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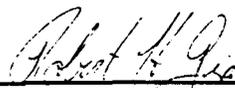




The Contractor, Amherst Systems Inc., hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. DAAK70-91-C-0051 is complete, accurate, and complies with all requirements of the contract.

7 APRIL 1992

Date



Robert H. Giza, Program Manager

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Section 1 INTRODUCTION

1.1 Problem Statement

The effective application of camouflage and deceptive measures provides an invisible armor to Army personnel and equipment. Even on today's high-tech battlefield, there is no denying the effectiveness of such measures. In fact, it is very likely that there is no more cost effective means of enhancing survivability and mission effectiveness than the application of appropriate camouflage measures.

Current methods of camouflage and decoy evaluation typically resort to the observation of candidate measures in the field. This is both a costly and time consuming process and, because of varying environmental conditions (weather, terrain, visibility, etc.) the results of the test are difficult to quantify and to compare with previous observations. The more recent need to develop camouflage measures to defeat multispectral sensor threats has further complicated the problem.

The Army has an immediate need for a digital simulation capability to supplement the current methods employed for developing counter-surveillance measures. Such a system would permit the enhanced development of camouflage measures and materials at significantly reduced cost. Even without the constraints imposed by a tightening defense budget, resulting in the reduction in funds available for field test and training, the development of a graphic workstation for the development and evaluation of such measures would provide significant assistance to the Army in defending against current and emerging threats. These improvements in camouflage effectiveness will directly impact the survivability of Army troops and materiel.

1.2 Phase I Objectives

The Camouflage Visualization System software developed under this Phase I SBIR effort addresses the Army's need for camouflage evaluation tools. The overall objective under the Phase I development was to demonstrate the feasibility of providing the Army with an interactive graphic workstation to be used in the application and evaluation of concealment and deception measures, observed under realistic field conditions. The desired features of such a system address the following key concerns:

- Simulation Accuracy

- Simulation Versatility

- Friendly Access to System Features

- System Expandability

Accuracy implies that the scenes presented for evaluation are radiometrically correct. This is in contrast to many computer graphics applications which create aesthetically pleasing images by allowing the arbitrary selection of color and intensity. Realism in the simulated scenes dictates the need for accurate representation of the natural illumination, atmospheric attenuation, and precise representation of the optical properties of camouflage paints and materials. These elements of the simulated scene must be described in terms which can be measured and verified through observation in the field. Interactions between the various parameters, such as the impact of the sun position on sky illumination and brightness, should be handled in a manner which consistently modifies all dependent features of the environment.

Among the primary advantages provided by the digital simulation of camouflage measures is the convenience and relatively low cost provided for the evaluation of candidate measures. Through digital simulation, the system operator may place candidate measures into a variety of situations and environments and analyze the results. Such interaction provides the user, not only with a more thorough evaluation of the proposed design, but helps to develop an intuitive understanding of the effects of varying parameters. To fully realize these potential benefits however, the system software must provide the versatility to vary parameters over a broad range of values. Specification of the environment should take into account varying sun positions and meteorological conditions. The capability to view the camouflaged assets against a variety of terrain types is also desired. Within this environment the user may choose to specify the relative orientation of the object of interest and modify the measures applied to disguise or conceal it.

The original application of camouflage measures was somewhat of a "black art" based on intuition and subjective appeal. Today's approach is far more scientific and draws from the knowledge base of such diverse fields as physics, engineering, meteorology, and psychology. While an understanding of each of these areas is important to the development of counter-surveillance measures, seldom does one have an in-depth knowledge of all these areas. The graphic workstation designed to support the development of camouflage measures should ease this requirement by hiding the details of its implementation and by providing higher level access to system features through a user-friendly interface. For example, the system should permit the specification of the atmospheric visibility without burdening the system operator with the details associated with absorption and scattering within the atmosphere, and the density and distribution of the various atmospheric constituents.

A key component in the development of a graphic workstation for camouflage evaluation is the provision of a friendly user interface. Friendly implies that assistance is available to the operator while executing the software, and that the software is tolerant of mistakes made by the operator while entering data or applying system functions. The system interface should fully support the rendering and display of target images, providing access to all aspects of file input, system execution and analysis.

The pace of modern warfare has risen significantly due to increases in target mobility and weapon lethality which demand both earlier detection time and shorter reaction time. In addition, more complex threats (variety and density of platforms, low observability, countermeasures sophistication) require improved detection/discrimination capabilities. These factors, coupled with the increased cost of personnel and equipment, have dictated the development of advanced targeting systems which incorporate several sensors which

may operate over multiple spectral bands. To keep pace with the rapid developments in target acquisition sensors and the countermeasures conceived to defeat them the Camouflage Visualization System must be capable of expanding to meet the requirements for developing multispectral counter-surveillance measures. Given the modular structure of the software design developed and demonstrated under Phase I, it is feasible to provide extensions to the software to address simulation requirements over the ultraviolet, visible, and infrared spectrum.

1.3 Phase I Scope

The work conducted under the Phase I effort supports the development of a computer graphic workstation with the features described above. The following tasks provided the basis for the development of the system prototype under the Phase I effort:

Review and define system requirements.

Development of target rendition and image display algorithms.

Define and implement an object-oriented system design using C++.

Design and implementation of a "windowed" interface based on the Windows 3.0 operating system for the IBM personal computer and compatibles.

Define display calibration procedures.

The objectives associated with each of these program tasks have been met under the Phase I contract. A detailed description of the results of these tasks are described in this report.

1.4 Phase I Accomplishments

Tasks performed under the Phase I contract provide the Army with a detailed study of the requirements and methods for digitally displaying counter-surveillance measures. The results of this study are embodied in the software prototype of the Camouflage Visualization System, implemented to test and evaluate the system design. The prototype developed under the Phase I contract provides a basis for Phase II implementation and demonstrates the utility of camouflage design and evaluation on a computer graphic workstation. The prototype has been implemented using an object-oriented approach with modular software components that may be easily extended. The early demonstration of a working prototype, combined with the modular nature of its implementation, assures the realization of the desired system features and performance under later development efforts (i.e., Phase II).

As demonstrated under the Phase I contract, the Camouflage Visualization System software provides the system operator with the means to specify and control the parameters defining the target, the environment, and the viewer. Our goal is to develop a simulation in which counter-surveillance measures may be applied quickly and with little difficulty, allowing the operator to examine many camouflage applications and select the best of these for further field evaluation.

The task to define the requirements and functional capabilities of the Camouflage Visualization System software resulted in the completion of a System Requirements

Document. The System Requirements Document served as a guide to development of the system software and as a definition of the goals set for the Phase I effort and beyond. A summary of these requirements is provided in Section 2. The mapping of these requirements onto a system design resulted in the creation of the Top-Level System Design. This Top-Level Design described in greater detail the software and data structures developed under the Phase I effort. A description of the top-level software design is provided in Section 4.

Functionally, the Camouflage Visualization System prototype supports the creation of one or more computer generated targets and their insertion into a measured background image. The user is permitted to specify and change the position and orientation of targets in the composite scene, and will be provided with the tools to alter the colors and patterns applied to the target surface. The target image may be inserted into a selected background color image. Selection and implementation of these system features is provided to the system operator through a user-friendly interface featuring pull-down menus and a control panel-like display.

The Camouflage Visualization System software prototype demonstrates the advantages of digital simulation applied to the development of counter-surveillance measures. Although initially limited in it's capability, due to the constraints of both time and money, the system is written using an object-oriented programming approach to provide for easy extension of the system features and capabilities in the future. We have taken advantage of existing software and hardware standards to provide widespread system compatibility.

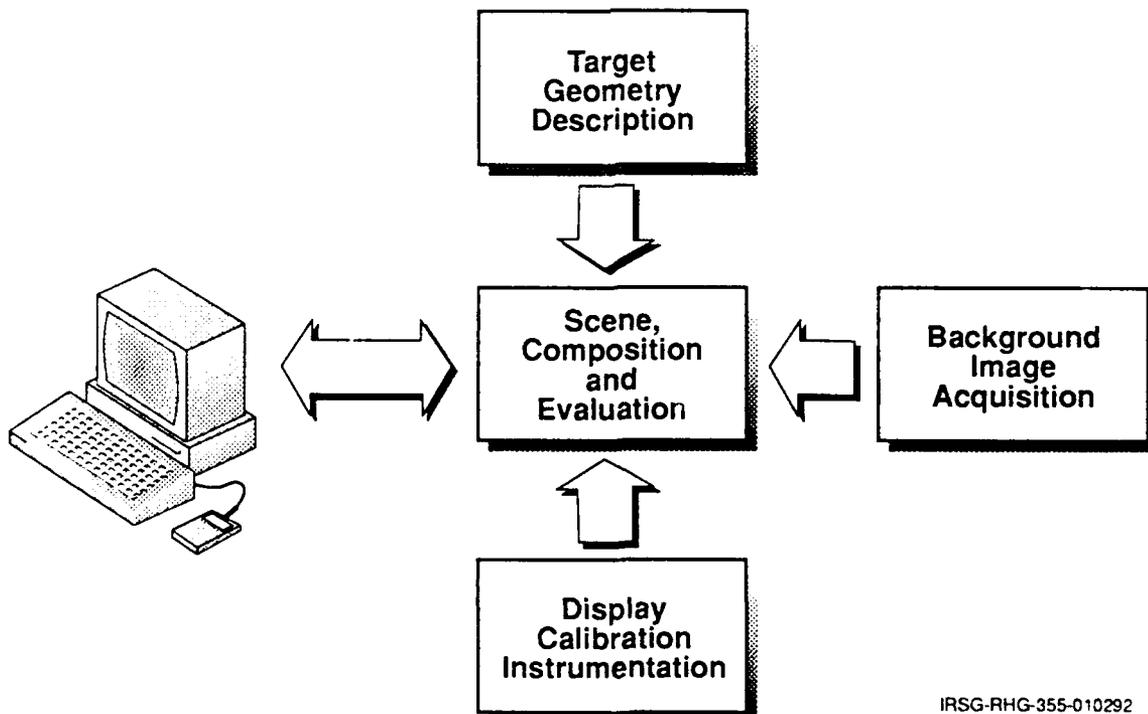
Section 2 REQUIREMENTS

2.1 Definition

The Camouflage Visualization System shall provide for non-real time composition of scenes consisting of camouflaged ground targets or decoys and measured background imagery. The resulting scenes may be displayed for immediate evaluation or saved for later processing. In its initial implementation, the software shall provide for generation of the target/background scene in the visible portion of the spectrum for presentation to an unaided human observer.

The Camouflage Visualization System displays a composite image with a simulated field-of-view which may range from 5 degrees to 120 degrees, in both azimuth and elevation. The system defaults to a 90 degree viewing angle at system start up. The actual field-of-view will vary depending on the resolution and size of the system display.

A conceptual illustration of the Camouflage Visualization System architecture is provided in Figure 2.1-1. At the heart of the system is the capability to compose and evaluate a scene containing one or more synthetically created target images over-laid on a measured background. Supporting this, is software to read in the target geometric description and assign surface attributes, select and read-in a background image, and calibrate the display.



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Insert Figure 2.1-1

Camouflage Visualization System Concept

As defined under the Phase I effort, the functional requirements for the Camouflage Visualization System are:

Select target geometric descriptions and translate these into an internal format. Subsequent efforts shall provide for the translation of BRLCAD and/or FRED target descriptions.

Rotate and scale the target description to provide for simulation of varying range, orientation and viewing perspective.

Select and apply material attributes to the target surfaces.

Provide for the specification of the target environment and calculate the level of target illumination, due to sun and sky, and the contrast attenuation along the viewing path.

Calculate the luminance of target surfaces and convert these to appropriate values for display on a color monitor.

Select and read-in a colored background images.

Insert one or more target images into the background, with the option to save the composite image.

Calibrate the system color display.

Provide software tools to assist in both the quantitative and subjective evaluation of the displayed camouflage measures.

2.2 Performance Characteristics

The Camouflage Visualization System conceptually supports five major functional modes; Apply Attributes, Render Target, Insert Target, Calibration, and Evaluation. In each of these modes, data and functions may be selected and/or applied to compose and evaluate the displayed scene. The relationship between system data, functions, and the system operational modes is illustrated in Figure 2.2-1. Each of the operational modes is described in detail in the following sections.

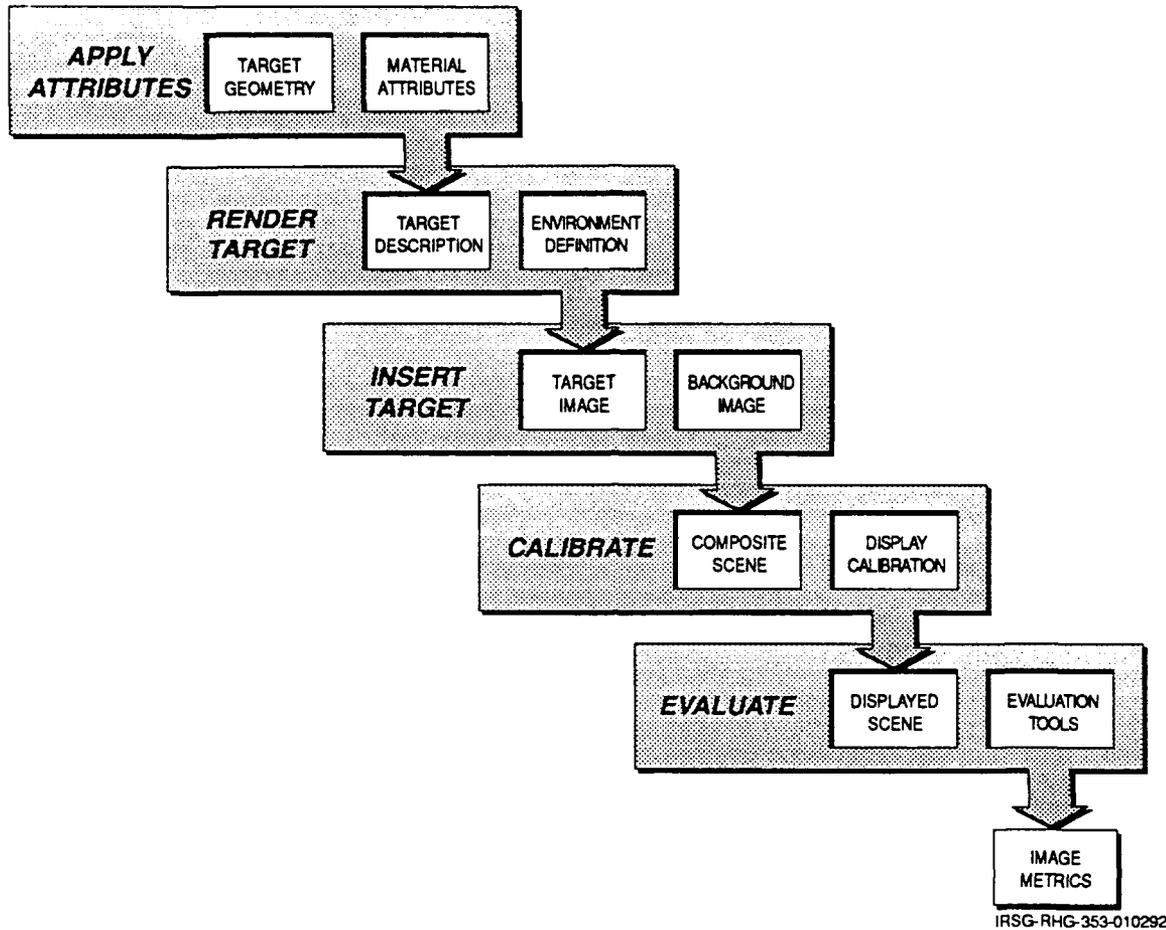


Figure 2.2-1 System Functional Modes and Associated Data

2.2.1 Apply Attributes Mode

In the Apply Attributes mode the user may read in a target geometric description and assign material attributes to its surface. The target geometric description shall consist of a collection of polygons and their vertices used to describe the position and orientation of the target surfaces. The surface attributes may be selected from a "palette" of materials and interactively applied using a mouse or other interactive pointing device.

The target geometry is internally represented using a two-level hierarchy as described in Section 3.2-1. Each target will be composed of one or more surfaces, which will in turn be composed of one or more plane, convex polygons. The number of polygons used to represent a curved surface will determine the visual accuracy of the final target image. Access to available memory is currently the only restriction imposed on the number of polygons required to accurately describe the target. Note, however, that as the number of polygons used to describe the target increase, the processing time will increase in proportion.

Target descriptions of Army ground vehicles and equipment currently exist in a number of available formats. Target descriptions in such data formats as FASTGEN, ACAD, FRED, and BRL-CAD are readily available to government agencies and their contractors. In addition, a

number of commercially available software products, such as AUTOCAD and Swivel 3-D, support the creation of three-dimensional target geometric descriptions. The use of existing data sources relieve the user of the arduous task of creating the needed target descriptions, while the use of CAD software provides the capability of creating target configurations for which no data exists.

The Camouflage Visualization and Analysis Software currently accepts targets in a format compatible with an internal representation defined to support the computer rendering process. In the future, the software shall support the translation of one or more of the above mentioned formats into into the internal representation of the target geometric description. The details of the transformation from the external to internal data file format shall be transparent to the system operator.

Functions to rotate, translate, and scale the target have been provided to facilitate the application of material attributes to the target surface. The user may specify these parameters through the system interface.

A default palette of material attributes shall be provided to the user for specification of surface reflectance and color. These materials may be selected from an extendable palette which currently consists of the 11 colors that form the basis of traditional Army camouflage paint schemes. Associated with each color are the parameters which describe the overall reflectance and gloss of the color. To edit or extend the default palette the user may specify new colors by entering the CIE color coordinates of colors selected from the Federal Standard 595a color catalog. Conversion of the CIE color coordinates to RGB (red, green, blue) display values is internally provided by the system software.

While in the Apply Attributes mode the user shall be able to save the changes made to either the target description file or the material palette. The saved changes may be written to the original file or saved as an altogether new file. The user shall also be provided with the option to quit from the Apply Attributes model without saving the changes.

2.2.2 Render Target Mode

The Render Target mode shall provide the user with the means to create and save a color-shaded target image. The target description used in the rendering process shall consist of a combination of the target geometry data and material attributes assigned to the target in the Apply Attributes mode. While in the Render Target mode the user may specify the target orientation and range, as well as the sun position and atmospheric visibility.

The target description used to generate the rendered image may be created in the Apply Attributes mode or selected and read from an external data file.

The user shall be provided with the option to rotate and position the target by specification of the target roll, pitch and yaw, and viewer-to-target range. The user will be required to specify all rotations in degrees, while internally the target orientation angles are assumed to be in radian units. Internal and external expressions of linear dimensions are assumed to be in meters.

The lighting conditions for the target are determined by the position of the sun and whether or not the sky is clear or overcast. By default the lighting description shall be defined such

that skies are clear and the sun is directly overhead. The user shall be provided with the option to select the sun position by specifying the sun azimuth and angle from zenith, and to specify clear or completely overcast skies. Specification of the sun position angles shall be in units of degrees.

The atmospheric visibility shall be determined by specifying the meteorological range in kilometers. A default value of 23 kilometers, corresponding to a standard clear atmosphere, is assumed if no value is specified.

The Render Target mode shall provide for the rotation and translation of the target geometric description from world coordinates to viewing coordinates, including the effects of range and perspective. The Render Target mode shall also provide for hidden surface removal, calculation of target surface luminance, and degradation of target contrast due to atmospheric effects along the viewing path.

2.2.3 Insert Target Mode

The Insert Target Mode shall provide the user with the tools to edit or create a composite scene of camouflaged targets and backgrounds. The composite scene shall consist of a measured background image into which the system operator may insert one or more target images created previously in the Render Target Mode. The result may be saved to an existing file or an altogether new image file.

The background image shall consist of a two dimensional array of pixels (picture elements) which indicate the color and intensity of a natural scene. The number of permitted colors shall be variable, up to 2^{24} colors, and automatically determined to take full advantage of the system hardware. Similarly, the size of the image shall be variable to adjust to the resolution limitations of the system host.

The composite image shall be created by combining a measured background image with target images created by the Camouflage Visualization and Analysis System in the Render Target Mode. The user shall be permitted to insert one or more non-overlapping target images into the background scene. The software shall automatically blend target and background image pixels at the target edge to provide a realistic merge of targets and background data.

The background and composite scene images shall be externally stored in either the TIF or PCX file exchange format. The current software prototype supports only the PCX file format. The TIFF file format shall be added under later developments to extend system compatibility across diverse processing platforms and operating systems.

2.2.4 Calibration Mode

The perception of the colors and contrast displayed on the screen will be influenced by many factors, including the phosphors used in the system display, monitor brightness, color settings, and room lighting conditions. These factors are subject to change and adjustment, and these variations must be taken into account. The Calibration Mode shall provide the user with the means to calibrate the system display by internally adjusting the systems' color palette to provide an accurate display of colors in the scene.

The Calibrate mode shall provide the methods to display a test pattern of various colors and intensities for measurement by a photometer/radiometer. Provision shall be made to enter the measurements associated with the calibration pattern. The system software shall provide for automatic mapping of the calculated scene luminance to an accurate color display. A complete description of the calibration procedures defined under this effort is provided in Section 3.7.

The initial system shall provide color correction only for an unaided human observer. Compensation for sensor responsivity and the application of various color filters shall be addressed in later developments. Under planned extensions to the Camouflage Visualization System software, the user will be permitted to select from several predefined sensor spectral responsivities. These shall be applied for determining the appropriate color correction.

While in the Calibration Mode the system operator shall be able to open a new or existing calibration file to review or edit current calibration parameters. The means to save the calibration data to an existing or new file shall be provided.

2.2.5 Evaluation Mode

The Evaluation Mode shall provide the user with various image processing functions to analyze and characterize the displayed scene. The resulting data will assist in the quantitative determination of the effectiveness of the camouflage measures applied to targets in the scene. This mode shall also provide the user with the means to "script" several scene images together to provide a sequence of scenes.

An extendable set of image processing tools shall be provided with the initial implementation of the Camouflage Visualization and Analysis System. These shall include image processing functions to provide point, area, and frame processing of the composite image. The system architecture shall provide for expansion of this basic tool set.

The Evaluation Mode shall provide the methods needed to "script" a sequence of scenes for subjective evaluation. A simple scene sequence editor shall be provided to permit the selection of images to be inserted or deleted from the script. The user shall have the option to save the script changes to an existing or new data file. The user shall also have the option to quit without saving the changes made.

The script feature provides the system operator with the capability to create a collection of test scenes for subsequent presentation to an observer for evaluation of the measures depicted in the images. Provided with this feature shall be the option to record and verify user responses pertaining to detection and recognition of targets and decoys.

2.3 System Software

The software developed to support the evaluation of camouflage and deception measures shall be structured in a modular fashion to permit the easy modification and extension of the software to meet changing or expanding requirements. Interaction with the system shall be supported by sufficient error checking and trapping to prevent inadvertent errors and system crashes. Where possible, industry wide standards shall be used to support widespread system compatibility.

The C++ programming language was used as the design language for the development and implementation of the Camouflage Visualization System prototype. C++ fully supports the object-oriented programming approach adopted for this effort. The object-oriented approach has been found to enhance the development of software for large systems, and is particularly helpful in the development of interactive systems where system features are typically accessed at random.

Object-oriented design supports three basic concepts: data abstraction, polymorphism, and inheritance. Data abstraction refers to the ability to define abstract data types that encapsulate some data together with some well-defined operations. This combination of data and functions, referred to as a class, hides software implementation details and helps to limit software changes to a very well-defined portion of the code. Inheritance implies a hierarchy of classes with derived classes inheriting behavior from the base classes. Inheritance aids software development by allowing new code to be generated by extending existing software components. In the context of software development, inheritance promotes the sharing of code and data among classes. Polymorphism refers to the fact that different objects react differently to the same message. Through this feature, the software is kept conceptually simple by permitting the same function to perform similar tasks in all classes in the hierarchy.

The Camouflage Visualization System software has been, and will continue to be developed under the Windows 3.0 operating system developed by Microsoft Inc. Windows will run on all PC-AT 286, 386, 486 and compatibles configured with at least 2MB of RAM. Windows provides extensive graphical support for the development of graphic displays for the PC and is among the most widely used interface standards.

Development of the user interface on the PC shall take advantage of the ObjectWindows software developed by Borland International Inc. ObjectWindows is an object-oriented class library that encapsulates the behaviors that Windows applications commonly perform. ObjectWindows eases Windows application development by providing:

- A consistent, intuitive interface to Windows
- Supplied behavior for window management and message processing
- A basic framework for structuring a Windows application

This base functionality is inherited, leaving the systems programmer free to concentrate development effort on the unique requirements for camouflage visualization.

2.4 System Hardware

The Camouflage Visualization System prototype was implemented on an IBM-PC AT 386 compatible computer. The AT 386 is an excellent prototype platform because of the extensive software and hardware support available for it. The AT 386 is a relatively inexpensive computing platform with sufficient hardware capabilities to support the implementation of the software design.

The system used in the development of the software design and prototype was configured with 4MB of random access memory (RAM). This amount of memory is the minimum

required to support image processing requirements and execution of the Camouflage Visualization System software running under the Windows (Version 3.0) operating system.

An ATI Graphics ULTRA Accelerator card was added to provide the required number of colors and screen resolution. The ATI accelerator card supports a high resolution mode providing 1000x680 pixels and a palette of up to 256 colors from a range of 2^{24} . A 13 inch NEC Multi-Synch monitor was used to display the images. A microsoft compatible mouse supports the access to functions displayed on the system monitor.

The PC platform is recommended for continued development of the Camouflage Visualization System software. The PC platform is inexpensive and the programming environment under the Windows operating system was found to be both easy to use and very efficient. Because of the popularity and relatively low cost of this platform, more operators can realize the advantages of the software developed for camouflage evaluation.

Despite the advantages of the PC platform, there are several concerns which are best addressed by a more capable processing platform. Both processing and display capabilities will be enhanced by transporting the system software to a graphics workstation. Workstations, such as those developed by Silicon Graphics and Sun Systems, are designed to specifically address the processing requirements for graphic display. In many cases, specialized hardware is provide for transformation and rendering of the target. These system features enhance the utility of the software by permitting the generation of images of greater detail in less time. Greater detail provides improved simulation realism and faster processing enhances the interaction with the software.

Amherst Systems recommends that further development of the software be conducted in parallel for implementation on the PC and on a graphic workstation. This approach will provide the Army with the option to install a few high-powered processing stations for editing the target descriptions and generating complex images, and many low-powered imaging stations to be used for playback of the images and less demanding analysis. In addition, with the development of laptop and notebook personal computers, this dual implementation will support the access and verification of test results in the field. Amherst Systems envisions the use of compact personal computer systems as a connection between workstation processing in the office and the acquisition and validation of data in the field.

Section 3

ALGORITHM DEVELOPMENT

3.1 Introduction

In this section we describe the equations and algorithms developed to support the rendition and display of realistic target images. Providing a basis for the overall development is the definition of the target surface geometry and the various coordinate references. In the following sections we describe the target data formats used within the Camouflage Visualization System to describe the target geometry and the materials applied to target surface.

Attributes, such as color and reflectance, determine the appearance of the target and are the target features over which the camoufler has greatest control. A data format which allows the user to select from a library of camouflage paints and materials has been defined. Using this information, combined with a definition of the light sources and environment, we derive a third surface attribute, luminance. The approach taken supports the extension to include the calculation of the self-emitted component of the infrared target signature.

