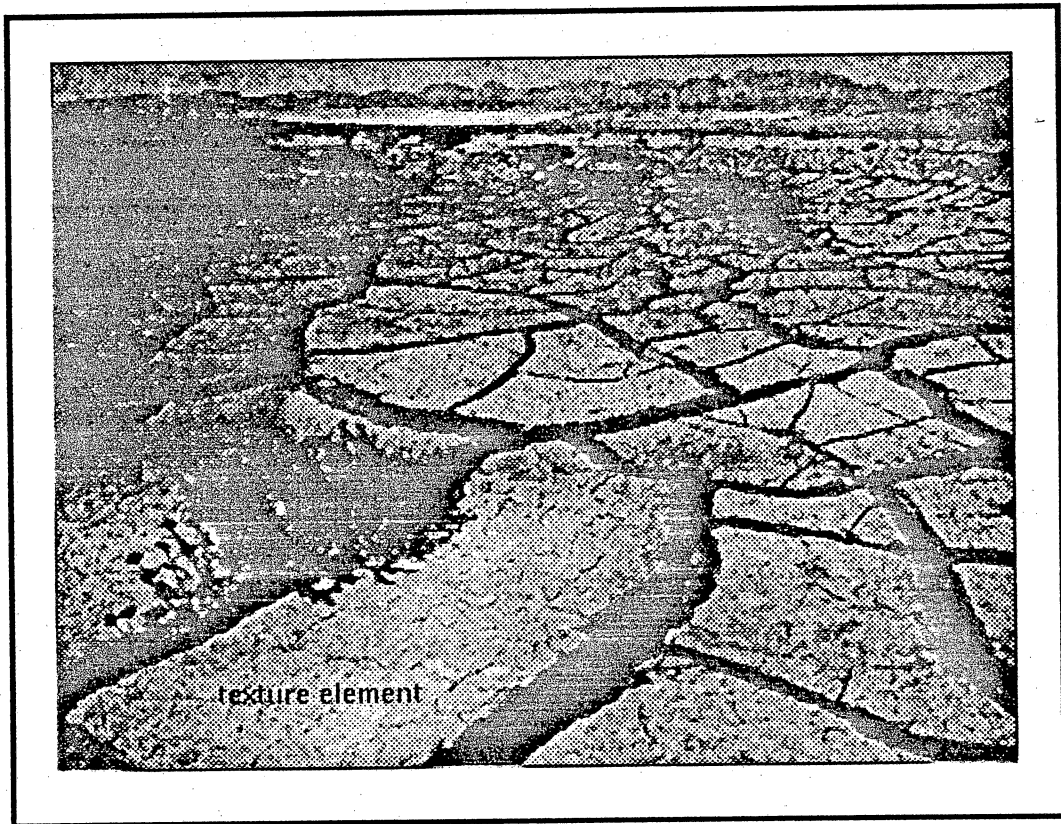
FIGURE 16. INDIVIDUAL TEXTURE ELEMENTS COMPRISE SURFACE
            TEXTURE GRADIENTS.   THESE GRADIENTS UNITE A
            SURFACE AND ALLOW OBJECTS THAT REST UPON THE
            SURFACE TO BE JUDGED IN RELATION TO EACH OTHER
            (ADAPTED FROM PAGE, 1974).

2.2 STEP TWO: Upland/Lowland Texture Differentiation:

The second step in the Global-to-Local Search Method involves the division of the layout into two broad, yet distinct areas - uplands and lowlands. Usually, upland areas such as mountains and cliffs appear coarse and corrugated in texture, while lowlands such as plains, valleys, and outwash areas tend to appear finer in texture. The purpose of initially dividing the layout into topographic highs and lows is to begin constraining the location of targets. Targets (when positioning) tend to avoid or circum-navigate steep and rugged terrain in favor of reasonably-sloped and low-lying terrain (Bergin & Collins, 1952; Musham, 1944). Passages do exist in rugged terrain however. Yet, these passages start in low-lying areas and gradually ascend into trafficable uplands that do not act as solid, steep-faced barriers. Figure 17 illustrates a highly contrasting area of upland barriers and lowland passages.

The apparent difference in texture between uplands and lowlands is easily noted. Recall the discussion earlier about Gibson's (1979) proposal that the coarse macro-structure of the layout can be broken down into faces. Upland areas appear as a combination of adjoining faces that meet at convex dihedral angles. A dihedral angle is the vertice of two flat surfaces. Convex adjoinings form surface ridges. For example, acute convex dihedrals form steep peaks.
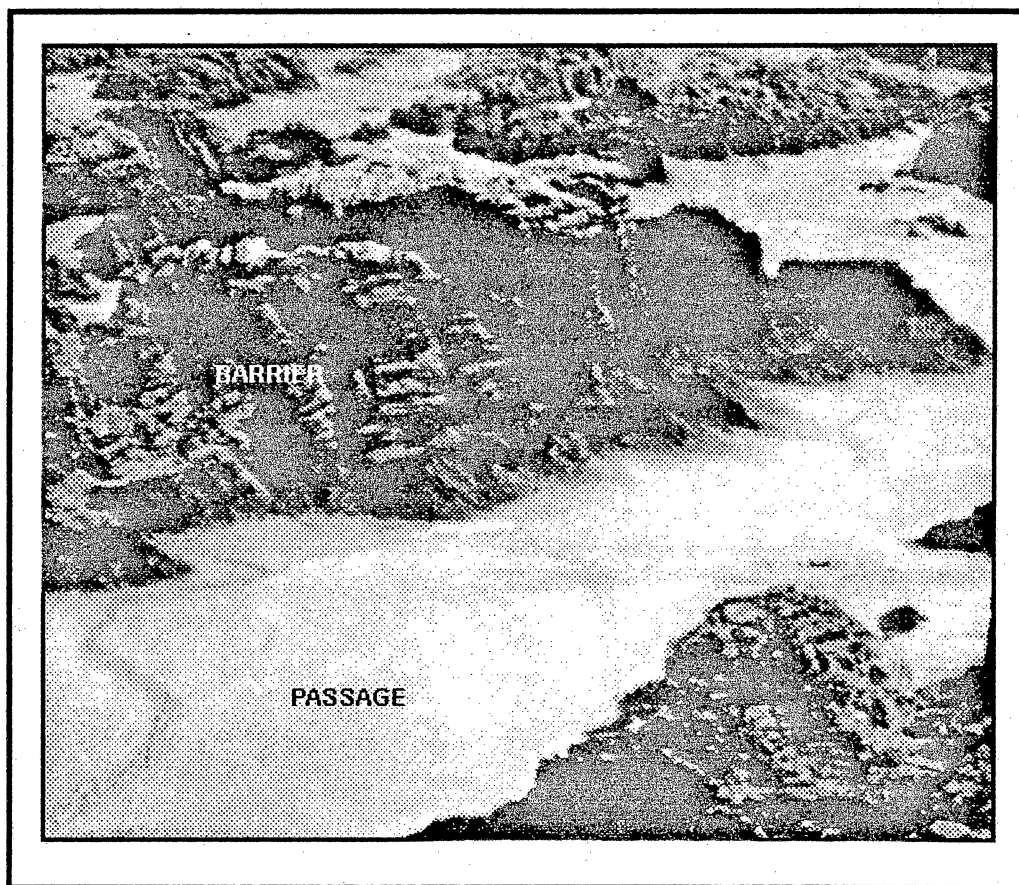
FIGURE 17. CONTRASTING PASSAGES AND BARRIERS (ADAPTED FROM
MONKHOUSE, 1960).

As a result of this convex uplift, surface concavities (enclosures and valleys) are also formed. A simple combination of convex and concave dihedrals creates the wrinkled texture associated with the greater surface layout as shown in Figure 8. A dense and complex combination of acute convex dihedrals creates very corrugated texture. This results in apparent rugged terrain. Conversely, broad areas of obtuse concave dihedrals suggest broad lowland passages such as plains and valleys.

Uplands and lowlands also have distinctive micro-texture as well as macro-texture. Upland surfaces are coarser because they are erosional surfaces, while lowlands are smoother in texture because they are dominated by deposits of fine sediment. Slopes divide these areas and are characterized by mixed, coarse-to-fine textured surfaces. Slopes are intermediate in texture because sediment becomes finer as slope angle diminishes from upland to lowland areas.

This spatial association between surface texture and topography can be seen in the oblique photo of the layout of Death Valley, California, as shown in Figure 18. In this photo, the encircling mountains (called bolsons) have a strongly corrugated texture that contrasts with the finer speckled texture of the alluvial fans. These fans coalesce in a ring of bahadas (piedmont slopes) around the mountain floor. Subsequently, the texture of these fans contrast further with

the even finer texture of the flat playa floor. Thus, each and every surface in the layout has a characteristic texture associated with its potential for erosion, deposition, and location within the layout. Estes, Hajic, and Tinney (1983) state that the interrelated and characteristic texture of natural surfaces helps to identify these surfaces from the air.
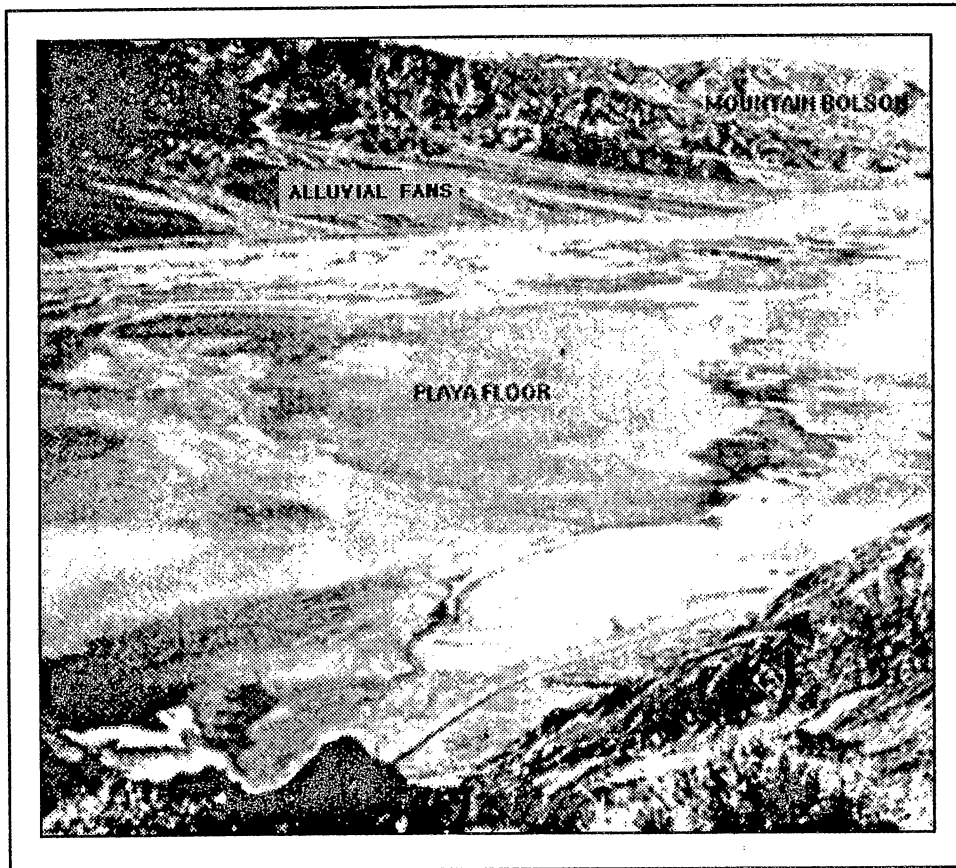
FIGURE 18. TEXTURE DIFFERENCES OF DEATH VALLEY, CALIFORNIA. NOTE THE CHARACTERISTIC TEXTURE OF THE UPLAND, LOWLAND, AND SLOPED AREAS (ADAPTED FROM HOWARD & REMSON, 1978).

2.3 STEP THREE: Passage Area Focus:

The third step involves the focus of passages primarily in the lowland areas. However, upland areas that appear to afford some degree of trafficability and passage are also considered. The biggest clue to the trafficability of any passage is the appearance of linear textures such as roads, railroads, rivers, streams, dry river beds, and outwash areas. Most targets use these features to traverse the terrain. Consequently, these features are sure to lead to the location of some if not most targets (Eardley, 1942). However, these features do not lead to all targets. Some targets may be hidden in canyon enclosures off the "beaten path." So, it is a good idea to look in passage areas that are off to the side and within the general vicinity of these linear features.

