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Image Blur

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Abstract

Knowing the amount of image blur is important for recording useful data. If there is too much blur, it becomes hard to make quantitative measurements. This report discusses image blur, the parameters used to control it, and how to calculate it.

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Introduction

The image blur in the photograph referred to in this report is produced by the exposure of a moving object. Image blur can be used in a number of ways. In artistic photography, an excessively blurred image enhances the feeling of motion. In scientific photography, image blur must be kept to a minimum so that information is not lost. Image blur in visual analysis should be kept below 0.002 inch. As blur increases it becomes noticeable, and quantitative measurements become questionable. The photographs in Figures 1 and 2 show motion with acceptable and unacceptable image blur, respectively. The amount of image blur in a photograph can be calculated if one knows the parameters used in taking the photographs. This paper explains image blur, the parameters that affect it, and how to calculate it.

By supplying the values for the parameters and using them in the equations provided later in this report, the image blur in the photo of Figure 1 works out to be 0.00146 inch. In Figure 2, it is 0.00583 inch. The blur is noticeable when comparing the vertical lines of the two vehicles. Seams along the doors stand out, and blurring in the hubcaps is also noticeable.

Figure 1. Movement with acceptable image blur.

Figure 2. Movement with unacceptable image blur.

Parameters

Before calculating blur, the customer's needs must be known. Once these are determined, the photographer's homework can begin. All of the information can be broken down into a few calculations which set the parameters of the camera(s) being used. These parameters are:

- subject velocity
- film format
- field of view
- shutter constant
- exposure duration
- angle between the subject motion and the film plane
- frame rate

The parameters are all interrelated. Some are determined by the customer, which then limits some of the others. Camera selection and frame rate limit the exposure duration and the available film formats. These factors must be calculated on a test-by-test basis.

In the discussion below, each of the parameters is explained, along with its effect on image blur when changed. This paper concludes with several equations used in calculating image blur. The image blur from the photos in Figures 1 and 2 will be calculated, along with some additional sample problems.

Subject Velocity

This parameter is obtained from the customer. It is a major factor in the selection of the cameras. The faster the action to be photographed, the higher the camera's frame rate.

First, determine the subject. Consider the case of a rotating gear where the gear teeth are the area of interest. The circumference of the gear must be calculated, then the circumference is multiplied by the rpm of the gear to determine the edge velocity.

Generally, image blur increases as the subject velocity increases, when all other parameters remain the same.

Film Format

Film format is another term for film size. Standard formats include 16mm, 35mm, and 4x5 in., among others. The exposed area of the frame is different for each size format. A frame is an individual exposure on the film. Motion picture film is made up of thousands of frames. In general, the larger the format the greater the risk for image blur, because it allows a larger image. But the acceptable image blur parameter of 0.002 inch is still in effect. At this point, a decision must be made. The larger format provides a sharper image when enlarged, but the remaining image blur parameters must be adjusted to keep the image blur acceptable. Also, larger format cameras cannot operate at the same high frame rates as the smaller format cameras. When image blur is acceptable, larger format film produces a better picture because the negative does not have to be enlarged as much as it would have to be for the smaller format cameras to make the same size print.

The exposed area of the film, determined by the camera manufacturers, is relatively standard for motion picture cameras. Nevertheless, consult manuals for the exact size of the exposed frame for each camera. This is especially true with ultra-high-speed cameras because there is no standard frame size.

Using either the frame width or height, be sure to match the direction of the subject motion with the appropriate frame dimension. Listed below are the frame width and height dimensions for some motion picture cameras.

Film Format (mm)	Horizontal (in.)	Vertical (in.)
16	0.410	0.296
35	0.995	0.745
70	2.25	2.25

While having a larger format is generally an advantage for sharper pictures when enlarging the image, it is a disadvantage when image blur is a concern. The image blur parameter is 0.002 inch regardless of the film size. Photographing an area of a given size with a larger format camera results in a larger image. Consequently, the same amount of subject movement produces more blur than a smaller format camera.

Field of View

Field of view refers to the area viewed by the camera/lens combination. When photographing a test, the planned motion should fill the camera's field of view as efficiently as possible.

A camera's field of view can be calculated using the ratio shown below.

$$\frac{\text{Frame Width}}{\text{Lens Focal Length}} = \frac{\text{Field of View}}{\text{Subject Distance}}.$$

By arranging the equation for the missing term, the fourth parameter can be calculated.

Frame width = 0.296 inch.
Lens focal length = 6 inches.
Subject distance = 100 feet.

0.296 x 100/6 = 4.9.