The environment encompasses the definition of the atmosphere and the illumination from the sun, sky and earth. These influences on the target signature may be calculated for a single wavelength or over the entire spectrum. The factors are calculated within the Camouflage Visualization System to provide for the greatest range of application and program flexibility.

Definition and calculation of the geometry, surface attributes, and the environment provide the pieces which must be tied together to provide a rendered target image. In this we draw heavily from the computer graphics community using standards and procedures defined for the rendition and display of synthetic target images. We have reviewed the graphic libraries associated with the PHIGS, Windows, X Window System, and Silicon Graphics GL standards to determine an approach which is as universal as possible, and takes advantage of the latest developments in both graphic hardware and software.

It wasn't until recently that much attention had been given to the problem of calibrating color displays. These developments come as the computer is being applied to color applications in advertising and industry. We have researched the development of color calibration standards and have derived an approach for establishing and maintaining true color display. The results of this work is described in Section 3.7.

3.2 Geometry

The design of the Camouflage Visualization System software supports the creation, manipulation and display of complex target models. The targets themselves are built in hierarchical fashion from simple components in a convenient local coordinate system. The basic elements used in the definition of the geometric description of the target's surface are planar convex polygons. The polygons may be combine to form components, which may in

turn be collected to define the entire target. This provides the much needed convenience of being able to add and delete components from the target description.

The target description is defined in a coordinate system specific to a particular target. To create an overall picture, the targets are placed into the scene using modeling transformations which convert local coordinates to world coordinates. The objects in the scene are then transformed to view coordinates subsequent to display on the system's color monitor.

A detailed description of the file structure for the target geometric model is described in the following section. Following this is a discussion of the various coordinate references defined for use by the Camouflage Visualization Software, and the transformations which convert from one reference to another.

3.2.1 Target Surface Description

The target geometry is internally represented using a two-level hierarchy as is illustrated in Figure 3.2.1-1. Each target may be composed of one or more surfaces, which may further be composed of one or more plane, convex polygons. The number of polygons used to represent a curved surface determines the visual accuracy of the final target image. Access to available memory is the only restriction imposed on the number of polygons required to accurately describe the target. The current system has been demonstrated to run with target descriptions of up to 1200 polygons.

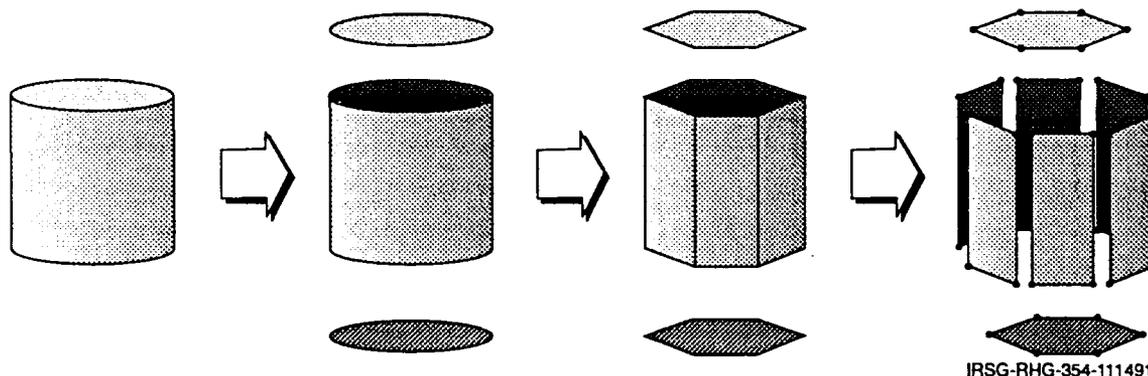


Figure 3.2.1-1 Target Description Hierarchy

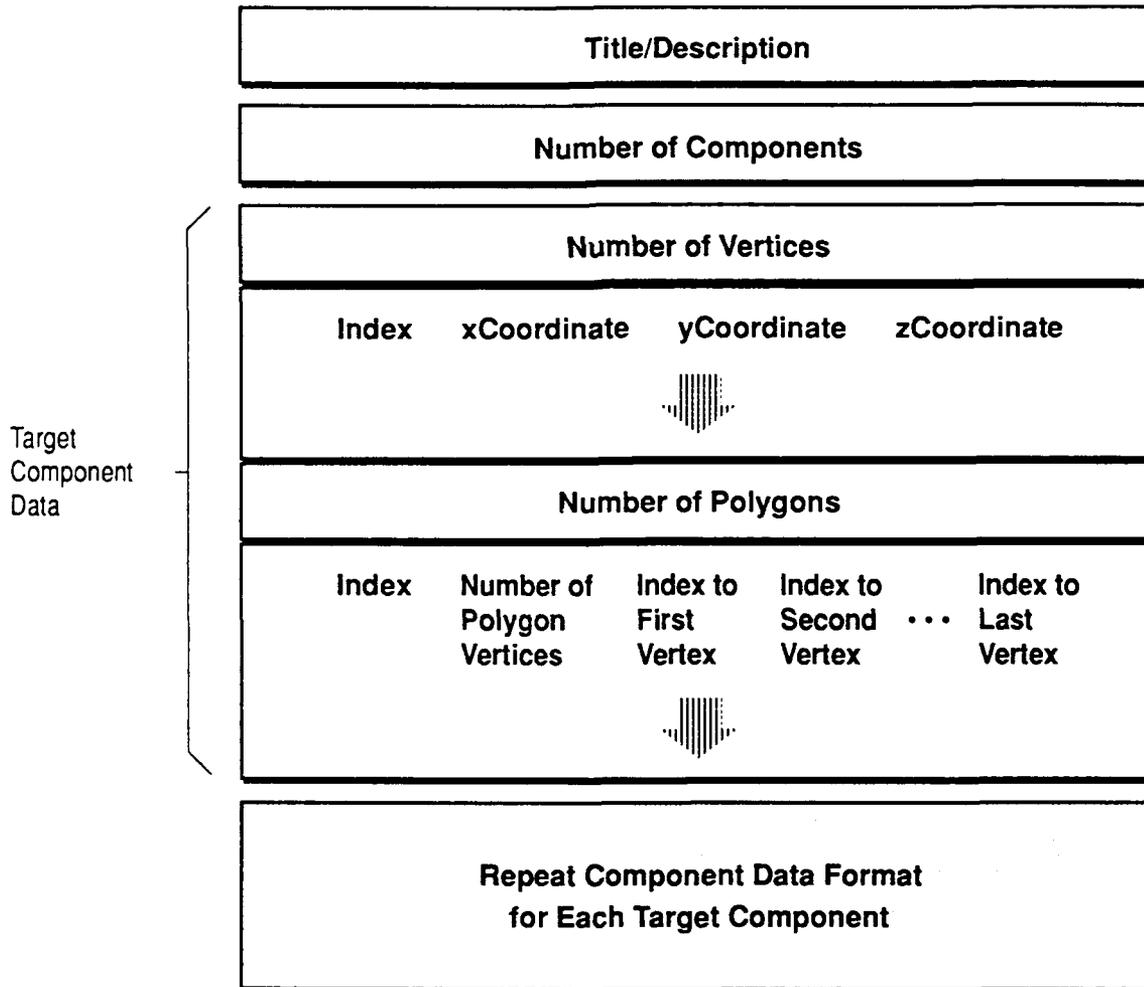
The target geometry data file contains the data which defines the three-dimensional position and orientation of the target surfaces. To simplify the rendering calculations the smooth surfaces of the target are approximated by planar convex polygons. The number of polygons used to represent the a curved surface will determine the visual accuracy of the final target image. In general, the smaller the radius of surface curvature, the greater the number of facets required to accurately represent the surface.

Each target will be composed of one or more components, which will in turn be composed of one or more planar convex polygons. The target is broken into components to permit easy modification of the target description. Components may be added or removed from the target description without effecting the other components. All the vertex and polygon data associated with the component is kept together within the target geometry file.

Included in the target data file is the following information:

- Target name or description
- Number of components
- Number of vertices
- Vertex coordinates
- Number of polygons
- Polygon vertices
- Polygon material type

This information is organized as shown in Figure 3.2.1-2. As indicated, the basic organization is repeated for each component in the target description.



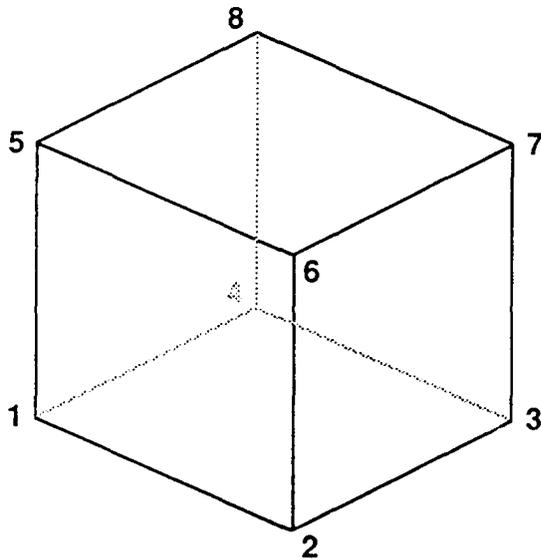
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Figure 3.2.1-2 Target Geometry Data Format

The index in the component data is provided only as an aid to assist the system operator in the creation and modification of the target description, and is not used by the Camouflage Visualization software. The value of the index starts at one and increases up to a value equal to the number of facets. The same applies to the index associated with the polygon data.

Definition of the polygons requires the specification of the vertices which, when connected, form the perimeter of the polygon. These indices should correspond to the indices associated with the vertex coordinates. It is assumed that the order of the vertices defining the perimeter of the polygon is such that the path traced by the series of points follows a counter-clockwise progression as viewed from the exterior of the target surface. This assures that the normal calculated from these points is properly oriented, and directed outward on the target surface.

As an example of the format required for input of the target geometry data, we have provided the data for a simple cube. An illustration of the cube and the corresponding data is provided in Figure 3.2.1-3. You will notice that the data file has various comments that may be used to describe the components and their associated data. Comments may be added any where in the target data file to assist in the modification of the target description and the identification of possible errors. Comments must be written on a separate line and are denoted by placing an asterisk at the beginning of the line. The software has been written to ignore any lines beginning with an asterisk.



- Only one component

1

- This component contains 8 vertices

8

```
1 -5.0 -5.0 -5.0
2 5.0 -5.0 -5.0
3 5.0 5.0 -5.0
4 -5.0 5.0 -5.0
5 -5.0 -5.0 5.0
6 5.0 -5.0 5.0
7 5.0 5.0 5.0
8 -5.0 5.0 5.0
```

- This component has 6 square polygons

6

```
1 4 1 4 2 3
2 4 1 2 6 5
3 4 2 3 7 6
4 4 3 4 8 7
5 4 4 1 5 8
6 4 5 6 7 8
```

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Figure 3.2.1-3 Cube and Associated Data

It should be noted that geometric data format described here is but one of many data formats used to define the coordinates and surfaces of objects. It is unfortunate that while the commercial sector seems to be converging a limited number of universally supported formats, the number of formats used for military applications seems to be growing. Various data formats have been defined to support such applications as vulnerability analysis, signature estimation, and training. While the same geometric information is provided in each of these examples, the formats are often considerably different. This trend is likely to continue as DoD contractors focus on the development of solutions to specific military applications, rather than satisfying broader goals.

The format selected for implementation within the Camouflage Visualization System software has been developed to support the internal rendering process and the creation of the target image. It corresponds closely with that of several commercial standards, as well as several data formats used in target signature and vulnerability estimation. While this internal format is likely to remain relatively constant through future revisions of the software, we plan to provide for conversion from several established geometric file formats in the future. The Camouflage Visualization System prototype is currently being tested using data created manually or converted from the ACAD format used by the Infrared Modeling and Analysis (IRMA) software. Extension of the software prototype to accept data in the DXF file format, made popular by the widely used AUTOCAD computer-aided design software, is being considered for development under the Phase II effort. Also considered, is the development of an interface to the FRED and BRLCAD geometric descriptions defined respectively by the U.S. Army Tank and Automotive Command (TACOM) and the Ballistic Research Laboratory.

Functions to rotate, translate, and scale the target are provided to facilitate the application of material attributes to the target surface and observation of the resulting image.

3.2.2 Coordinate Reference and Transformation

There are five different coordinate systems used in the Camouflage Visualization System. This may seem overly complicated, but in practice it is a logical approach, and not too difficult to understand. We shall look at each coordinate system in turn.

Model Coordinates Each target is separately defined in modelling coordinates. This is very convenient, since it permits the user to specify the target geometric description in the most appropriate coordinate reference and scale. The user selects a point of reference on the target, such as the center of gravity, and specifies the coordinates of points on the target surface relative to that reference.

World Coordinates The target and observer's position is defined in world coordinates. To do this, we define for each target, a modeling transformation to convert from modeling coordinates to world coordinates. In general, this will involve scaling the target to the correct proportions, rotating it to the correct orientation, and translating it to the appropriate position.

View Reference Coordinates The Camouflage Visualization System incorporates the idea of photographing the 3D scene with a camera, to produce a flat picture of the scene viewed from some position using a perspective projection. 3D viewing can be a tricky subject, and to simplify the definition

of views, the Camouflage Visualization System software introduces the view reference coordinate system which is similar to that found in many graphics applications. The system operator has control over the view through the specification of the viewpoint position and camera orientation.

Normalized Projection Coordinates This coordinate reference is also used in the specification of a view, and contains the image resulting from the perspective projection. The dimensions of the image are scaled to fit within a square with sides ranging from -1 to 1 in height and -1 to 1 in width. This is done to facilitate transfer between processing platforms possessing differing display dimensions and resolution.

Device Coordinates While considerable effort has been made to make the software developed for the Camouflage Visualization System independent of the graphical devices used for image display, it will be necessary to refer directly to positions on the display screen. For viewing, the software can specify exactly where on the display screen the selected portion of the view is to be placed.

3.3 Surface Attributes

Ultimately, we wish to calculate the intensity of the light which is reflected to the eye from a point on the three-dimensional description of the target. Before the target image can be rendered, however, we must specify the optical properties of the surface. This section describes the properties included in the surface attributes file and the format of this data.

For the present, we are concerned only with those properties which effect the reflectance of light in the visible portion of the electro-magnetic spectrum. The visible attributes required for calculation of the surface luminance or brightness include the color, reflectance, and the surface finish. This information is used to determine how much of the incident light is reflected from the surface, and how that reflected light is distributed.

Table 3.3-1 provides an example of the attributes that might be associated with a ground vehicle, camouflage netting, or decoy:

Table 3.3-1 Target Attribute Data

Data Item	Data Value
Description:	Forest Green Paint
x Chromaticity Value:	0.330
y Chromaticity Value:	0.355
Visible Reflectance:	0.065
Finish:	Matte

Included in this list is a label, "Forest Green Paint", which we may use to identify the material or coating. While not used directly in any of the calculations, this label simplifies

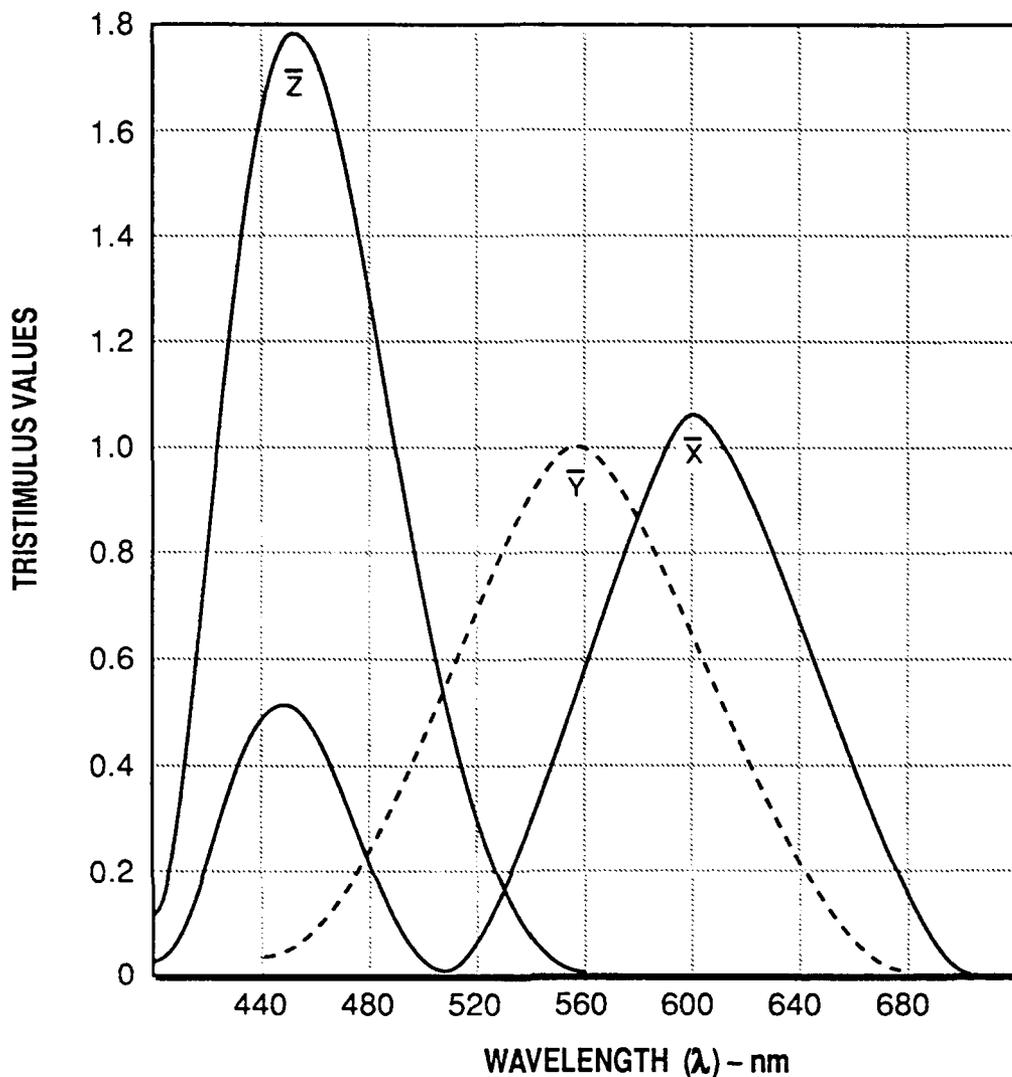
the identification and selection of the attributes data. The remaining attributes are described in detail in the following sections.

3.3.1 Color

Included in the attributes file is the specification of the material color. Color is perceived as a conscious sensation in terms of three major subjective attributes; luminance, hue, and saturation. Primary among these is luminance (often called brightness) which is determined by the percentage of the incident light reflected from the surface. The second major attribute, hue, which is the most characteristic of color, is the distinction between redness, yellowness, blueness, etc. The hue of colors in the physical spectrum relates directly to wavelength. The third attribute, which distinguishes strong colors from pale ones, is saturation or chroma. Saturation is related to the physical purity of the color.

Most color sensation can be matched by the mixture of three primary colors in suitable quantities. The three primaries may be, but are not necessarily, monochromatic. Typical primaries are red, green, and blue. In using such a set of colors for matching, it may be necessary to sometimes use negative amounts of one of the primaries ("negative" implies the addition of that primary to the color sensation being matched by the other two primaries. To avoid the use of negative amounts of color and to provide a standard for colorimetric use the Commission Internationale de l'Eclairage (CIE) proposed a set of idealized supersaturated primaries. (See also Section 3.7 Calibration)

The three curves marked x, y, and z in Figure 3.3.1-1 represent the amounts of the idealized primaries required to match any of the pure spectral colors in the visible range indicated on the abscissa. These particular curves were selected by the CIE so that y represents the relative spectral response of the photopic (daylight) eye, and thus provides luminance information in the matching function. The luminances of the x and z primaries are zero; these primaries provide only chromatic information.



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Figure 3.3.1-1 CIE Standard Color-Mixture Curves

Using the CIE primaries we may derive the Chromaticity Diagram illustrated in Figure 3.3.1-2. Each point in the Chromaticity Diagram specifies chromaticity (hue and saturation) independent of luminance. The locus of all spectral colors is plotted in the diagram. The open end of the spectral locus is closed by a non-spectral magenta. Enclosed within this region are all the colors visible to the human eye. Those points located in the central region of the diagram are recognized as "white".

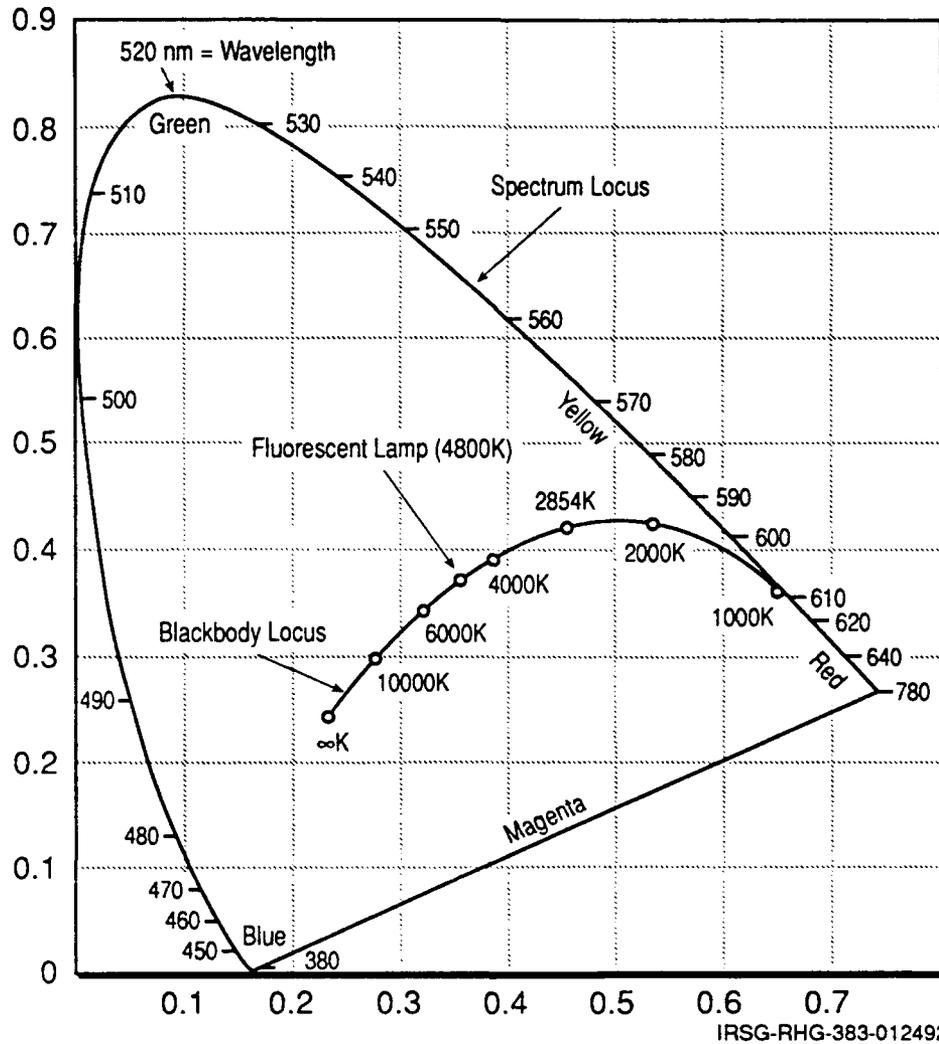


Figure 3.3.1-2 CIE Chromaticity Diagram

In our example the values, 0.330 and 0.355, are respectively the x and y values of the CIE Chromaticity coordinates which precisely determine the color of the material or coating, in this case a shade of green. This information is stored in the attributes data file.

Specification of the surface finish determines both the distribution of the light reflected from the surface and its color. The surface finish may be specified as matte or glossy. Matte surfaces reflect light into all directions, with the color of the light determined by both the color of the source and the reflecting material. The specular reflectance is confined to a relatively narrow range of angles, and its color is dependent only on the color of the incident illumination. Real surfaces are seldom characterized by either of these extremes, but rather by some combination of both specular and diffuse reflectance. To account for this the Camouflage Visualization software permits specification of the degree of surface gloss, which may also be specified in the surface attributes data file. A detailed description of the reflection models developed under this effort is provided in the following section (Section 3.3.2).

The surface attributes delivered under the current effort contain the parameters associated with the 12 colors which form the basis of traditional Army camouflage paint schemes. A standard file format has been defined so that the list of available colors may be extended, permitting the evolution of a library of material descriptions.

3.3.2 Reflectance

Reflectance is the basic factor in the look of a three-dimensional shaded object. It enables a two-dimensional screen projection of an object to look real - in the sense that a two-dimensional image of a photograph is an acceptable representation of three-dimensional reality to human perception. A reflectance model describes the interaction of light with a surface, in terms of the properties of the surface and the nature of the incident light.

The purpose of reflectance models in computer graphics is to render three-dimensional objects in two-dimensional screen space such that reality is mimicked to an acceptable level. The phrase 'acceptable level' depends on the context of the application. The higher degree of reality required, the more complex the reflection model and the greater the processing demands. Amherst Systems has developed two reflectance models under this effort. A simple model, implemented in the prototype, and a more complex model to be implemented in later development. Both are described in this section.

3.3.2.1 Simple Reflection

Simple reflection models attempt to synthesize the way in which light interacts with a surface. The 'standard' model in computer graphics that compromises between acceptable results and processing costs is the Phong model*. This models reflected light in terms of a diffuse component and a specular component together with an ambient term. The luminance of a point on the surface is taken to be the linear combination of these three components.

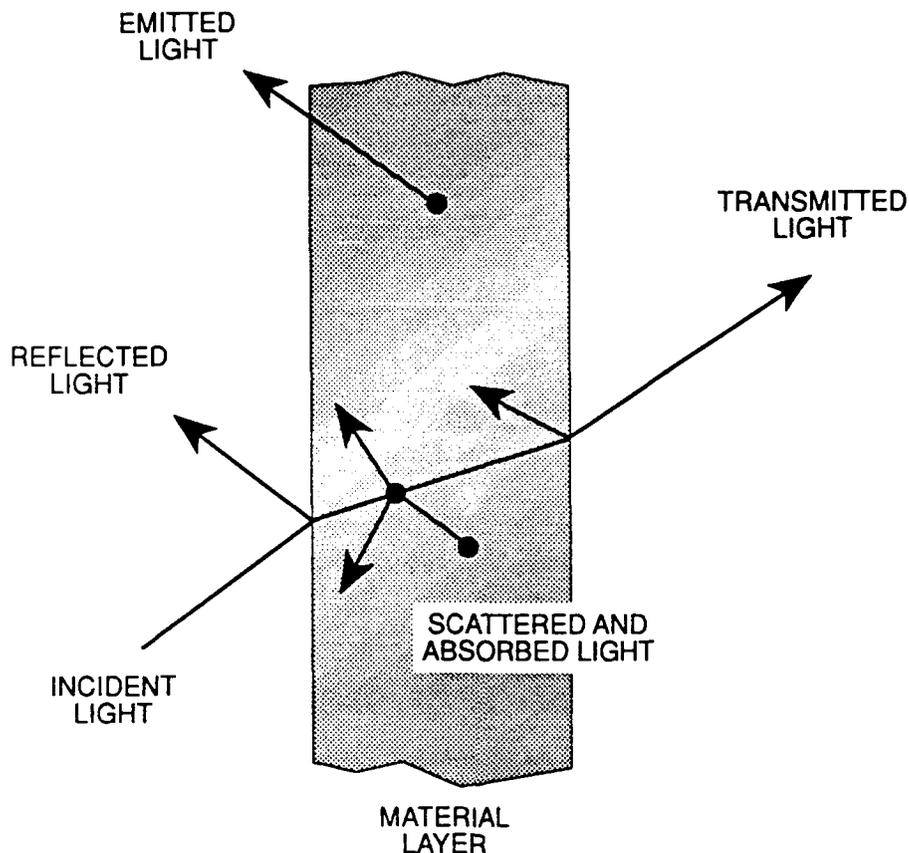
Simple reflection models in computer graphics are subject to two distinct approximations. First there are geometric processing approximations to cut down on the processing time, then there are physical approximations that constrain the complexity of the model. Geometric models are dealt with in context; here we briefly digress to discuss the nature of the physical model constraints.