Roads in particular are very useful in orienting target search. For instance, Betak (1967) performed an airphoto detection task and found that subjects used highly geometric street patterns in which to locate other surface objects of interest. In addition, recall the discussion of Snyder's (1973) study in chapter 3. In Snyder's study pilots tended to fixate on apparent road lines in the distant layout. Roads tend to run in low-lying areas, but may be seen circum-navigating upland areas as shown in Figure 19.
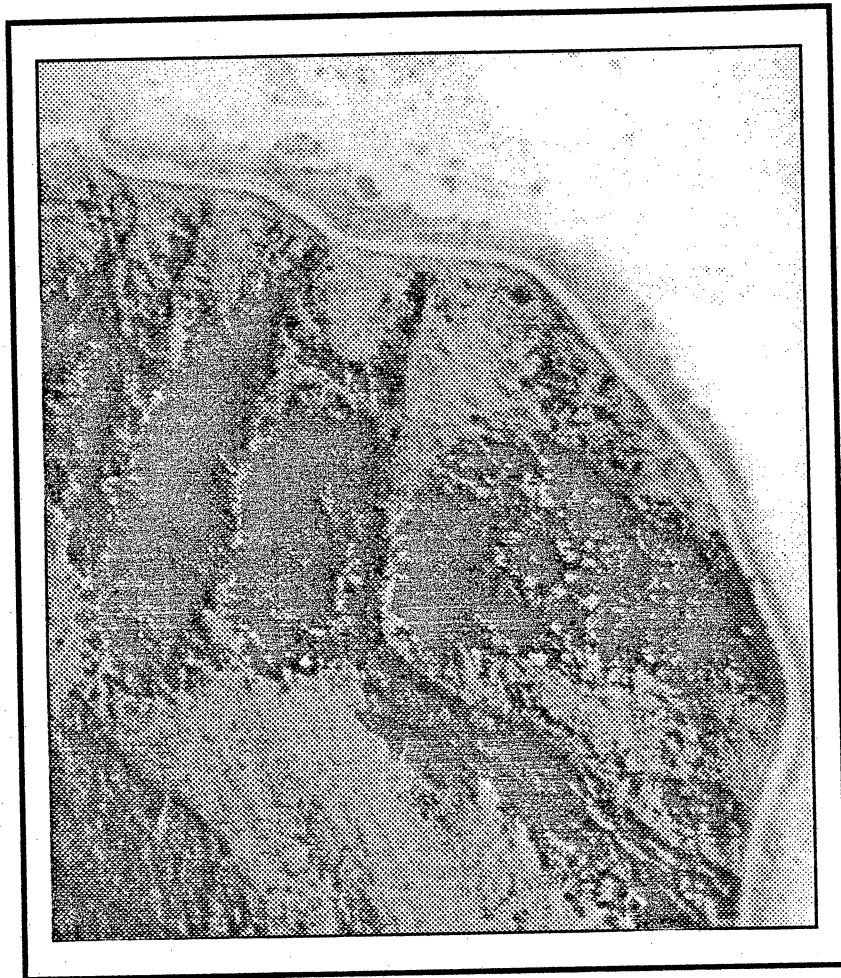
FIGURE 19. LINEAR FEATURES SUCH AS ROADS USUALLY CIRCUM-
NAVIGATE UPLAND AREAS.

Their course is followed near, around, and through these upland areas as well as lowland areas.

All passages (including roads) that run through or near upland areas are evaluated for their slope. Passage slope may constrain target positioning. Very few targets (in the process of positioning) can traverse passages greater than 33% grade (Coleman, 1987). This factor is considered when passages are evaluated. Usually, level or gently elevated passages suggest trafficability. Upland areas are avoided if they appear unable to afford unobstructed, gradually elevating passage. To illustrate the effects of passage slope, Figure 20 shows various sloped surfaces. Note how most human-made targets are located in gentle sloped areas such as on or near the alluvial fan. Note also that the majority of roads run along this landmark. Some roads may follow the canyon corridor/enclosure (shown extending in depth in the center of the photo). However, few targets are likely to traverse the steep mountain faces. Yet, some do at less than 33% grade. Also, some targets are likely to be located along these mountain ridge lines which provide level support and vistas for advantageous observation.
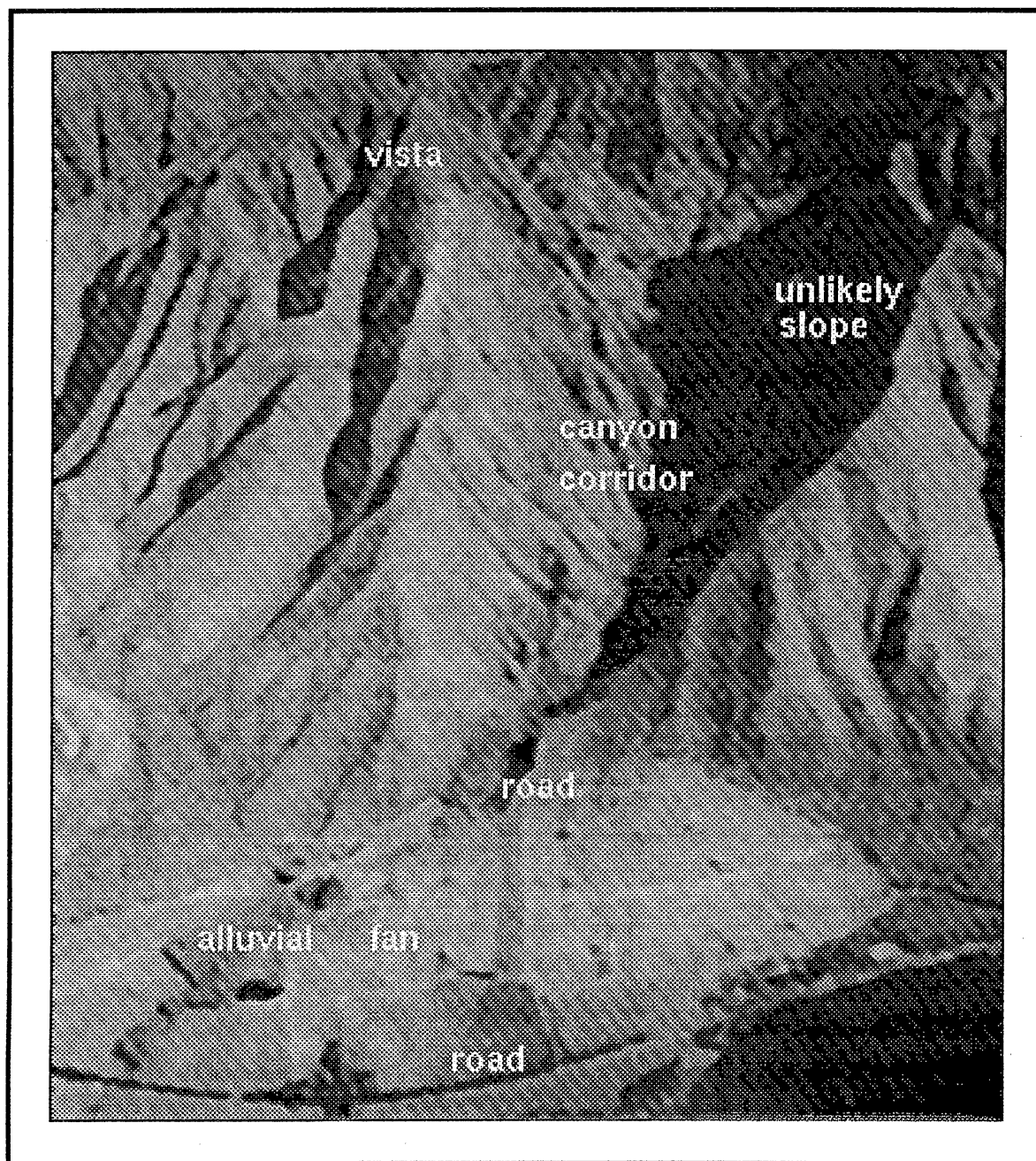
FIGURE 20. LIKELIHOOD OF TARGET POSITIONING BASED ON SURFACE
SLOPE (ADAPTED FROM LILLESAND & KIEFER, 1987).

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Surface slope is visualized by texture gradients (Gibson, 1979). Texture gradients specify slope by their change in density with surface direction and distance as shown in Figure 21. For example, upward increasing density of texture gradients suggests upward slope. Downward, leftward, and rightward increasing density suggests downward, leftward, and rightward slope, respectively. Similarly, repeated changes in texture gradients suggest surface undulations.

Stevens (1981, 1986) states that surface undulations imply surface trend. Pentland (1986b) suggests that shading emphasizes surface undulations. Gradual lighting coalesces upon a surface and creates contrast between individual grades of texture elements that span a surface. This graduated textural shading gives the impression of three dimensional relief and implies surface trend and alignment as seen in Figure 8. Todd (1989) supports this view and suggests that graduated shading implies object form, while abrupt discontinuity of shading suggests different forms.

a   b
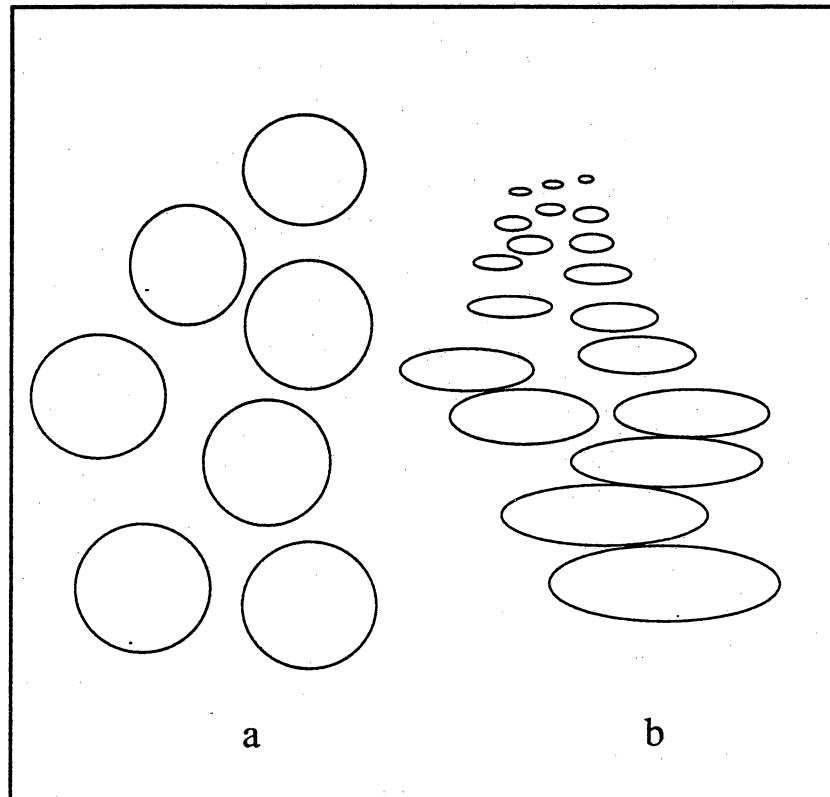
FIGURE 21. TEXTURE GRADIENTS IMPLY SURFACE SLANT: (a) IS A
           SURFACE SEEN STRAIGHT ON; (b) IS A SLANTED SURFACE.
           NOTE HOW TEXTURE GRADIENT STEEPENS IN (b) TO
           PRODUCE THE PERCEPTION OF SURFACE DEPTH (ADAPTED
           FROM HUMPHREYS & BRUCE, 1989).

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2.4 STEP FOUR: Local Texture Differentiation:

The fourth and final step involves noting any unusual texture differences that might exist in likely local passage areas. Julesz (1988) proposed that an understanding of texture discrimination has important implications for noting embedded targets. Target texture can apparently contrast with surrounding terrain texture despite general luminance similarity between the target and its surrounding terrain. Recall that Beck (1966) showed that textures are differentiated even when adjacent surfaces are of the same spectral reflectance. Plus, Lillesand and Kiefer (1987) state that the visual system is keener at discerning spatial features and dimensions of an object than at discerning spectral differences such as tone and color between an object and its surroundings. For example, they suggest that smooth texture of green grass can be distinguished from the rough texture of green tree crowns in medium scale airphotos.

Texture differentiation usually occurs because of two factors. First, human-made objects consist of refined materials and therefore have a finer density of texture elements than coarse terrain. Shipley (1991) proposes that the smoothness of objects in contrast with the coarser environment tend to create strong texture discontinuities. These texture discontinuities provide the boundaries between

objects and their surfaces. These texture density differences can easily be seen in Figure 22. Kohler (1929) provides an example of texture differentiation by density differences:

> "Even if a stone lies half-embedded in the sand, which is nothing but tiny fractions of the same kind of stone, the difference of coherence, and therefore of 'inner detail' between the surface-elements of the stone and those of the sand will be sufficient in most cases to make the stone optically one thing" (p. 173).

