MEASURING MODULATION TRANSFER FUNCTION

Introduction

The modulation transfer function (MTF) of an imaging system is a measure of the response of system to signals as a function of spatial frequency. It is a measure of the resolution of the imaging device, which is how well an imaging device can measure fine detail. The MTF is dependent both on the lens and the sensor array. If the zoom or focus changes so will the MTF. The finer the size of the CCD or CMOS pixels, the higher the MTF. However even if you have a good lens but a coarse CCD, or a poorly designed lens on a 24megapixel CCD you can still get poor resolution. In designing cameras for a satellite MTF measurement is one of the important tests done. In this activity we use the slanted edge technique to measure the MTFs of different cameras.

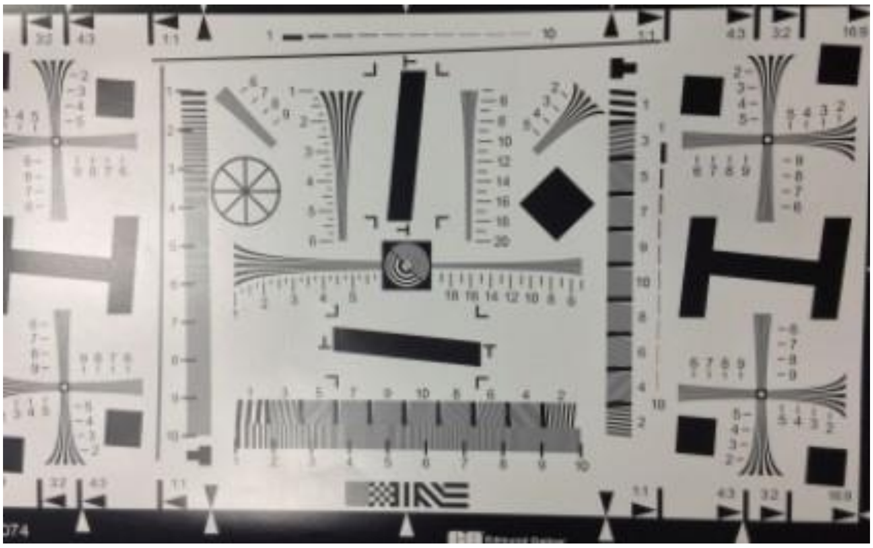
Technically, the MTF is the Fourier Transform of the point spread function of the system. Since FT of a function is complex, the MTF should have magnitude and phase response as a function of spatial frequency, similar to transfer functions of control systems. However, it is often sufficient to look at the magnitude response to get a measure of the resolution of the system.

There are two ways to measure the MTF. One is to use a slanted edge image. The derivative of an edge profile is the point spread function of the system. The Fourier Transform of several edge profile derivatives are obtained and the modulus or magnitude(using abs()) is obtained. Normalizing each to 1.0 as maximum and averaging them gives you the MTF profile of the imaging device.

Spatial frequency is expressed as line pair per mm (lp/mm) . A line pair is one white and black band. The distance from the edge of the white to the black band is the length of a line pair. Its inverse is its spatial frequence. Resolution targets have accurate prints of line pairs at varying spatial frequency. Thus, a quick estimate of the resolution of your camera is to image a resolution target line pair set and observe where the line pairs start to become undistinct.

MTF is also related to the Contrast function where contrast is $\frac{I_{max}-I_{min}}{I_{max}+I_{min}}$ where I_{max} and I_{min} are the highest and lowest grayscale of the image of a line pair. Plotting contrast as a function of lp/mm gives the contrast transfer function.

Alternatively, one can quickly inspect the contrast of an imaging device using resolution target charts such as the I3A/ISO 12233 Resolution Test Chart (shown below) or the USAF 1951 Resolution Target.



For more information on MTF read [Introduction to Modulation Transfer Function | Edmund Optics] [1].

Materials

Camera, I3A/ISO Resolution Test Chart, any camera for testing.

Procedure

1. Setup your camera on a stand and place the Resolution Test Chart at a fixed distance away from it. Make sure that the plane of the camera sensor and slanted edge image are parallel to one another.
2. Capture several images of the test chart using your camera under test. If your camera can do burst, then use it. Take the average of the images so that noise on the flat parts are minimized. If your camera does not have burst, make sure you register or align your images accurately before averaging.
3. Open the slanted edge image using your scientific software. Get the intensity profiles of a line crossing the edge (LE).
4. Get the derivative of this line (d(LE)/dx) and then get the Fourier transform of this derivative, that is, get FFT[d(LE)/dx].
5. Get the modulus of the FFT of the derivative abs (FFT[d(LE)/dx]) and keep only the positive half. Make sure the scale of the Fourier Transform plot is properly calibrated using the scale bar from your image. The spatial frequency units should be in cycles / mm or line pair (lp)/mm.
6. Repeat Steps 3 to 5 for several lines across the edge and get their average.
7. Normalize the average of the MTF to 1.0. Where the MTF is at 0.5 is the resolution of your camera in lp/mm. The higher the lp/mm the more your camera can resolve fine detail.
8. Observe the line pair images. Note at which line pair your camera loses detail or the phase of the line pairs flip.

Reference

[1] https://www.edmundoptics.com/knowledge-center/application-notes/optics/introduction-to-modulation-transfer-function/