PERSPECTIVE ERROR IN VISUAL DISPLAYS

ROBERT ENTWISTLE and NEIL MOHON
Naval Training Equipment Center

Perspective in photographic reproductions is one of the most important visual cues to a human observer primarily because it is almost always used subconsciously to make some determination about the photographed subject. Many photographs, especially in the advertising industry, introduce significant errors in the perspective of the object; but that error is rarely detected by the conscious mind of the observer.

Consider the example photographs of an automobile shown in figure 1. The two pictures were made with the automobile in exactly the same location relative to the background scene. However, quite a different impression is relayed to the mind from figure 1a than figure 1b. Figure 1a was made using a 200 mm focal length lens on a 35 mm camera, while figure 1b was made using a 35 mm focal length lens on the same camera. Advertising photographs are often made using short focal length lenses in order to make the car appear longer, more attractive, or to emphasize some particular detail.

One basic anomaly in our "advertising oriented" mind is that we accept the erroneous perspective of figure 1b without question. Maybe we expect it. The next time you see an automobile advertisement, or any advertisement, consciously look for the errors in perspective.

The problem in perspective arises because we do not view the photographic records from a proper distance, or viewpoint. Figure 1a will yield correct perspective when viewed from 60 cm; and figure 1b will be correct when viewed from 10 cm.

When we consider the environment of a military training simulator in conjunction with its ultimate purpose, it becomes imperative that we give careful attention to perspective and the impression it makes. In a simulator the trainee is frequently called upon to make rapid judgments about range, relative size, or rate of movement of a target based solely upon a photographic type display. Obviously the scene should have as little error in perspective as possible in order for the trainee to make accurate estimates. Hence, perspective is a factor in the training value of a display.

We have designed two photographs to illustrate this concept and they are shown as figure 2. The two people are located in exactly the same relative positions in both photographs; and yet there is a dramatic difference in the apparent perspective presented to a viewer. Figure 2a was made using a 200 mm focal length lens on a 35 mm camera; and figure 2b was taken using a 50 mm lens on the same camera. If two situations, similar to figure 2, were presented to a novice trainee in a simulator, it is quite possible that he would make erroneous judgments in range and/or relative positioning. If a target were moving from position A to position B, the judgment of the trainee as to velocity and direction of movement could easily be distorted for the two situations.

We observe from figures 1 and 2 that perspective is the angular relationship between objects in the scene as viewed from the camera position. When a picture is made from a relatively short distance from the objects, the angular relationship between the objects is greater than if the picture were made from a longer distance. The perspective in a picture is exactly correct when the relative angles in the photographic reproduction are identical to the camera viewpoint angles that existed in the original recording geometry.

The correct viewpoint distance, and hence the correct viewing angle, may be derived from the optical relationship inherent in the camera-projector-observer system. Figure 3 represents the entire system from the object, O, through the camera, through the projection (or enlarger) apparatus, and to the observer at the viewpoint, V. The angle subtended by the object is given by

$$\tan a = h/s, \qquad (1)$$

where h is half the object height and s is the object to camera lens separation. To maintain this angle, a, at the viewpoint, we require that

$$h''/d = \tan a. \qquad (2)$$

Equating 1 and 2 and solving for d, the correct perspective viewpoint, we find

$$d = h''s/h. \qquad (3)$$

From the magnification relationship of the projector, we know

$$m = \frac{h''}{h}. \qquad (4)$$

Using this in equation 3, we find that

$$d = mh' s/h. \quad (5)$$

From the magnification relationship of the camera, we know that

$$h'/h = -s'/s, \quad (6)$$

or that

$$s' = -h's/h. \quad (7)$$

Now substitute equation 7 into 5 to yield

$$d = -ms'. \quad (8)$$

The lens imaging equation states that

$$1/s + 1/s' = 1/f, \quad (9)$$

or rearranging

$$s' = f/(1 - f/s). \quad (10)$$

Now, substitute equation 10 into 8 to find

$$d = -mf/(1 - f/s). \quad (11)$$

But, in cameras, it is almost always true that $s \gg f$; therefore, we say that

$$\boxed{d = mf} \quad (12)$$

where we have absorbed the negative sign into the magnification factor, m. Equation 12 states that the viewpoint distance, d, of a photographic recording for correct perspective is found by multiplying the focal length, f, of the recording camera lens by the magnification, m, of the projector (or enlarger) system. Note that this viewpoint must be on the optical axis as shown in figure 3 in order to maintain the correct angular relationships.

