Chapter 1
Introduction

The last 30 years have seen a steady migration from film-based imagery to electronic display of imagery. This migration has occurred in the medical community, the reconnaissance and surveillance community, and in the publication industry. It has been accompanied by a proliferation of advances in display technology. Unfortunately, these advances have not always improved the conveyance of image information. Further, the wide variety of display technology now available and rapid changes in the marketplace make the selection of a display increasingly difficult. Are flat-panel displays superior to the classic CRT? Will plasma displays make LCDs obsolete? What is the difference between a flat CRT and a flat-panel display? Will FEDs replace LCDs? We explore these issues and many others in this book.

1.1 The Image Chain

The electronic display can be considered as an element in an image chain (Fig. 1.1) whose purpose is to capture and convey information in a form most useful to the human observer. Each element of the chain, including the observer, affects the conveyance of information. The chain begins with a capture device, which acquires data using energy in some portion of the electromagnetic spectrum ranging from x rays to radio waves. The capture device may form an electronic image as with a digital camera, or it may simply acquire a file of intensity and position as with, for example, computed tomography. Regardless of the original capture device, the information must be displayed in a form useful to a human observer. Intensity information outside the visible spectrum must first be processed to convey variations in light or color. For example, radiographs code variations in x-ray tissue density as shades of gray; multispectral scanners code variations in reflectivity as variations in color. Beyond the basic coding of intensity relative to position, there are certain image manipulations that can be performed to enhance the conveyance of information. They range from simple transforms in intensity space to complex neural network processing algorithms designed to at least partially replace the human observer in the detection process. The scope of this book is limited to film digitizers as a capture device and to basic pixel processing transforms.

The main thrust of this book is on the electronic display element of the image chain. Although the electronic display is the primary medium used to extract information from an image, hard-copy imagery is still frequently used to convey the extracted information to others because prints and viewgraphs can be annotated

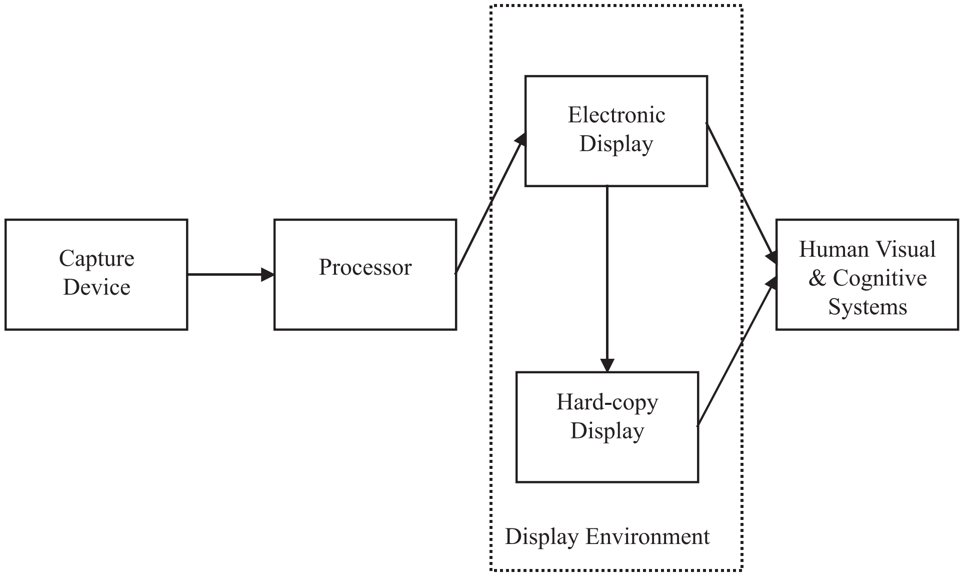

Figure 1.1 Image chain.

and displayed to large groups. Thus, this book discusses digital image printers and printing operations. But electronic projection devices are becoming more common (and affordable) as replacements for hard copy; therefore, this book also covers these devices as an element in the image chain.