First we consider an obvious equation:

$$\begin{aligned} \text{light incident at a surface} = & \text{light reflected} + \\ & \text{light scattered} + \\ & \text{light absorbed} + \\ & \text{light transmitted} \end{aligned}$$

* Foley, J.D., and Van Dam, A., *Fundamentals of Interactive Computer Graphics*, Addison-Wesley, New York, 1984

The interaction of light with a solid is shown in Figure 3.3.2.1-1. For now we consider only the reflected light, leaving the other components to be addressed in later development.



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Figure 3.3.2.1-1 Light Interaction With a Solid

The intensity and wavelength of the light reflected from a surface depend on the incident wavelength, the angle of incidence, the nature (roughness) of the surface material and its electrical properties (permittivity, permeability and conductivity). The exact interaction is extremely complex. For example, the same surface may be smooth for some wavelengths and rough for others; or for the same wavelength, it may be rough or smooth for different angles of incidence. Also we have the well-known empirical fact that any, surface regardless of its roughness, will reflect specularly at grazing incidence. Generally, we can define a bidirectional reflectance function that is a function of the incident and reflected angle: $R_{brdf}(\theta_i, \phi_i, \theta_r, \phi_r)$ where (θ, ϕ) is a direction in spherical coordinates. In the Phong reflection model the R_{brdf} is split into two components, dropping the directional dependence of the diffuse component.

Diffuse and specular light are both reflected components from the same surface. In the case of specular light we are viewing the reflected component at or near the mirror direction and a smooth surface tends to reflect much of the light along this direction. Diffuse light is scattered in all directions and is also responsible for the color of the object. This component of the reflected light is due to incident light that has been both reflected and selectively absorbed according to material dependent properties.

Most objects that we see around us do not emit light of their own. Rather they absorb daylight, or light emitted from an artificial source, and reflect part of it. This interaction is due to molecular interaction between the incident light and the material surface. A green object, for example, absorbs white light and reflects the green component in the light. The detailed nature of such interactions need not concern us, but we note that a surface reflects colored light when illuminated by white light and the colored reflected light is due primarily to diffuse reflection.

A surface that is a perfect diffuser scatters light equally in all directions. This means the amount of reflected light seen by the viewer does not depend on the viewer's position. Such surfaces are dull or matte and the luminance of the diffuse reflected light is given by Lambert's law:

$$L_d = E r_d \cos\theta // \quad \theta \leq \theta \leq \pi / 2$$

E is the illuminance of the light source. The angle θ is the angle between the surface normal and a line from the surface point to the light source (assumed to be a point source). The constant r_d is the portion of the total reflectance diffusely reflected from the material surface.

The above equation may be written in a more efficient form for numerical computation by using the dot product of two unit vectors:

$$L_d = E r_d (L \cdot N) / \pi$$

where N is the surface normal and L is the direction from the light source to the point on the surface.

In Figure 3.3.2.1-2, surface 1 is parallel to the incident light and θ is 90° . Surface 2 is normal to the light source and θ is 0° . For surface 3, θ is less than 90° . Thus surface 1 would not be illuminated and surface 2 would be brighter than surface 3. The constant r_d is related to the directional-hemispherical reflectance of the surface and assumes a value between 0 and 1.

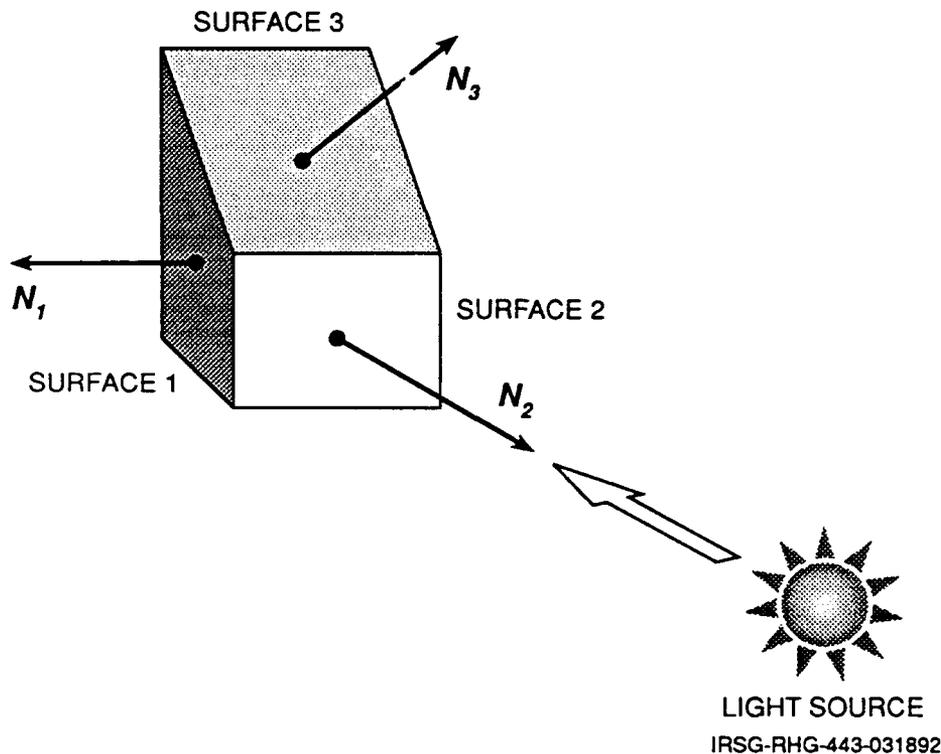


Figure 3.3.2.1-2 Three Diffuse Reflecting Surfaces

In Figure 3.3.2.1-2 surface 1 is parallel to the light source (and therefore invisible to it) but visible to the observer. Such a surface is illuminated by ambient light, otherwise it would unnaturally rendered black.

Ambient light is the result of the scattering and multiple reflection of the incident sunlight from the atmosphere, the terrain and surrounding vegetation. In our current development we have ignored the contribution from the ground and vegetation and reflect only the skylight.

Generally, the reflectance of the ambient light is approximately represented as a global value, constant over all the three-dimensional space of the scene. In effect, this simplification means that we are considering the objects as if they are floating in free space, with no interaction between the objects themselves, or between the objects and the background. We have improved on this common implementation by allowing the ambient contribution provided by skylight to vary with the orientation of the surface relative to zenith. This approximation takes into account the fact that as the normal to the surface moves away from the zenith direction, a smaller fraction of the sky illuminates the surface.

The empirical equation derived to describe the ambient reflection from the target surface is given by:

$$L_a = E_{sky} r (1 + \cos\theta) / 2\pi$$

where θ is the angle between the surface normal and zenith.

The factor $(1 + \cos\theta)/2$ is an approximation to the fall-off of the contribution provided by the incident sky light. When the surface normal points along the zenith direction the value of this term is one. When the surface points opposite zenith (i.e., towards the ground) the value of this term is zero. The vector dot product of the zenith pointing vector and the surface normal is substituted in this term to improve the processing efficiency in the software implementation.

Most surfaces are not perfectly matte and do not behave as perfect diffusers of light. Surfaces usually have some high degree of glossiness. A perfect glossy surface is an ideal mirror. Glossy surfaces are different from matte surfaces in a number of important respects. Firstly, as illustrated in Figure 3.3.2.1-3, light reflected from a glossy surface leaves the surface at an angle θ , where θ is the angle that the incident light beam makes with the surface. This means that the degree of specular reflection seen by a viewer depends on the viewing direction. Consider the case of a perfect glossy surface illuminated by a single point source. All the light from the source is reflected along one particular direction, the specular direction, and will only be seen when the surface is viewed from this direction. The surface will only appear bright for a single viewing direction and dark for all others. In practice, specular reflection is not perfect and the reflected light can be seen for viewing directions away from the specular direction, as is illustrated in Figure 3.3.2.1-4. The area over which the specular reflection is seen is commonly referred to as a highlight and this phrase describes a second important aspect of this type of reflection: the color of the specularly reflected light is different from that of the diffuse reflected light. In the approach described here, the specular component is assumed to be the color of the color of the light source. If, say, a green surface is illuminated with a white light then the diffuse reflection component is green but the highlight is white.

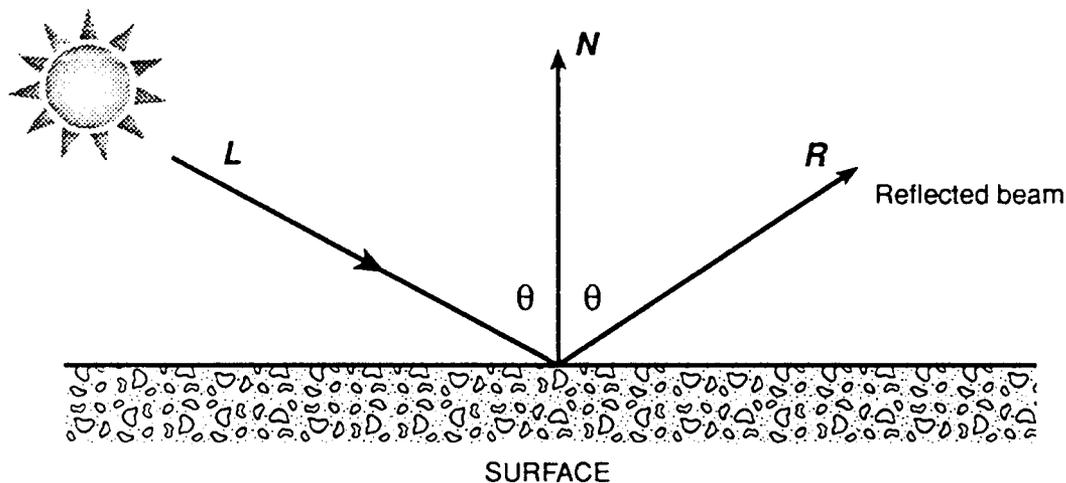


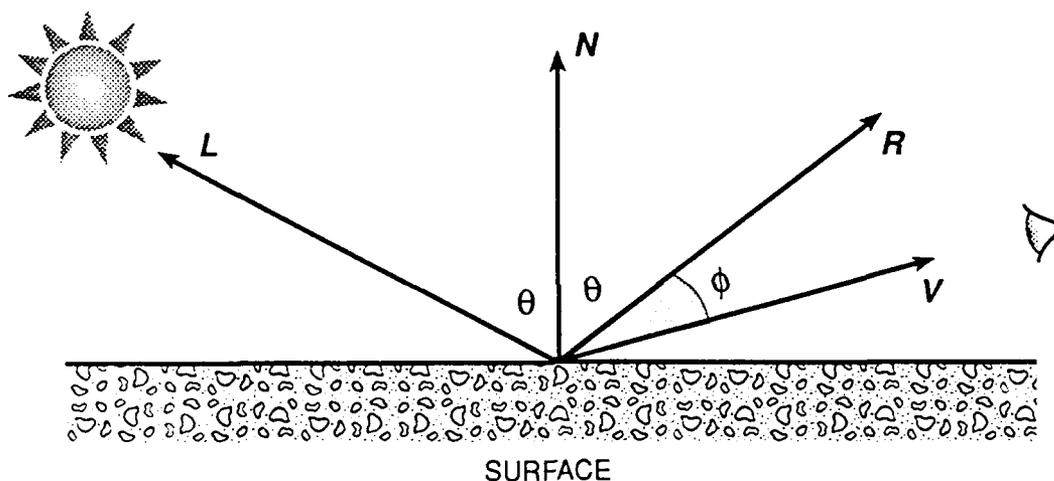
Figure 3.3.2.1-3 Reflection From a Perfectly Smooth Surface

For a single ray or single point on the surface we can model specularly reflected light by considering two more vectors. In Figure 3.3.2.1-4 L and N are as described above, R is the direction along which specular light is reflected and V is the viewing direction. The angle ϕ is the angle between the viewing vector and the reflection vector (both unit vectors). For a perfect mirror this angle must be zero for any specular light to be seen. In practice, as we have already mentioned, specular reflection is seen over a range of ϕ that depends on the surface gloss. Using a simple and common approach, we model the

specular behavior empirically with a term $\cos^n \phi$. For a perfect reflector n is infinite. A very glossy surface produces a small highlight area and n is large. As a surface becomes less specular the highlight areas becomes more spread out and their intensity diminishes relative to the diffuse reflection component. The equation for the specular contribution is:

$$L = E_{\text{sun}} r_s \cos^n \phi / \pi \text{ or } L = E_{\text{sun}} r_s (R \cdot V)^n / \pi$$

Like the diffuse term this simple model of the specular reflectance is a local model. Only the interaction at a surface point from the sun is considered. Light is reflected onto the surface that originates from light reflected by other objects in the scene is not considered. This is a much more severe constraint than the locality of the diffuse term. It excludes reflections of other objects, and multiple reflections on the object itself, in the determination of the surface luminance. This may be solved by using a simple but extremely expensive global model for specular reflection called raytracing. However, before going to this more compute intensive approach, it is important to determine the validity of this simpler approach as applied to the evaluation of camouflage measures.



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Figure 3.3.2.1-4 Specular Reflectance Geometry

3.3.3 Complex Reflection

The reflection model discussed here is considerably more accurate than that described in the previous section, and consequently more complex. The model is based on earlier work, originally proposed by Torrance and Sparrow*, and further developed by Torrance by Cook and Torrance**. This enhanced model of surface reflectance was originally developed to describe the reflectance from rough surfaces for use in the accurate calculation of radiative heat transfer. Robertson has recently adapted the Cook and Torrance model for application to IR target signature estimation. The results of the predicted model very closely match

* Torrance, K.E., and Sparrow, E.M., "Theory of Off-Specular Reflection from Roughened Surfaces", Journal of the Optical Society of America, Vol. 57, No. 9, 1967, pg. 1105

** Cook, R.L., and Torrance, K. E., "A Reflectance Model for Computer Graphics", ACM Transactions on Computer Graphics, Vol. 5, No. 1, 1986, pg. 307.

those obtained through measurement and include a number of effects not accurately represented by the simpler model.

The more complex model is distinguished from the simpler model by the following factors:

It is based on a consideration of incident energy rather than luminance.

The specular term is based on a microfacet representation of the rough surface.

Color change within the highlight is based on Fresnel's law and measured characteristics of the material.

The more complex model is developed from a reflectance definition that relates the luminance of an object to the illuminance and size of the illuminating light source. The basis for the model is the bidirectional reflectance R_{brdf} which relates the incident illumination E_i to the reflected luminance L_r :

$$R_{brdf} = L_r / E_i$$

E_i is defined as the energy incident on a surface element per unit time per unit area and is:

$$E_i = L_i (N \cdot L) dw_i$$

where dw_i is the solid angle of the incident light beam. This is equal to the projected area of the light source divided by the square of the distance to the light source and approximates a constant for a distance source. Thus:

$$\begin{aligned} L_r &= R_{brdf} E_i \\ &= R_{brdf} L_i (N \cdot L) dw_i \end{aligned}$$

It is important to note that this is the reflected luminance for one particular direction and the R_{brdf} varies over the hemispherical surface that specifies all reflecting directions. The bidirectional component is split into a diffuse and a specular contribution and we have:

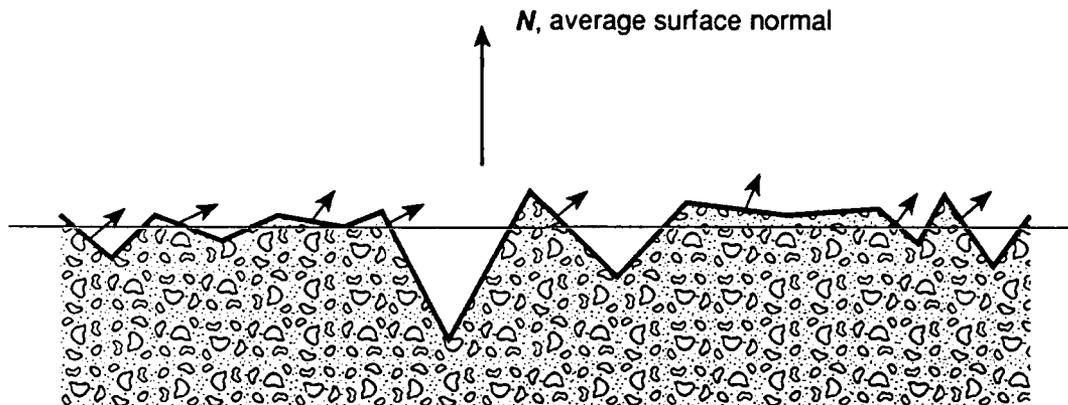
$$R_{brdf} = sR_s + dR_d \quad (\text{where } s + d = 1)$$

This accounts for the component of illumination seen in a particular direction - the viewing direction, for example - originating from a direct source, such as the sun. To this must be added, as with the previous model, a term due to the ambient illumination provided by skylight.

This model is distinguished from the simpler approach by the fact that it contains a reflectance definition that relates the luminance of an object to the luminance and size of the light source that illuminates it. The other major distinction of the complex approach is incorporated in the specular term. In the simpler model the angular spread of the specular contribution about the reflection vector R was modelled empirically using an exponential cosine term. Here the model is physical, based upon a microfacet description of the surface introduced by Torrance and Sparrow. This is based on the notion of a reflecting surface that consists of a large number of microfacets, each with perfectly reflecting or mirror-like faces

as illustrated in Figure 3.3.3-1. The geometric extent of a surface element - the unit of surface area from which a reflected luminance is calculated - means that it is made up of a collection of such microfacets. These can be described by a distribution function of the slope or orientation of the reflecting planes of the microfacets. The specular terms of this geometric surface model is:

$$R_s = F D G / ((N \cdot V) (N \cdot L) \pi)$$



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Figure 3.3.3-1 Microfacet Model of a Reflection Surface

The influence of the terms F , D and G and $N \cdot V$ is now explained. The specular reflectance along the V direction originates from those microfacets with their surfaces oriented along the direction, H , which bisects the angle between the vector to the light source and to the observer. This is determined by a microfacet orientation distribution function. The function used by Torrance and Sparrow in their work was a simple Gaussian distribution:

$$D = k \exp[-(a/m)^2]$$

where k is a constant, a is the angle of the microfacet with respect to the normal of the (mean) surface, that is the angle between N and H , and m is the root mean square slope of the microfacets. For low values of m the surface is shiny or glossy. (If m is 0 the surface is a perfect mirror and H must be equal to N for there to be any contribution of the specular reflection analog V .) A high value for m implies the dependence of R_s on the angle between N and H . The later development of the model by Cook and Torrance used a distribution proposed by Beckmann and Spizzichino* :

$$D = (1/(m^2 \cos^4 a)) \exp[-((\tan^2 a)/m)]$$

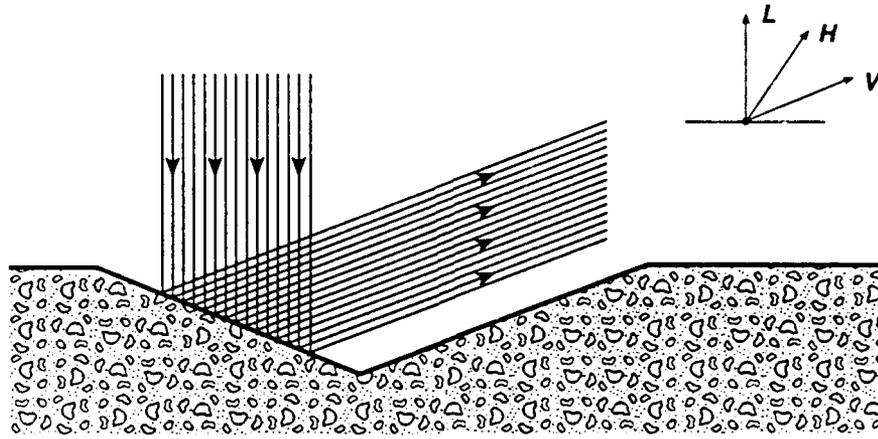
This is computationally more expensive but is a function of m and a only and does not include an arbitrary constant.

* Beckman, P., and Spizzichino, "The Scattering of Electromagnetic Waves from Rough Surfaces", Pergamon, Oxford, 1963

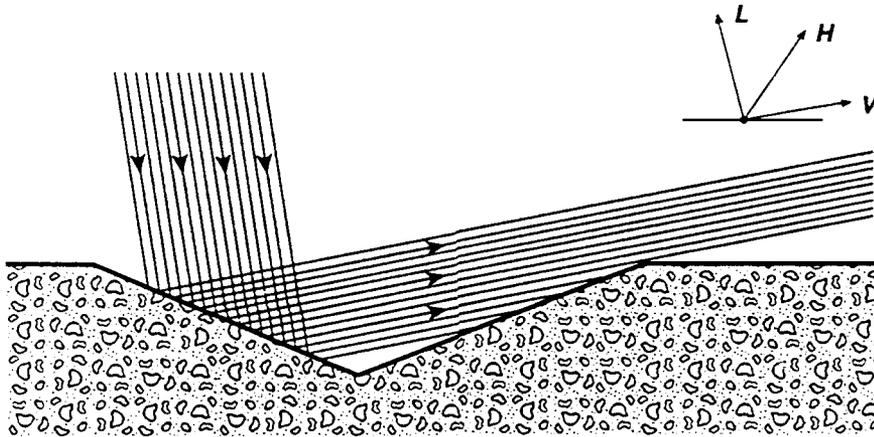
The next term to be considered is G . This is an attenuation factor due to the effect of shadowing of the incident light and masking of the reflected light by the microfacets. Figure 3.3.3-2 shows the three possible cases which depend on the relative positions of L and V with respect to the microfacets.

For Case 1, in Figure 3.3.3-2, the angle between L and V is small and all the light falling on the microfacet escapes. In this case we have

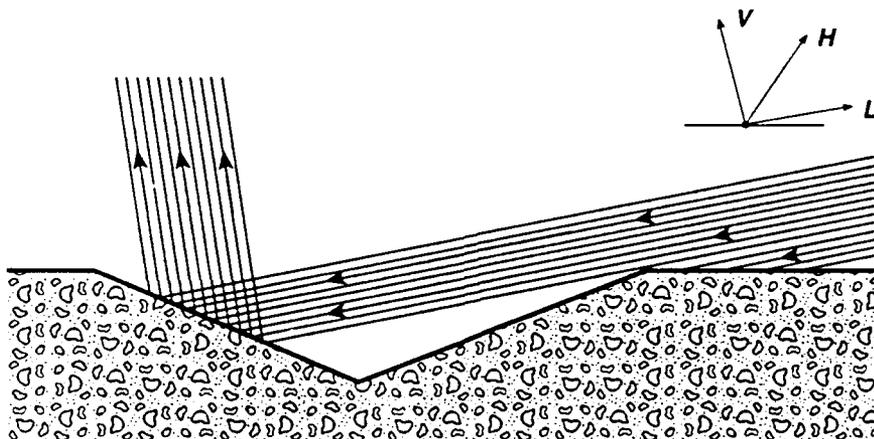
$$G = 1$$



Case 1. No Interference: Angle between L and V is small – all light falling on the microfacet escapes.



Case 2. Some reflected light is trapped – 'masking'.



Case 3. Some incident light is 'shadowed' (inverse of case 2).

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Figure 3.3.3-2 Three Cases Associated with the Calculation of the Geometric Term

For masking, some of the reflected light

$$G_m = (2 (N \cdot H) (N \cdot V)) / (V \cdot H)$$

For shadowing the situation is geometrically identical with the roles of the vectors L and V interchanged. For shadowing we have:

$$G_s = (2 (N \cdot H) (N \cdot L)) / (V \cdot H)$$

The value of G that must be used is the minimum value of G_s and G_m :

$$G = \text{minimum_of}(1, G_s, G_m)$$

F , the Fresnel term in R_s , accounts for the color change of the specular highlight as a function of the angle of incidence of the light source. This equation expresses the reflectance of a perfectly smooth mirror surface in terms of the refractive index of the material and the angle of incidence of the light source:

$$F = \frac{1 \sin^2(\phi - \theta)}{2 \sin^2(\phi + \theta)} + \frac{\tan^2(\phi - \theta)}{\tan^2(\phi + \theta)}$$

where ϕ is the angle of incidence, and θ is the angle of refraction, with $\sin \theta = \sin \phi / \eta$, where η is the refractive index of the material.

F is minimum, that is the most light is absorbed, when $\phi = 0$ (normal incidence). No light is absorbed by the surface and F is equal to unity for $\phi = \pi/2$. The wavelength-dependent property of F comes from the fact that the refractive index is a function of wavelength.

3.4 Environment

The environment consists of the atmosphere and the lighting sources which illuminate, and are reflected from, the target. The calculations of these atmospheric effects and the levels of illumination due to both sun and sky are described in this section.

3.4.1 Atmospheric Transmission

An essential element in the calculation of target contrast is the determination of the atmospheric transmission. A representation of the variations in the transmission with altitude and line-of-sight is required for estimating the incident solar and sky irradiance at the target, as well as the propagation of the target contrast to the observer.

The physical mechanisms of attenuation as well as the composition of the atmosphere are very complicated, and a general calculation of the atmospheric attenuation can be computationally demanding. While the Camouflage Visualization System software is not intended to run in real-time, it is still important to provide for fast and efficient processing of the displayed results. To avoid a detailed calculation of the atmospheric transmission, and thereby reduce the computational requirements, a simple engineering model of the atmosphere and its attenuation mechanisms has been developed for use with the Camouflage

Visualization System. The transmission model was developed specifically for application within the spectral range from 0.28 to 1.0 micrometers.

The simple physical model described here was developed to provide sufficient accuracy within the visible spectrum without resorting to the complex calculations of the more general atmospheric attenuation models, such as LOWTRAN. As a reference, the calculated results are compared to LOWTRAN predictions to show the performance of our simple model relative to a more complex treatment and as a means of validating the simple model.

Transmission through the atmosphere may be characterized by the extinction coefficient, a , which is a function of wavelength and includes both absorption and scattering. The absorbed radiation may alter the temperature or chemical composition of the atmosphere, whereas the scattered energy is redistributed into other directions. The absorption and scattering vary within the atmosphere due to variations in the concentration of the atmospheric constituents. In addition, each atmospheric constituent has its own scattering and absorption coefficients which may also vary with wavelength. Within the spectral range from 0.28 to 1.0 micrometers the attenuation is dominated by molecular and aerosol scattering, and by ozone absorption. While we acknowledge a minor contribution due to the attenuation of long wavelength radiation by water vapor, it has been ignored in our current treatment.