Usually a photograph or projected image is not or cannot be viewed from the correct perspective distance (d). The actual distance from which it is viewed we will call distance (D), and we will define a new parameter, Perspective Error Ratio, as

$$PER = d/D \quad (13)$$

Or, substituting equation 13 into 12,

$$\boxed{PER = mf/D} \quad (14)$$

Where the actual distance viewed (D) is larger than the correct perspective distance (d) we obtain a number larger than one, and where it is smaller we obtain a number smaller than one. Multiplying PER by 100 we may obtain a value for the percent perspective error (PPE) which may be useful in some descriptions.

We have used the concept of perspective error ratio to analyze a simulator in which riflemen are taught marksmanship against a series of targets approaching them on a wide front. The requirement involved ten trainees firing onto a wide-angle screen for accuracy score. Figure 4 illustrates the configuration of the simulator. One constraint required that the trainees be positioned along a straight line 25 meters long and be able to fire completely across their 50 meter front. Because we had to have satisfactory screen brightness, good resolution, and a minimum screen size, we wanted to move the screen as close as possible. The result was a cylindrical screen of 30 meter radius having viewing positions generally indicated by the three dots 0m, 10 m, 20 m, to represent respectively positions on-axis, 10 meters off-axis, and 20 meters off-axis. From the 0M on-axis viewing position, the screen subtends 30^o on each side of the optical axis.

Figure 5 illustrates the PER across the 60^o screen for each of the three positions of figure 4. The perspective error ratio for position 0m, which is directly under the projector lens, is one everywhere on the screen; i.e., this is the position defined by equation 12 above. The PER, from equation 14, varies considerably across the screen for the other two positions and is not linear. The errors in perspective are greatest when the trainees are firing across the screen to the opposite corner of the simulator. As of this writing, there are no definitive results as to the tolerable limits of PER in a training simulator -- or any photographic type scene. So our approach is to minimize perspective error as much as possible by pushing PER toward one while fulfilling the system requirements. We know of no published information on the effects of perspective error on a trainee's learning and/or accuracy. To date, the best approach has been to make some assumptions from acceptable perspective error in portrait photography and apply them to this simulator; all of which may or may not be valid.

Perspective is a significant visual cue in the display of a training simulator because it is needed to make accurate estimates of range, size, and velocity of objects in the viewed scene, and is normally used in a subconscious manner. We have introduced the mathematical concept of perspective error ratio as an approach to measuring and evaluating the perspective in a scene. And we have introduced a graphical type analysis of perspective error ratio to easily study the perspective error in a display. We propose that the next step is to produce standard objects for measuring experimentally the perspective error in a display and determining what tolerable limits can be placed upon such errors for various type simulators.

Figure 1a. Perspective of 200 mm focal length lens on a 35 mm camera.

Figure 1b. Perspective of 35 mm focal length lens on a 35 mm camera.

Figure 2a. Perspective of 200 mm focal length lens on a 35 mm camera.

Figure 2b. Perspective of 50 mm focal length lens on a 35 mm camera.