A display is designed (hopefully) to convey image information. We can measure the ability of a display to convey information in both the physical and the perceptual realms. For example, a display's contrast ratio and resolution are measured with the implicit assumption that more is better. It will be shown that this is not always the case. We can also apply various perceptual and task measures to evaluate the performance of a display. The reconnaissance and surveillance community relies on task-based scales such as the National Imagery Interpretability Rating Scale (NIIRS);[1] the medical community performs detection studies based on the theory of signal detection (TSD).[2] Ideally, a set of physical measures would predict perceptual performance, but this is not yet the case—we can understand the physical parameters that affect performance but cannot today model their relative contributions.

The performance of an electronic display is strongly affected by the environment in which it is operated, particularly the surrounding light level. With film display systems (light tables and light boxes), room lighting is relatively unimportant because the strong light sources used to illuminate the film generally overpower any effects of room lighting. However, electronic displays are much more limited in their intensity, and the output of the display can easily be affected by the room lighting. With text, the quality of a display is rather obvious—ultimately, the observer can either read the text or cannot. With imagery, performance quality may be less obvious because the observer may not know that details are missing. Figures 1.2 and 1.3 show examples to illustrate this point. The image on the left in Fig. 1.2 was taken under bright room lighting conditions, the image on the right under darkened conditions. The numbers are more legible on the image at the right. Figure 1.3 illustrates portions of an MRI scan with the same relationship as the images in Fig. 1.2. Differences are not apparent, and it is possible that detail in the "dark" image might be lost in the "bright" image.

The final element in the chain is the human observer. The human visual and cognitive (brain) systems act together to determine whether or not the desired information is conveyed. The visual system has a limited capability to detect small

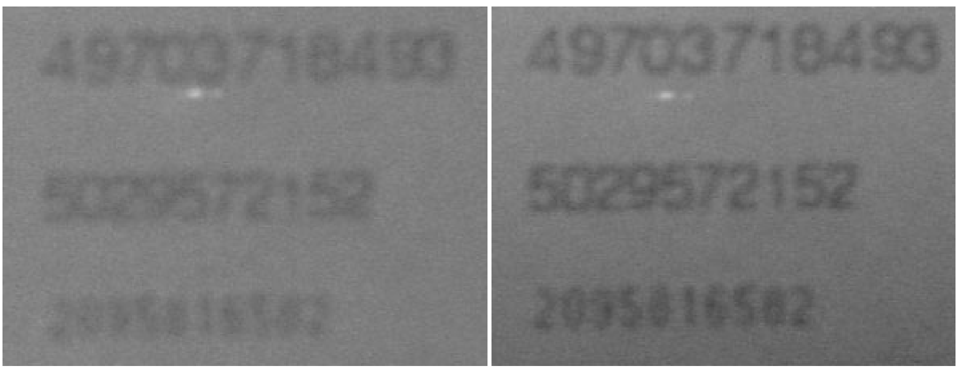

Figure 1.2 Effect of room lighting on text image appearance.