The transmission of a monochromatic ray of light may be written in the form of Bouguer's Law,

$$T(s) = \exp\left[-\int (a_M + a_A + a_o) ds'\right]$$

The elements of this expression are described in detail in the following sections. It should be noted that, although the transmission and attenuation coefficients are a function of wavelength we have not explicitly indicated this dependence in our descriptions. Bouguer's Law holds only for monochromatic light, but will, in some instances, provide an accurate estimation of the transmission within a broad band. It is assumed to be valid over the 0.01 micrometer interval used in the model described here.

The transmittance and radiance along a path through the atmosphere depend upon the total amount, and the distribution of the absorbing species along the path. However, because we are interested in the net transmission along the path, we shall consider only the integrated absorber amounts. The integrated amount along a path is known by various names, including "column density", "equivalent absorber amount", and "air mass". While the term air mass specifically applies to the total amount of gas along the path, it will be used here to refer loosely to the integrated amounts for all three species relative to the amount for a vertical path. With the application of this concept, the element of path length may be written as, $ds = m dx$, where m is the relative air mass.

While an exact calculation of the air mass requires that the Earth's curvature and atmospheric refraction be taken into account, we have ignored the impact of atmospheric refraction. As we shall show, refraction is significant only for large angles from zenith, and the difference which results is comparable to variations caused by meteorological and geographical variations. The influence of the Earth's curvature may not be neglected and is therefore represented within the model.

To estimate the relative air mass we consider a spherical Earth with a homogeneous layer of thickness, H , the so-called scale height. Since we are interested only in integrated amounts, this approximation is useful in spite of the fact that the distribution of scattering and absorbing species is far from homogeneous. The scale height is determined by considering the thickness of an atmosphere for which all the gas is compressed to a state of constant pressure or density. For molecular scattering and ozone absorption the scale height has been determined to be approximately 8.4 kilometers. For aerosols, which are concentrated in a thin layer near the Earth's surface, integration of measured aerosol concentrations yields a value of 1.58 kilometers for the height of the layer.

As shown in Figure 3.4.1-1, the path length through a homogeneous layer increases with increasing angle from zenith. For small angles, curvature has little impact and the Earth may be approximately treated as flat. Thus for small zenith angles, the path length approximately varies as the inverse of the cosine of the angle measured from zenith.

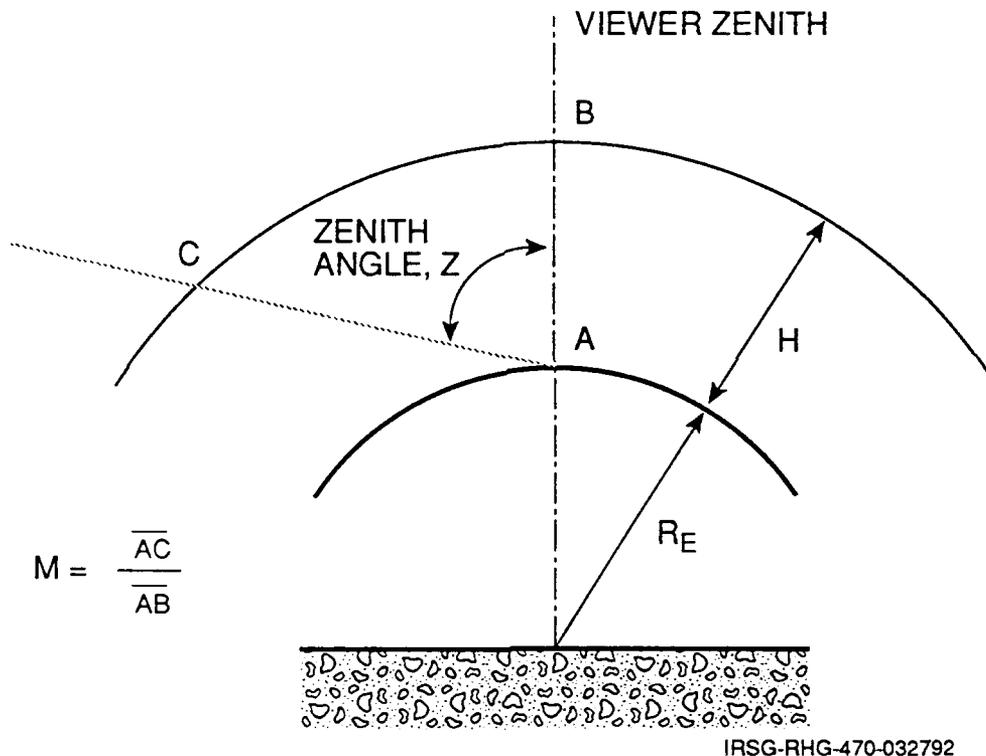


Figure 3.4.1-1 Curved-Earth Viewing Geometry

For zenith angles greater than 60 degrees the curvature of the Earth's surface must be taken into account. From the simple geometry shown in Figure 3.4.1-1 we find that the relative airmass for the layer is given by the equation,

$$m = \sqrt{\{[(R/H)\cos Z]^2 + 2(R/H) + 1\} - (R/H)\cos Z}$$

The results predicted using this equation are plotted in Figure 3.4.1-2 using a value of 6370 kilometers for the mean Earth radius, R . For comparison we have also plotted the function

$1/\cos Z$ and the results of a more exact calculation by Bemporad* for which atmospheric refraction and temperature variations have been taken into account. It should be noted that Bemporad's analysis has been determined for a so-called "standard atmosphere", and that variations of the meteorological conditions with respect to this standard may result in deviations comparable to the differences between the accurate and approximate solutions.

Comparison of Air Mass Calculations

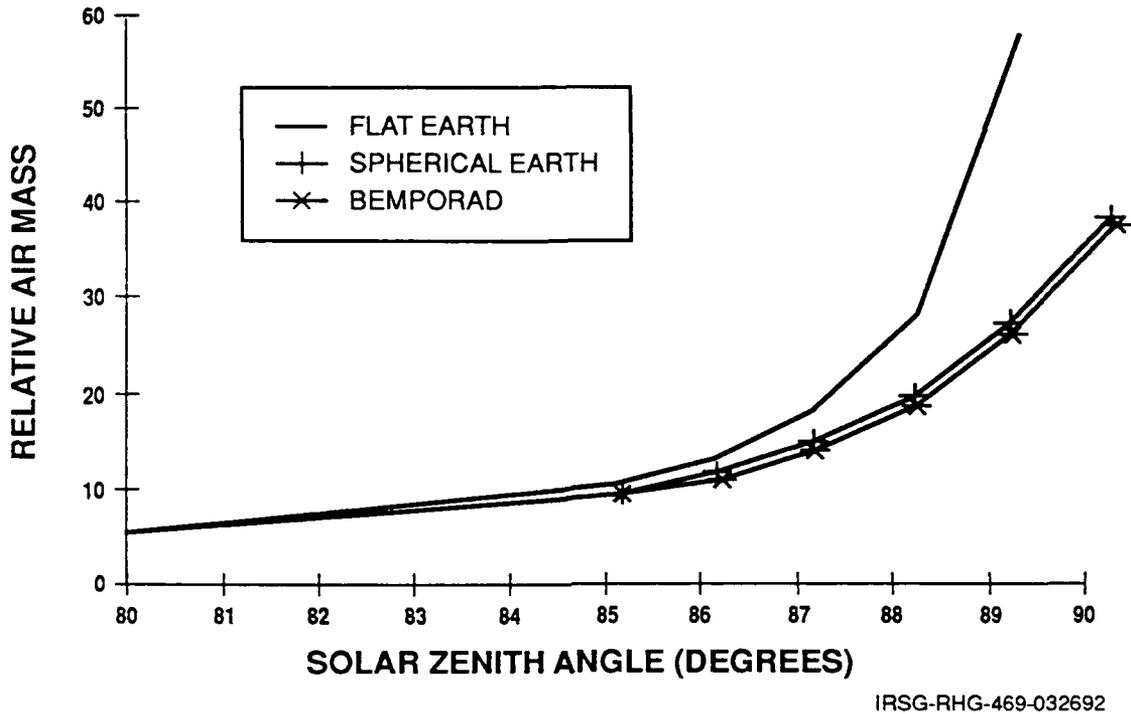


Figure 3.4.1-2 Comparison of Air Mass Calculations

3.4.1.1 Molecular Scattering

An expression for the molecular attenuation coefficient as a function of wavelength has been adapted from the LOWTRAN atmospheric transmission model developed by the Air Force Geophysics Laboratory. The equation,

$$a_M = 1.1 [(926.799 - 10.712/\lambda^2)\lambda^4]$$

as described in the LOWTRAN 5** documentation, was obtained from a least-squares fit to the molecular scattering coefficients published by Penndorf.

In determining the concentration of the air molecules it was assumed that the atmospheric pressure is an exponential function of altitude, with a scale height of 8.4 kilometers. Given

* Levi, L. *Applied Optics*, John Wiley and Sons, New York, 1980

** Kneizys, F.L., et. al., *Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 5*, AFGL-TR-78-0053, AD A088215, 1980

this, the sea level attenuation coefficient decreases in proportion to the pressure due to a decrease in the number of gas molecules. The transmission from space to an altitude, h , due to molecular scattering along is given by

$$T_M = \exp[-a_M \exp(-h/8.4) 8.4m]$$

3.4.1.2 Aerosol Scattering

Aerosols are produced by various processes, both natural and man-made. They are concentrated within a relatively thin layer near the Earth's surface and are an extremely variable component of the lower atmosphere. Variations in the aerosol concentration give rise to the day-to-day variations in the atmospheric visibility and are thus an important consideration in the calculation of target color and contrast. Since aerosols are concentrated in a layer near the Earth's surface they are particularly important for observation from the ground. For altitudes above 5 kilometers aerosols are of minor importance.

Within the visible and near visible spectral regions the absorption by aerosols is small and has thus been neglected in our development of the transmission model. As with the uniformly mixed gases of the atmosphere, nearly all the attenuation resulting from aerosols is due to scattering. However, there is an important difference. Because aerosol particles are generally much larger than the gas molecules, the scattering is not as strongly dependent on wavelength.

As stated previously, variations in the aerosol content effect the atmospheric visibility. The visibility, V , is defined as the horizontal range at which a target of unit inherent contrast decreases to an apparent value of 0.02. Given an exponential decrease in the transmission with range, and assuming the transmission at 0.55 micrometers to be representative of the average transmission over the entire photopic band, we get the following equation for the total atmospheric extinction coefficient,

$$a(0.55) = a_M + a_A + a_O = \ln(0.02)/V = 3.912/V.$$

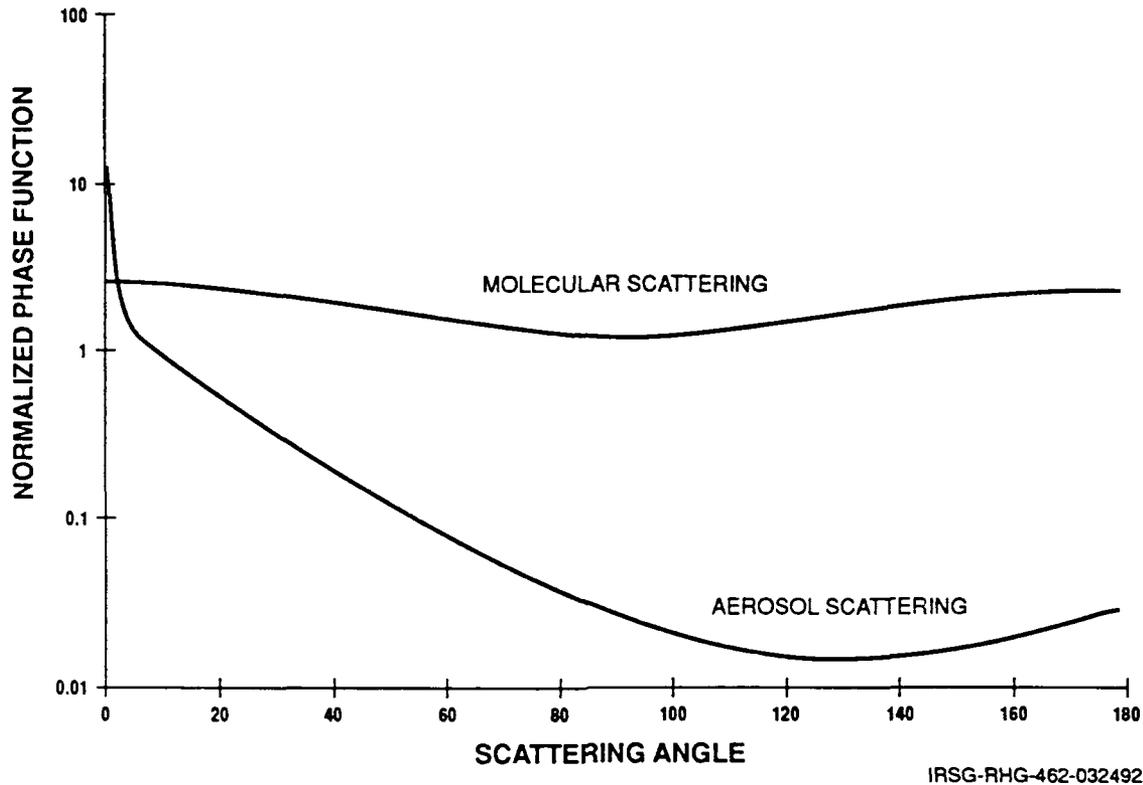
Since ozone absorption at this wavelength is insignificantly small the total extinction is simply the sum of the molecular scattering coefficient and the aerosol attenuation coefficient at 0.55 micrometers. Working backwards and constraining our results so that we are in agreement with the definition of visibility, we get the following result,

$$a_A = (3.912/V - 0.0123) (0.55/\lambda)^{1.24}$$

Implicit in this result is the assumption that the aerosol size distribution is constant with respect to changing visibility, and that only the aerosol concentration varies.

The value of 0.0123 in equation 3.6 is the molecular attenuation coefficient at 0.55 micrometers, as determined by the equation which determined the molecular attenuation. The exponent in this expression was determined from a least squares fit to the measured data. A comparison of the scattering coefficient predicted by this expression, and the rural extinction coefficients used within LOWTRAN, is provided in Figure 3.4.1.2-1. The empirical equation is an excellent fit to the measured data within the visible spectrum.

Scattering Phase Functions for a "Clear" Atmosphere



IRSG-RHG-462-032492

Figure 3.4.1.2-1 Aerosol Scattering Coefficient

The aerosol concentration as a function of altitude was taken from the measurements of McClatchey* for a "clear" atmosphere with a visibility of 23 kilometers. The aerosol concentration decreases exponentially with altitude to height of 4 kilometers. The concentration of aerosols in the upper atmosphere is relatively constant up to an altitude of about 18 kilometers, and thereafter decreases exponentially. The data was integrated to give equivalent aerosol path length, p_A , along a vertical path from a given altitude to space. These values are stored at one at one kilometer intervals and are used to interpolate the value of the equivalent path length at any altitude. Combining the aerosol absorption coefficient, the equivalent path length along a vertical path, and the relative airmass we get the following equation for the transmission due to aerosol scattering only,

$$T_A(h) = \exp[-a_A p_A(h)m]$$

3.4.1.3 Ozone Absorption

Ozone is created by photochemical processes in the upper atmosphere and is the primary absorber of radiation in the visible and near visible spectrum. Absorption within the Hartley and Huggins bands strongly attenuate radiation at wavelengths shorter than 0.36

* McClatchey, E., Optical Properties of the Atmosphere, AFGL-72-0497, AD 753075, 1972.

micrometers. At wavelengths shorter than 0.28 micrometers essentially none of the incident solar irradiance is transmitted into the lower atmosphere. Ozone is also responsible for weak absorption in the visible and near infrared spectral region from about 0.44 to 1.18 micrometers, referred to as the Chappuis band.

The Vigroux absorption coefficients for ozone were taken from the measured data compiled by Elterman*. Linear interpolation is used to determined the attenuation coefficient between tabulated values. A plot of the ozone absorption data used within the Camouflage Visualization System Software model is provided in Figure 3.4.1.3-1.

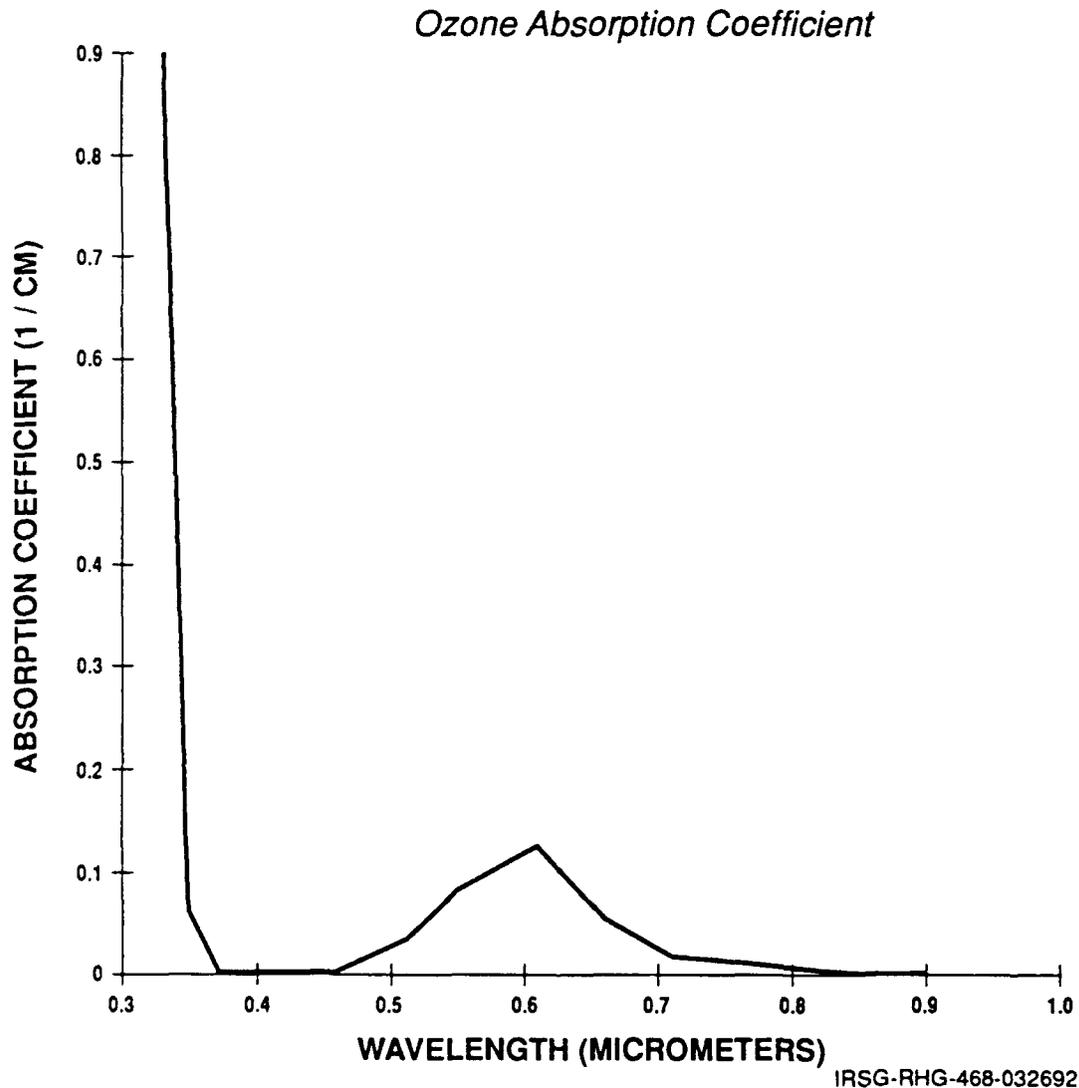


Figure 3.4.1.3-1 Ozone Absorption Coefficient

* Elterman, L., Atmospheric Attenuation Model in the Ultraviolet, Visible, and Infrared Regions for Altitudes to 50 km. AFCRL-64-740.

The ozone concentration as a function of altitude was also taken from Elterman's report. As shown in Figure 3.4.1.3-2 the ozone concentration peaks at an altitude of approximately 22 kilometers (66,000 feet). The ozone concentration data has been integrated and tabulated in the form of an equivalent vertical path length, p_O . This information, together with the ozone absorption coefficient, is used to determine the transmission along a path from a given altitude, h , to space. The transmission due only to the absorption by ozone is given by

$$T_O(h) = \exp[-a_O P_O(h)m]$$

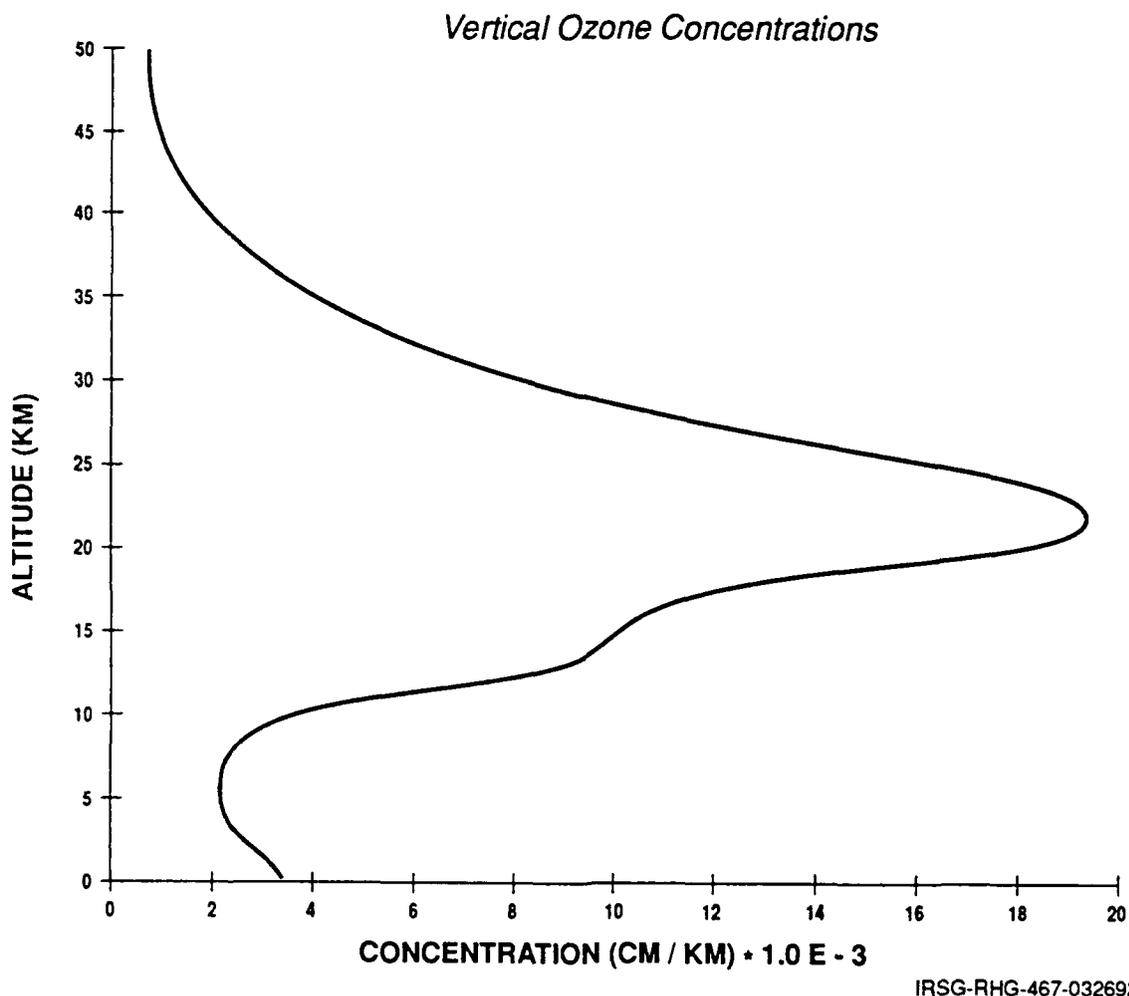


Figure 3.4.1.3-2 Vertical Ozone Concentrations

3.4.1.4 Vertical and Slant-path Transmission Between Altitudes

The transmission model discussed above is used to determine the transmission from a given altitude to a point outside the atmosphere. From the geometry illustrated in Figure 3.4.1.4-1, the transmission between two points may be determined from

$$T(h_1 - h_2) = T(h_1)/T(h_2)$$

This equation is used to determine the contrast propagation along a path between two altitudes. A separate calculation is done when the viewing path is horizontal.

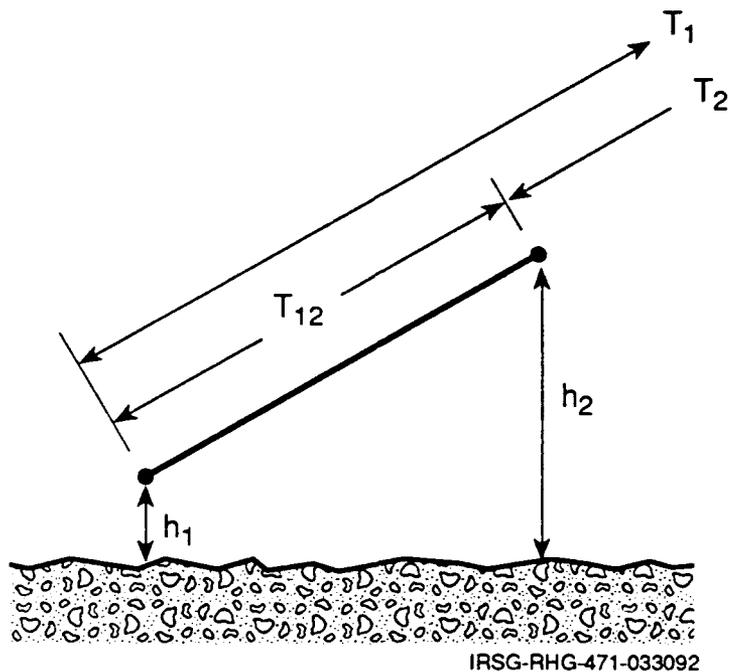


Figure 3.4.1.4-1 Transmission Along a Slant Path Between Two Altitudes

3.4.1.5 Comparison of the Model Predictions to LOWTRAN Results

LOWTRAN is a digital computer code for predicting the atmospheric transmission and radiance for wavelengths from 0.25 to 28.5 micrometers. The software was developed by the Air Force Geophysical Laboratories and has been continually improved over its history of nearly 20 years. The model is in widespread use and has been the subject of several validation studies. Even those who dispute LOWTRAN's predictions must concede that LOWTRAN is the standard by which all other models are measured.

Among LOWTRAN's many features are representative models of the atmosphere (i.e., pressure, density, and temperature) and aerosol distributions for seasonal and geographical variations. The LOWTRAN software takes into account the vertical variations in the atmosphere in its determination of the path length and absorber amounts. A distinction is made between aerosols of the lower atmosphere and that of the upper atmosphere.

A comparison of the predictions of the spectral transmission made by LOWTRAN 7 and the algorithm developed for the Camouflage Visualization System Software is provided in Figure 3.4.1.5-1. The data is provided for comparison at sun elevations of 30 and 60 degrees. Over the visible spectrum the difference is less than 5 percent. For wavelengths near 0.8 and 0.9 microns the difference is much greater due to the absorption by water vapor. The absorption by water vapor was not considered due to the emphasis on the visible spectrum. Improvements can be made which would extend the validity of the model into the near infrared spectrum.