Second, apart from density differences, there is usually a slight deviation in the angles of texture elements between a target and its surrounding terrain and this produces a noticeable distinction between the two surfaces. For instance, a target and its terrain may usually have differentially arranged granularity even when they have the same textural density (Bruce & Green, 1985). Beck (1982) and Julesz (1988) proposed that the orientation of texture elements between adjacent surfaces provide a very distinct measure of discrimination between the two surfaces. This difference in orientation may be more apparent at a distance than the individual texture elements themselves. In support, Drury (1987) states that the visual system can notice linear offsets better than linear separations when the angular separation equals the angular degree of offset. The minimum offset that can be detected by the visual system is 2 seconds of visual angle subtended at the retina (Drury, 1987).

FIGURE 22. SEGMENTATION THROUGH TEXTURE DENSITY DIFFERENCES.
NOTE THE FINER TEXTURE OF THE BUILDINGS IN CONTRAST
WITH COARSER TERRAIN.

This capability is very important for detecting local target-terrain differences in texture alignment. Figure 23 illustrates the profound effect texture offsets can have on detecting hidden targets.

As mentioned, texture differences between a local target and its surrounding terrain emphasize a target's spatial attributes despite spectral similarity between the two areas. Lowe (1985) states that the visual system is very adapted at noting spatial correlation among surface elements. These spatial correlations usually infer some non-accidental property of the surface. A non-accidental property means that the correlation is not a happenstance of view point. That is, given normal probability, it is likely an object with structure. This notion is relevant when considering hidden or embedded targets. Target-terrain texture differences may hint at the non-accidental spatial correlations of a hidden target's underlying structure. In particular, a target's intrinsic texture may recede across its surface in such a way that horizontal and vertical dimensions are detected. Wickens (1984) states that spatial dimensions that co-vary in horizontal and vertical space are easily perceived by the visual system as objects. Landwehr (1990) suggests several types of texture gradients which imply correlated dimensions. They are shown in Figure 24 and include horizon-bound converging parallels, and horizontal and vertical parallels.
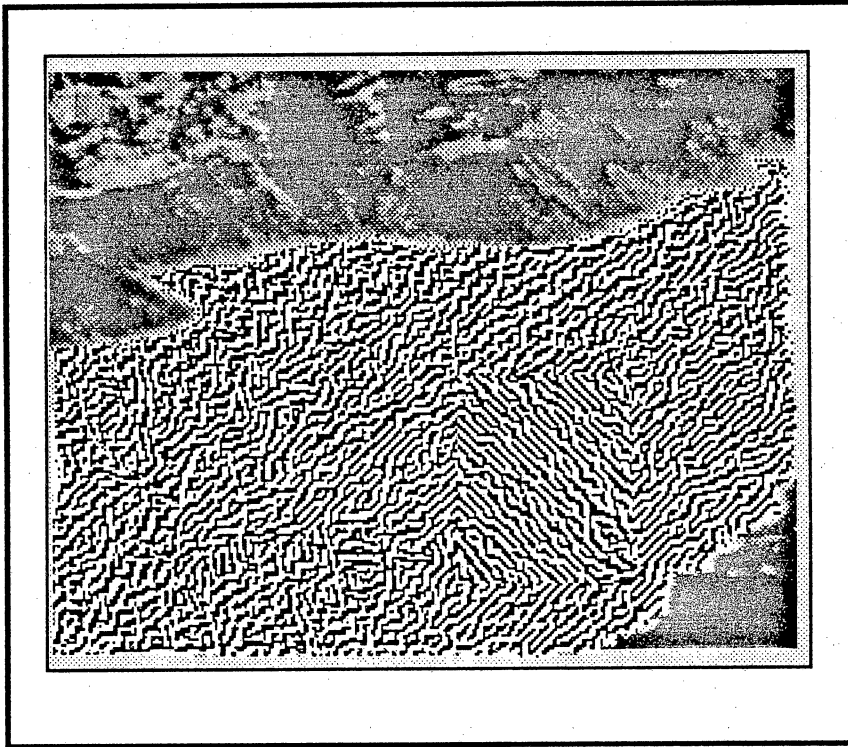
FIGURE 23. SEGMENTATION THROUGH TEXTURE ORIENTATION
DIFFERENCES. NOTE THE SQUARE THAT IS
MANIFESTED FROM THESE DIFFERENCES.

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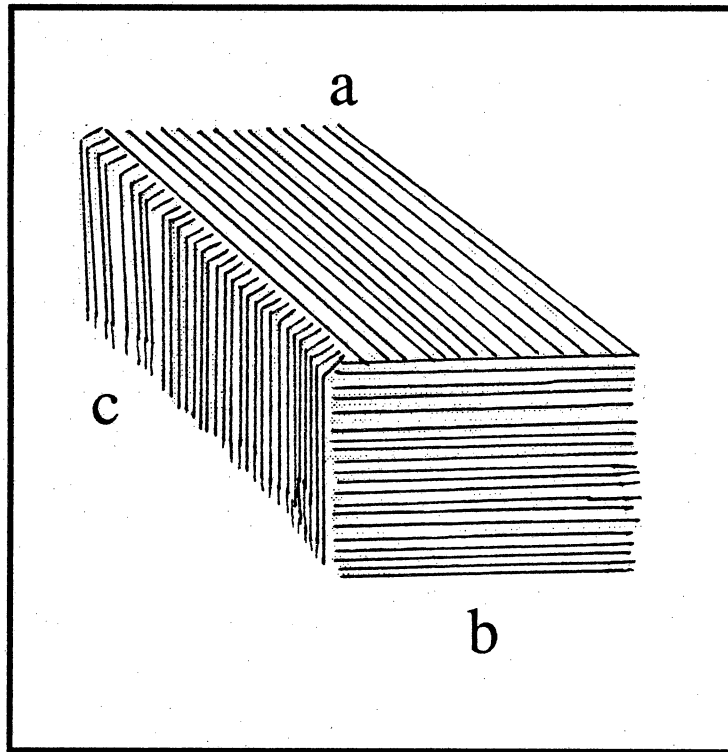
FIGURE 24. THREE FORMS OF TEXTURE GRADIENT VISUALLY COMPRISE
THIS CUBE: THEY ARE: (a) HORIZON-BOUND CONVERGING
PARALLELS, (b) HORIZONTAL PARALLELS, AND (c)
VERTICAL PARALLELS (ADAPTED FROM LANDWEHR, 1990).

Local texture differences may be noted better at certain perspectives than at others. Thus, it is important to de-focus from time to time when examining a suspected target area. This de-focusing allows more efficient comparisons and contrasts to be made between the local textured area and its surrounding terrain texture. Granovskaya, Bereznaya, and Grigorieva (1987) agree. They proposed that observers must periodically de-focus (return to more low spatial frequency information) from time-to-time when examining local detail. This allows local detail to remain in context with its more global surroundings during local analysis. This notion of focusing and de-focusing is supported by Shulman and Wilson (1987) who found that subjects tended to be more responsive to low spatial frequency gratings when noting the large structure of a pattern. Conversely, subjects were more responsive to high spatial frequency gratings when noting a local part of that pattern.

Once non-accidental target dimensions are detected, steps three and four are repeated for other likely target areas. This cycle continues until all likely target areas are examined. An experimental analysis of this method is investigated next.

CHAPTER FIVE. AN EXPERIMENTAL ANALYSIS OF THE SEARCH METHOD

It is hypothesized that an analyst's detection performance improves when the Global-to-Local Search Method is followed. Detection improvement is defined as a greater number of correctly located and detected human-made targets and fewer false alarms on imagery. Consequently, those who receive the Global-to-Local Search Method instructions should be able to find more targets with fewer mistakes in a specified period of time than those who do not. Previous researchers have shown that learned and applied search strategies can improve an observer's performance.

Several researchers, including Braly (1933), Djang (1937), Hanawalt (1942), and Schwartz (1961) found that subjects detected more simple figures embedded in complex figures after instruction and practice. In these experiments, the task required that subjects locate and detect a small simple figure within a complex figure. These previous studies demonstrated a significant link between experience and detection performance. That is, subjects became better at detecting obscure figures masked by more complex background figures after instruction and practice. These findings are relevant to the present proposal which advocates that search instruction can improve the location and detection of local targets in varied terrain.

In addition to these previous findings, McDonald (1989) recently found that the best image analysts had "superior visual-spatial schemata" for interpreting images. A visual-spatial schemata refers to an analyst's mental storage of collected and associative knowledge concerning the organization and classification of visual scenes. Analysts with superior visual-spatial schemata have a greater ability to organize observed scenes and to make informed detections and recognitions about objects that lie within the observed scenes. Apparently, cognitive strategies do in fact improve basic visual tasks (see also Jonides, 1981; Kinchla & Wolfe, 1979). From these findings, it follows that detection performance should improve when the Global-to-Local Search Method is learned and applied by analysts. This leads to the present experiment to support this premise.

5.1 Method:

Subjects:

Seventy-two college students (34 males and 38 females) volunteered to participate in the study. Subjects ranged in age from 18 to 36 years of age. All subjects had little or no prior experience in image analysis. A vernier (or minimum-separable) acuity test was given to all subjects as a screening test prior to the experiment. This test consisted of an achromatic sine wave grating that spanned approximately

7 cycles per degree of visual angle (subtended at the retina) when held at arm's length (see Appendix A). Spatial frequency with sine waves of seven cycles per degree of visual angle is considered near optimum modulation for the human visual system (Cornsweet, 1970). Subjects were asked to count the number of dark bars contained within the length of the ruler which was placed just under the sine wave grating. The ruler spanned approximately one degree of visual angle (subtended at the retina) when held at arm's length (1 visual angle = .3 millimeters subtended at the retina; an arm's length = ¯600 millimeters). All subjects (with aided or unaided vision) were able to discern the number of dark bars (which was seven). at arm's length. Thus, all subjects had visual acuity (aided or unaided) that was at least suitable for detecting the low-contrast, high frequency targets in this experiment.

Materials:

Two black-and-white airphotos of the Mojave Desert terrain were used as the experimental stimuli in the study. One was recorded at approximately 32 degrees, 37 minutes north latitude, and 116 degrees, 01 minutes west longitude (see Appendix B, Experimental Airphoto B1). The scale of this airphoto was approximately 1:25,000. The recorded aerial scene consisted of an upland area in the center of the airphoto which was flanked on all sides by lowland areas. Dry

river beds traversed these lowland areas. The texture of the upland and lowland areas was distinct. The upland area contained darker-toned, highly-corrugated textures while the lowland areas contained light, fine-grained textures. In the lowland areas, dry river beds were accentuated by vegetation that formed dot-clustered linear textures. Eight buildings were embedded (blended with the luminance of the surrounding terrain) in the airphoto. They are circled in Airphoto B1.

The other airphoto was recorded at approximately 32 degrees, 30 minutes north latitude, and 113 degrees, 12 minutes west longitude (see Appendix B, Experimental Airphoto B2). The scale of this airphoto was approximately 1:11,000. Its scene characteristics were similar to Airphoto B1. An upland area was recorded in the center of the airphoto and flanked on three sides by lowland areas. Dry river beds traversed these lowland areas as well. Plus, eight buildings were embedded in this airphoto as with Airphoto B1. They are circled in Airphoto B2.

Procedure:

A pilot study was performed prior to the actual experiment to see if any difficulties would arise with the understanding of the treatment instructions. In addition, this pilot study provided an estimate for the time limit to be used during the actual experiment. The investigation was conducted

using 10 subjects (4 males and 6 females who ranged in age from 21 to 32 years of age). Before the start of the investigation, subjects were told that they were participating in a test to see how well they could find human-made objects in airphotos using specified instructions. Afterwards, subjects were given the instructions presented in Appendix C and told that they were to use these instructions to assist them in finding the human-made objects. They were then briefly told that they would be using a global-to-local search method when using these instructions. They were also told to ask questions if they did not understand any or all of the instructions presented. These instructions explained the search method steps discussed in the text and visually illustrated the subdivision of the layout scene.

Next, subjects were given both of the experimental airphotos after reading these instructions. The order in which the airphotos were given was counter-balanced to prevent practice effects. Half of the subjects got Airphoto B1 first, half got Airphoto B2 first. At the start of the test, subjects were told that they were to find as many human-made targets as possible. They were told to circle these targets with a pen or pencil and that roads were not to be considered targets.

Subjects had no difficulties finding the targets in either airphoto, although Airphoto B1 did appear to be harder

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then Airphoto B2. It took subjects on average 45 seconds to find all targets in Airphoto B1, while it took them an average of 25 seconds to find targets in Airphoto B2. These two times were then combined to get the time limit of 1 minute and 10 seconds to be used for the actual experiment.