The camera's field of view is 4.9 feet.

Figure 3 shows how the different factors relate to each other.

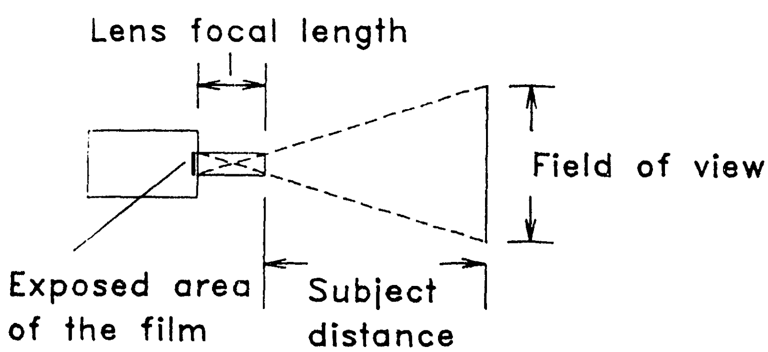

Figure 3. Image/subject relationship.

Customers seldom ask for a specific field of view. The field of view becomes apparent with an explanation, and the information needed, of the test. Generally, an increase in the field of view results in a reduction of image blur, providing all the other parameters remain the same.

Shutter Constant and Exposure Duration

All high-speed motion picture cameras operating under 500 frames per second, and some of the cameras capable of 11,000 frames per second, have shutters. The shutter does two jobs: it limits the exposure duration on the film and obstructs the light while the next frame is moved into place. The shutter, which is a rotating disc with a portion missing, is positioned between the lens and the film. Figure 4 shows a rotating disc shutter.

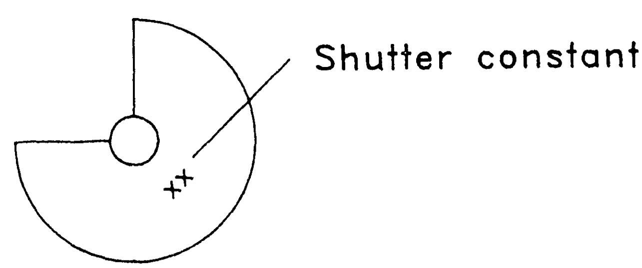

Figure 4. Rotating disc shutter.

The shutter constant expresses the ratio of time that the shutter is open to the time it is closed. It is derived from the shutter itself in one of two ways:

1. The constant is in degrees. To calculate the constant, the number listed is divided by 360. In the case of Figure 4, the shutter constant is 90/360 = 0.25.

2. The constant may be a whole number or a fraction. If it is a whole number, in this case 4, the reciprocal 1/4 is used. If it is a fraction, use it directly.

Change the shutter factor by either adjusting the opening of the disc or replacing one fixed disc shutter for another.

Some of the cameras operating in the 500 to 11,000 frames per second range do not use disc shutters. These cameras control the exposure through the movement of the film/rotating prism mechanism. Figure 5 shows six sequential steps of a four-sided rotating prism.

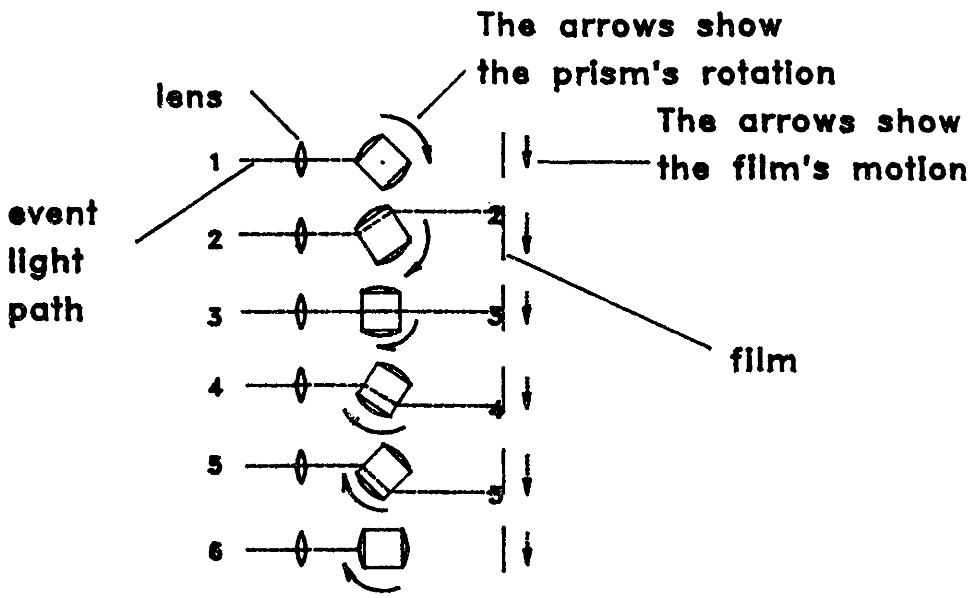

Figure 5. Rotating prism mechanism.