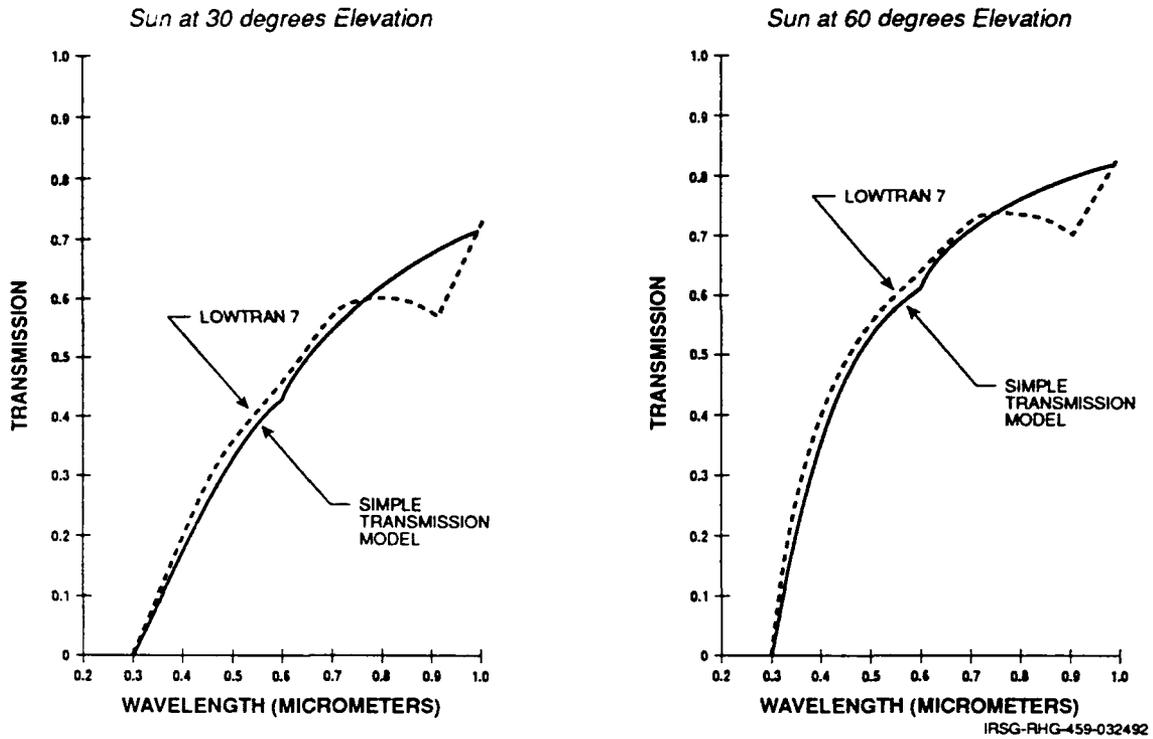


Figure 3.4.1.5-1 Comparison of Calculated Transmission Values

In Figure 3.4.1.5-2 we compare predicted results for varying lines on sight, as a function of elevation above the horizon. The results again show a close correspondence between the two predictions. We note that our treatment of the atmospheric aerosols is not as exact as that used in LOWTRAN, and it is this difference which accounts for most of the error. The reader should appreciate, however, that natural variations in the aerosol size distribution and concentration yield even greater variations than that between our model and LOWTRAN. We feel that the model provides results which are representative of the atmospheric transmission within the limits described above.

Clear Sky Transmission to Sea Level

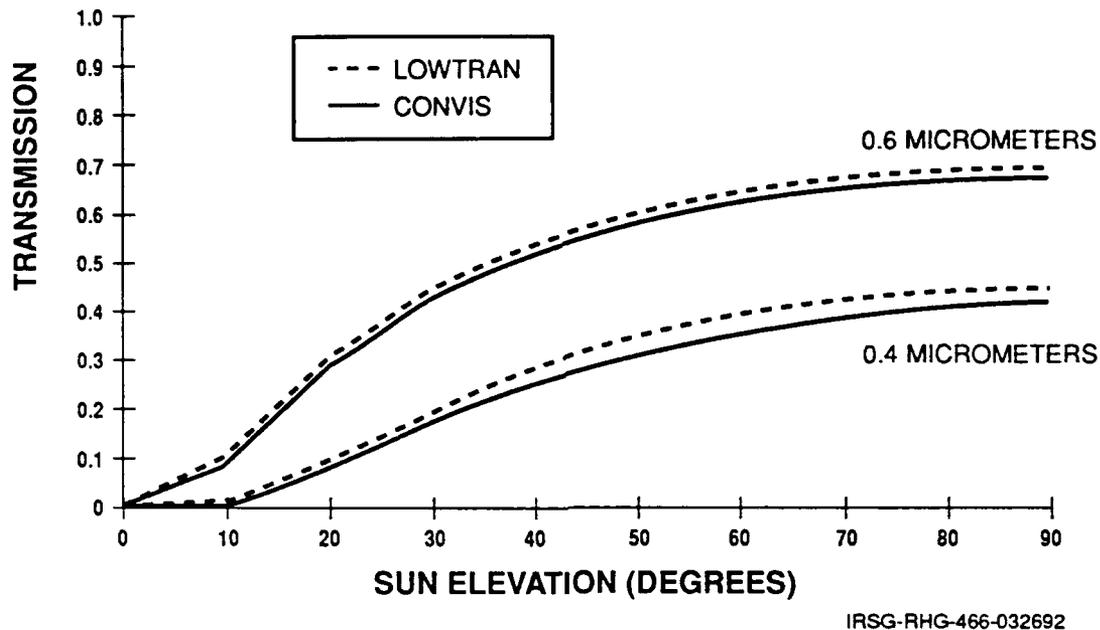


Figure 3.4.1.5-2 Clear Sky Transmission to Sea Level

3.5 Target Illuminance

The target luminance is primarily determined by the reflectance of sun light reflected from the surfaces of the target. Luminance results from the reflectance of the light incident on the target surfaces. In most cases, much of the target luminance can be attributed to the scattering of the direct solar illumination, however, the diffuse illuminance contributed by the sky cannot be ignore. In fact, under some conditions, the sky illuminance can be a more important source than the sun.

Another source of illumination on the target is the light reflected from the terrain and surrounding vegetation. Since we have not yet developed a satisfactory model for representing the spectral illumination from this source, terrain illumination is not represented within the prototype version of the Camouflage Visualization System software. This contribution shall be considered again in later model developments.

3.5.1 Solar Illumination

To determine the spectral distribution of the incident solar illumination at any point in the atmosphere we must first have an accurate representation of the exo-atmospheric solar spectrum. A knowledge of solar spectrum outside the atmosphere is important to researchers in a number of disciplines and, consequently, the solar spectrum has been extensively studied and accurate data is readily available. The most recent and most accurate

measurements are those of Thekaekara and Drummond*. This data has been adopted by NASA as the standard distribution of extra-terrestrial radiation and may be found in most modern references on atmospheric radiation. It is this data which is used in the prototype version of software developed for Camouflage Visualization, as well as codes such as LOWTRAN, to determine the solar irradiance and scattered radiance.

The solar illumination data has been tabulated and included within the model. The data is provided for wavelengths from 0.28 to 1.0 micrometers at a minimum resolution of 0.01 micrometers. At the long wavelength end of this band the illumination is a slowly varying function of the wavelength and is therefore tabulated at lower spectral resolution. Linear interpolation is used in this region to provide values at 0.01 micrometer resolution across the entire band.

To determine the solar illumination at any point below 30 kilometers the exo-atmospheric values are attenuated using the transmission algorithm discussed in Section 3.4. The sunlight received at any point is thus a function of altitude and solar elevation above the horizon. Furthermore, the spectral distribution of the solar illumination may be expected to vary due to spectrally varying attenuation mechanisms within the atmosphere.

A plot of the sea level, spectral illumination calculated by the model for the sun at 30 degrees above the horizon is provided in Figure 3.5.1-1. The fall-off of the solar irradiance at short wavelengths may be attributed to the approximate black body distribution of the sun's energy, molecular scattering, and the absorption by ozone within the atmosphere. Virtually none of the sunlight at wavelengths shorter than 0.28 micrometers reaches the Earth's surface.

The variation of the solar illumination with sun elevation is illustrated in Figure 3.5.1-2. For elevations above 50 degrees the solar illumination is relatively constant. The fall-off with low sun elevations is attributed to the increase in atmospheric path length. Near sunset the sun's light traverses a path more than 30 times longer than the path travelled at mid-day. The solar spectrum also shifts towards longer wavelengths (gets redder) due to increased attenuation of the shorter wavelengths by aerosol and molecular scattering. This shift in the solar spectral illumination can be seen in Figure 3.5.1-3 where the spectra at 10 and 40 degrees are compared.

* Paltridge, G.W., and Platt, C.M.R., Radiative Processes in Meteorology and Climatology, Elsevier Scientific Publishing Company, New York, 1976.

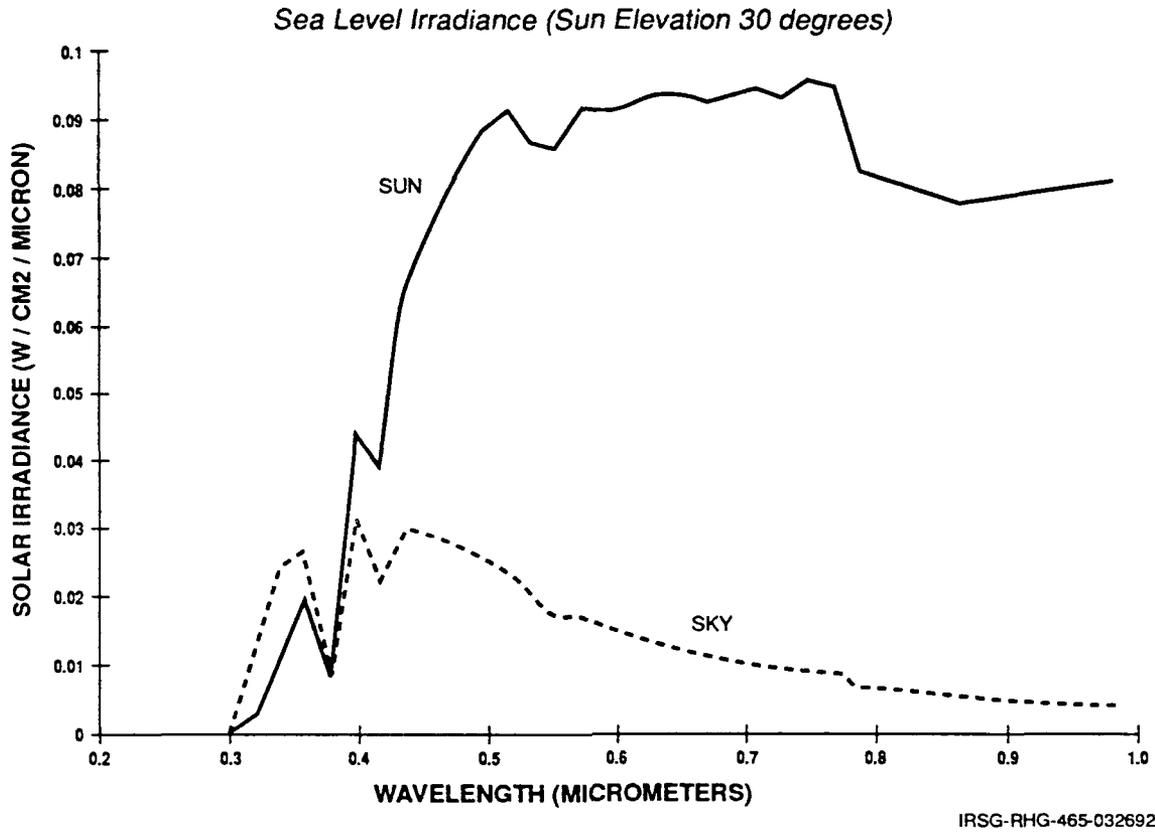


Figure 3.5.1-1 Sea Level Spectral Illuminance (Sun Elevation 30 degrees)

Sea Level Irradiance at 0.55 micrometers

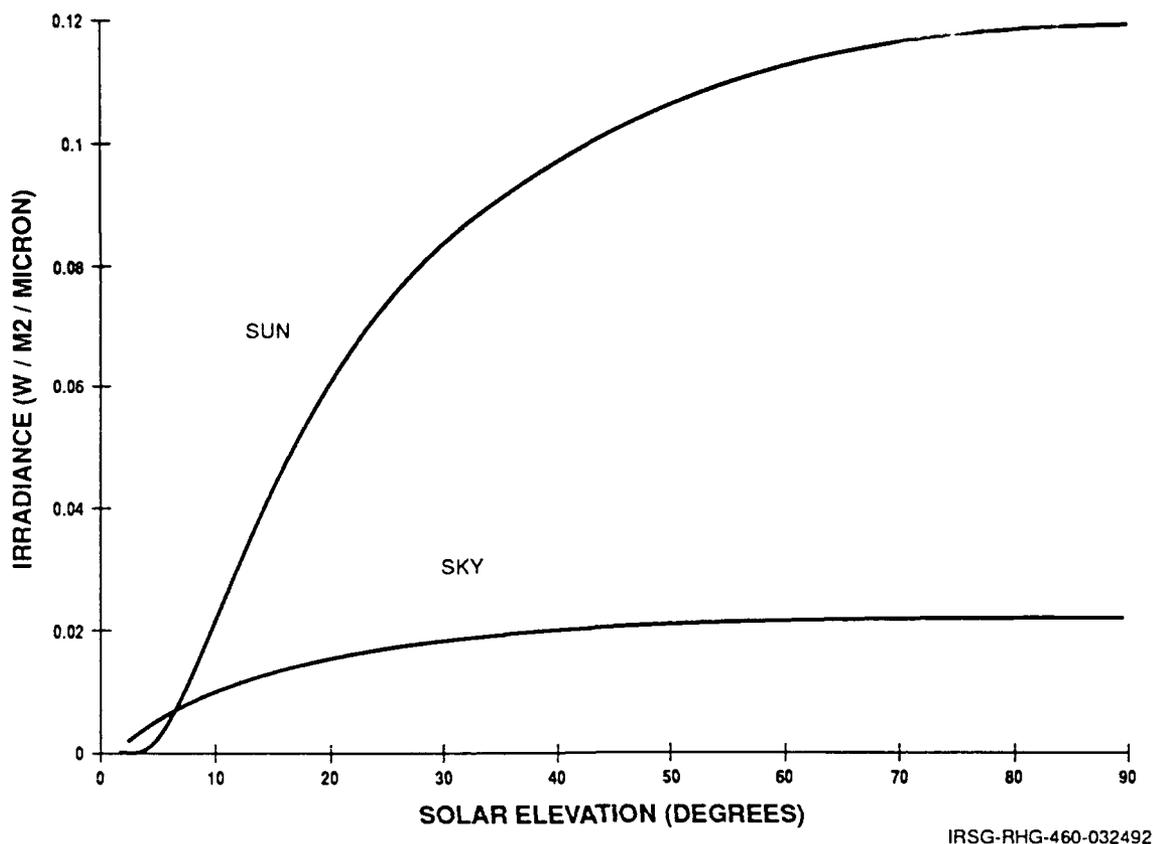


Figure 3.5.1-2 Sea Level Illuminance at 0.55 Micrometers

3.5.2 Sky Irradiance

An exact calculation of the diffuse illumination from the sky would require the integration of the contribution of the sky radiance from all directions. This is, in general, a very complex and time consuming computation, even for relatively clear skies. Because of the difficulties in determining the sky irradiance from an exact calculation we have concluded that an approximate, empirical approach is preferable for application within the Camouflage Visualization System.

An expression which closely estimates the diffuse sky irradiance from a clear sky onto a horizontal surface is expressed as the difference between the direct beam of radiation and a fictitious beam subject only to absorption. Assuming that ozone is the only significant absorption mechanism within 0.28 to 1.0 micrometer band, the sky illumination may be determined from,

$$E = 0.5 (E_0 T_O - E_0 T_M T_A T_O) \cos Z$$

where E_0 is the exo-atmospheric solar irradiance,
 T_M is the transmission due to molecular scattering,
 T_A is the transmission due to aerosol scattering

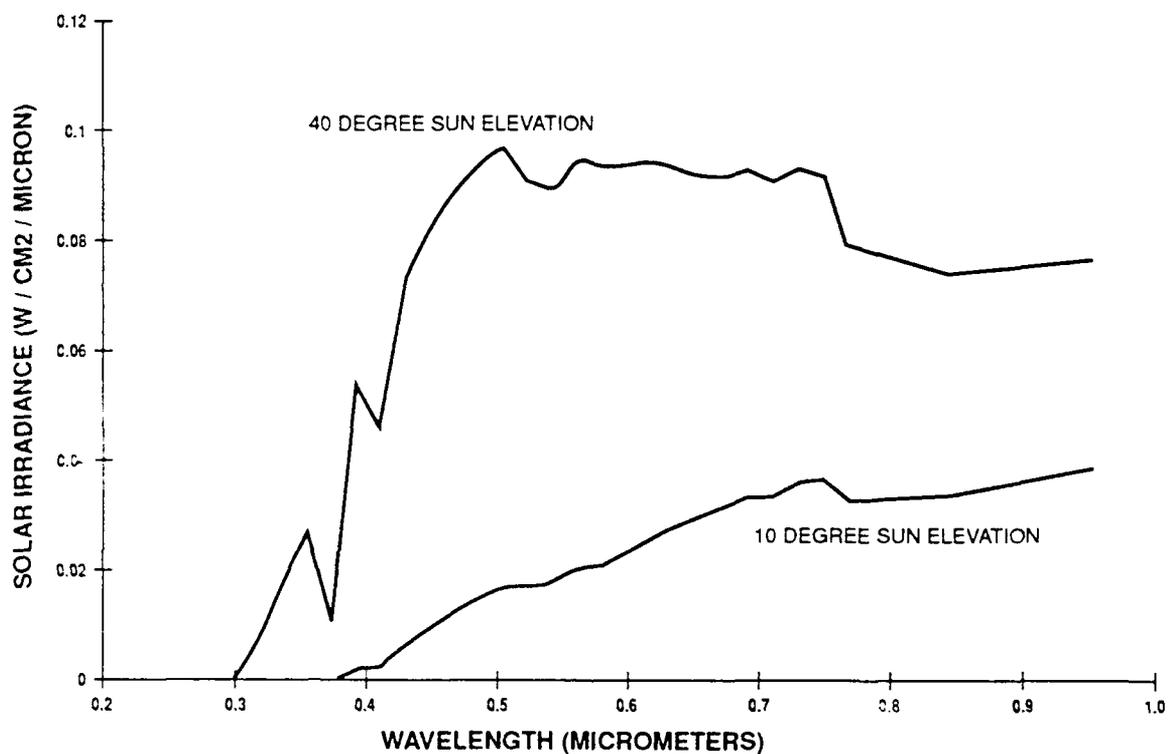
T_O is the transmission due to ozone absorption, and
 Z is the solar zenith angle.

The factor, 0.5, in the equation above was empirically chosen to agree with measurements of the diffuse illumination, and is assumed to be independent of wavelength.

The exo-atmospheric illumination used in the calculation has been determined from measurements as described in the previous section. The components of the atmospheric transmission are determined using the algorithms described in Section 3.4.

The variation of the sky illumination with sun position is plotted in Figure 3.5.1-2 and may be compared to that of the sun. From this graph we see that the sky illumination at mid-day is nearly an order-of-magnitude less than the sun. It is also interesting to note that a comparison of the sun and sky illumination shows that the skylight exceeds the solar illumination near sunset.

Variations in the Solar Spectral Irradiance with Sun Elevation



IRSG-RHG-464-032692

Figure 3.5.1-3 *Variations in the Solar Spectral Irradiance with Sun Elevation*

The relative contribution of the sun and sky to the total irradiance are plotted in Figure 3.5.2-1. The two sources contribute equally to the total irradiance at a wavelength of about 0.4 micrometers. From these curves we should expect that the sky irradiance dominates the plume signature at short wavelengths while the solar irradiance dominates the longer wavelengths.

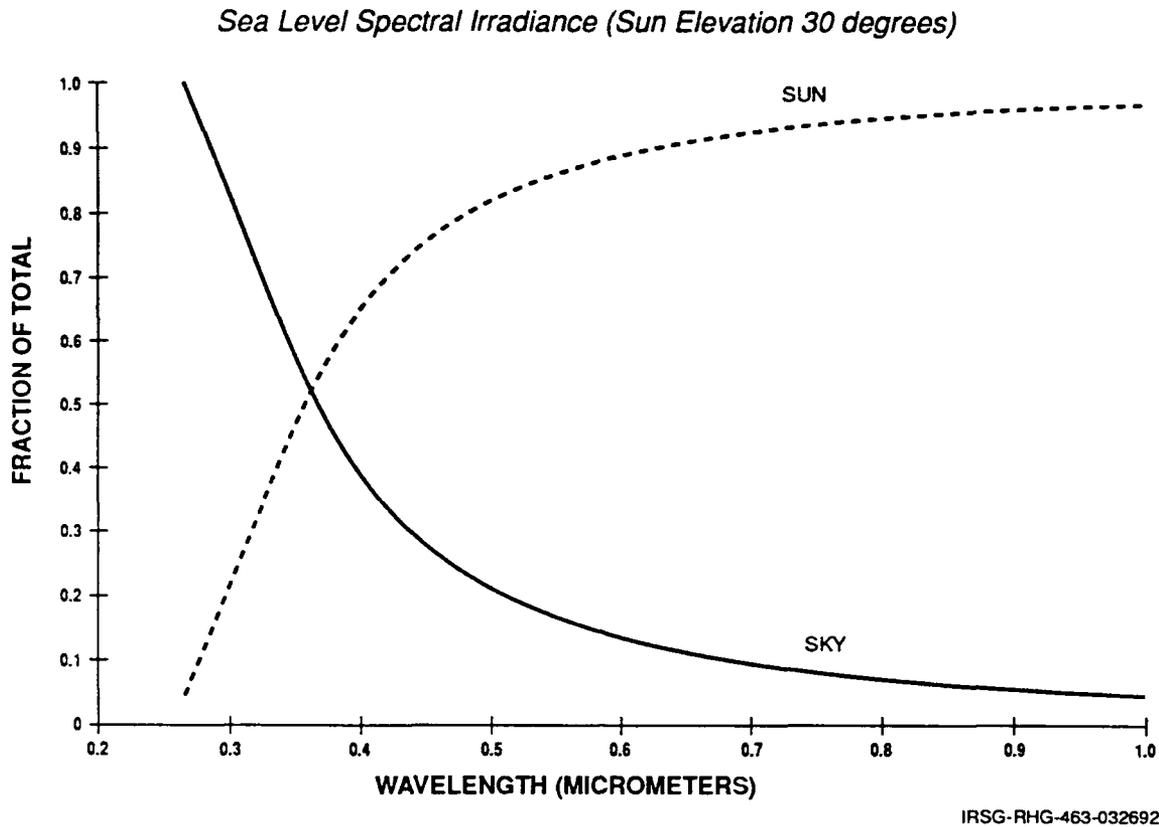


Figure 3.5.2-1 Sea Level Spectral Irradiance (Sun Elevation 30 degrees)

3.6 Sky Background Radiance

An exact calculation of the sky radiance would require that we include the effects of the Earth's curvature and higher order of multiple scattering. These considerations significantly complicate the solution and increase the run-time of the model. An approximate solution has been derived for use in the Camouflage Visualization software, which, in spite of the limitations, matches measured levels and trends surprising well. Furthermore, the approximate solution is sufficiently simple to allow the speedy computation of the target signature.

In our approximation we consider a uniform atmosphere of height, H , above a flat Earth. The geometry for the problem considered is shown in Figure 3.6-1. The equation for the scattered radiance of a elemental volume of atmosphere, at an altitude, h , may be written,

$$dL = E_0 T^{ms(H-h)} a_s P(\theta) T^{mv(h)}$$

where

E_0 is the exo-atmospheric solar irradiance,

$T(H-h)$ is the atmospheric transmission from space to an altitude h , along a vertical path,

ms is the air mass along a path to the sun,

a_s is the atmospheric scattering coefficient,

$P(\theta)$ is the scattering phase function,

$T(h)$ is the transmission from an altitude, h , to sea level along a vertical path, and
 m_v is the air mass along the observer's line-of-sight

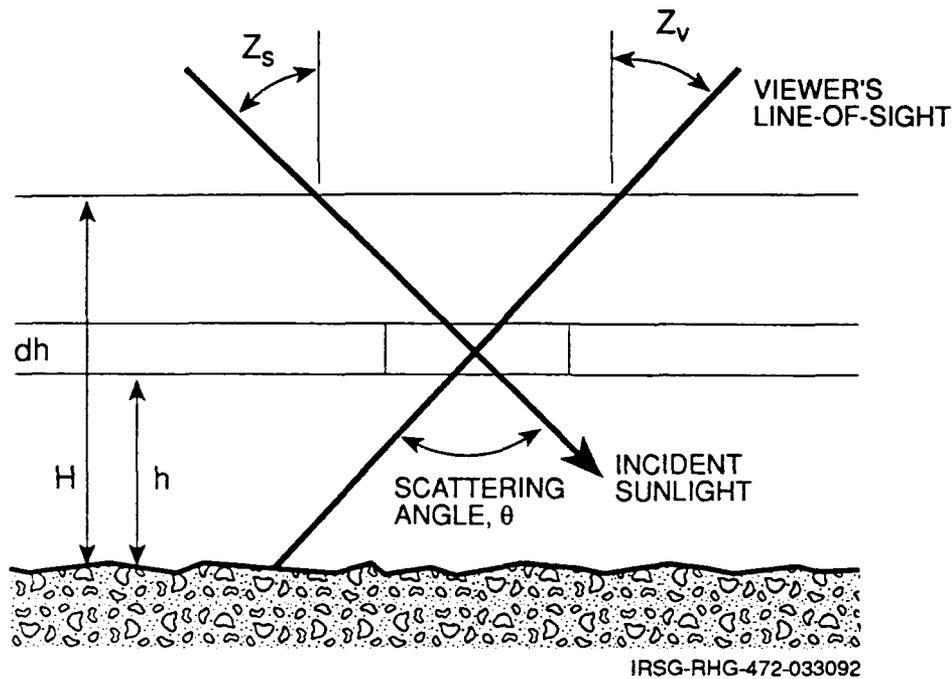


Figure 3.6-1 Geometry for Determining the Sky Radiance

If the air mass is approximated as the inverse of the cosine of the zenith angle, Z , the above equation may be integrated analytically to determine the sky radiance. Integration from sea level ($h=0$) to altitude, H , yields to the following equation for the sky radiance along the observer's line-of-sight,

$$L = \frac{E_o(a_s / a)P(\theta)[T^{ms}(H) - T^{mv}(H)]\cos(Z_s)}{\cos(Z_s) - \cos(Z_v)}$$

The transmission in the equation above is determined using the algorithm described in Section 3.4. The algorithm used to calculate the atmospheric transmission includes the effects of slant path so that the air mass terms in the above equation are not needed in the implementation of this expression. The ratio of the scattering to total attenuation is often referred to as the single scattering albedo.