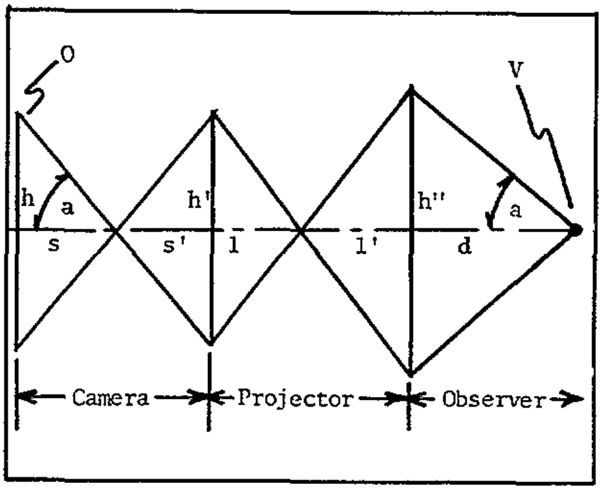

Figure 3. Viewpoint for correct perspective.

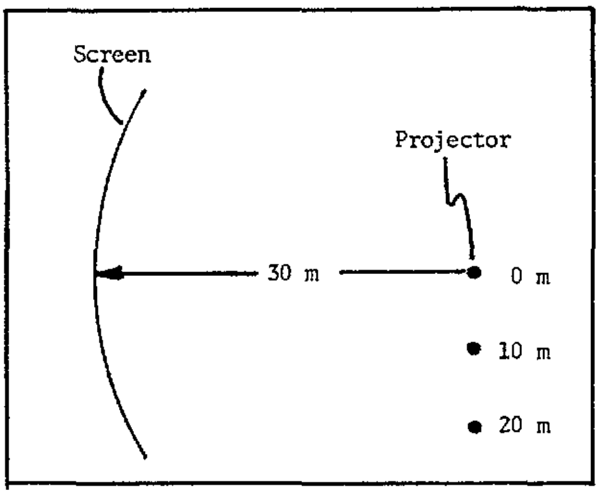

Figure 4. Simulator configuration with three representative viewing positions.

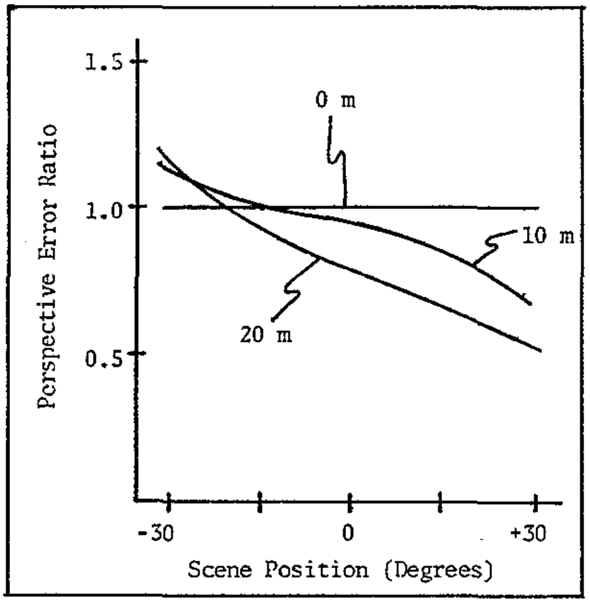

Figure 5. Perspective Error Ratio (PER) as a function of scene angle for three viewing positions.

ABOUT THE AUTHORS

MR. ROBERT J. ENTWISTLE is a Photographic Technologist in the Physical Sciences Laboratory at the Naval Training Equipment Center. He has invented numerous training device systems including the Observed Fire Trainer now under procurement, and the directional effects capability used on most radar simulators now in the field. He received his education at the Rochester Institute of Technology.

MR. NEIL MOHON, is a Physicist in the Physical Sciences Laboratory at the Naval Training Equipment Center and serves on various teams which investigate specific optical problems in the development of training equipment. He has performed application oriented research in lasers, holography, photography, optical aberration, vision, polarization, perspective, and optical system design during the eight years he has been with the laboratory. He has a Bachelor of Science degree and a Master of Science degree from the University of Kentucky with a major in physics. In 1973 he received an Optical Specialist degree from the Optical Sciences Center of the University of Arizona.