The prism transmits light to, and tracks with, the film. While the exposure is made, the relative motion between the prism and the film is zero. When the prism rotates past the point of transmitting light, the exposure is ended. Consequently, the shutter constant is fixed. Check the manuals for each camera's shutter constant.

Exposure Duration

The shutter constant divided by the camera frame rate determines exposure duration. For a camera running at 500 frames per second with a shutter factor of 0.25, the exposure is:

$$0.25/500 = 0.005 \text{ second.}$$

The reciprocal of 0.005 is 2000, or an exposure of 1/2000th of a second.

Some cameras have shutter constants up to 0.0125. These cameras have great stopping ability because of their short exposure times. The disadvantages of short exposures is the large amount of light needed to get the necessary exposure on the film.

As the shutter factor decreases, the exposure duration decreases. When calculating image blur, a decrease in the shutter factor/exposure duration results in a reduction in image blur, when all the other factors remain the same.

Angle of Subject Motion to the Film Plane

The angle between the subject motion and the film plane of the camera should be kept as close to zero as possible. When the subject motion is parallel to the camera's film plane, little or no parallax error enters into the measurements of the subject's movement. Parallax error is explained below.

The film's position while being exposed is in many cases the camera's film plane. Knowing the camera's film plane is important in determining the angle between it and the subject's motion. Many high-speed motion picture cameras have the film plane marked on the side of the camera. This plane can be extended in all directions to find the angle between the subject motion relative to the film plane. In calculating image blur, the cosine of the angle between the film plane and the subject motion is used.

Parallax error comes into account when (1) the film plane is not parallel to the subject motion, and (2) when the subject is offset some distance from a calibrated background used to measure velocity. The subject appears to move at a different rate because of the offset and the angle from which the motion is recorded. Figure 6 shows parallax error and the film plane of a camera.

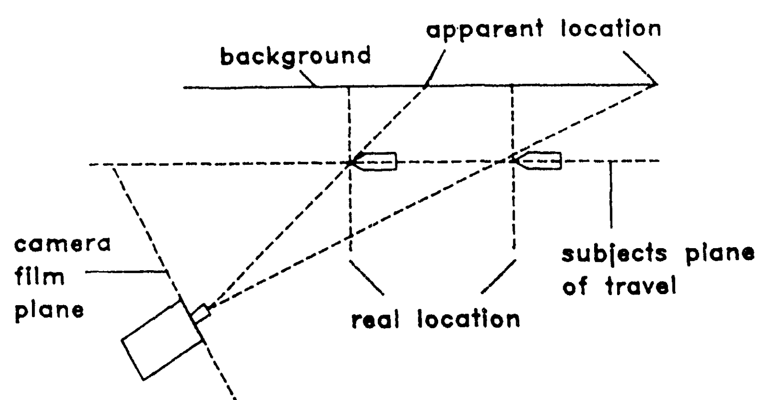

Figure 6. Parallax error and camera film plane.

Parallax error can be factored out if the camera angle and the distance between the subject and background are known. The best way to eliminate parallax error is to have the film plane parallel to the subject motion. Mirrors are sometimes used to move the film plane so that it is parallel to the motion when the camera cannot be set in the appropriate position.

Parallax can also be used to reduce image blur. By looking at movement at an angle, the apparent motion is faster than the actual motion, but image blur is less. This effect can be used to reduce image blur, but the other image blur factors should be adjusted first, to keep the blur acceptable. Using this effect brings in a number of additional factors that must be calculated to accurately reduce the data.

Frame Rate

This parameter is dictated by the speed of the event. Multiple pictures of an event are needed to determine the velocity of an object. If the camera frame rate is too low, the event can be missed.

The camera frame rate can be determined by using two of the same parameters used for calculating image blur: field of view and subject velocity. The other piece of information needed is the number of pictures wanted of the event. The time it takes for the subject to move through the field of view is calculated from the equation:

$$\text{Time} = \text{Distance}/\text{Velocity}.$$

Time is used in the next equation to calculate the frame rate. This equation requires input from the customer regarding the number of pictures wanted of the event.

$$\text{Frame Rate} = \text{Number of Pictures}/\text{Time}.$$

For an object moving 5000 feet/second, with a field of view of 2 feet, the time would be

$$0.0004 = 2/5000$$

or 0.0004 second. If ten pictures are wanted when the subject is in the field of view, the equation becomes

$$25{,}000 = 10/0.0004.$$

The camera has to run at 25,000 frames per second to obtain ten pictures of the event with that given field of view.