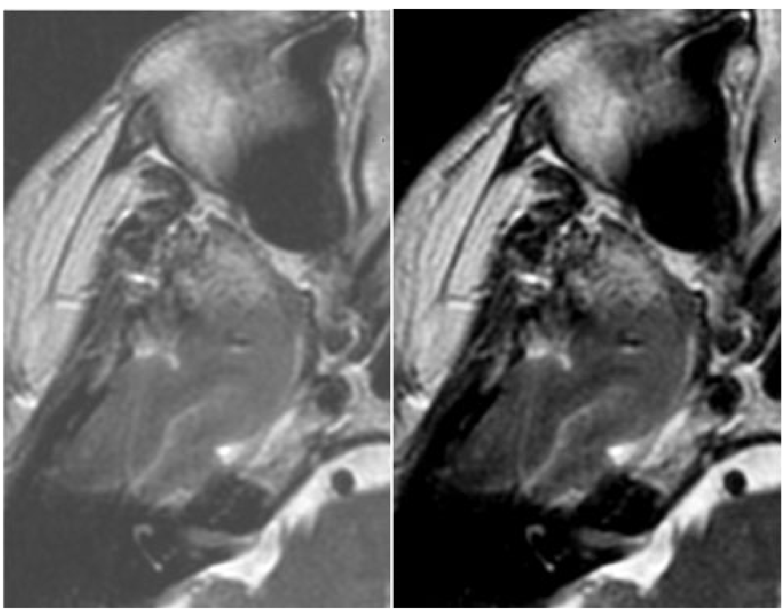

Figure 1.3 Effect of room lighting on appearance of MRI scans.

Figure 1.4 Effect of contrast and display size on legibility.

spatial detail and low-contrast information. Figure 1.4 illustrates this point. The numbers on the image in A are of a size and contrast that makes them nearly illegible. The contrast has been increased in B and the numbers are legible. In C, the contrast is the same as in A, but the size of the numbers has been increased to make them legible. On typical displays, low-contrast detail is too small to be seen by the observer, so either the image must be enlarged or the contrast must be increased. Text is typically viewed at very high contrast (black on white) so small details can be seen. With imagery, the contrast is often much lower so magnification is required.

The ability to detect light intensity differences is not linear with display intensity variations. Unless the display is matched to the visual system, information is lost. One technique, called "perceptual linearization," applies a look-up table to better match the display output to the observer.[3] But the brain does not always respond to physical differences as we might expect, particularly with color. Further, the ability to detect features in an image is a function of both the visual process and the thought process. Finally, not all observers are alike, and our visual performance degrades with age. We need to understand this degradation and learn how to compensate for the loss.

1.2 The Display as a System

Although we may think of a display as the device on which we view an image, we can also consider it as a system (Fig. 1.5). The display system is comprised of a storage and processing device, a display controller or video card, and the display itself. The quality and usefulness of the displayed image are affected by all three components. The processor (and its hosted software) transforms the image into a form that best matches the requirements of both the display and the observer. As discussed previously, the eye cannot see all of the detail present in an image on a typical display. The processor thus enlarges or magnifies the image using a transform that minimizes information loss. The processor also applies other transforms that are designed to maximize information conveyance using contrast adjustment, noise reduction, and edge sharpening. Thus the processor can, in some cases, make up for limitations of the display. The sequence in which the processing is applied has a significant impact on the final appearance of the image. The processor software can also degrade the appearance of images relative to their optimum.

The display controller is the interface between the processor and the display. With conventional CRT displays, the controller transforms digital data to an analog signal that drives the display. The controller also performs a variety of other functions including signal timing, graphics acceleration to speed up the display of imagery, and the application of look-up tables designed to optimize the relationship between digital image values and output light intensity. A poorly performing controller can add noise and various artifacts to images and slow the process of writing new images to the display. Even the physical connection between the processor/controller and display can impact quality. Excessively long connectors and improperly matched signals can produce a variety of image artifacts or anomalies.

The display itself is where we see the visible evidence of image or display quality. The display outputs light or color in proportion to input voltage from the controller. The display also has hardware to vary perceived brightness, contrast,

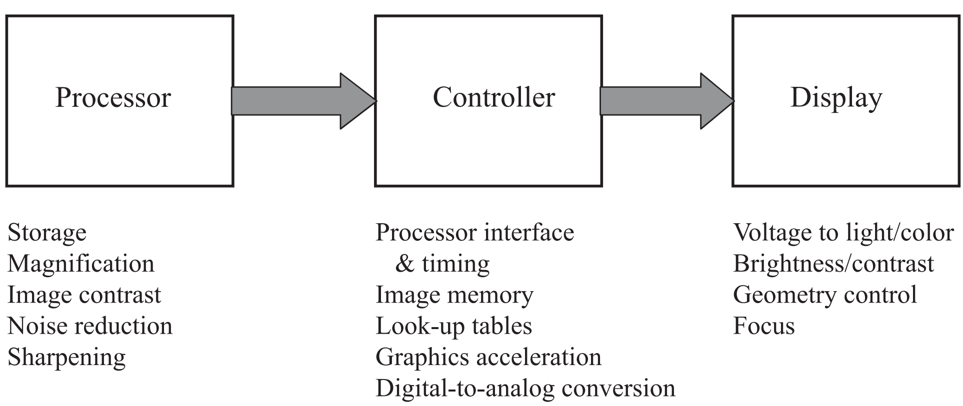

Figure 1.5 Display system.