In addition to 10 treatment subjects, 10 control subjects (3 males and 7 females) who ranged in age from 18 to 26 years of age) were tested in the same counter-balanced fashion, but without the search method instructions shown in Appendix C. A stem-and-leaf plot was prepared to note any visible difference in performance between these two groups. As shown in Appendix D, a difference in overall performance is visible. Some of this apparent difference may be attributed to the use of two experimenters during this pilot study. One experimenter conducted the study with the treatment group, the other experimenter conducted the study with the control group. This potential for experimenter effects was not encountered during the actual experiment, as only one experimenter was used for both the treatment and control group.

For the actual experiment, two equal-numbered groups were randomly selected to either receive search method instruction or not. Each group was tested separately at random times and in sub-groups. The treatment group was tested in two sub-groups. One treatment sub-group consisted of 21 subjects (9 males and 12 females) who ranged in age from 19 to 27 years.

The other treatment sub-group consisted of 15 subjects (8 males and 7 females) who ranged in age from 22 to 36 years.

The control group was tested in two sub-groups, also. One control sub-group consisted of 20 subjects (7 males and 13 females) who ranged in age from 18 to 24 years. The other control sub-group consisted of 16 subjects (10 males and 6 females) who ranged in age between 18 to 31 years. The treatment and control groups were tested in random order. No group knew the existence of the others.

Subjects in both the treatment and control groups were told that they were participating in a study that was investigating the ability of humans to locate and detect embedded targets in airphotos. They were told that they would be looking for low-contrast, human-made objects in airphotos of unpopulated desert terrain. They were told that low-contrast meant that the target objects would appear similar in tone to the surrounding terrain. In addition, they were told that although these target objects consisted of human-made constructions, they were not roads. Subjects were not told the number or location of these targets for either airphoto.

After these initial verbal instructions, the treatment group subjects then received the treatment instructions presented in Appendix C (which include the treatment illustrations) and were told that they were to use these

instructions to find targets. The control group subjects did not get these instructions. Treatment group subjects were then told that these instructions would help them find targets by systematically narrowing their view of the scene layout. They were also told that this narrowing consisted of subdividing the scene based on broad texture differences between upland and lowland areas, then pinpointing linear features and passage areas in the lowland areas, and finally pinpointing local target areas in the linear and passage areas. Treatment group subjects were asked to read the instructions carefully, exactly, and in the order that they were presented. They were not timed during the reading of the instructions. After reading, the experimenter asked subjects if they understood the instructions. Answers to questions were restricted to simple explanations of the steps and no additional information was given.

The treatment group subjects then received copies of the airphotos. The control group subjects received copies of the airphotos after being presented with the initial verbal instructions and without any written instructions. Half of the subjects in each group saw Airphoto B1 first, the remaining half saw Airphoto B2 first. The subjects were told not to look at the second airphoto until they had finished finding all the targets in the first presented airphoto. This counter-balancing prevented practice effects which would arise

if the same airphoto came second with every subject. Subjects were told to circle human-made targets (except for roads) with a pen or pencil in both airphotos. Subjects were told that they had 1 minute and 10 seconds to find all the targets in both airphotos. After this time period, subjects were told to stop searching. All airphotos were collected.

Subjects were debriefed on the correct location of all targets in both airphotos. Upon completion, the treatment group received a questionnaire concerning the effectiveness of the written instructions (shown in Appendix E). These subjects were asked to answer the questions in the questionnaire. When finished, the questionnaires were then retrieved.

5.2 Results:

The experimenters later tallied the number of correctly circled targets (hits) and the number of incorrectly circled targets (false alarms) in both airphotos and for both groups. A multi-variate analysis was performed using the Hotellings T-square to examine the simultaneous level of significance among the means for both dependent measures (hits and false alarms) for both instruction conditions (instruction or no instruction) and per airphoto (Airphoto B1 and Airphoto B2). These means are shown in Figure 25.

MEAN PERFORMANCE BY GROUP PER AIRPHOTO

NUMBER OF HITS AND FALSE ALARMS

Legend:
- ■ B1 HITS
- ▨ B1 FALSE ALARMS
- ▢ B2 HITS
- ▧ B2 FALSE ALARMS

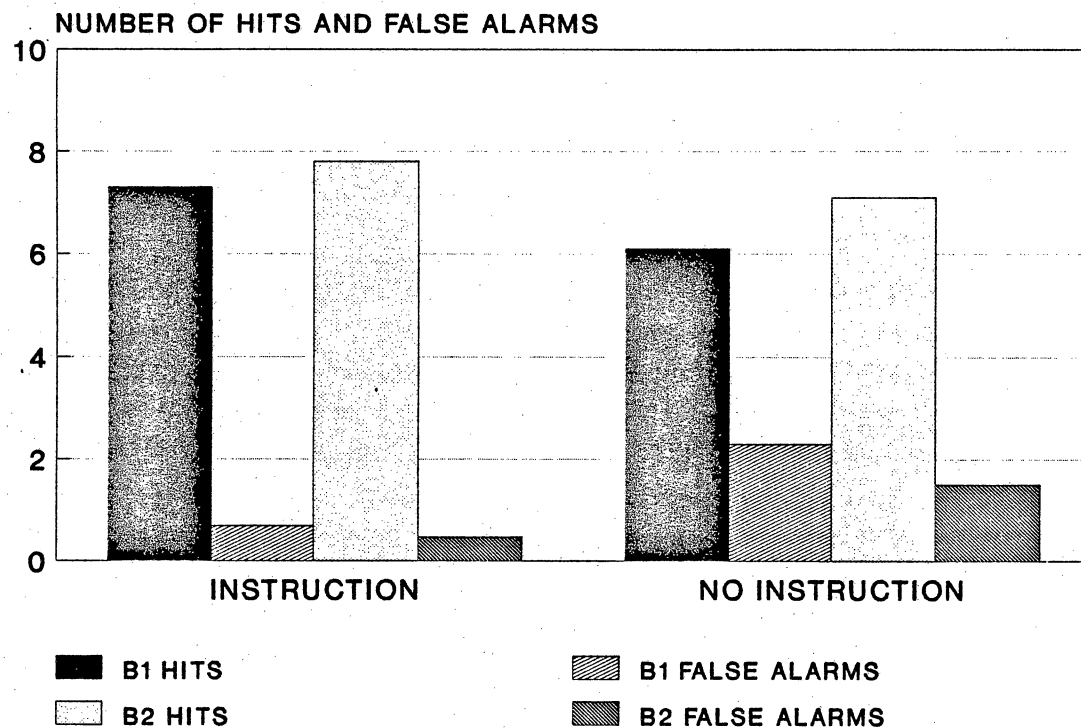(X-axis: INSTRUCTION, NO INSTRUCTION)

FIGURE 25. MEAN PERFORMANCE OF EACH EXPERIMENTAL GROUP ON EACH AIRPHOTO. NOTE THE GREATER NUMBER OF DETECTED HITS AND FEWER FALSE ALARMS ATTRIBUTED TO THE INSTRUCTION GROUP AS OPPOSED TO THE NO INSTRUCTION GROUP.

As shown, the mean performance for the instruction group was higher for both airphotos in hits (B1 hits = 7.3; B2 hits = 7.8) and lower in false alarms (B1 false alarms = 0.69; B2 false alarms = 0.47) than the mean performance of the no instruction group (B1 hits = 6.1; B2 hits = 7.1; B1 false alarms = 2.3; B2 false alarms = 1.5). This mean difference was significant (T-square (4,67) = 12.98, $p < 0.01$). The related uni-variate F-tests (with 1,70 degrees of freedom) are presented in Table 1.

In addition, two uni-variate t-tests were performed to examine the difference between the two airphotos (Airphoto B1 and Airphoto B2) in terms of their level of difficulty as expressed by the response in mean number of hits and false alarms associated with each airphoto. These means are shown in Figure 26. As shown, the mean number of hits is less and the mean number of false alarms is greater for Airphoto B1 (hits = 6.7; false alarms = 1.5) than for Airphoto B2 (hits = 7.4; false alarms = 0.97). This difference was significant (hits: t (142) = 2.68, $p < 0.01$; false alarms: t (142) = 2.78, $p < 0.01$).

UNIVARIATE F-TESTS WITH (1,70) DEGREES OF FREEDOM

VAR	HYPOTH SS	ERROR SS	HYPOTH MS	ERROR MS	F	SIG OF F
B1HITS	24.50	45.94	24.50	0.65	37.33	.001
B1FAS	46.72	71.28	46.72	1.02	45.88	.001
B2HITS	8.00	21.78	8.00	0.31	25.71	.001
B2FAS	18.00	49.94	18.00	0.71	25.23	.001

TABLE 1. RELATED UNI-VARIATE F-TESTS WITH (1,70) DEGREES OF FREEDOM. ALL F-TESTS ARE SIGNIFICANT AT P < 0.01.

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OVERALL MEAN PERFORMANCE PER AIRPHOTO

NUMBER OF HITS AND FALSE ALARMS
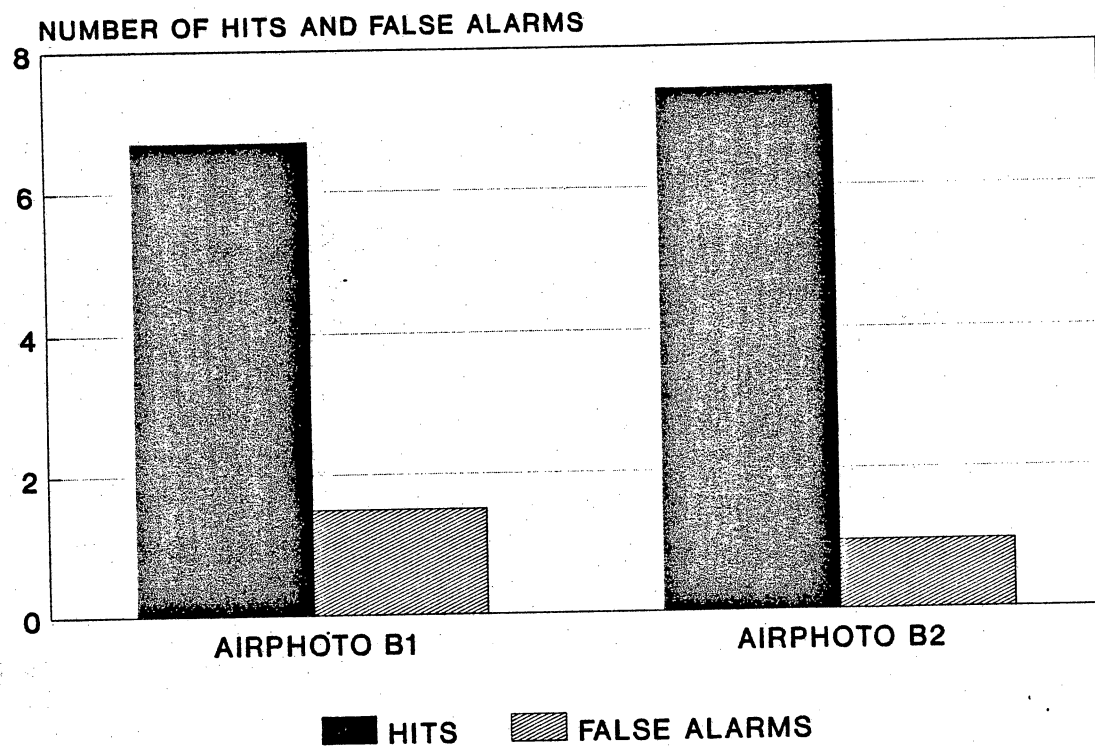
FIGURE 26. MEAN PERFORMANCE ASSOCIATED WITH EACH AIRPHOTO. NOTE THAT THE MEAN FOR AIRPHOTO B1 IS LOWER THAN THE MEAN FOR AIRPHOTO B2 FOR HITS AND HIGHER FOR FALSE ALARMS.

5.3 Discussion:

The effectiveness of the Global-to-Local Search Method was supported by the present findings. Those that received the Global-to-Local Search Method instructions found more targets and produced fewer false alarms than those who did not. In addition, since the mean performance was farther between groups on Airphoto B1 than on Airphoto B2 and these two airphotos were found to be significantly different, it may be concluded that the search method instructions were more useful with airphoto B1. The questionnaire response of the instruction group does seem to support this notion. Sixty-seven percent of the respondents thought that Airphoto B1 was harder than Airphoto B2. Likewise, thirty-six percent of the respondents thought that the instructions were more useful with Airphoto B1. These response percentages are shown in Table 2.