The phase function describes the variation of the scattered sunlight with increasing phase angle, θ , from the direct solar path. The phase function is normalized such that the integration over solid angle is equal to 1. Because the sunlight is scattered by aerosols, as well as, the molecules of the uniformly mixed gases, the phase function is determined from a weighted combination of the molecular and aerosol scattering phase functions. The molecular scattering phase function may be derived analytically and is given by,

$$P_M(\theta) = (3/16\pi) (1 + \cos^2\theta)$$

The phase function for aerosol scattering has been taken from data compiled by McClatchey. This data has been tabulated for use in interpolating the aerosol phase function. A plot of the molecular and aerosol scattering phase functions are provided in Figure 3.6-2. In both cases the phase function has been normalized so that integration of the phase function over all directions yields a value of 1.

Scattering Phase Functions for a "Clear" Atmosphere

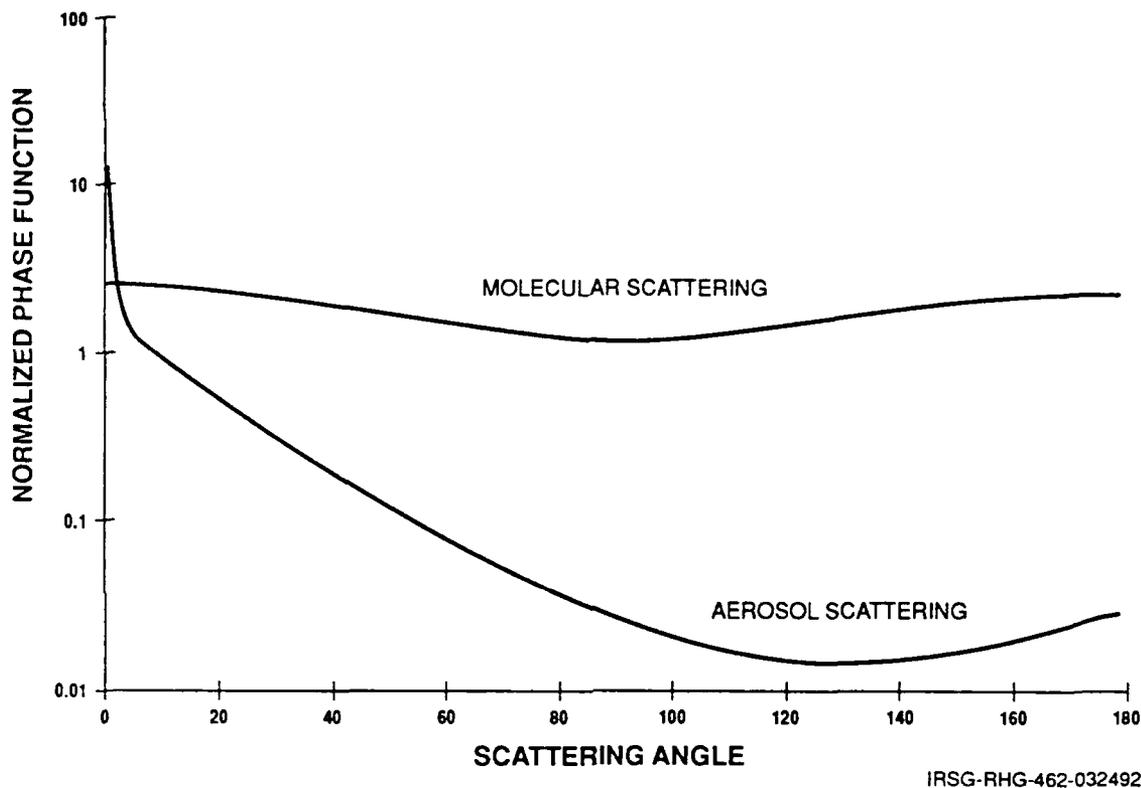


Figure 3.6-2 Scattering Phase Function for a "Clear" Atmosphere

If the sky radiance were solely determined by the scattering phase function the radiance would always decrease as one looked further from the sun. However, because scattering is also dependent upon the amount of atmosphere through which the observer looks, the sky luminance increases near the horizon due to an increase in the relative air mass. At viewing angles near the atmosphere. Since higher orders of multiple scattering become important with increasing concentration our simple approximation breaks down. We expect, and find, that our estimation of the sky radiance near the horizon is less than observed.

Spectral measurements of the sky radiance distribution have been made by the SCRIPPS Oceanographic Institute under the OPAQUE program*. The predictions of our simple model and the measured results acquired under the opaque program are plotted in Figure 3.6-3. Comparison of the calculated predictions with the measured data show that our simple model not only provides a reasonable representation of the angular distribution, but follows the spectral trends as well. Due to multiple scattering effects, the predicted radiance at the horizon, and within a few degrees of the sun, is less than measured.

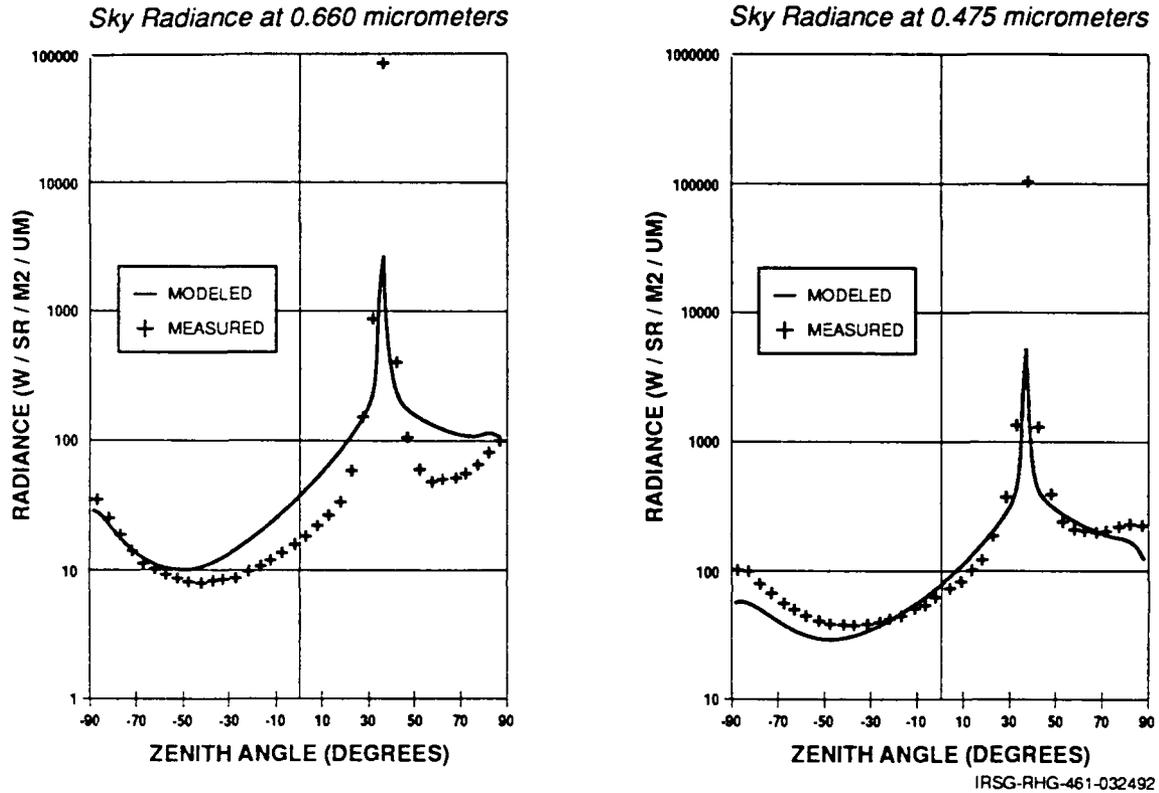


Figure 3.6-3 Comparison of Measured and Modeled Sky Radiance

The present calculation of the sky radiance also ignores the contribution of ground reflectance. We have determined that the contribution of ground reflectance has a small impact when the underlying terrain has a low reflectance. However, over highly reflecting surfaces such as snow contribution of terrain reflectance can be significant.

The sky luminance model developed under the Phase I efforts shows promise for providing an estimate of the sky background which is reasonably accurate and consistent with other environmental factors. The environment model describes both the variations in the overall levels of illumination and luminance, and the variations in the sun and sky spectrum. These predictions are both accurate and fast, and useful for interactive analysis. Several changes

* Johnson, R.W., and Hering, W.S., "An Analysis of Natural Variations in European Sky and Terrain Radiance Measurements", AFGL-TR-81-0317, 1981

for improving the validity of the model over a wider range of environmental conditions have been identified and will be implemented under later efforts.

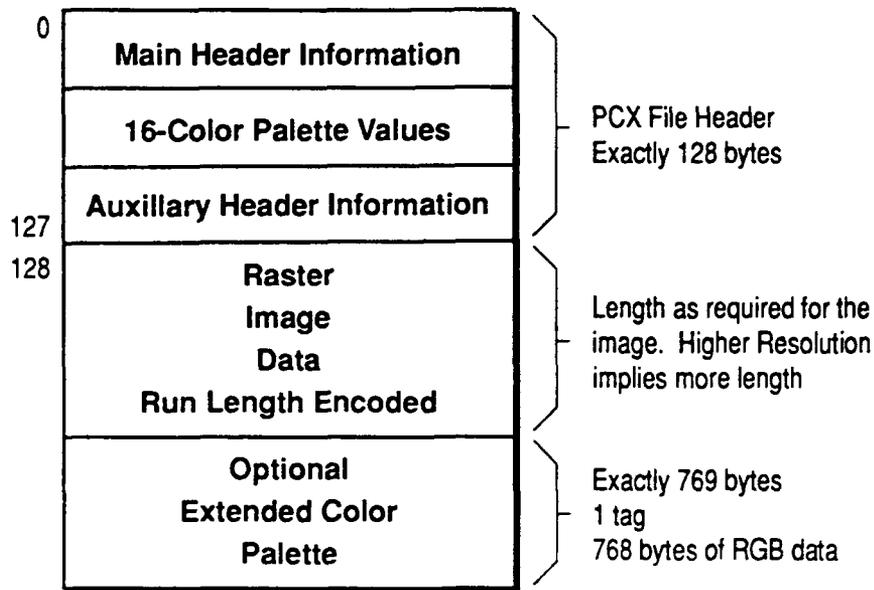
3.7 Image Data Files

The measured background images and the composite images created by the Camouflage Visualization System software are stored as digital representations of the background and scene brightness. These digitized images in themselves have limited value outside our application. The images become useful when they are put into a form that may be created or manipulated by other applications. In order for this to occur, it is necessary to put the image data into a "standard form" that other application can interpret and use. It is to our benefit, and the Army's, to chose a standard which is widely supported so that the images read or created by the Camouflage Visualization System software can be readily used in other applications. This will allow us to read images captured or created by various applications or to incorporate the images created by our software into presentations and/or reports.

The three of the most popular image file formats adopted by users in the PC world are PCX, TIFF, and GIF which are supported by Aldus, Microsoft, Hewlett-Packard, and many desktop publishing packages. In addition, several still-video system support these file formats, providing access to a very convenient means of acquiring the background images used by the Camouflage Visualization System software. Images in PCX and TIFF file formats were acquired for use in the development of the Camouflage Visualization System software, and software was written to read and save each. The PCX file format is the data format currently supported by the system software and will be used in the system demonstration. Extensions to include the TIFF and GIF image file format are planned for later software development.

The PCX file format is one of the earliest attempts in the PC world to enable storage and standardization of graphic images. A standard format was necessary, both to allow the movement of images between applications and to provide file compression to save disk storage space. The PCX file storage system is an example of a method used in industry which became a standard by default. Because it has been around for such a long time, the PCX graphics file format is probably supported by more graphics application programs than all other (PC-compatible) graphics file formats combined.

The PCX graphics file format is simple but not very flexible with regard to the information it can contains. The file format is rigid, with a file header of fixed length followed by the image data, optionally followed by an extended palette structure. Figure 3.7-1 shows the layout of a typical PCX file. The simplicity of this file format makes the code required to support PCX easy to understand, develop, and use.



IRSG-RHG-381-012392

Figure 3.7-1 PCX Image File Format

3.8 Calibration

The Commission Internationale d'Eclairage (CIE) system of colorimetry is a method of measuring colors that has been standardized, and is widely used by industries involved with color. Knowing the CIE coordinates of a color allows it to be reproduced easily and exactly in many different media. For this reason graphic workstations which utilize color extensively ought to have the capability of knowing the CIE coordinates of displayed colors, and of displaying colors of given CIE coordinates. Such a capability requires a function which transforms video monitor gun voltages (RGB color space) into CIE coordinates (XYZ color space), and vice versa. The function incorporates certain monitor parameters. This section describes the form that this function takes, and describes how measured monitor parameters can be measured using little more than a simple light meter. This discussion below owes much to the work of Cowan.*

Color graphics applications use raster CRT technology for color generation. Voltages, which are applied to each of the three guns of a color video monitor, produce distinct levels of excitation in the three phosphors of the monitor, and the consequent light, when it reaches the eye, produces the sensation of color. The voltages are controlled by digital to analog converters whose inputs come from the application software. In many cases the users of that software select colors by trial and error. That is, a peripheral device alters the inputs to the D/A and the user alters the color (using a set of valuator or a mouse) while observing the results on the monitor. When the operator sees the color he/she wants he/she accepts it, and uses it. Now suppose the same color is to be retrieved on another occasion.

* Cowan, W.B., "An Inexpensive Scheme for Calibration of a Color Monitor in Terms of CIE Standards Coordinates", Computer Graphics, Vol. 17, No. 3, July 1983

1. The user may wish to produce exactly the same color on the same monitor at a later time.
2. The user wish to produce the same color on another monitor, or graphics system.
3. The user may wish to produce the same color in a different medium, e.g., paint, dye.

Each of these proposals raises a different set of problems.

1. It is easy to reproduce the voltages that were applied to the monitor when the color was generated. But is the color the same? This amounts to asking how stable the monitor is, and there is no immediate sets of units for measuring stability, and obviously no way of telling how much instability is objectionable.
2. It is easy to reproduce the voltages, and apply them to the second monitor, but not very likely that the color is the same. How should the voltages be changed to produce the same color?
3. For colors produced in different media there is no reference to voltages at all.

What is needed in each case is a visual match. In other words, it should be the case that a "normal" observer, looking at the two colors under appropriate viewing conditions, should see them to be the same. This does not necessarily mean that these two colors have the same spectral distribution; this objective is impossible for most monitor and cross medium transfers. Rather, it means that two impressions of color must be made the same, which involves quantifying the human response to light.

Problems similar to those described above have been addressed by industries that utilize color. They have been solved by devising a method for deciding when two color samples will be seen to be the same. This method standardized by the Commission Internationale d'Eclairage (CIE), is an interface for users of color. Thus, in our application, we need know only how to measure the CIE coordinates of the colors it produces, and how to generate colors of given CIE coordinates.

3.8.1 The CIE System

The basic CIE system has been set up to allow a determination of whether or not two color samples will be perceived to be the same color. It is based on two concepts: metamerism and additive color mixture. Metamerism expresses the empirical fact that lights of different spectral composition can be seen to be the same color. For example, white can be produced by light which has roughly equal numbers of photons at each wavelength, such as sunlight, or by a mixture of relatively narrow-band red green and blue components, such as in a color monitor. Lights of differing spectral composition that are the same color a said to be a metameric match. We can say that the set of all possible spectral compositions is divided by color matching into subsets such that all members of any subset are metameric to all other members. Then, the problem of transferring color across systems amounts to finding on the

target system colors that are metameric to those of the source system. Thus, we cannot reproduce the spectral composition of sunlight on a color monitor, but we can produce its color by appropriate values of red green and blue components.

Metamerism is closely linked to additive color mixture. Additive color mixture occurs when two lights coincide spatially and temporally so as to be seen as a single color. Specifically, the photons from each sources add together in stimulating a single area of the visual field. Such mixture occurs in theater lighting and offset printing. Yellow on a color video monitor is an example of additive mixture, since red and green phosphors are active in such close proximity that they are mixed additively into yellow. Metamerism is preserved under additive mixture, which means that when additive mixture is preformed the resulting color is independent of whichever of the metameric possibilities are used for the component colors.

Taking metamerism and additive mixture together it is clear that there is a minimal set of primary colors from which any color can be reproduced by additive mixture. Furthermore, the method of production, for a given minimal set, is unique. Trichromacy, which is almost certainly related to the existence to the three types of photoreceptors, is the statement that the minimal set has exactly three members for observers with normal color vision. Thus for a given set of three primaries there is a unique way to specify each color, which is the same for all spectral distributions that match the color, and is different for all those that do not. The CIE is responsible for specifying a standard set of primaries, which allows common use of the system. The ones in most common use are the (XYZ) set of primaries, standardized in 1931. Using them, a color is specified by a triplet of positive numbers, known as tristimulus values, which are defined in terms of spectral power, $P(\lambda)$.

$$X = \int P(\lambda) \bar{x}_\lambda d\lambda$$

$$Y = \int P(\lambda) \bar{y}_\lambda d\lambda$$

$$Z = \int P(\lambda) \bar{z}_\lambda d\lambda$$

The functions x_λ , y_λ , and z_λ are the color matching functions. They are defined in terms of empirical data, and tabulated, by Wyszecki* , where a much fuller account of these matters is presented. For our present purposes, however, all we must know is how to determine X, Y, and Z for colors on a color video monitor, and how, given X, Y, and Z, to display the color they signify.

The color systems in common use in color graphics are easily related to XYZ space. All utilize the same metamerism relations as XYZ. Some are linear, as is the XYZ space. (Linearity means that when two lights are mixed additively their sum is at the color space point which is the vector sum of points corresponding to the two component light.) Three examples are RGB, YIQ, and CIELuv. Others are non-linear, such as Munsell, HSV, and CIELab. Below we describe the interconversion between the RGB and XYZ color spaces.

3.8.2 Calibration Generalities

A video monitor is calibrated if we know the functions

* Wyszecki, G. and Stiles, W.S., Color Science, Second Edition, New York, 1982

$$X = f_X(v_R, v_G, v_B)$$

$$Y = f_Y(v_R, v_G, v_B)$$

$$Z = f_Z(v_R, v_G, v_B)$$

which give the tristimulus values X , Y , and Z for the color produced in terms of voltages v_R , v_G , and v_B applied to the three guns of the monitor. These functions, and their inverses, can be implemented in software to transform voltages to tristimulus values, and vice versa. Such an implementation calibrates the monitor.

There is a brute force solution to this problem, using a spectrophotometer to measure the spectral power of the emitted light. It is straight-forward to sample exhaustively the voltage space, calculating X , Y , and Z for each sample. The results can be used as a calibration, either in parameterized form, or as an interpolated table. This approach is unsatisfactory for several reasons:

1. Spectrophotometers adequate for this task are quite expensive.
2. Because many phosphors have narrow spectral lines, $P(\lambda)$ must be measured at 1-2 nanometer intervals, so that the spectral scan is very time consuming.
3. The main reason for using this method would be its potential accuracy (better than 1%), but our experience suggests that color monitors are insufficiently stable to warrant this precision, especially when the time needed to make a complete calibration (many hours) is considered. It is not likely that the monitor has the same calibration function (to the degree of precision of which the calibration is capable) at the end of the calibration as it did while the calibration was in progress.

An approach which is considered better than the brute force method breaks determination of the calibration functions into several stages. Most of the stages can be done without needing spectrophotometry (i.e., inexpensively), and those that do need it will have the necessary spectrophotometric data available from the monitor manufacturer or some other source. The phosphor chromaticities are among the most stable of monitor properties, so that there is likely no need for spectrophotometry. Furthermore, the calibration stages admit of quick visual checks, which can be programmed into the Camouflage Visualization System. Through them the calibration can be checked each time the monitor is used, giving confidence that the calibration is accurate, and minimizing the need for recalibration.

3.8.3 Preliminaries

Before the monitor is calibrated it should be set up exactly as it will be when in use. This includes:

1. Its position in the laboratory, since moving or rotating a monitor can change its calibration.
2. Purity and convergence adjustment.

3. Adjustment of picture size, brightness, contrast, relative gains of the three guns, etc.

3.8.4 Phosphor Chromaticities

When phosphor a ($a = R, G, \text{ or } B$) of a color monitor is excited it emits light of relative spectral power $p_a(\lambda)$, which is independent of the level of excitation. Thus, if $E_a(v_R, v_G, v_B)$ is a variable representing the degree of excitation of phosphor a , which can, in general, depend on all three voltages, the light output from the monitor is

$$P(\lambda) = \sum_a E_a(v_R, v_G, v_B) p_a^{(\lambda)}$$

To find out the color of this light calculate the tristimulus values

$$\begin{aligned} X &= \sum_a E_a(v_R, v_G, v_B) x p_a^{\lambda \Delta} \\ &= \sum_a x_a E_a(v_R, v_G, v_B) \\ Y &= \sum_a y_a E_a(v_R, v_G, v_B) \\ Z &= \sum_a z_a E_a(v_R, v_G, v_B) \end{aligned}$$

The quantities

$$\begin{aligned} x_a &= \int x p_a^{(\lambda) \Delta} \\ y_a &= \int y p_a^{(\lambda) \Delta} \\ z_a &= \int z p_a^{(\lambda) \Delta} \end{aligned}$$

are known as the chromaticity coordinates of phosphor a . They are normalized so that

$$x_a + y_a + z_a = 1$$

with any normalization factor absorbed in $E_a(v_R, v_G, v_B)$.

Thus, it is necessary to find the chromaticity of the three phosphors. There are several methods, listed here from worst to best.

1. Do not use the standard P22 chromaticities, since many monitors have phosphors which do not match the P22 chromaticities.
2. Measure the phosphors with a tristimulus colorimeter. Such an instrument uses a filter/photoconductor combination that mimics the spectral response of the color matching functions: x , y , and z . Although the meter does not precisely reproduce the desired functions, the error is not serious for measuring broad band spectral distributions, such as occur in natural

objects, pigments, etc. It is more a problem when measuring samples with narrow spectral bands, such as monitor phosphors.

3. Use chromaticities supplied by the manufacturer. These are presumably the result of a spectrophotometric measurement, though not of the exact tube to be calibrated. There is not much variation from tube to tube, but one must be confident that convergence and purity are good to use this method. Care must be taken to be sure that the manufacturer is not specifying "nominal" chromaticities.
4. Make a spectrophotometric measurement of the phosphors. This method is best, catching narrow spectral lines, misconvergence, and lack of purity. It should be done at 1-2 nanometer intervals for best results.

As long as purity and convergence remain well adjusted, it is not necessary to redetermine phosphor chromaticities when preliminary adjustments, described in Section 3.8.3 are redone.

3.8.5 Phosphor Excitations

In general, the excitation of the phosphor a depends on the voltages of all three guns. Thus, we have written $E_a(v_R, v_G, v_B)$. It is possible, but unduly complicated, to calibrate such a monitor using only a simple light meter. The purpose, however, of convergence and purity adjustments is to make the phosphor a excited only by gun a , and we can assume that this condition, which is called gun-independence, is fulfilled for all well-adjusted monitors. When gun-independence, which is expressed as

$$E_a(v_R, v_G, v_B) = E_a(v_a)$$

is true, the relationship of phosphor excitation to gun voltage is known as gamma correction. We must remember, however, that it holds only for a range of gun voltages, albeit a wide one. The range varies from monitor to monitor, and must be determined empirically. Outside the range the calibration is not valid.

3.8.6 Gamma Correction

Gamma correction can be accomplished using any light meter whose output is linear with the number of input photons. The meter's spectral sensitivity need not be known. A photodiode, or hand-held luminance meter is ideal for this measurement. To make it, split the phosphor excitation function is split into two factors

$$E_a(v_a) = N_a e_a(v_a)$$

where $e_a(v_a)$, the relative excitation function, gives the voltage dependence, and N_a , the phosphor-gun normalizing factor, is determined by how the three guns have been balanced. Normalize $e_a(v_a)$ so that

$$e_a(v_{amax}) = 1$$

with v_{amax} at the top of the gun-independent range.

Now, when gun a only is turned on to voltage v_a the meter reads

$$R(v_a) = N_a e_a(v_a) \int F(\lambda) p_a(\lambda) d\lambda$$

where $F(\lambda)$ is its unknown spectral sensitivity. From the readings we get the three excitation functions

$$e_a(v_a) = R(v_a)/R(v_{amax})$$

These functions can be stored for table look-up, or maintained in parameterized form.

Gun-independence should be confirmed by measuring these functions with the other guns having various values within the gun-independent range. For such measurements

$$R(v_a) = N_a e_a(v_a) \int F(\lambda) p_a(\lambda) d\lambda + \sum_{a \neq b} N_b e_b(v_b) \int F(\lambda) p_b(\lambda) d\lambda$$

and

$$e_a(v_a) = (R(v_a) - R(0)) / (R(v_{amax}) - R(0))$$

If gun-independence holds the same function will appear in each case. These functions should be checked fairly frequently.

The phosphor excitation function is generally written

$$e_a(v_a) = (v_a/v_{amax})^\gamma$$

where gamma is normally in the range between 2.3 and 2.8. However, depending on the monitor settings, this results of this equation may be in error by as much as 100%. Brightness and contrast may be adjusted to improve this, but even when the proper adjustments are made, the simple exponential law may not be reasonable. In most cases a two parameter expression of the form

$$e_a(v_a) = A_a \ln(v_a/v_{amax}) + B_a (\ln(v_a/v_{amax}))^2$$

is adequate.

It is important to periodically check whether the calibration parameters continue to be correct. This can be done by eye, without needing a meter. To accomplish this two patterns are displayed in such a way that they are additively mixed, either by temporal succession (e.g., two patterns alternate so fast that they are perceived as one) or by spatial contiguity (e.g., the two patterns are mixed together spatially - dithered - so that any discriminable visual area contains elements of both patterns). Different areas of the patterns will sum to the same reading only if those areas have the same sums. Thus, we can set up two patterns, each comprising many areas, such that the sum of the two patterns is the same in every area if the relative excitation function is right. Such a pattern is, of course, visually homogeneous, so that by displaying it on the monitor we have a quick visual check that this part of the calibration is correct. Such a visible check, which requires only a minute or two,

should be performed frequently for each gun, and with more than one gun turned on to ensure gun independence.

Visual parameter setting can also be done, using patterns like those just described, and adjusting parameters until the display is homogeneous. It is not as precise, however, as using a meter, and it is very important to use a meter at least once to establish the right parametric form for a particular monitor.

3.8.7 Gun Normalization

To complete the calibration we must find the phosphor-gun normalization factors. If a color sample with known tristimulus values is available, this process is straightforward. Adjust the gun voltages until the screen matches the sample. Then

$$X = \sum_a N_a x_a e_a(v_a)$$

$$Y = \sum_a N_a y_a e_a(v_a)$$

$$Z = \sum_a N_a z_a e_a(v_a)$$

and the three normalizing factors can be found directly. This might be done using a standard TV color comparator. Alternatively, if a spectrophotometer is available, measure the tristimulus values corresponding to a set of gun voltages and solve the above equations. It is essential to match or measure several different values to test the consistency of the calibration. This procedure completes the calibration.