and geometric positioning. In terms of the display, quality is a function of the type of display, the display design, and a long list of performance parameters.

1.3 Characterizing Quality

The VESA's Flat Panel Display Measurements Standard lists 44 different measures of display quality.[4] The EIA's "Display Measurement Methods under Discussion" lists 29.[5] These measures characterize the ability to see small detail and distinguish small brightness or color differences. However, no single measure or even a simple combination of measures fully characterizes quality. The number of potential measures defies our ability to make rational purchase choices. Compounding the problem is the fact that most vendors supply information on only four or five quality parameters. The popular literature has stopped providing in-depth performance reviews; thus there are few sources of in-depth information on display quality. Display users are largely left on their own to choose from among several vendors and competing technologies. This book addresses the issue.

Each user has a set of tasks to perform using the display system. These tasks can be defined in terms of detection objectives, such as the radiologist seeking to detect pulmonary nodules on a chest radiograph or the military analyst looking for tanks. In both cases, successively more detailed detection is often required. For example, the military interpreter, having detected a tank, seeks to detect features of the tank that will enable tank model identification. At each level of detection, the objects or features have a range of sizes and gray level or color contrast. If the features are presented to the observer with sufficient size, contrast, and sharpness, the detection task can be performed. Figure 1.6 illustrates this concept. The listed display quality measures represent only a small subset of the nearly 50 measures discussed in this book.

The original capture device places fundamental limits on size, contrast, and sharpness—the display system cannot add information. It can process the information to better match the characteristics of the human visual system (HVS) or it can degrade the information that is presented to the display observer. It is this degradation that we seek to avoid in the selection and operation of a display system.

The fundamental quality issue is "Will the display system provide the information I need for a price I can afford?" Although a quality/cost trade-off exists, the optimum point in that trade-off depends on the user's requirements. Thus, this book guides the user through a series of choices in order to select the type of display that will best satisfy the user's requirements. Once the display type is selected, further choices will determine performance—detail size, sharpness, and contrast. Information is provided on the meaning of the many quality measures used in the display literature as well as a more practical subset of those measures. A set of recommended minimum performance requirements is provided, along with instrumented measurement methods. Wherever possible, noninstrument methods are provided for users lacking access to measurement instrumentation.