RESPONSE PERCENTAGES

<u>QUESTION</u>	<u>PERCENT RESPONDING</u>
1. Instructions helpful? Yes / No / no reply	83% / 17% / 0%
2. Which step most helpful? 1/2/3/4/all/none/no reply	3% / 12% / 29% / 56% / 0% / 0%
3. Which airphoto harder? B1 / B2 / no reply	67% / 16% / 17%

4. Instructions more helpful
   with which airphoto?
   B1 / B2 / no reply
	36% / 29% / 35%

TABLE 2. RESPONSE PERCENTAGES FROM TREATMENT QUESTIONNAIRE

The greater difficulty with Airphoto B1 was possibly a result of the fact that targets were more obscure in Airphoto B1. Consequently, it is proposed that subjects had to examine the airphoto more thoroughly in Airphoto B1 than in Airphoto B2. They could not rely on innate, random scanning of the image, but instead had to resort to some systematic method of search. Those that had an existing method of search (the instruction group) clearly had an advantageous under these terms. Thus, the mean difference in performance between the two groups was emphasized with Airphoto B1.

As a whole, the Global-to-Local Search Method instructions appear to improve an observer's ability to locate and detect low-contrast targets in desert terrain. The present experimental findings support this. In addition, eighty-three percent of those that received these instructions prior to the search task felt that these instructions were helpful. However, the individual effectiveness of each step was not experimentally investigated. Some steps may have been more effective than others. For instance, although the majority of subjects who received the instructions believed that all the steps were equally effective, twenty-nine percent felt that step three (passage area focus) was most helpful in finding targets. This response raises some questions as to the relevance of each step in the search sequence.

In general, the Global-to-Local Search Method steps

appear to represent a logical progression to the subdivision of the scene layout. That is, a scanning of the entire scene layout appears to be logically followed by the next largest observation - upland and lowland differences. Similarly, this observation appears to be logically followed by an intermediate scale-of-view such as linear feature focus and a local scale-of-view such as target area focus. In addition, these steps were strategically selected from what is known and could be extracted from previous research in the areas of visual search, air-to-ground acquisition, vision research, and ecological perception. However, the possibility that some of these steps may be improved upon or removed in favor of others needs to be investigated.

On the other hand, an imbalance of step effectiveness may be unavoidable. That is, some steps, although not seemingly as effective as others, may in fact be needed to "set the stage" for other more effective steps. For instance, scanning the entire layout and dividing it up into uplands and lowlands may not be as apparently effective as following linear features, but these two initial steps are needed in order to focus efficiently on linear features. The apparent imbalance of step effectiveness found in the response of the instruction group may be explained by the fact that some steps appear more obvious than others and therefore are labeled less effective. For instance, scanning the entire layout and looking for

target regularity appears more obvious to people in general than looking for linear features. Thus, these steps are given less weight than the latter.

Another explanation as to why linear features were perceived as most helpful may be because the visual system is best at discerning medium spatial frequencies as associated with linear features in reconnaissance airphotos. Recall the discussion in chapter two, section 1.2 concerning the transfer of low, medium, and high spatial frequencies. The modulation transfer function of the human visual system peaks a middle frequencies (see Figure 4). However, again further research is needed to investigate these notions.

One final experimental limitation should be noted. It is possible that the significantly greater performance of the treatment group could be explained in terms of their privy to what the target would look like in the actual experiment. Step Four of the treatment instructions (see Appendix C) does include a square drawing similar to the targets found in the experimental airphotos. This prior knowledge could have provided a leading advantage for the treatment group, since it is possible that the control group required a longer period of time to understand what was to be searched.

Still, it is argued that the illustrations are apart of the search method instructions and although obvious, they constitute part of the learning process of the treatment

group. Recall, the discussion in chapter four concerning target-terrain differences. The search for geometric regularity is a vital step in the Global-to-Local Search Method. As with other steps in the search method, this step should be illustrated. However, some other geometric form other than a square may have been more appropriate to use in the treatment instructions. Again, further research is needed to explain just how much this illustration alone contributed to the significant advantage of the treatment group.

In concluding discussion, there is the possibility that the control group could have performed as well as the treatment group given enough time. No recordings were made of average reaction times for either group during the actual experiment. However, there is rationale for not recording reaction times. The reconnaissance task of a military photo interpreter requires that he or she perform quickly and efficiently in a specified period of time. This time period is critical to saving lives. Consequently, one of the aims of this experiment was to investigate interpreter performance within the shortest time period possible. The average time taken by the treatment group during the pilot study was set as the maximum limit for this time period. Since it is proposed that the Global-to-Local Search Method maximizes time and efficiency, this average time period should have represented a cut off point between the performance of the treatment group

and the control group. This assumption appears to have been
supported by the present findings.

CHAPTER SIX. SUMMARY AND CONCLUSIONS

6.1 Project Summary:

It has been shown that when an observer scans an airphoto of desert terrain from the global-to-local level in a specified manner, his or her performance in detecting targets in that terrain is improved. Performance, in this case, refers to a greater number of detected targets and fewer false alarms. This specified manner involves four steps. The first step requires that the scene layout be scanned in its entirety. The second stop requires a subdivision of the layout in terms of upland and lowland texture differences. The third steps requires that linear features such as roads and. rivers, and unobstructed, gentle-sloped areas be focused on in the lowlands. These features and areas are referred to as lowland passages. The final step in this global-to-local search requires that local texture differences between a suspected target and its immediate terrain be noted. A target is suspected when geometric texture regularity is detected. The utility of this style of search is found in its ability to swiftly and efficiently channel search. This channeling allows inferences to be made from the systematic application of target-terrain constraints and allows local target areas to be found based on their inclusion within super-ordinate terrain structures.

6.2 Recommendations for Further Development of the Global-to-Local Search Method:

The effectiveness of the Global-to-Local Search Method may be improved further through digital image analysis. This is an area for future research and application of the Global-to-Local Search Method. For example, many existing image enhancement functions can be used or adapted to simulate the Global-to-Local Search Method. Recall that the visual system is best at discriminating the spatial attributes of an image, more so than the spectral attributes of an image. Computer-assisted texture differentiation is one means of capitalizing on the visual system's spatial capabilities while overcoming its spectral limitations. For one, texture synthesis can assist in making local texture differentiations. Plus, image enhancements can improve the spectral differences between a local target and its background. These and other functions can be integrated in a series of steps that simulate the Global-to-Local Search Method. Speculations as to how these software operations may be performed with the Global-to-Local Search Method are presented in the following paragraphs. Examples of these operations are provided to illustrate their effects on global-to-local search.

The first step in computer-assisted search begins with a display of the entire image within the CRT window and a contrast enhancement of this image. A negative zoom may be

needed to see this entire image. A conception of what this step might look like on a CRT display is shown in Figure 27. From here, an analyst starts with the global perspective.

Contrast enhancement increases the range of brightness variation in the image to insure the responsiveness of the visual system to surface differences. The visual system has a limited range for discriminating gray-level changes (Friedhoff & Benson, 1989). This function insures that this range is optimized. In the process of contrast enhancement, the limited range of grey-levels occurring in an image is assigned a broader range of grey-levels in the display or output image. In an histogram-equalized contrast enhancement (as shown in Figure 27), only the gray-level values that occur most frequently are "stretched" to fit a greater range of display values. This insures that the areas of the most concentrated information are contrasted. The maximum range for grey-levels is 0 to 255. If an image contains most of its grey-levels between 100 and 200, for example, then this range is spread out to fit the majority of the 0-to-255 display range.

The second step in computer-assisted search involves a means of visually clustering the coarse upland textures from the finer lowland textures associated with the surface layout. One way of doing this is by using a low spatial frequency pass which filters only the broadest textures in an image.
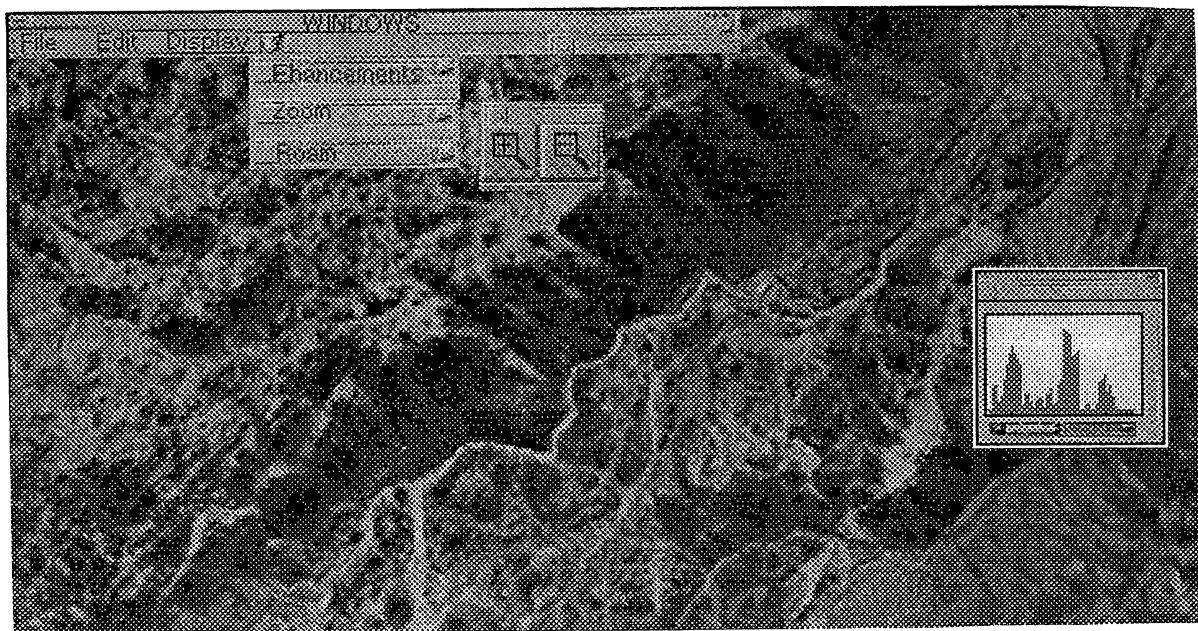
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FIGURE 27. STEP 1: CONTRAST ENHANCEMENT AND OVERALL LAYOUT
OBSERVATION.

A conception of this filtering function is illustrated in Figure 28. Low frequency filtering enhances the large-scale tonal changes in an image. This reduces local noise and emphasizes the broad, gradual change in homogeneous grey-levels between upland and lowland areas.

In the third step of computer-assisted search, an analyst focuses on the lowland areas using the positive zoom control. This function is illustrated in Figure 29. Positive zoom magnifies the display image at the area marked by the analyst. During enlargement, the global image is retained in a small portion of the screen as shown at the bottom, right of Figure 29. The location of enlargement is highlighted on the global image. This allows an analyst to retain global context during local search.