Section 4

SOFTWARE DEVELOPMENT

4.1 Approach to Software Design

The application of recent developments in software technology, particularly object-oriented design (OOD) techniques and graphical user interfaces, have greatly assisted the software development effort so far. With continued development of these techniques, software engineering moves closer to the goal of being able to produce reusable and interchangeable software components for application to a broad range of problems. Amherst Systems embraces this ideal and has, where possible, incorporated widely used standards and components in the development of the software for the Camouflage Visualization System. Evidence of this is in the use of Borland's Object Window Library for development of the graphic interface, and the incorporation of the PCX image file format. This practice will continue into later developments.

One of the key features of the object-oriented programming approach is the definition of abstract data types representing complex real-world objects or abstract objects. Software is organized around these abstract data types with an eye toward exploiting their common features. Abstraction refers to the process of defining these abstract data types, or "objects". Other key aspects of the object-oriented approach are inheritance and polymorphism which enables the system programmer to take advantage of the common characteristics of the defined objects.

The use of object-oriented programming methods does not impart anything to the finished product that the user can see. However, there are significant advantages gained by using object-oriented methods. In particular, OOD methods encourage modularity resulting in relatively independent units that are easy to maintain and extend.

4.2 Top-Level Software Design

A top-level organization of the functional elements of the Camouflage Visualization System software is provided in Figure 4.2-1. Shown here are the data and the software components which provide for the processing of the input and creation of the composite image output. At the computational heart of the system is the software which supports the Render Target mode which allows the user to position the target, define the lighting environment, and create the target image. Providing support to the rendering process is the Apply Attributes module which reads in and processes the geometric and optical data required to describe the target's surface. The Insert Target software model supports the creation and output of composite imagery, combining measured backgrounds with the target image created by the software supporting the Render Target mode. The Calibrate module accepts user input and sets display parameters to accurately display colors and image intensity.

Providing overall support for both the system interface and graphical output is the Windows operating system. All system software modules utilize the Windows library of functions to

accept and process keyboard and mouse inputs, and for display of graphical objects on the system color display.

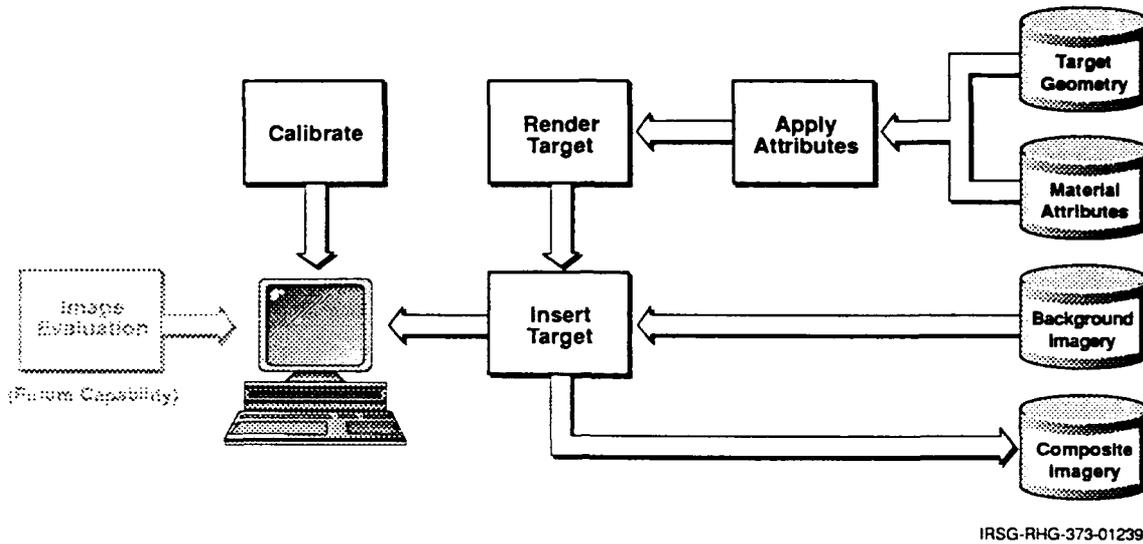


Figure 4.2-1 Camouflage Visualization System Architecture

As just described, the Camouflage Visualization System supports four major functional modes. Provision for a fifth mode, Evaluation, was considered in the design development but was not implemented as part of the Phase I prototype. All this sits on top of the Windows operating system. In each of these modes data and functions may be selected and/or applied to compose and evaluate the displayed scene. The relationship between system data, functions and these operational modes is illustrated in Figure 4.2-2. Each of the operational modes is described in detail in the following paragraphs.

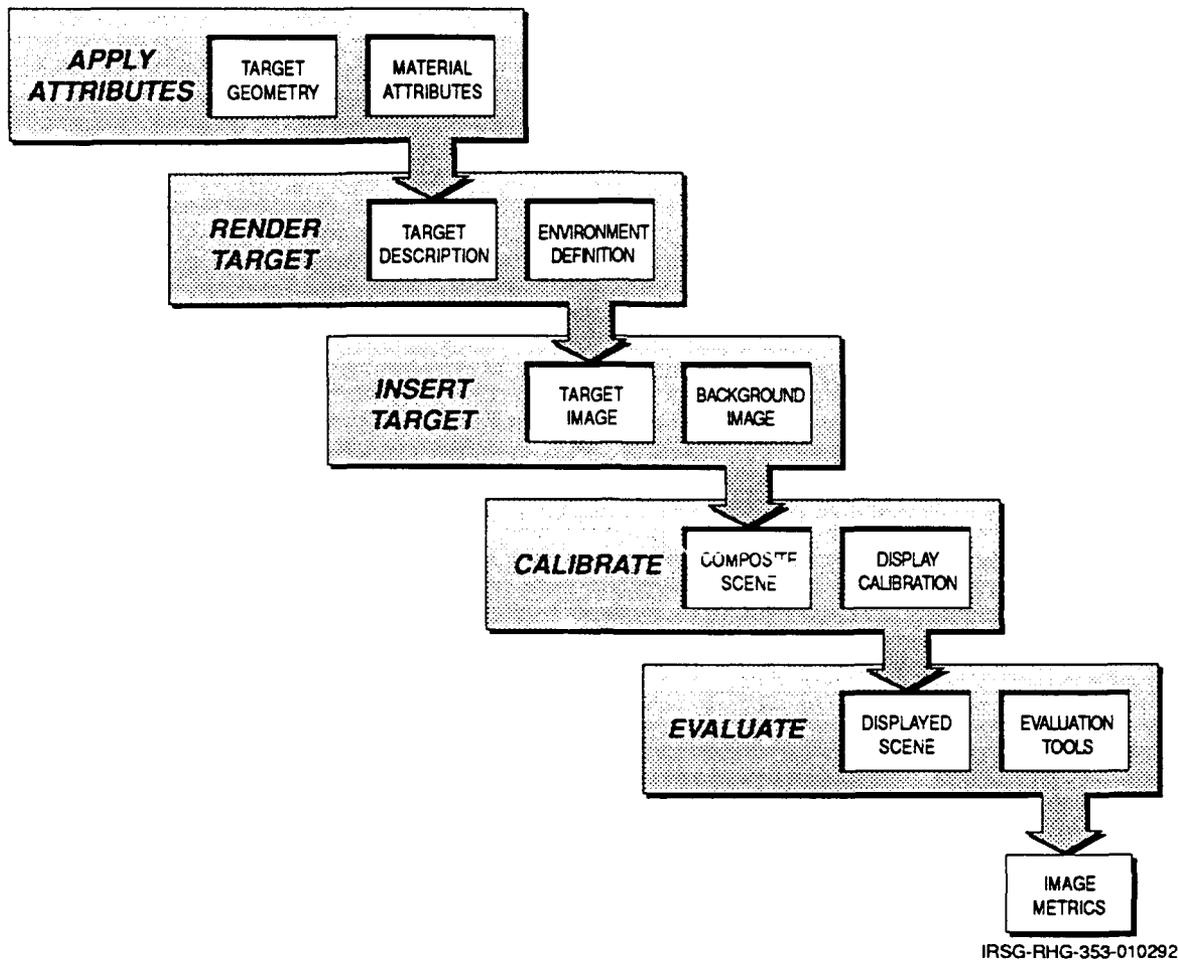


Figure 4.2-2 Functional Mode of the Camouflage Visualization System

In the Apply Attributes mode the user may read in a target geometric description and assign material attributes to its surface. The target geometric description consist of a collection of polygons, and their vertices, used to describe the position and orientation of the target surfaces. The surface attributes may be selected from a library of materials and interactively applied using a mouse or other interactive pointing device.

A default file of material attributes has been provided to the user for specification of surface reflectance and pattern. The library of materials created under the Phase I effort contains the 11 colors that form the basis of traditional Army camouflage paint schemes, as well as several miscellaneous colors. Associated with each color are the parameters which describe the overall reflectance and gloss of the paints. The colors in this file are defined by their CIE chromaticity coordinates and are internally converted to RGB (red, green, blue) values for presentation on the systems color display.

The software components associated with the Render Target mode provide the user with the means to create and save a color-shaded target image. The target description used in the rendering process consists of a combination of the target geometry data and material attributes assigned to the target in the Apply Attributes mode. While in the Render Target

mode the user may specify the target orientation and range, as well as the sun position and atmospheric visibility.

The levels of natural illumination represented within the system prototype are determined by the position of the sun. Through the user interface the system operator is provided with the option to select the sun position by specifying the sun azimuth and angle from zenith. The software developed under the Phase I effort modifies both the sun and sky spectrum to properly provide the illumination incident on the target (see Section 3.5). The method used takes into account the wavelength of the incident illumination and the atmospheric visibility in its determination of the illumination levels. The computed results have been compared to predictions generated through execution of the LOWTRAN atmospheric transmission code and found to be accurate for application within the visible spectrum.

The Render Target mode supports the rotation and translation of the target geometric description from world coordinates to normalized viewing coordinates, including the effects of range and perspective. Also supported are hidden surface removal, calculation of target surface luminance, and degradation of target contrast due to atmospheric effects along the viewing path.

The software supporting the Insert Target Mode provides the user with the tools to edit or create a composite scene of camouflaged targets and backgrounds. The composite scene consists of a measured background image into which the system operator may insert one or more target images created previously in the Render Target Mode. The result may be saved to an existing file or an altogether new image file.

The background image consists of a two dimensional array of pixels (picture elements) which indicate the color and intensity of a natural scene. Due to hardware limitations in the prototype the number of permitted colors is currently limited to 256. However, the software design has been implemented to provide up to 2^{24} colors. As supported by the Windows operating system, the number of supported colors is automatically determined based on the capabilities of the system hardware. Similarly, the size of the image is adjusted to the resolution limitations of the system host. No operator intervention is required in either case.

The composite image scene is created by combining a measured background image with target images created by the Camouflage Visualization and Analysis System while in the Render Target Mode. The user may insert one or more target images into the background scene. The background and composite scene images are externally stored in PCX file exchange format.

The perception of the colors and contrast displayed on the screen are influenced by many factors, including the phosphors used in the system display, monitor brightness and color settings, and room lighting conditions. These factors are subject to change and adjustment, and these variations must be taken into account. The software components supporting the Calibration Mode provides the user with the means to calibrate the system display by adjusting the systems' color palette to provide an accurate display of colors in the scene. Since the eye has a logarithmic sensitivity to variations in brightness, the calibration provides log-stepped increments in the displayed colors rather than a uniform distribution of colors over the range of possible values.

The Camouflage Visualization System software was developed on an IBM-PC AT, 386 compatible, personal computer. An ATI Graphics Ultra Accelerator was installed in the system to support the high resolution and number of colors required for development. The software itself was written in C++ and compiled using Version 3.0 of Borland's C++ compiler.

The Phase II implementation of the Phase I software design shall support the following system features:

- Selection and import of the target geometry and surface attributes.

- Rotation, translation and scaling of the target description.

- Selection and assignment of material attributes to the target surfaces.

- Specification of the target environment and determination of the level of illumination and degradation along the viewing path.

- Calculation of the luminance of target surfaces and their projection onto the image display.

- Selection and import of measured background imagery.

- Insertion of the target into a background.

- Calibration of the system's color display.

The requirements for these functional components were outlined in detailed in the Camouflage Visualization System Requirements Document, delivered under the Phase I contract.

4.3 User Interface

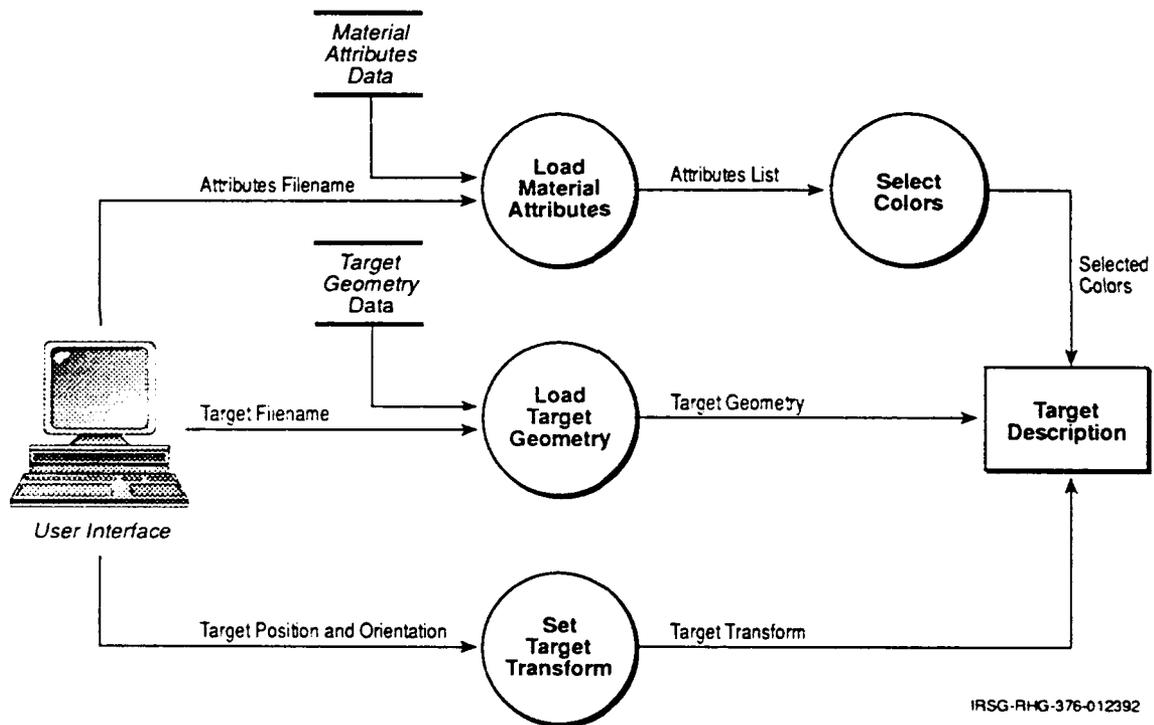
A key feature of the Camouflage Visualization System is the user interface. A system which fully supports the controls and display of rendered target images has been designed and demonstrated under the Phase I effort. Under follow-on development efforts the Phase I design will be implemented to provide a graphical interface which supports all aspects of file input, system execution, and analysis. The initial implementation will continue to utilize Version 3.0 of Microsoft's Windows operating system.

Our implementation of the Phase I design shall support four fundamental interface design goals: apparentness, responsiveness, permissiveness, and consistency. Apparentness suggests that each action required of the operator is intuitive and based upon information presented to the operator. All possible actions and choices that an operator can make will be explicitly indicated. At no time should the interface have hidden controls or commands that require reference to an external document. Responsiveness insures that the operator's actions have directly visible results. This feedback will instill confidence that the operator's actions have a specific effect and that the operator is in control at all times. Permissiveness means that the interface support the diverse, possibly non-sequential, choices of the operator, rather than imposing arbitrary restrictions on the operator's interaction with the

system. Finally, consistency requires that the interface employ common control and display methods for all functions supported by the system. This property significantly accelerates the operator's ability to learn the system since few functions need to be exercised to gain experience with the whole interface.

4.4 Application of Target Attributes

A top-level functional illustration of the Apply Attributes component of the Camouflage Visualization Software is provided in Figure 4.4-1. Through the user interface the user shall select a target geometric description file from data stored either on a floppy diskette or the system hard-drive. The user specifies the filename for the description, which is passed to the **LoadTargetGeometry** component. The **LoadTargetGeometry** module reads in the target geometry and converts the data to a format required by the system's internal processing. An interface supporting the conversion from the FRED target description format (developed by Optimetrics Inc. to support infrared signature analysis) will be provided under the proposed Phase II effort.



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Figure 4.4-1 Function Model of the Apply Attributes Mode

The graphical system interface shall also provides the user with access to material descriptions stored in external data files. These descriptions contain the parameters which define the optical properties of the paints and materials applied to the target. The filename for the data is selected and passed to the **LoadMaterialAttributes** module. Here the data is read and properly formatted for processing by the Camouflage Visualization Software. A list of the selected material attributes is sent to the **SelectColors** module where the user selects and assigns material properties to the planar facets contained in the geometric description.

The attributes describing the color and reflectance of camouflage paints and materials are specified in terms of their CIE chromaticity values. Currently 11 such materials have been defined in an extendable material data file provided under the Phase I contract. These 11 materials correspond to the 11 colors which form the basis for Army camouflage and decoy design. An example of the data provided in this expandable data file is provided in Table 4.4-1.

Table 4.4-1 Camouflage Material Attributes

Description:	Forest Green Paint
x Chromaticity Value:	0.330
y Chromaticity Value:	0.355
Visible Reflectance:	0.065
Surface Finish:	Matte

In addition to the surface attributes, the user may specify the position and orientation of the target relative to the viewing position. If neither position nor orientation is specified then default values shall be assigned. The x, y and z translation of the target and its roll, pitch, and yaw about the coordinate axes are sent to the SetTargetTransform module where a 4x4 coordinate transformation is defined.

The selected target geometry, the target material attributes, and the target transform are combined to form a target description. The target description is subsequently sent to the Renderer for processing of the description into a shaded image of the target.

4.5 Creating the Synthetic Target Image

The most complex portion of the proposed Camouflage Visualization Software is contained within the Render Target module. Here the target and description of the environment shall be combined to provide a shaded image of the target. A functional illustration of the rendering process is illustrated in Figure 4.5-1.

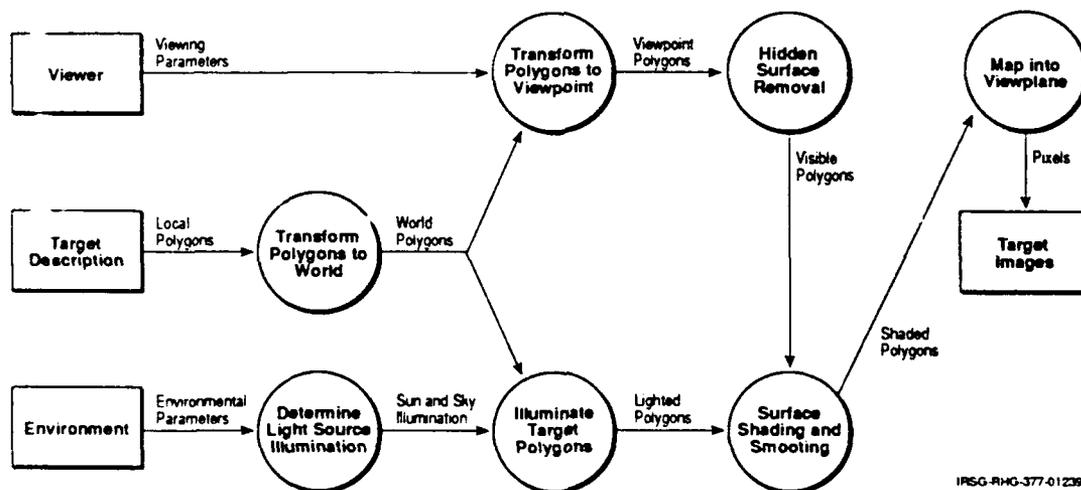


Figure 4.5-1 Function Model for Target Image Generation

The three objects accepted as input to the Render Target module are the Viewer, the Target Description, and the Environment. The Viewer description shall contain all the data and methods needed to define the viewing position and the magnification of the target image. The Target Description shall contain the geometric data, surface material attributes, and positional data. The Environment shall contain the data and methods needed to define the lighting due to sun and sky, and the transmission of the target image through the atmosphere.

The first step in the so-called rendering pipeline is the transformation of the target polygons from a local coordinate reference to the world coordinate reference. Once transformed, the world polygons are further processed to determine those faces which are hidden from view, and to determine the reflected brightness of the surfaces.

Prior to processing of the hidden surfaces the world coordinates of the target description must be translated into the coordinates of the viewport. The viewport coordinate reference is a left-handed system defined such that the x axis lies along a row in the image display and the y axis lies along the vertical. The origin of the view coordinates coincides with the lower left corner of the display. The left axis is perpendicular to the display and points in the screen. Processing of the hidden surfaces is accomplished using the so-called Depth-Buffer approach whereby target pixels written to the screen are first checked to determine if they lie in front of, or behind (the target pixel previously written to that position in the image. Prior to projection of the target into the display, the depth-buffer is initialized to the maximum range of 65,000 - the maximum value of an unsigned 16 bit integer.

The depth-buffer algorithm has been selected for this application because it is a relatively simple algorithm to implement and is easily adapted to provide the higher level processing required for anti-aliasing and smooth shading of the target facets. More importantly, hardware support for the depth-buffer implementation for hidden surface removal is provided by most computer graphic workstations. This approach thus supports future enhancements of the processing hardware.

Processing within the Render Target module shall yield an array of image pixels with associated data to indicate the color and intensity of the target at a particular position in the image. The color and intensity of the target shall be described by an 8-bit (0-255) value for each of the red, green and blue phosphors used in the color display. Definition of the range and distribution of intensities in the system palette shall be determined by the software components supporting the Calibrate Display feature of the system.

4.6 Creating the Composite Image

Once created, the target image may be inserted into a measured background image. A functional illustration of the Insert Target option is provide in Figure 4.6-1. This component of the Camouflage Visualization software shall allow the system operator to select a background image from external storage and insert the target image created in the Render Target process. Selection of a background image filename shall be made through a file select dialog box in the graphical user interface. The filename shall be sent to the LoadBackgroundImage process where the image data is read in and stored in a format consistent with internal processing requirements. The software developed under Phase II shall support the access of image data in either the PCX and TIFF file formats.

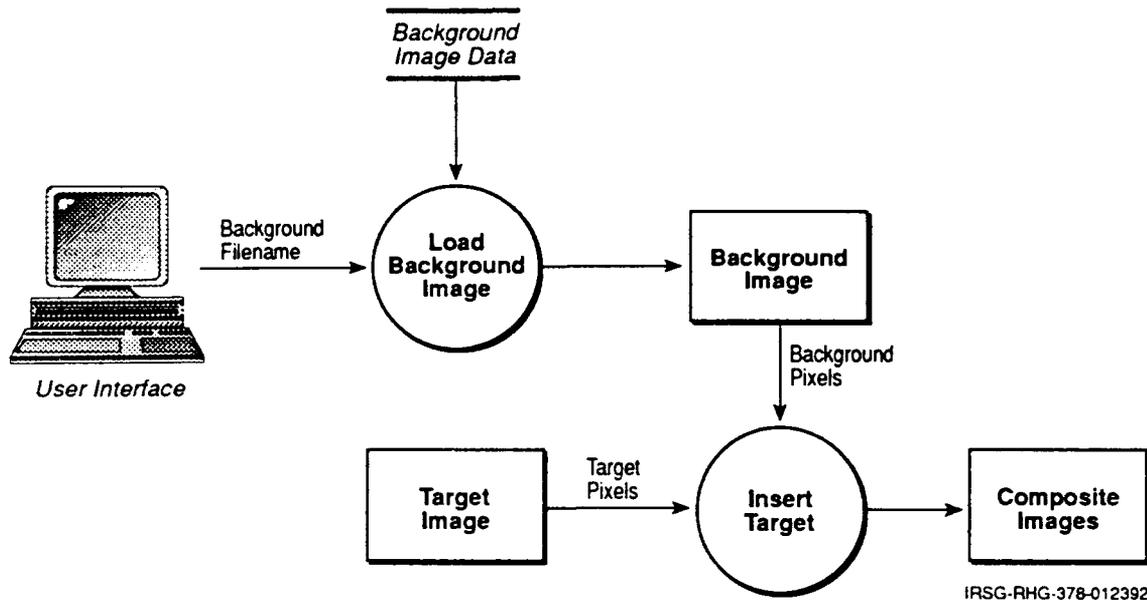


Figure 4.6-1 Function Model of the Insert Target Mode

This Insert Target option shall produce a composite image which may be written to an external file or retained for further processing.

4.7 Image Analysis and Evaluation Software

While not implemented as part of the Phase I prototype, consideration has been given to extensions which would allow the system operator to modify and process the composite image. Figure 4.7-1 shows where the Image Evaluation software fits into the overall system architecture.

Under future development Amherst System would extend the software prototype to include the capability to process images displayed by the system. The proposed extensions would permit the point, area and frame processing of the data.

Point processes are fundamental image processing operations. They are the simplest and yet probably the most frequently used of the image processing algorithms. Point processes are algorithms that modify a pixel's value in an image based solely on that pixel's value (and sometimes its location). No other pixel values are involved in the transformation. Individual pixel values are replaced with new values that are algorithmically related to the pixel's original value. As a result of the algorithmic relationship between the original and new pixel value, point processes can generally be reversed. Point process algorithms scan through an image pixel by pixel, performing the pixel transformation.

Area, or group, processing algorithms use groups of pixels to derive information about an image. The group of pixels used in area processing processes is referred to as a neighborhood. The neighborhood is generally a two-dimensional matrix of pixel values with each dimension having an odd number of elements. The pixel of interest (i.e., the pixel whose old value is being replaced by its new value as a result of an algorithmic computation) resides at the center of the neighborhood. Having a cluster of pixels in the

neighborhood around the pixel of interest furnishes brightness trend information (in two dimensions) that is utilized by most area processes.

Frame processing uses information from two or more images together with a combination function to produce a brand-new image. This new image depends not only upon the content of each input image but also upon the type of function used to combine them.

A functional illustration of the recommended implementation of the image processing capabilities as an integral part of the Camouflage Visualization Software is provided in Figure 4.7-1. With this extension, analytical tools may be selected by the user from an expandable library of image processing functions. The selected function will be passed through a standard interface to a portion of the software which applies to the data in the composite image. The processing may produce a modified image (as would be created by a function which enhances contrast or reduces image noise) or a numerical value which summarizes some aspect of the image (such as determining the peak or average contrast). The option to provide a printed summary of the resulting data has also been considered.

