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7.2 A DISCUSSION OF IMAGE SHARPNESS*

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There has been a great deal of work done on image sharpening, image filtering and related areas. It is a very large field of activity with hundreds of references which you could site in this area. The image sharpness problem can be perceived in terms of the block diagram in Figure 1. Basically a scene is viewed by a sensor, and the sensor has some sort of function which is a non-point observing function. It's a function that gathers energy from some region around a point in the scene. That energy is integrated and is contributed to each point or each sample that is taken of the scene. The samples become the pixels, and the pixels are assembled together into the digital image. Each one has some blurr or some of what is called the point's spread function creating the value of information or data that you see in each pixel. Then the sensor and electronic part of the system acts on that signal out of the sensor and perhaps adds more blurring, more loss of resolution to the system. Finally, sampling and quantization of the data produce their effects. You sample the signal at some rate and create the ditigal image from that. The sampling or digitizing process puts the continuous voltage or whatever you have into a number of discrete binary levels, and you have another error introduced there.

After quantization you end up with the digital array of numbers known as the remote sensing image. It should be noted that the point spread function of the atmosphere is something in addition that causes blurring in the image at the point the sensor sees it.

The terminology of the imaging process often creates confusion. Table 1 summarizes the definitions frequently used. The only term or function that I feel comfortable with is the point spread function, the function which describes what an infinitely small source in the scene would look like in the image. The image is spread by the optics and by the other effects in these systems to produce the final image. How that is affected by the system is what we call the point spread function.

The point spread function is a two-dimensional function describing how a point is blurred in the scene. The IFOV we take as a number; a single number telling you what the resolution or size of the point spread function is. That can be any functional derivation of the PSF and we like to use the gaussian point spread function due to the mathematical ease of applying it, and we feel it relatively well expresses the imaging system. Effective field of view and resolution field of view is something to be discussed in the panels later in trying to define what those mean. They describe the imaging aperture associated with the imaging process.

The point spread function is what we use to describe what's going on in the imaging process and that can include the filter-like effects of the sensor, actual optical effects, and perhaps the atmospheric effects also. Right along with that is a function called the modulation transfer function which is the Fourier transform of the point spread function (Figure 2). It is the frequency domain representation of the blur properties of your system. That is

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what you seek to find for an imaging system. It's what defines the sharpness, what will result in the particular image sharpness that you have, and the problem then is to figure out what to do about that. Is it a satisfactory characteristic for your system? If it isn't, what do you do to compensate for the effects of that? How do you sharpen the image that you have other than building a whole new sensor that has a sharper optical characteristic? Can you mathematically process the imagery to improve the sharpness?

Some other terms are shown in Figure 3; these include the edge spread function, the one-dimensional version of the point spread function which tells you how the response will look going over an edge in one direction in an image. Then there is the term resolution, defined as the number of black and white square bars that can be discerned from a particular unit distance in an image. Accoutance is another term I'm not familiar with but related to the slope of the edge spread function. We have not used that in any of our work.

Defining the point spread function or the sharpness of an image is done after the system is built and in the platform. That is a hard job; you normally do that in the laboratory by special test panels, scenes that you use to evaluate the system. Once it's in orbit, trying to check it out you need to to find optics in the scene that will simulate line or point sources so that you can measure what those blurr function are. You usually assume separable point spread functions so that lines in one direction or another can be used to estimate that function. If it's not symmetric, you have a problem like the computer-aided tomography problem where you're trying to image the solid by using projections and you have to define lines at many different directions and use techniques of tomography to try and estimate the point spread function.

One can look at an image as a one-dimensional sequence of stair-step changes that is convolved with the point spread function in the imaging process as the sensor scans across the scene and produces a smooth or blurred version of the scene (Figure 4). The idea is to try and get back the original image or original signal. The output is the convolution of h, the point spread function and the image called x there. It would appear that a simple division in the frequency domain takes the Fourier transform of these functions. This becomes a simple division to remove the effect of h and you would get x back. But it doesn't work out that easily. There are noise effects, and there's the problem of zero's of the point spread function in the frequency domain causing discontinous points in the solution. And it turns out to be a rather tricky problem to try and do this. And a great deal of literature is in existence on attacking this problem.

There are problems with the inverse in that as 1/h(f) goes to zero, you have singularities, you find ghosts can be created, artifacts in the restored image due to the combination of these problems of taking the inverse, noise effects and quantization. Quantization can amplify the effects of noise and there is more to that problem than initially meets the eye. Therefore, we form a model that describes the way you want to take a look at the problem and set up the mathematical representation of the model, and then define the means of solving for the filter you want which would be here.