Edge enhancement is performed next to emphasize linear features in this enlarged area. These effects of edge enhancement are shown in Figure 30. Edge enhancement consists of high spatial frequency filtering followed by a reinstatement of the low spatial frequency information that was lost during the high frequency pass. An image must be contrast enhanced for the successful operation of this function (Lillesand & Kiefer, 1987). Edge enhancement insures that all surface texture information is retained while local detail such as surface linearity is enhanced. Note the pronounced river bed in Figure 30.
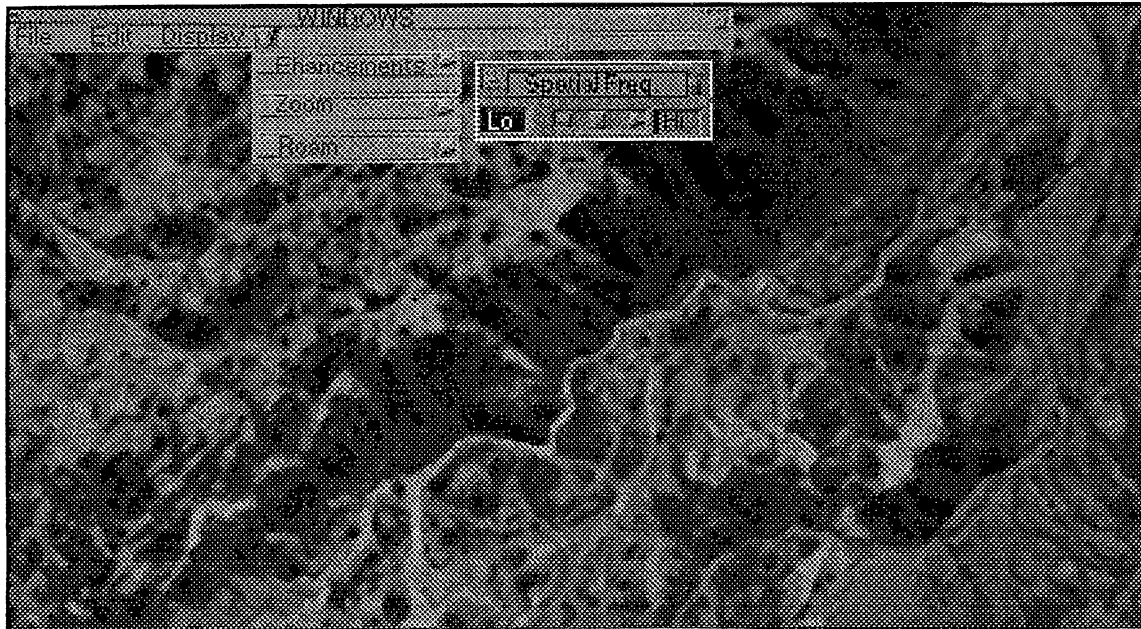
FIGURE 28. STEP 2: LOW SPATIAL FREQUENCY PASS TO HIGHLIGHT
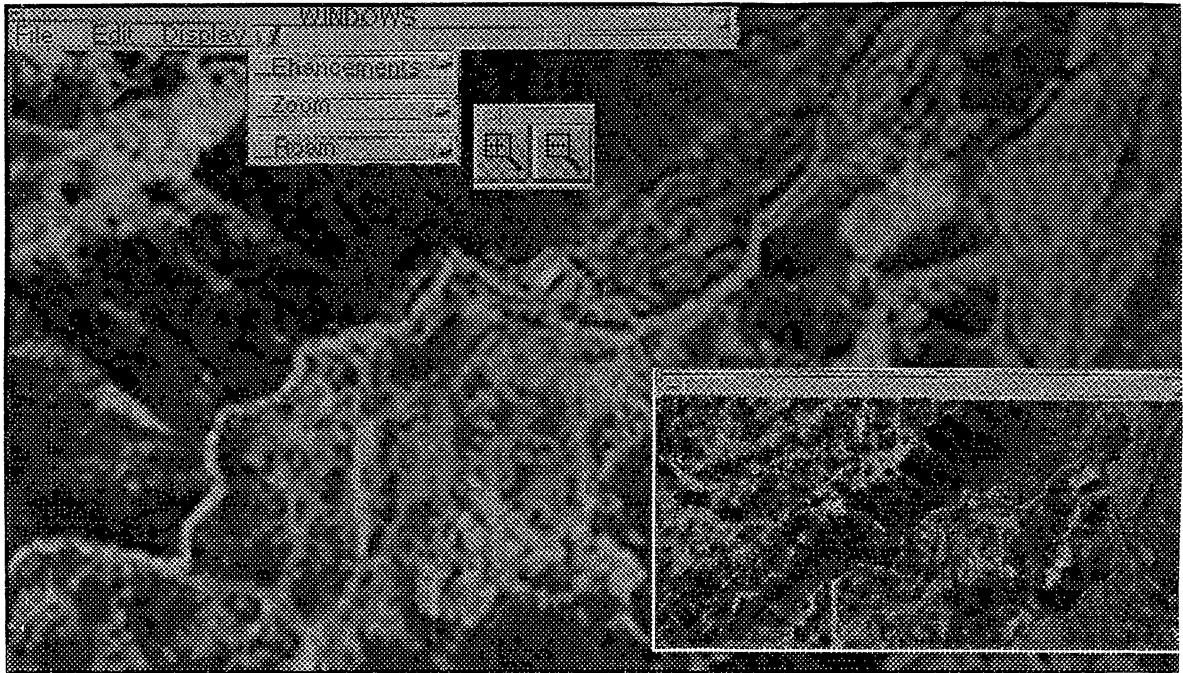DIFFERENCES BETWEEN UPLAND AND LOWLAND AREAS.

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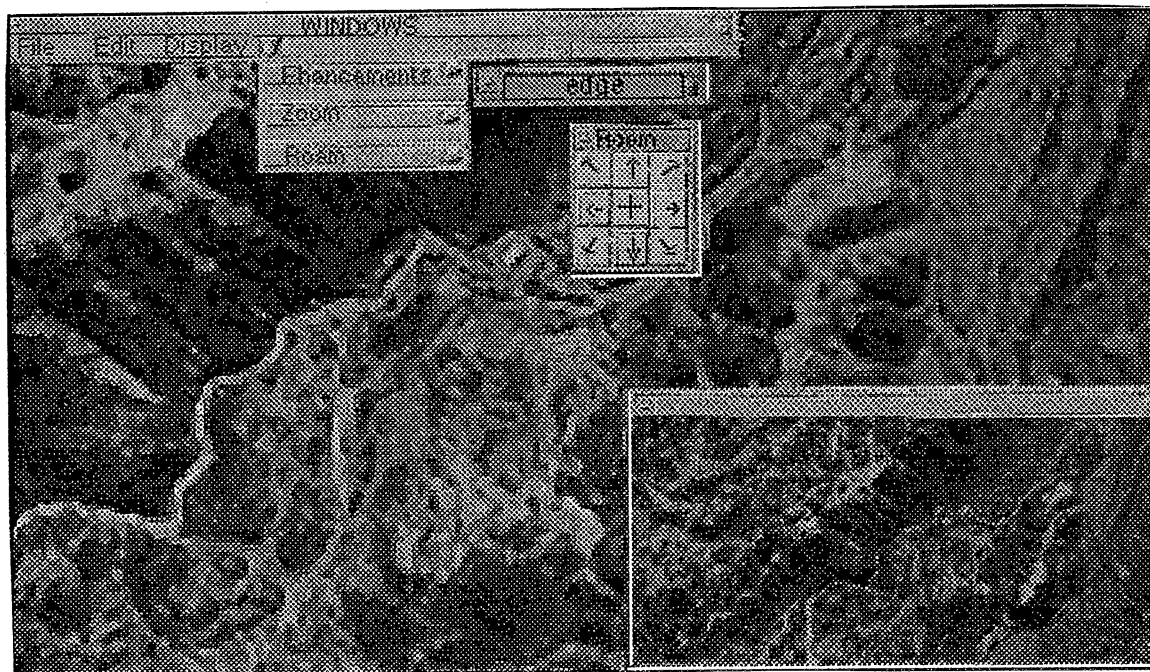FIGURE 29. STEP 3: POSITIVE ZOOM INTO LOWLAND AREAS.

FIGURE 30. STEP 4: EDGE ENHANCEMENT AND ROAM ACROSS LINEAR FEATURES.

Compare this with the same river bed in Figure 29.
After edge enhancement, a roam function (also illustrated in Figure 30) allows the analyst to span across linear features in this enlarged display mode. This movement is also recorded on the global image.

The fifth step involves shadow enhancement. This is illustrated in Figure 31. As shown, the surface relief is accentuated. This includes surface slope as well. Recall the discussion in chapter 4 concerning the effects of shadowing on relief. Shadowing increases the light-dark contrast among grades of texture across a slope with relief. This effect provides information in which to judge a slope's angle and ability to support a target.

Next, further zooming can be accomplished if a local area is suspected of containing a target. De-focusing (or negative zoom) can also be accomplished when an analyst wants to regain context from the greater terrain. This intermediate-scaled image can also be retained with the global image in a small portion of the screen as shown in Figure 32. This provides different levels of context.

During local focus, texture synthesis is utilized to enhance the differences between fine human-made texture and coarser terrain texture. To accomplish this procedure, an analyst-specified region is outlined around the suspected target area.
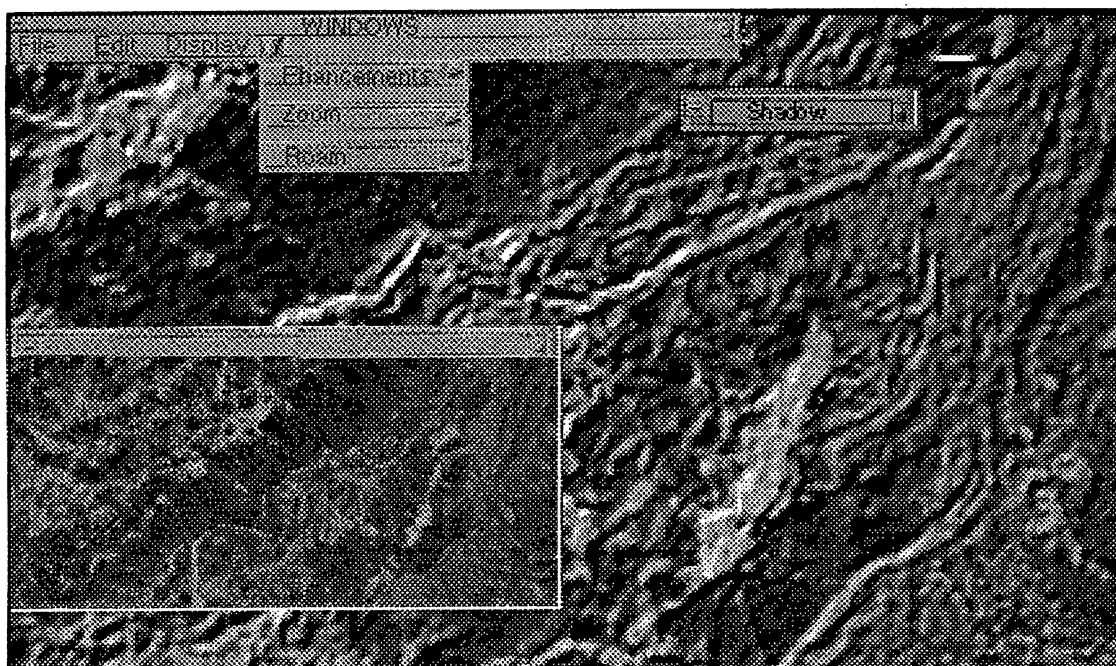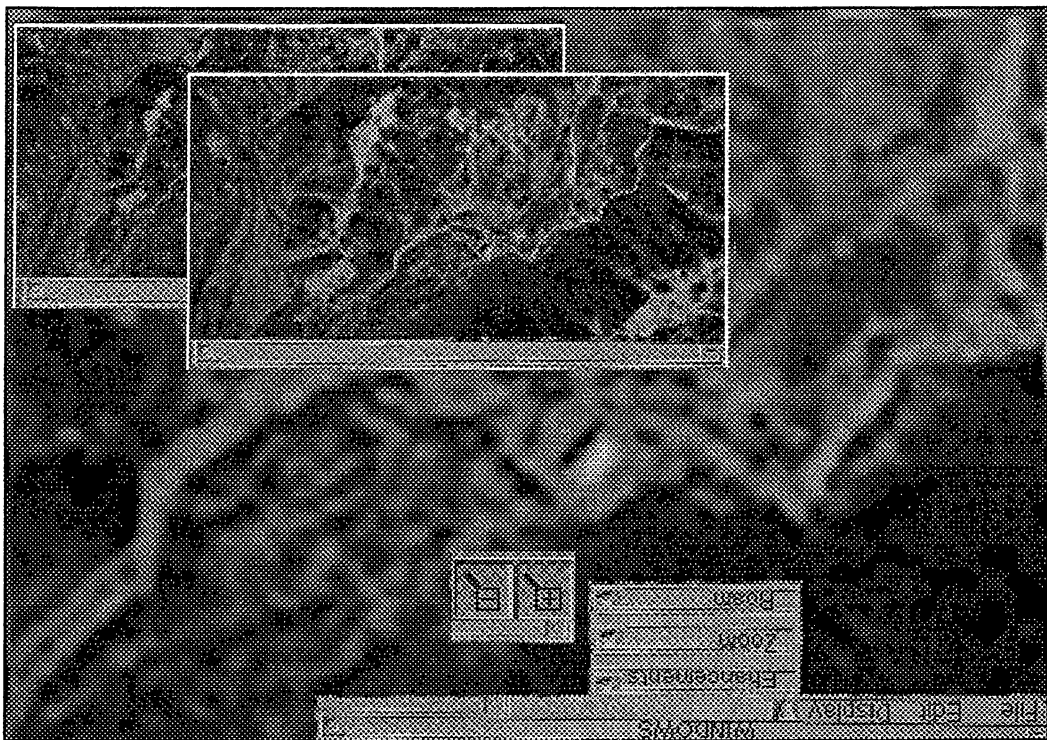
FIGURE 31. STEP 5: PRONOUNCED RELIEF FROM SHADOW ENHANCEMENT.

This selected region is created by drawing a box or circle around the suspected target area. The computer analyzes all grey-level areas (blocks or kernels of pixels) in the selected region. Areas of similar grey-level variance are uniformly clustered. This is done by finding areas of co-variance among grey-levels in the selected region and then assigning these areas a cluster mean and an averaged variance. If a human-made target is present, its clustered grey-level variance will be contrasted with the clustered variance of the surrounding terrain. That is, a target will be smoothed in contrast with its coarser terrain. A conception of how texture synthesis might appear is illustrated in Figure 33. As shown, texture synthesis emphasizes a target's spatial attributes. The target in Figure 33 is greatly accentuated by the function.