The frame rate calculated using this equation does not take image blur into consideration. This will be explained more fully in the next section.

Generally, as the frame rate increases, image blur decreases, when all other factors remain the same.

Calculating Image Blur

The acceptable limit for image blur is 0.002 inch. As the image blur increases, blur becomes noticeable, and quantitative measurements from the photographic data become questionable.

All of the factors mentioned earlier are used in calculating image blur. The following list shows the variables used as well as the units of measure used in this paper.

- b = image blur in inches, preferably ≤ 0.002 inch.
- d = exposure duration in seconds.
- S = subject velocity in inches per second.
- ϕ = angle between direction of motion and film plane in degrees.
- w = film frame width in inches.
- W = field of view in inches.
- F = frame rate in frames per second.
- F_{min} = minimum recommended picture-taking frequency.
- p = shutter constant.

As with all mathematical calculations, the units of measure must be the same.

Image blur is calculated with the basic formula:

$$b = \frac{d\,w\,S\cos\phi}{W}\,. \tag{1}$$

This equation uses exposure duration directly. The following equation substitutes the shutter factor and camera frame rate for the exposure duration:

$$b = \frac{p\,w\,S\cos\phi}{W\,F}\,. \tag{2}$$

The minimum recommended picture-taking frequency is calculated with the following equation:

$$F_{min} = \frac{p\,w\,S\cos\phi}{W\,b}\,. \tag{3}$$

This equation includes the parameter for image blur, so the minimum frame rate calculated using this equation results in a frame rate with acceptable image blur.

Equation (1) is used to show how image blur is calculated using the parameters from the photos in Figures 1 and 2. A 4x5 camera was set up with a 135mm lens at a distance of 80 feet from the traffic. The field of view worked out to be 5 x 80/5.3 = 75.5 feet (field of view equation).

The parameters used for the photo in Figure 1:

$d = 0.001$ second.
$S = 15$ mph, or 264 inches per second.
$\phi = 0$ degree, cosine = 1.
$w = 5$ inches.
$W = 75.5$ feet, or 906 inches.

Substituting the numbers for the variables, the equation becomes

$$b = \frac{0.001 \times 5 \times 264 \times 1}{906}.$$

The blur for the Figure 1 photo is 0.00146 inch.

The exposure duration was the only parameter changed for the photo in Figure 2. That was changed to 0.004 second. Substituting the numbers in this equation:

$$b = \frac{0.004 \times 5 \times 264 \times 1}{906}.$$

The blur for the Figure 2 photo works out to be 0.00583 inch. Making accurate measurements of the vehicle in this photograph would be difficult.

Different parameters are used for Equation (3). A bullet is moving at 1000 feet/second. A 16mm camera is used with a frame height of 0.296 inch and a shutter factor of 0.2. The camera's field of view is 10 feet with the subject moving parallel to the film plane. Using these factors, the minimum frame rate can be calculated:

$$F_{min} = \frac{0.2 \times 0.296 \times 12000 \times 1}{120 \times 0.002}.$$

The minimum frame rate using these parameters works out to 2960 frames per second. A higher frame rate would add more pictures of the bullets' travel on the film, but it would not appreciably cut down on image blur. (The frame rate would have to be doubled to halve the image blur.)

Using the same parameters with a 35mm camera, the equation becomes:

$$F_{min} = \frac{0.2 \times 0.995 \times 12000 \times 1}{120 \times 0.002}.$$

The minimum frame rate works out to be 9950, using the 35mm format. The reason the frame rate must be higher is because of the larger film format.

Image blur should be kept as close to or below 0.002 inch for data analysis. Below that figure improves the image somewhat but the improvement is minimal. As mentioned before, meeting with the customer plays a significant role in the final product.

Summary

Many factors are involved in calculating image blur. Some are set by the customer, whereas others can be adjusted by the photo technician to improve the image quality. Information shared between the photo instrumentation technician and the customer leads to better data collection. A blurred image may show some information, but specific details may be lost.

Image blur is just one of the factors in covering a test photographically; film selection, lighting, and camera start times, among others, must also be considered. But adjusting the parameters associated with image blur can really make a picture worth a thousand words.

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