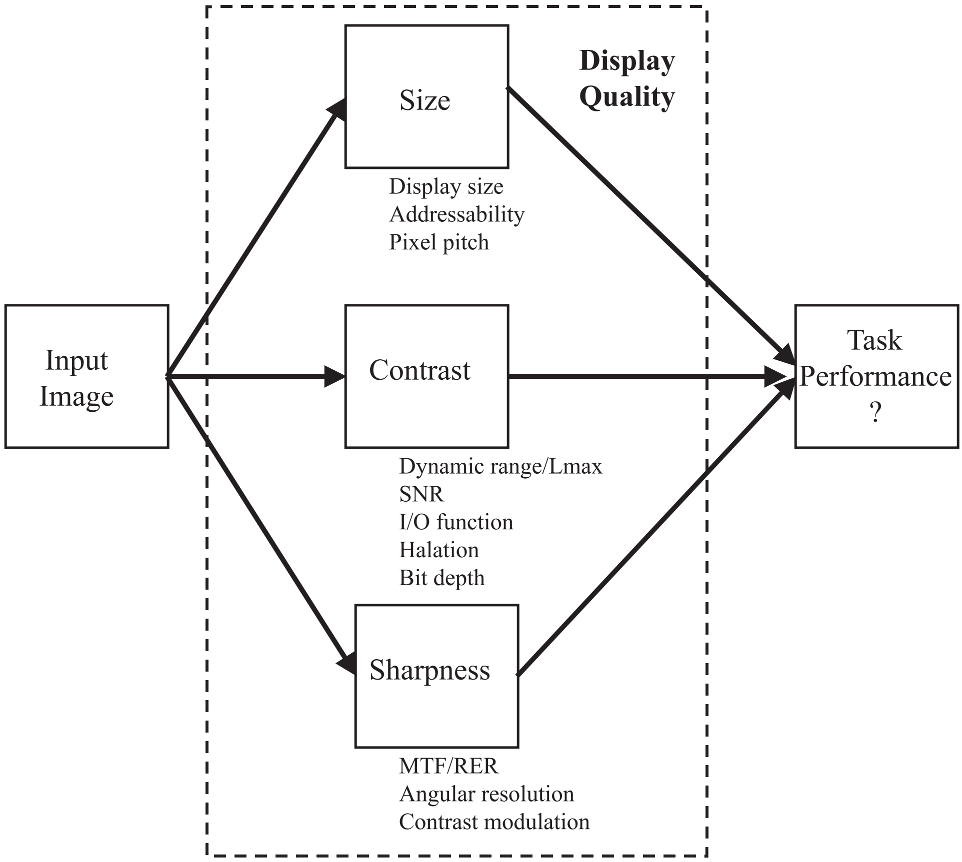

Figure 1.6 Display quality and task performance.

1.4 Reader Road Map

This book is written for a wide variety of users of soft-copy image display systems. It should be emphasized that the focus is on tasks using continuous-tone imagery, both monochrome and color. Recommendations thus do not necessarily apply to office tasks such as word processing or related tasks where the display is typically only two tones (e.g., black and white).

The contents of this book are of special interest to those in the medical and reconnaissance and surveillance fields, but users from other fields with critical image viewing applications will also find useful information. The intended audience ranges from individual display system users to management and facilities personnel involved in the procurement and setup of soft-copy display systems, including information technology (IT) and image science personnel involved in system design and maintenance. Because of the diversity of the intended audience, some readers may prefer to read only the sections most pertinent to their interests.

For the reader new to the field of soft-copy display, Chapter 2 discusses light and color measurement, and Chapter 3 describes display system operation. For readers interested in display quality metrics, Chapter 4 describes physical quality measures and Chapter 5 describes perceptual and cognitive measures. The information in these chapters will enable the reader to readily understand the large body of available display performance literature.

Because the display user is a significant element in the display image chain, Chapter 6 discusses the performance of the HVS. Display users should be aware of the noncorrectable visual performance effects associated with aging. Chapter 6 also addresses models that describe and predict the performance of the visual system.

For those involved in display performance assessment, Chapters 7 through 9 provide measurement procedures for the subset of measures considered most important in defining display performance. Procedures are defined for those users having the necessary instrumentation; alternatives are provided for those users without instrumentation. Detailed information on display quality requirements is also provided in these chapters along with the rationale for each requirement. Chapter 4 presents a more comprehensive list of measures and provides references to additional sources of information on measurement procedures.

The reader interested solely in display system purchasing advice can find it in Chapter 10. Those looking for guidance on selection and operation of scanners and printers are referred to Chapter 12.

Since the quality of imagery displayed on a soft-copy system is dependent on how it is set up and operated, system users, managers, and IT personnel will find Chapters 10 and 11 of special interest. Those engaged in facility design for soft-copy systems will find relevant information discussed in Sec. 10.2.

The CD provided with this book contains a wide variety of test targets that can be used to perform the quality measures described in Chapters 7 through 9. They also provide the basis for comparing the relative quality of alternative display systems and components. Finally, they can be used to measure display performance on a continuing basis as a means of quality control.

References

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