Once the target is found, the analyst prompts the system to return to the global image. Upon return, the location of this target is highlighted on the global image. An analyst can then recover this location again at any time and use it to infer other target locations in the global scene. A pattern may emerge with enough marked locations. An analyst gains greater confidence with less room for error when locating and detecting targets using this method of computer-assisted search.
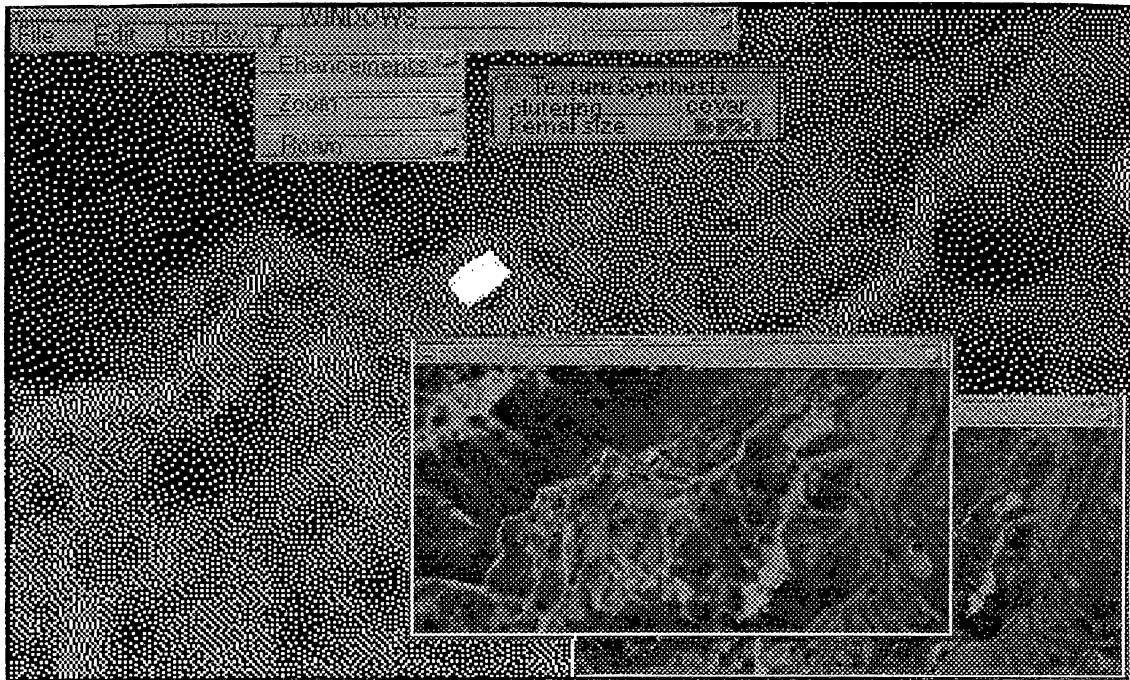
FIGURE 33. STEP 7: ACCENTUATED TARGET AND TERRAIN DIFFERENCES FROM TEXTURE SYNTHESIS

A simulated run of this computer-adapted version of the Global-to-Local Search Method is needed to verify its usefulness. The preceding discussion was meant only to introduce the concept of this method's possible applications to existing software. Other ideas may include an application of this method to existing job tasks such as the aerial search for illegal drug labs, isolated bunkers, or the make-shift dwellings of lost hikers. Other applications exist. In addition, the Global-to-Local Search Method could be expanded to include more complex cognitive processes beyond initial detection such as target recognition and identification. However, much more research is needed to accomplish this level of modeling.

The main theme behind the Global-to-Local Search Method is that it presents a very useful and efficient way to visually organize natural scenes. Fundamentally, this could mean improving people's awareness of the world around them.
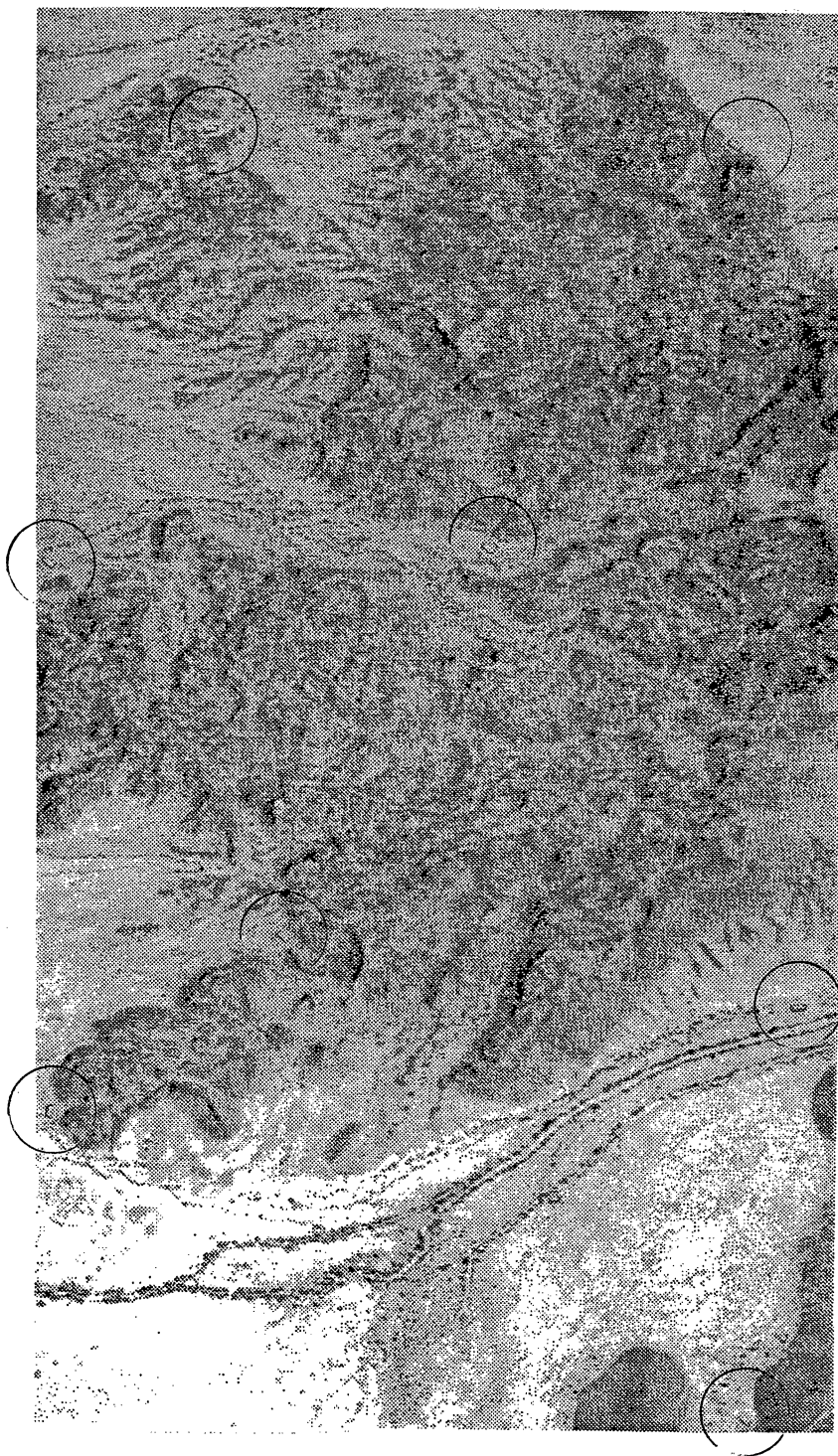
APPENDIX A
Acuity Grating for Screening Test
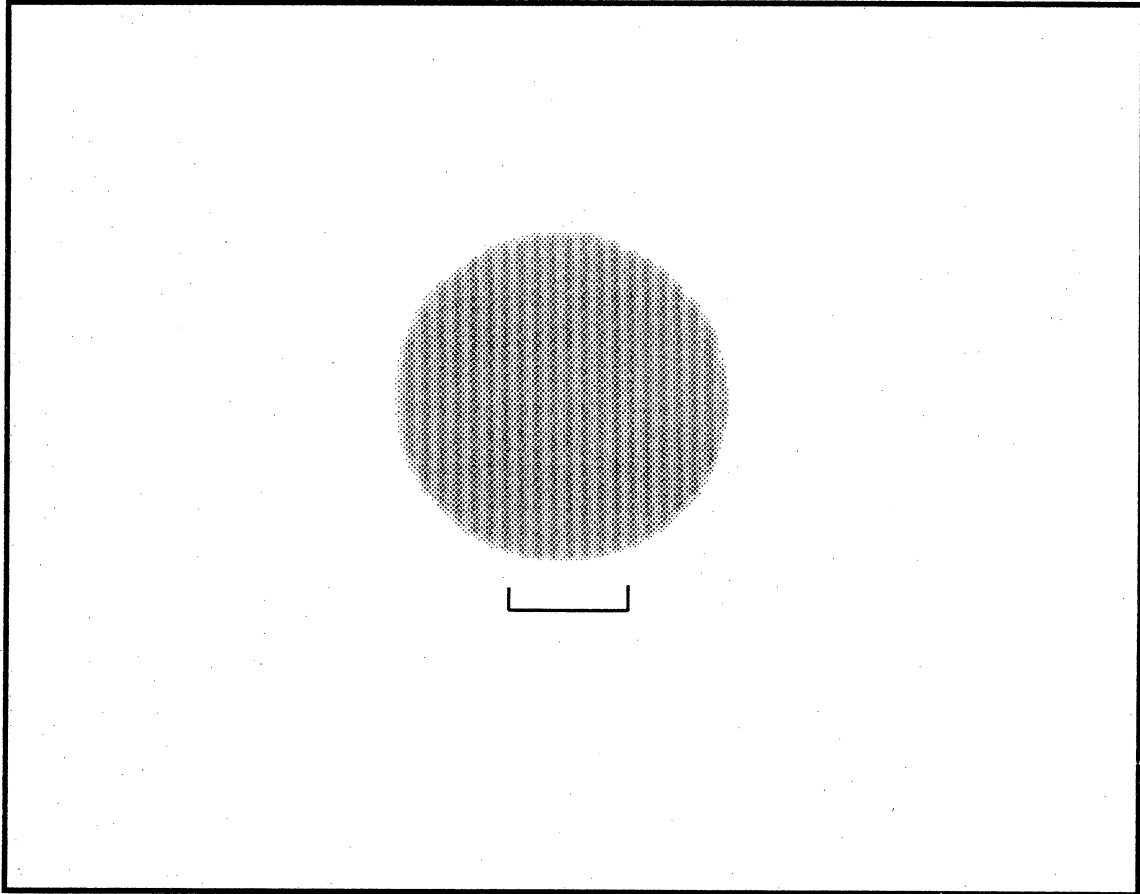
APPENDIX B. Experimental Airphoto B1
(1:25000, 9/10/92, 196th Tactical Squadron)
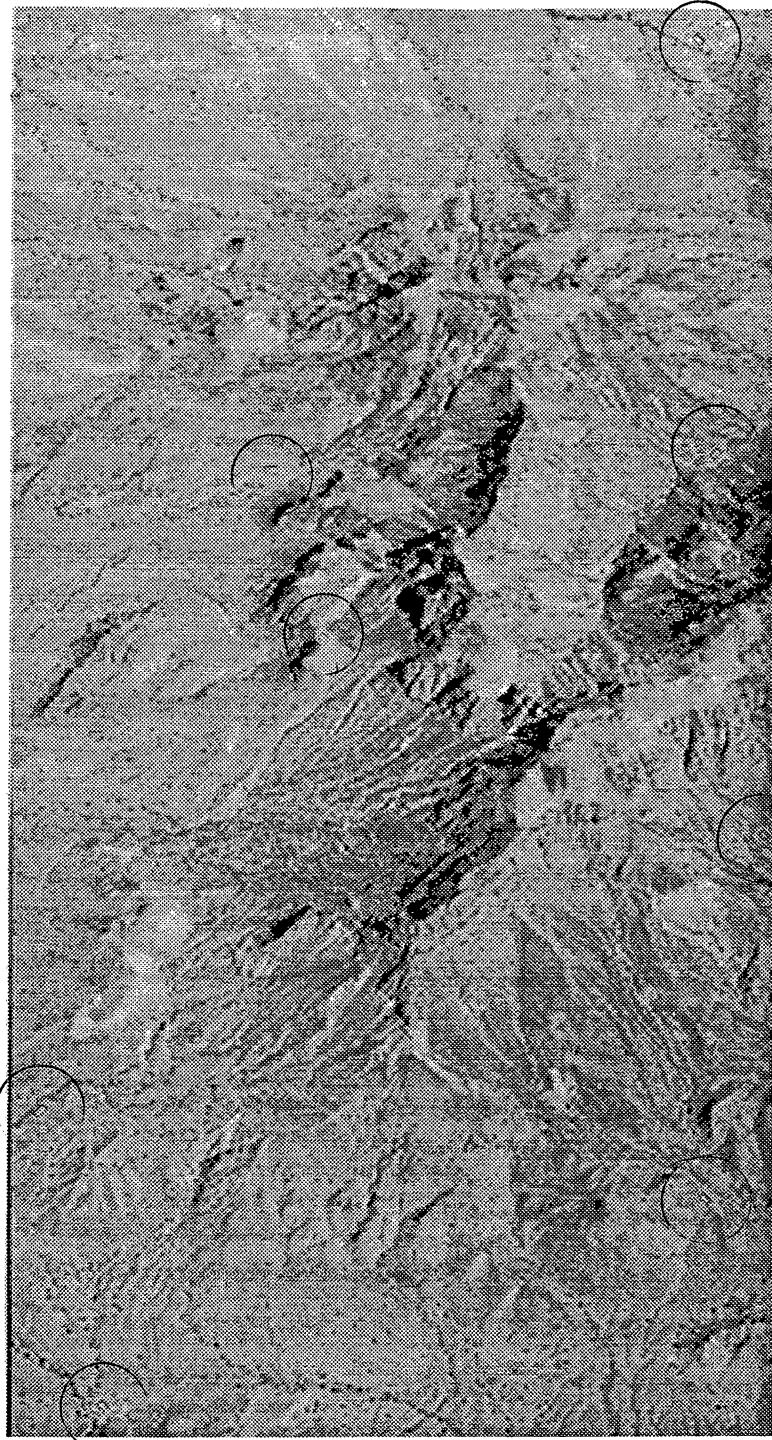
(reduced)