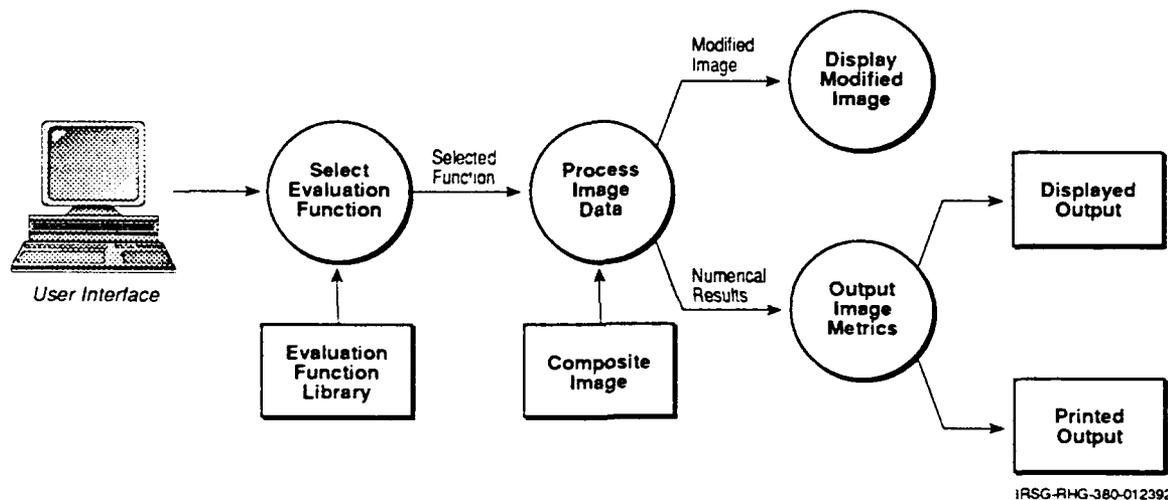


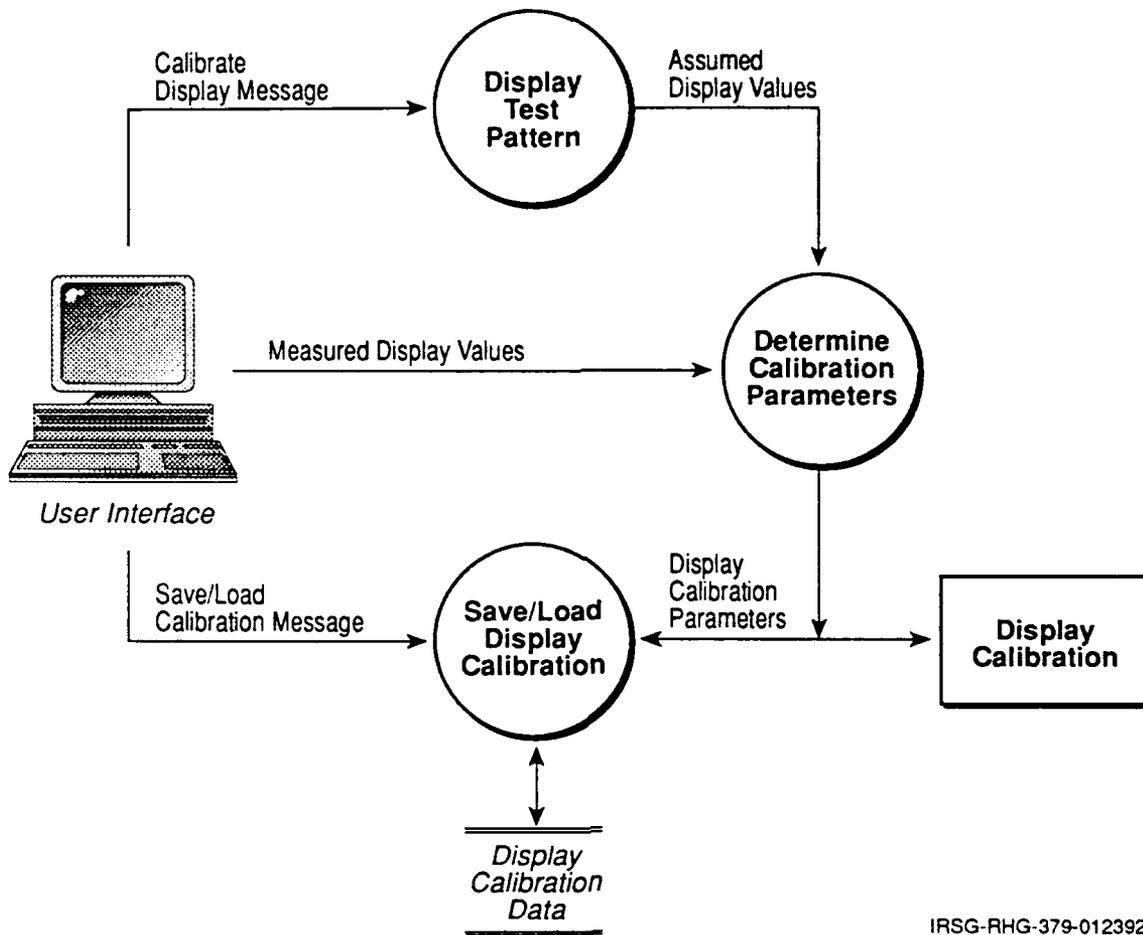
Figure 4.7-1 Function Model for Image Evaluation

In addition to the various analytical tools just described, Amherst System plans to implement software to support the "scripting" of images so that a sequence of images may be presented to a number of users. With these planned extensions, the system operator shall be able to create a sequence of composite background and target images for presentation to one or more observers. The observer shall be allowed to indicate the presence (or absence) of camouflaged assets in the composite scene. If a detection is indicated, the observer may be required to indicate the position of the detected asset using the system mouse. Statistics summarizing the number correct detections, as well as the number of false alarms shall be compiled and made available for later analysis.

4.8 Display Calibration

The Calibration software component supports the Camouflage Visualization System by providing the user with a means to adjust the monitor output to account for the non-linear display of brightness on the color monitor, and to compensate for the response of the

camera of film use to acquire the background imagery. A functional depiction of the software providing support for calibration to the system display is provided in Figure 4.9-1. Calibration procedures were described in Section 3.



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Figure 4.8-1 Function Model for Display Calibration

The user shall invoke the system calibration option by selecting from the options provided through the user interface. This shall result in the presentation of a calibration target consisting of fixed pattern of gray shades and color. Since periodic calibration of the Camouflage Visualization System may be required, our goal is to provide the a calibration procedure which is as simple and as automatic as possible. The materials and procedures required for calibration shall be defined under future efforts.

At the present time there is no standard procedure for calibration of color displays, although an effort to develop a device independent color standard has been under development since August 1989. A device independent toolkit is being developed as American National Standards Institute (ANSI) standards to be known as IT8.7. These come in four separate, but related, parts. The first two parts, IT8.7-1 and IT8.7-2, deal with the input calibration targets that can be used with input scanners and displays. IT8.7-3 deals with transparency targets while IT8.7-4 deals with reflection targets. This work brings true and and effective tools to the calibration of input scanners and displays.

In the future, Amherst System plans to select a calibration target and the instrumentation required to correctly display the color images on the system display. A calibration procedure will eventually be defined and documented in a User's Manual.

The basic procedure for calibration of the system shall proceed as described in Section 3.8. A calibration target will be acquired with information describing the CIE XYZ data for that standard target. The standard target will then scanned and digitized for display. This provides two sets of data which may be used to determine the color transformation which, when multiplied by the calibration data, will provide the values of the displayed data. The inverse of this color transformation may be applied to the displayed image to obtain calibrated system output. The photometers and calibration targets required for system calibration will be selected and purchased under future efforts.

Section 5

PHASE I DESIGN EVALUATION

5.1 Introduction

In this section we describe the operation and performance of the current software. This implementation of the software was developed to test and evaluate the software design. It was used to determine how well the conceptual design performed when put into practice and to identify areas in which the design could, or should be improved.

The system was implemented with a functioning graphical user interface. This interface was developed so that we could evaluate the user's interaction with system and, again, identify areas requiring improvement.

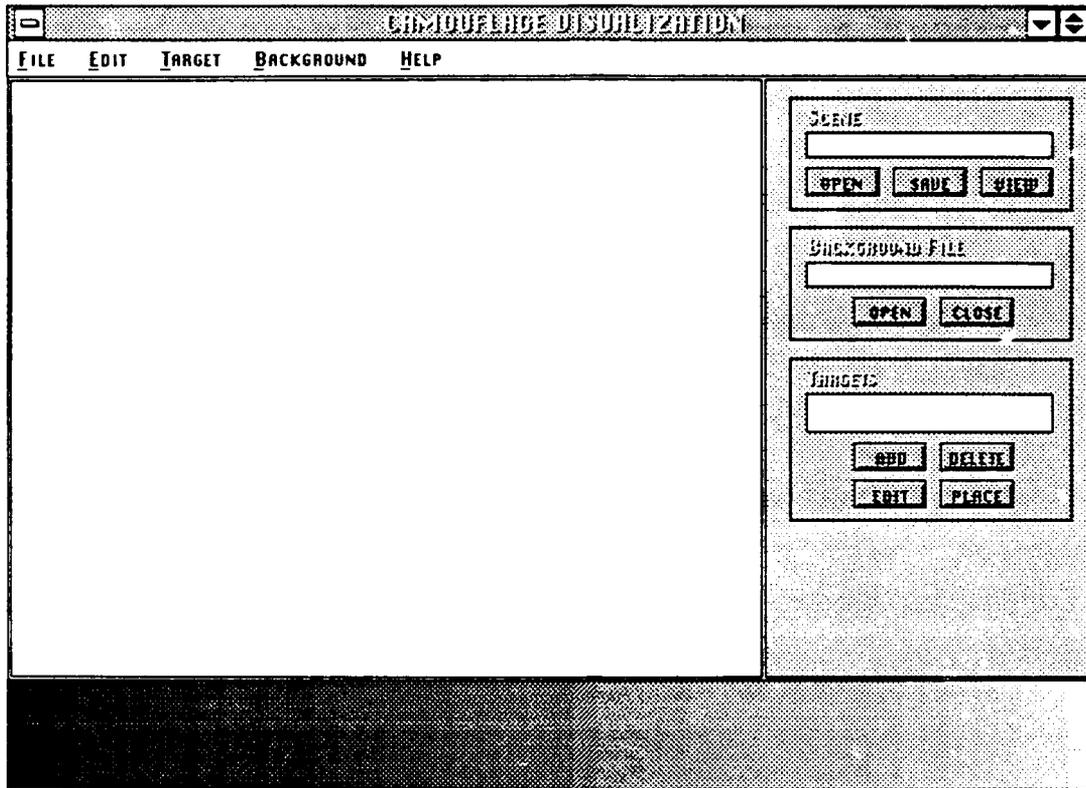
The operation and performance of the Camouflage Visualization System prototype are described in Section 5.2. Following this, is a discussion of the changes and improvements to be considered under later development efforts.

5.2 Prototype Performance

Figure 5.2-1 provides an illustration of the main window which appears upon execution of the Camouflage Visualization System software. At the top of the screen is the caption or title bar which identifies the application. When the upper left corner of the title bar is selected, the user has access to the system menu which provides further access to the standard set of window operations that can be performed. These operations are referred to as system commands, and include the capability to move, re-size and close the window. Closing the window terminates the execution of the Camouflage Visualization System software.

Directly below the title bar is the menu bar which provides the user with access to all of the system functions. The large white area directly below the menu bar is the region of the screen where the target surface is painted and where the background and composite scene is displayed. The area to the right of the display window also provides the user with access to the system functions. The narrow region at the bottom of the window provides the user with an indication of the gamut of colors used in the display.

All of the system functions included in the pull-down menus are also provided by the buttons provided on the control panel to the right of the screen. While exercising the software we have found that we prefer the control panel to the menus and have considered the elimination of the pull-down menus in future revisions. In addition to providing access to the system functions this area provides the user with information regarding the background and target data files currently selected. The gray area below the target function buttons is reserved for future use and will very likely be used to either specify the sun position and other environmental parameters, or to provide a "god's eye" view of the scene to assist in the placement of targets.



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Figure 5.2-1 Main Window

The Scene commands apply to the composite target and background image and may be used to either read a file created during a previous session, or to save a composited scene. The filename of the current scene file is written to the display region above the command buttons. The functions Open, Save, and View are executed by selecting the button with the mouse. Selection of the Open button opens a dialog box on the screen which assists the user in the selection of the scene data file. The Save command lets the user overwrite the previous version of the scene file, or save the file as an altogether new file. The View command lets the user look at the data associated with the scene file, such as the environmental parameters, the name of the background image, and the targets placed in the scene.

Associated with the background file are the commands to open and close the measured background images. Selection of the Open command button opens a dialog box on the screen which assists the user in the selection of the background image data files. The software currently looks for all files with the file extension .PCX and list them for the users review and selection. Once selected, the background filename appears in the display region above the background command buttons. Selecting the Close command closes the background image file and clears the display area.

The user may select and modify targets using the commands provided at the bottom of the control screen. The Add command opens a dialog window on the screen and lets the user select from available target descriptions. As targets are selected the target filename appears in the window above the target buttons. The filenames of up to three targets may be displayed in the window at one time. If more than three targets are selected scroll bars will

appear to the right of the window. The operator may view the files by scrolling up and down the target list. Targets in this list are selected using the mouse, and the selected target is highlighted.

Once a target is selected the remaining target functions may be applied. The Delete function removes the selected target from the list. The Edit function opens the Edit Target window in which the user may assign and modify colors applied to the target surfaces. The Place command opens a dialog window in which the user may specify the coordinates and orientation of the target within the scene.

The Edit Target window is shown in Figure 5.2-2. Here the target may be rotated and sized as colors are applied to the target surfaces. This portion of the system software is not fully functional at this point. While we have provided the means to rotate and magnify the target within the Edit Target window, we have not yet provided the means to interactively select and assign colors to the target surface.

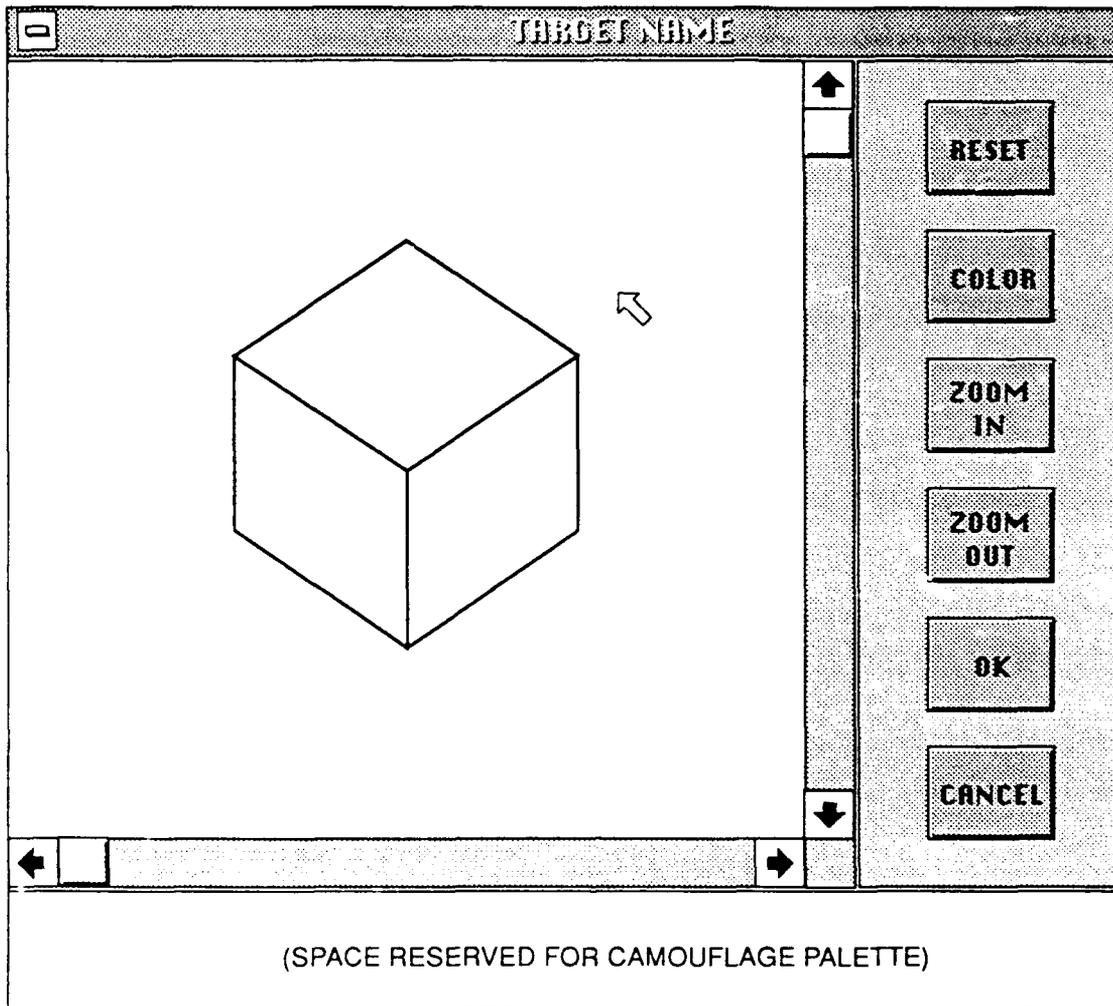
The space at the bottom of the window has been reserved for the palette of camouflage colors. Once functional, the system operator will be permitted to select from the available colors and assign the color to the target surfaces using a mouse. The Edit Target window provides the user with controls to select the palette of camouflage materials and to position the target for assignment of the selected colors.

The scroll bars shown in Figure 5.2-2 are currently used to pan the target right and left, and up and down within the Edit Target window. In our execution of the software we found that we often left the object of interest in the center of the window and that we seldom use this feature. In the future we will use the scroll bars to rotate the target about the vertical and horizontal axis. The reset button, will be used to return the target object to its original orientation.

The color button is currently a non-functioning icon within the Edit Target window. In the future, this button will allow the user to select and delete colors from the camouflage material palette.

The zoom-in and zoom-out buttons effectively decrease and increase the field-of-view so that the target may be enlarged or reduced.

Once the user has made the necessary changes and is satisfied with the results, he/she may select the OK button to return to the main window with the indicated changes. Selecting the Cancel button exits the Edit Target window without saving the changes made.



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Figure 5.2-2 Edit Target Window

The Camouflage Visualization System prototype has provided us with an excellent tool for evaluating the current software design and its implementation. Early demonstration of the software and its use has revealed a few problem areas and portions of the software and interface which may be improved. Two of the principle problems identified pertain to the use of color and the speed of the software. A number of relatively minor improvements to the interface are being considered as a result of our use of the model and suggestions made during the final software demonstration.

The processing speed provided by the AT 386 class personal computer has been sufficient for the display of the simple targets used in the development and demonstration of the software prototype, however, for more detailed target descriptions the processing times would be unacceptable. There are several reasons for this. First of all, it is again noted that the current implementation is a prototype and its performance has not yet been optimized. Our approach has been to make the software work, and to then subsequently make it work fast. Having completed a working version of the software we plan to evaluate the code to determine where the greatest processing demands occur. Our experience suggests that the likely problem areas will be in the transformation of the target geometry and in the filling of

the polygons which describe the surface. Possible solutions to improving the processing speed include the provision of look-up tables to avoid processing of complex functions (i.e. sine, cosine, tangent and their inverses), or re-writing the slow portions of the software in assembly language. Another solution would be to improved processing capabilities by hosting the software on a faster AT-486 personal computer.

A working user-interface has been demonstrated with much of the functionality of the planned final product. This has provided both Amherst Systems and the Army with the opportunity to observe how the operator and the software interact, and to suggest changes to enhance the use of the Camouflage Visualization System. Among the suggestions for improvement of the user interface are the incorporation of a "god's eye" viewing window for the placement of targets within the measured background image. To support the insertion of targets behind hills and the evaluation of targets in defilade, it has been suggested that the background topography be represented using a faceted description similar to that used to describe the targets. This would provide the means to remove those portions of the target hidden by features on the terrain.

5.3 Prototype Development

Amherst Systems plans to extend the capabilities of the Camouflage Visualization System prototype. It should be emphasized, that while the current implementation provides many desired features, it was created primarily to develop and demonstrate the software design. Much of the prototype will be reused in later efforts, but much remains to be developed.

An evolutionary approach is recommended for the development of the prototype demonstrated under the Phase I contract. The Phase I effort addressed the rendition and display of target images against a measured background. Implementation of this design will be the initial concern under follow-on development efforts. With this goal accomplished, later development shall proceed to extending the Camouflage Visualization Software capabilities. Among the more significant improvements planned, is the implementation of the system software on a more capable computer graphic workstation and the extension of the software to include image processing and evaluation tools. Our objectives for further development of the current implementation and our recommended technical approach to realizing these goals is described in this section.

Our objectives for the continued development of the Camouflage Visualization System software under later efforts can be defined in five broad goals. These are:

- Implement the detailed level Phase I software design
- Extend current software capabilities
- Provide improved hardware capabilities to support image generation and display
- Provide hardware and software support for the acquisition of background imagery and calibration of the displayed image.
- Verify system performance and validate the predicted output.

Our primary objective under the current contract was not to provide the Army with a fully capable image generation workstation, but rather to demonstrate the feasibility of such a system and to suggest how such a system could be used in the design and evaluation of concealment and deception measures. Understandably, given the time and budget constraints imposed under the Phase I SBIR guidelines, there were a number of shortcuts taken in our efforts to realize this goal. The current implementation was developed to evaluate the proposed system design. Before extending the capabilities of the present software we need to address various omissions and short falls in the current implementation. Specifically, we would like to improve the error handling capabilities of the system and optimize the software for improved interaction. In the interest of time these implementation details were left out so that the more difficult problems could be fully addressed.

Extensions to the existing software, recommended for later development, include the addition of image processing and analysis functions. These additions to the system would provide the user with the means to quantify the evaluation of proposed measures by reducing the results to values which may be compared to other data obtained from the analysis on variations of the proposed design.

Also recommended as an extension to the current implementation is the addition of the capability to "script" a sequence of images created with the system so that they may be presented to an observer for comparison of proposed concealment and deception measures. The intention here is to simulate field test by providing various targets and camouflage measures for evaluation. Conceptually, the observer would be permitted to view a particular scene and indicate whether the target can be seen. If a target is detected the user may then indicate the position of the camouflaged asset using a mouse-directed cursor to verify the response as a true detection or a false alarm. Further interaction may be permitted to determine if the target can be recognized, or if the object detected is merely a decoy. The option to provide several images to many observers should be implemented so that statistically meaningful results can be derived.

The initial software development was implemented on an IBM-PC, AT 386 compatible, personal computer. This was, in our opinion, the ideal platform for development of the system prototype, given its relatively low cost and the excellent software development resources. The availability of class libraries for the Windows operating system further enhanced the development effort. We anticipate the continued use of this platform and the associated software as development tools under later development efforts.

Despite our satisfaction with the platform chosen for implementation of the prototype, there are several limitations of this system which are better addressed by specialized commercial hardware. Among the options available for further development we recommend the purchase of a graphic workstation and the modification of the current system software to run under the Unix operating system. Additional software modifications will need to be made to take advantage of the specific features of the hardware supporting graphics generation and display. Hardware support for hidden surface removal and anti-aliasing, provided by a number of workstation vendors, will considerably enhance the use and execution of the Camouflage Visualization System software.

Images acquired for demonstration of the software under the current contract were reduced to a digital format by Integrated Images, Lansing Michigan. This was convenient, inexpensive, and entirely acceptable for the system demonstration, however, DoD agencies

and their contractors will require that this resource be provided as a component of the Camouflage Visualization System. The images used in camouflage design and evaluation Army will, in many cases, be classified or require immediate evaluation and so in-house digitizing capabilities are essential to the application of the software. Under future efforts we plan to provide the hardware and supporting software necessary to provide color images of army assets and backgrounds in both PCX and TIFF formats.

The system developed under the Phase I effort has built-in provisions which permit the modification of the palette of available colors. This feature was provided to support the calibration of the system display. As mentioned in the Section 3.3 the distribution of the intensity of the colors detected by the eye is logarithmic while the display is linear. Therefore, without compensation the image will appear unnatural due to the enhanced contrast associated with a linear variation in displayed intensity. Specification of the parameters defining the calibration transformation may be done subjectively (as it is now) or by using the procedure defined in Section 3. However, for quantitative analysis and repeatable performance evaluation it is essential that the system calibration be defined in precise terms. Implementation of the calibration procedures defined in Section 3.8 need to be implemented if the predicted results are to be of any value. The implementation of this capability is also planned.

Before the system can be used with the confidence that the predicted results are accurate the Camouflage Visualization System results must be validated. Validation is taken to imply that the scenes generated by the system software are not only created as expected (i.e., there are no logical or programming errors), but that resulting image is radiometrically correct. The difference between verification and validation should be clear. Verification determines whether the equations and algorithms developed to manipulate the target and to predict its brightness have been properly implemented. Validation determines that these same equations, and the assumptions upon which they are based, accurately predict the same results measured in the field. Verification naturally precedes validation, and both are required if the predicted results are to be believed.

Amherst Systems has drafted a plan for the continued development and validation of the Camouflage Visualization System. Building on the development initiated under the Phase I effort, the following development goals have been defined:

1. Implement the Phase I Software Design
2. Provide Image Analysis and Evaluation Software
3. Extend Image Processing and Display Hardware
4. Provide Support Capability for Image Acquisition
5. Provide Support Capability for Display Calibration
6. Verify and Validate Software Performance
7. Create a comprehensive guide to the execution of the software and interpretation of the results.

This list of objectives embodies our short term development plans for the Camouflage Evaluation System. Beyond these immediate objectives is the desire to extend the capabilities of the system to include the ultraviolet and infrared portions of the electromagnetic spectrum. These far term extensions will support the evaluation of multispectral counter-surveillance techniques that will be needed to defeat developing sensor and target acquisition systems. The ability to provide synthetic video imagery may also be added to assist in the development of counter-surveillance measures for moving vehicles and decoys.

Section 6 PROJECT SUMMARY

6.1 Summary

Under the current Phase I contract Amherst Systems has reviewed and defined the Army's requirements for the development and evaluation of counter-surveillance measures applied to ground vehicles and equipment. Based on these requirements, a software prototype for a graphic workstation to view and evaluate camouflage measures was designed and implemented. The prototype supports the display of colored camouflaged targets, synthetically created and displayed against measured background imagery. Through a user-friendly interface, the system operator may specify the target position and orientation, as well as the state of the environment.

The prototype was developed to demonstrate the feasibility of using synthetic imagery in the evaluation of camouflage measures and to provide a basis for further system development. Both goals have been realized to our satisfaction. Computer image generation provides a convenient and cost effective means of evaluating counter-surveillance under field-like conditions. While this application will not replace field observation as a true test of a proposed camouflage measure, simulation does:

- Give the user the ability to evaluate a wider range of potential solutions prior to full scale development.

- Extend field measurements to conditions that may be difficult or impossible to obtain.

- Assist in the development of camouflage concept for vehicles which do not yet exist.

- Help to establish acceptance criteria for vehicles and camouflage measures produced for the government by non-government contractors.

- Help to develop an intuitive understanding of the influence of problem parameters on the predicted outcome.

- Provide a quantitative and repeatable means of comparing proposed solutions observed under similar environmental conditions.

As is the purpose of a prototype, the current implementation has revealed several areas for improvement. These modifications have been worked into the final design and will be addressed under later developments. In particular, there are several areas where the software may be optimized for improved performance and interaction, and there are a few places where improved model fidelity is required.

The dramatic improvements in the ability to create realistic computer generated imagery, combined with the reduction of the size and cost of computer workstations has provided the marvelous capability to visualize what may not yet exist. Quite naturally, this has been applied with spectacular success in the advertising and entertainment industry, but more importantly, it is being applied with increasing frequency to design and evaluation. Given the increasing pace of modern warfare, and of weapons development, it is important that the Army apply the advances in computer simulation to the enhancement of counter-surveillance and survivability measures. These applications will help the Army protect our country's investment in both personnel and equipment, and maintain our tactical advantage over potential adversaries.