1
INTRODUCTION

Electro-optical imaging system analysis is a mathematical construct that provides an optimum design through appropriate trade studies. A comprehensive model includes the target, background, properties of the intervening atmosphere, optical system, detector, electronics, display, and the human interpretation of the displayed information (Figure 1-1). While any of these components can be studied in detail separately, the electro-optical imaging system cannot. Only complete end-to-end analysis (scene-to-observer interpretation) permits system optimization.

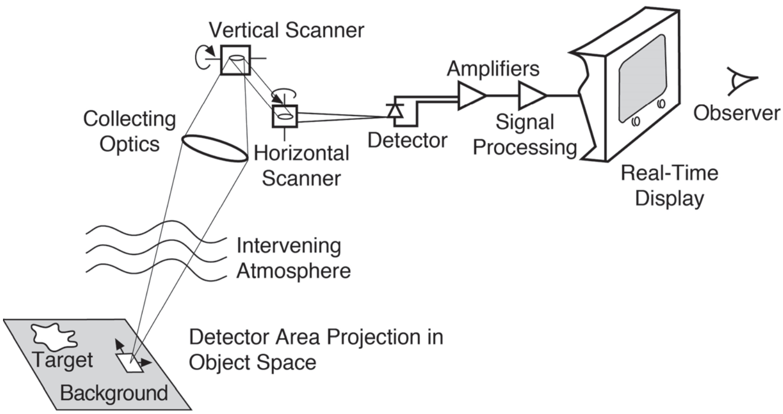

Figure 1-1. Generic sensor operation that applies to all electro-optical imaging systems. The scanning mechanism will vary according to the overall design and number of detectors. Staring arrays (the focus of this book) do not have a scanner.

Finding the optimum design is an iterative process. Every step in the design process that has conflicting needs requires a trade study analysis. Many performance parameters can only be increased at the expense of others. For example, increasing the resolution can decrease sensitivity.

Effective modeling requires an orderly integration of diverse technologies and languages associated with radiation physics, optics, solid-state sensors, electronic circuitry, human interpretation of displayed imagery (human factors), computer models, and the software embedded in the system. Each field is complex and is a separate discipline. The system analyst must be conversant in all these fields.

Hudson[1] stated, "*System engineering is the discipline that offers an orderly approach to the design of systems, and, in particular, to systems that are so complex that no one individual can possibly understand all the pertinent details*." As system complexity increases and technology advances, it is increasingly necessary to succinctly define performance requirements for each subsystem to ensure that the overall system requirements are met. This is an ever-increasing challenge to the system analyst.

System optimization starts with a conceptual design. Then, the various subsystems are designed. Each subsystem will behave slightly different than the original design due to hardware constraints (limited availability of components, space limitations, power constraints, etc.). The analyst must then modify the model parameters to reflect the current design. As the system is built up, real components will perform differently due to variations in manufacturing tolerances. Based on actual components, the analyst can finalize the model parameters. It is only now that the analyst can be assured that the predicted performance will match measured values.

According to Shumaker and Wood, a model should answer four basic questions:[2]

1) What characteristics (specifications) must an electro-optical imaging system have to perform a given task?
2) What design parameters will enable a system to satisfy given specifications?
3) What laboratory performance values will verify that a design provides desired characteristics?
4) Given an electro-optical imaging system design, how can it best be deployed and what are the expected results?

There are many factors affecting design that cannot be easily incorporated into any performance model. These include environmental issues, covertness, countermeasures, size, weight, power consumption, cost, technology maturity, customer demand, "ilities" (maintainability, reliability, etc.), and other support issues.

1.1. SYSTEM MODELING

System modeling drives future design, system requirements, and quality assurance specifications (Figure 1-2). Connecting specifications to well-understood physical parameters gives the designer, manufacturer, and customer confidence that the design objectives have been achieved.