Experimental Airphoto B2
(1:11000, 9/10/92, 196th Tactical Squadron)

(reduced)

APPENDIX C. Treatment Group Instructions

You have been asked to find human-made targets in airphotos of desert terrain. The following instructions should help you find these targets. Please read them carefully and make sure you understand them. Ask questions if you do not understand. These instructions consist of four steps which systematically narrow your search. They do this by bringing to your attention the observation that the recorded scene layout can be subdivided into nested areas of view. For instance, you should start your search by observing the largest areas of the scene layout such as the upland and lowland areas. Next, you should "zoom in" on linear features such as dry river beds and roads, and passage areas in the lowland areas where you think a target can maneuver freely without barrier from steep rock. Finally, you should pinpoint local targets in or near these linear features and passage areas.

To clarify these steps, several illustrations are presented below with each step. These illustrations should help you visualize the subdivision of the recorded scene. For example, **STEP ONE** asks you to scan the entire scene. Therefore, scan the airphoto from left to right and from top to bottom. Make sure you note every area of the scene. Next, **STEP TWO** asks you to divide the scene up into upland and lowland areas. These areas are the next largest feature of the scene layout. This step is done by noting the broad texture differences between the upland and lowland areas. The upland areas are darker and rougher in texture than the fine-weathered lowland areas. **STEP THREE** now asks you to focus on the lowland areas and observe the linear features and likely slopes in these areas. Likely slopes refer to passages in which a target can traverse without barrier. Most targets traverse across linear features such as dry river beds and roads. Finally, **STEP FOUR** asks you to look for geometric texture on or near these linear features and passage areas. Human-made objects appear finer in texture and have distinct geometric dimensions in contrast with the surrounding terrain.

STEP ONE: Scan the
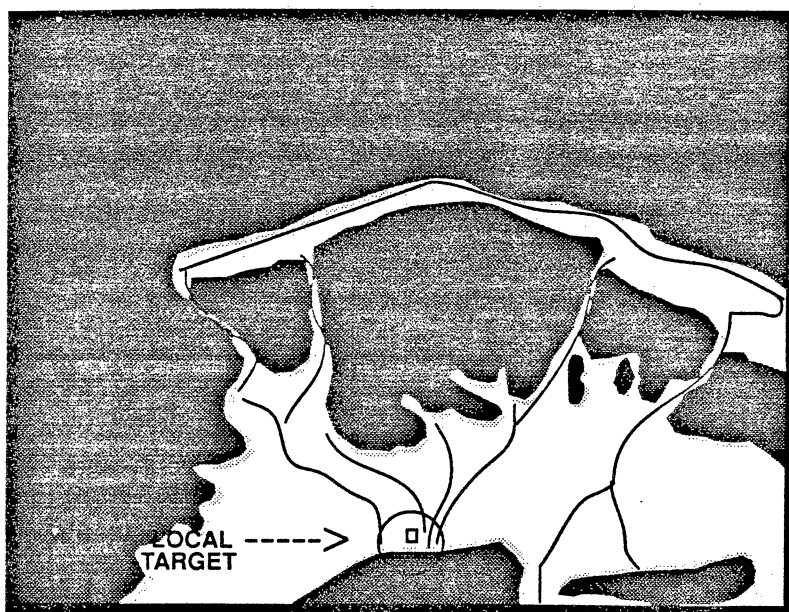entire layout.
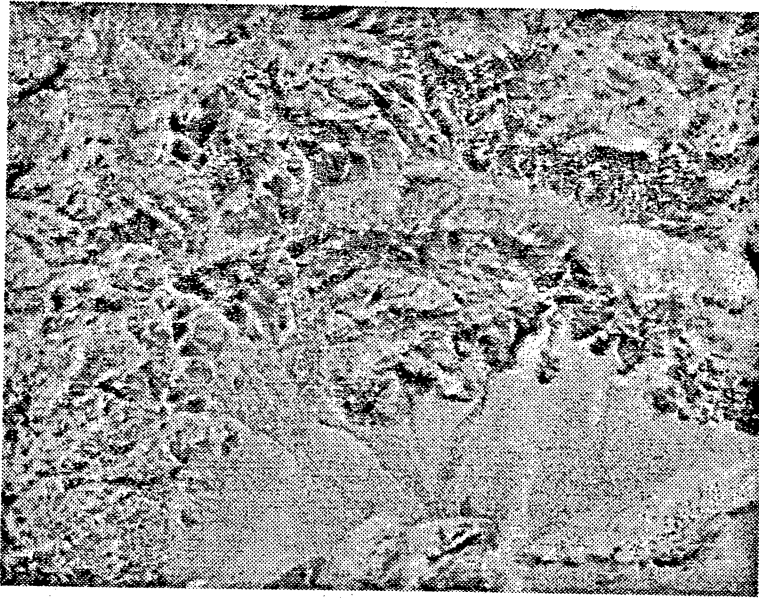
STEP TWO: Divide the
uplands from lowlands.

UPLANDS

UPLANDS
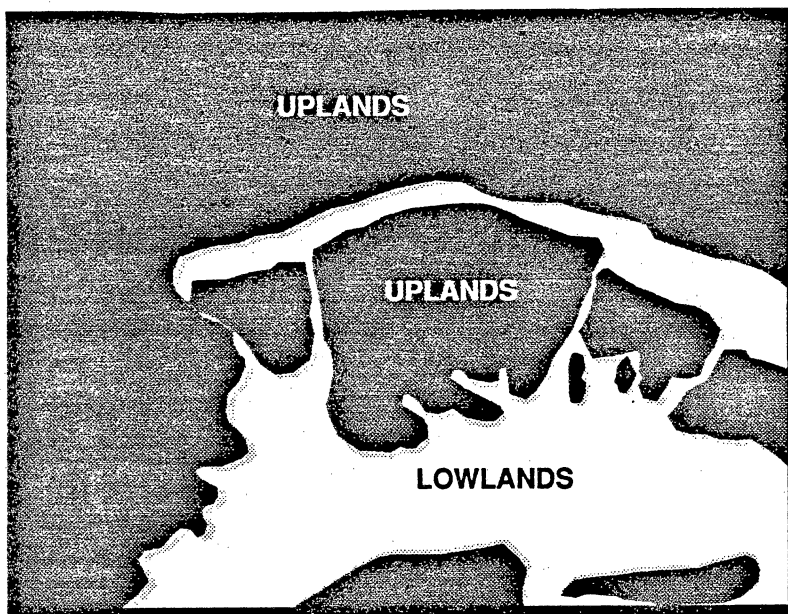
LOWLANDS

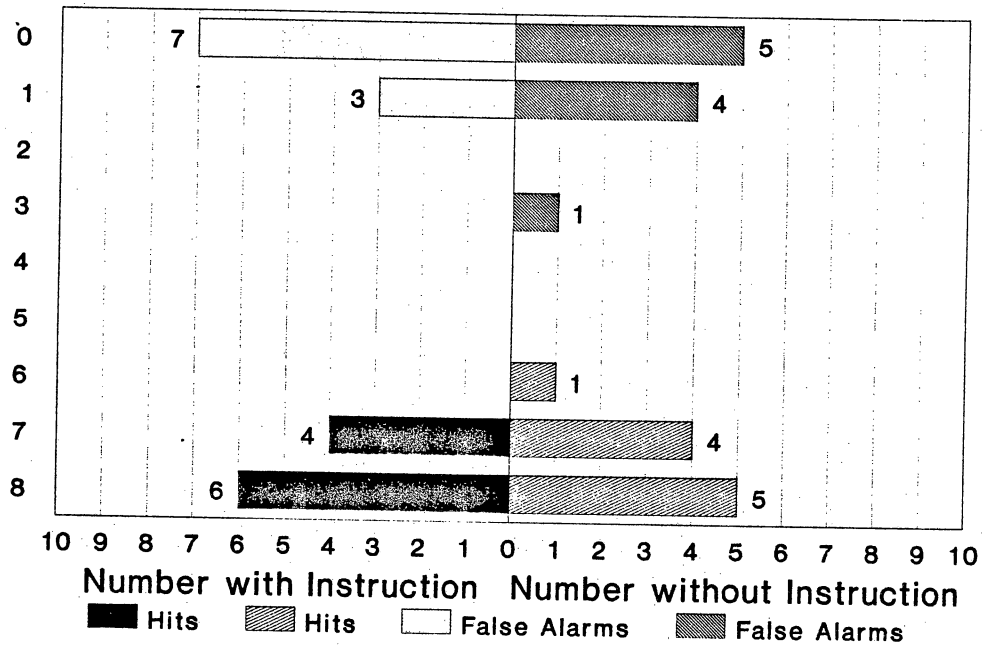**STEP THREE:** Focus on
linear features and
passage areas in
lowlands.
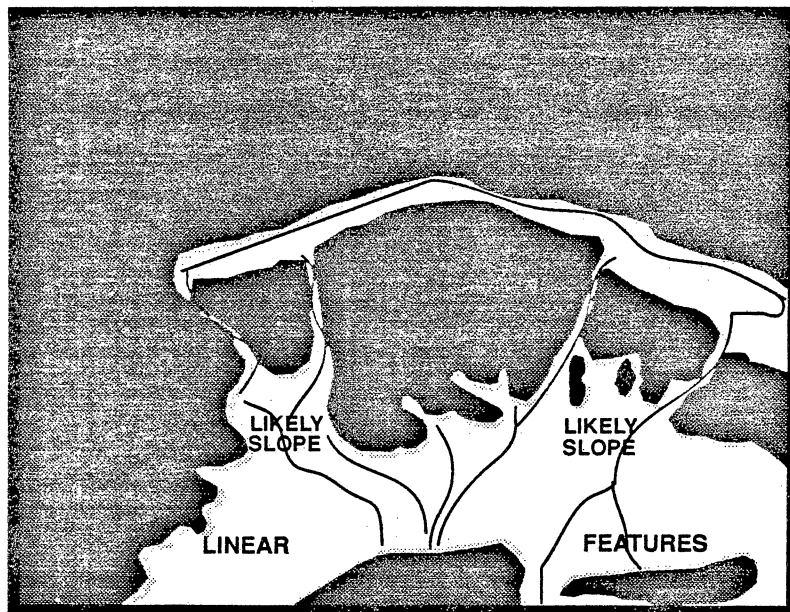
STEP FOUR: Pinpoint geometric
texture on or near linear
features and passage areas.

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STEM-AND-LEAF PLOT OF GROUP DIFFERENCES
Number of Hits and False Alarms

APPENDIX E. Treatment Group Questionnaire

There are four questions outlined below. They pertain to the written instructions given to you prior to the search task. Please circle the appropriate answer where indicated.

1. Overall, did you feel the instructions helped you during the search task?   Yes or No.

2. What step or steps were the most helpful (if any) during the task? Circle one or more steps below. If all steps were equally helpful, circle all. If none were helpful, circle none?

        (a) step 1
        (b) step 2
        (c) step 3
        (d) step 4
        (e) all
        (f) none

3. Did you think that one airphoto was harder than the other? Yes or No. If so, which one? Airphoto B1 or Airphoto B2.

4. Were the written instructions more helpful with one airphoto more than the other?   Yes or No. If so, which one? Airphoto B1 or Airphoto B2.

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