Background References or Sharpness

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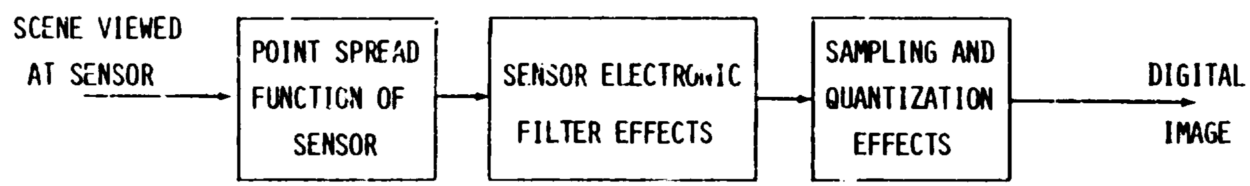


<u>OTHER FACTORS</u>

POINT SPREAD FUNCTION OF ATMOSPHERE

ATMOSPHERIC SCATTERING

Figure 1. Factors Related to Sharpness

TABLE 1.

TERMINOLOGY OF THE IMAGING APERTURE

IFOV -- INSTANTANEOUS FIELD OF VIEW

APERTURE SHADE OF SENSOR OPTICS

PSF -- POINT SPREAD FUNCTION

OVERALL TRANSFER FUNCTION DUE TO ALL SENSOR AND ENVIRONMENTAL FACTORS

EFOV -- EFFECTIVE FIELD OF VIEW

RFOV -- RESOLUTION FIELD OF VIEW

- POINT SPREAD FUNCTION -- H(X,Y). THE FUNCTION WHICH EXPRESSES THE OUTPUT OF AN IMAGING SYSTEM FOR A POINT SOURCE INPUT.

- MODULATION TRANSFER FUNCTION -- M(U,V). THE FUNCTION WHICH EXPRESSES THE FREQUENCY RESPONSE OF THE IMAGING SYSTEM. IT IS THE MAGNITUDE OF THE FOURIER TRANSFORM OF H(X,Y). THE TRANSFORM IS CALLED THE TRANSFER FUNCTION:

$$H(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(x,y)\, e^{-j2\Pi(ux + vy)}\,dx\,dy$$

$$= \left|H(u,v)\right| e^{j\Phi(u,v)}$$

$$\text{MTF} \longrightarrow M(u,v) = \left|H(u,v)\right|$$

THE PHASE TRANSFER FUNCTION IS $\Phi(u,v)$

Figure 2. Measures of Image Spatial Quality

- Edge Response -- Expresses response to step inputs. Expressed by Edge Spread Function (ESF).

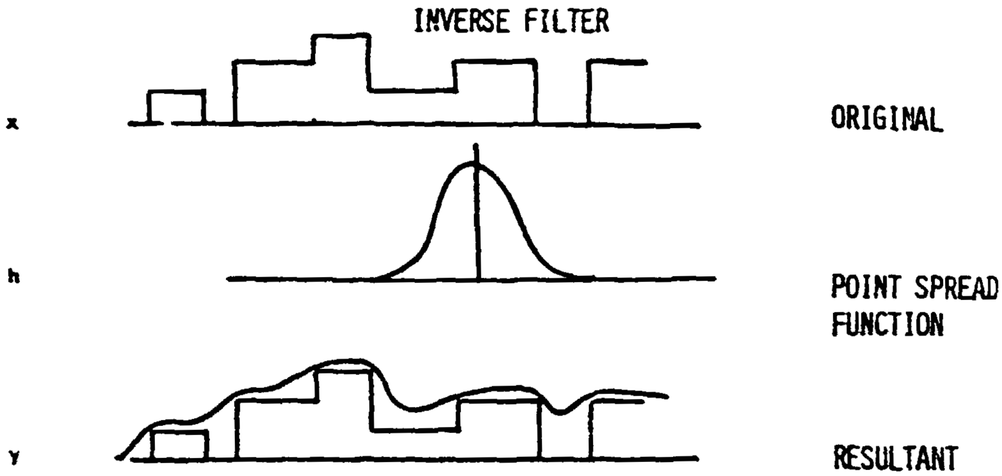
- Resolution -- Classical definition is minimum width of black and white bars which can be distinguished. Stated in terms of line pair width or line pairs per unit distance. This is qualitative definition.

  Another definition is the half amplitude width of the PSF.

- Acutance -- A measure of edge sharpness in output image. Can be expressed as the average slope of the Edge Spread Function.

$$\frac{1}{H_E(B)-H_E(A)} \int_A^B \left(\frac{D\,H_E}{DY} \right)^2 DY$$

Figure 3. Edge Spread Function: One-Dimensional Version of PSF



CAN WE RECOVER ORIGINAL?

$$y = h * x$$

$$Y = H \cdot X$$

$$X = \frac{Y}{H}$$

$$x = y * h^{-1}$$

$$h^{-1} = \mathcal{F}^{-1}\left\{\frac{1}{H}\right\}$$

Figure 4. Inverse Filter Concepts