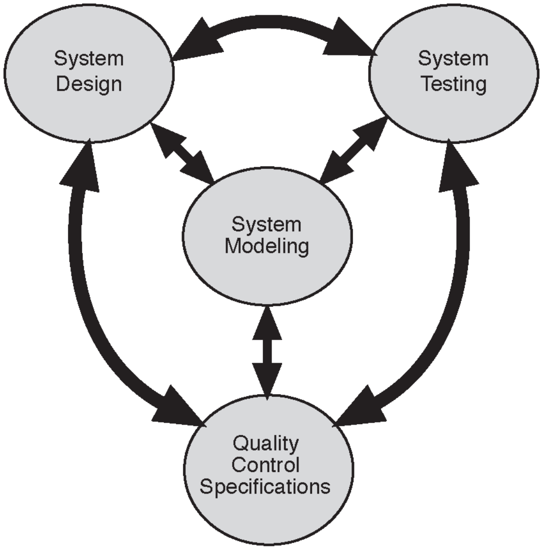

Figure 1-2. System modeling is a continuous process.

As a system is built with real hardware, new values are used to refine range predictions. Simultaneously, modeling is used to help select quality control specifications. Once a model is validated for a particular design, it is used to develop the next design. The overall goal is to deliver a system that will operate as designed. Concurrently, "good" imagery is desired. There are a myriad of factors that affect the perceived image quality (Figure 1-3).

Referring to a list of variables similar to that shown in Figure 1-3, Howe[3] stated, "*Although the list is by no means complete, its length underscores the complexity of target acquisition. No single model...could possibly account for all the factors listed; because of this, many models are specialized to a particular handful of scenarios and system types. Frequently they incorporate simplifying assumptions, and they are usually validated for only a small portion of the possible mission or situations. Using a model to predict performance for scenarios where the model is not validated or specialized can lead to very inaccurate predictions.*"

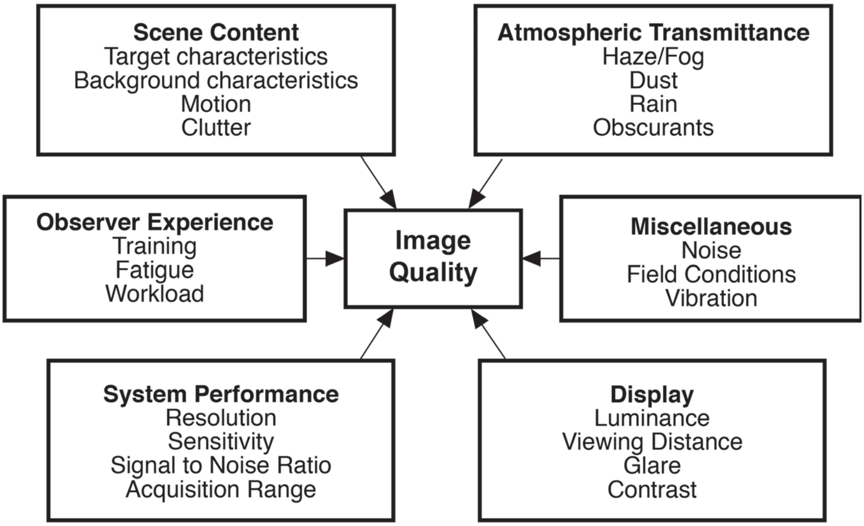

Figure 1-3. Image quality contributors. This book focuses on acquisition range. However, there is a multitude of performance parameters.

Models must be able to relate design parameters, laboratory measurables, and operational performance. Three levels[2] of models contribute to satisfying these requirements:

Component/phenomenology models

These are separate models for the system modulation transfer function (MTF_{SYS}), atmospheric transmittance, target signature, and signal-to-noise ratio. These individual models relate quantifiable design and environmental parameters to higher-level summary parameters.

System performance models

These models are built upon component-phenomenology models. They characterize the total system performance for controlled tasks such as the detection of a periodic bar pattern. They predict standard measures such as the minimum resolvable temperature and minimum resolvable contrast.

Operational models

These models combine system models with other models to characterize overall operational tasks. When operational models include target signature models, they are used to calculate detection, recognition, and identification ranges.

Each of the above models can be separated into three categories:

"Standard" models

These are the models that are used most often by the modeling community and are readily available.

Special application models

These are models that are unique to a specific application or a specific design.

Nonlinear models

Nonlinear models cannot be described mathematically in closed form. They are used on a case-by-case basis.

1.2. SYSTEM APPLICATIONS

In 1969, Hudson[4] listed more than 100 separate applications for thermal imaging systems. He divided the list into four major categories: military, industrial, medical, and scientific. Each category was then subdivided into 1) search, track, and range; 2) radiometry; 3) spectroradiometry; 4) thermal imaging; 5) reflected flux; and 6) cooperative source. His 1969 list is surprisingly complete, with only a few applications added since.

Today, two broad categories are in use: military and commercial. Table 1-1 highlights a few applications in each category. Military and commercial systems are similar in basic design, but each system is built for a specific purpose. As a result, military and commercial systems tend to be described by different performance parameters. Some generic differences are listed in Table 1-2. Imaging systems have an observer as the image interpreter, whereas hardware and/or software assess machine vision imagery. An important subset of machine vision is infrared search and track systems (IRSTs). These systems are designed to detect point sources. The specific system design depends on the application, atmospheric transmittance, and availability of optics and detectors. This list is brief. Detailed information on all phases of electro-optical systems can be found in the eight-volume *The Infrared and Electro-Optical Systems Handbook*.[5]

Key to the design of an electro-optical imaging system is the overall application. The design depends on the mission and how the mission is to be accomplished. Compare the requirements for pinpointing a target with that of high-speed aircraft navigation. The military wants low noise with maximum reliability. In the commercial world, low cost and ease of maintenance are important; they are often willing to accept less performance. However, these distinctions are getting blurred in today's environment. There is a desire for a single imaging system to perform all functions. This may be possible as new image processing algorithms are developed. The next-generation system might be called a computer with a built-in camera.

Table 1-1
THERMAL IMAGING APPLICATIONS

COMMUNITY	APPLICATIONS	
Military		Reconnaissance Target acquisition Fire control Navigation
Commercial	Civil	Law enforcement Fire fighting Border patrol
	Environmental	Earth resources Pollution control Energy conservation
	Industrial	Maintenance Manufacturing Nondestructive testing
	Medical	Arterial constriction

Table 1-2
TYPICAL DESIGN REQUIREMENTS

DESIGN AREAS	MILITARY	COMMERCIAL
Vibration stabilized	Required for very narrow fields of view	Usually not required
Image processing algorithms	Application specific (e.g., target detection or automatic target recognition)	Menu-driven multiple options
Resolution	High resolution (resolve targets at long distances)	Typically not an issue since the image can magnified by moving closer
Image processing time	Real time	Real time may not be required
Target signature (sensitivity requirements)	Usually just perceptible (requires low NEDT)	Usually high contrast target (NEDT not necessarily a dominant design factor)

1.3. NOMENCLATURE

Due to atmospheric spectral transmittance, electronic imaging system design is partitioned into seven generic spectral regions (Figure 1-4). The ultraviolet (UV) region ranges in wavelength from 0.1 to 0.4 μm. The visible region ranges in wavelength from 0.4 to 0.7 μm. Televisions and most digital cameras operate in this region. The near infrared (NIR) region spans approximately 0.7 to 1.1 μm. Low-light-level televisions (LLLTVs), image intensifiers, starlight scopes, and night vision goggles (NVGs) operate in this region. For historical reasons, the UV, visible, and NIR technologies have developed their own terminologies. For this book, the first infrared imaging band is the short wavelength IR (SWIR), which covers approximately 1.1 to 2.5 μm. The second infrared imaging band is the mid