http://dx.doi.org/10.21611/qirt.1992.009

The MFT of thermal imaging cameras - its relevance and measurement

by T.L WILLIAMS

Sira Ltd, CHISLEHURST, Kent, UK

Abstract

The use of MTF (modulation transfer function) for correcting thermal measurements is discussed and an equipment for measuring the MTF of thermal cameras described.

1. Introduction

When a thermal imaging camera is used for measuring temperature or temperature difference, it is important to be aware of the influence of the MTF of the camera on the accuracy of the measurement.

In simple terms, the influence of the MTF is to make the temperature difference between a small object and its background appear to be less than it actually is.

This paper discusses the relationship between MTF and these temperature errors and the advantage of using MTF, rather than other criteria, for evaluating it. The paper also describes suitable MTF measurement techniques, referring briefly to the special problem of staring array cameras.

2. Slit response function

A traditional method of obtaining quantitative information about the effect of target size is by measuring what is sometimes referred to as the SRF (slit response function).

For this measurement a slit, whose width can be varied, is placed in front of a plate which is at a suitable uniform temperature (see *figure 1*). The apparent temperature difference, between the plate and the slit jaws, is measured as a function of the angular width of the slit. If ΔTa is the measured temperature difference for a very wide slit and $\Delta Tm(\alpha)$ is the measured temperature for a slit of width α, then the SRF is given by:

$$SRF(\alpha) = \Delta Tm(\alpha)/\Delta Ta \qquad (1)$$

A typical SRF is shown in *figure 2*.

Strictly speaking the SRF curve can only be applied when the object is also a slit on a uniform background. When, as is more often the case, the object is 2-dimensional (e.g. a rectangular or circular shape) the SRF curve will give incorrect results. In such a situation a more generally applicable function is required to characterise this aspect of imager performance.

3. Modulation transfer function

The MTF (or more correctly the OTF (optical transfer function), i.e. the MTF and the PTF (phase transfer function)) in principle provides all the information required to predict the errors in a measurement of the temperature distribution, arising from a known temperature distribution in the external scene.

The procedure for calculating the effect of the OTF/MTF on the measured temperature of an object is as follows:

If the 2-dimensional OTF of the thermal imaging camera is given by $OTFcam(u,v)$ and the Fourier transform of the object by $FTobj(u,v)$, then the Fourier transform of the image is given by:

$$FTimg(u,v) = OTFcam(u,v).FTobj(u,v) \qquad (2)$$

so that:

$$FTobj(u,v) = FTimg(u,v)/OTFcam(u,v) \qquad (3)$$

http://dx.doi.org/10.21611/qirt.1992.009

The original temperature distribution can in principle be retrieved by taking the inverse Fourier transform of *FTobj(u,v)*, however this is only possible over the spatial frequency range for which *OTFcam(u,v)* is non zero (i.e. up to the cut-off frequency). Image restoration using the known OTF of imaging systems is a well established procedure in many fields, and it may not be long before software for processing thermal images in this way becomes standard.

For determining temperature correction factors for simple 1-dimensional or 2-dimensional objects one can use the well known relationship:

$$f(0,0) = \iint_{-\infty}^{\infty} F(u,v)\, dudv \qquad (4)$$

where $f(0,0)$ is the value of $f(x,y)$ at the position with coordinates $x=0, y=0$ and $F(u,v)$ is the Fourier transform of $f(x,y)$.

Using equation (4) the ratio of the effective peak temperature difference in the image to that in the original object is given by:

$$\Delta Timg/\Delta Tobj = \iint_{-\infty}^{\infty} \mathrm{F}Timg(u,v).du.dv / \iint_{-\infty}^{\infty} \mathrm{F}Tobj(u,v).du.dv =$$

$$\iint_{-\infty}^{\infty} OTFcam(u,v).FTobj(u,v).du.dv / \iint_{-\infty}^{\infty} \mathrm{F}Tobj(u,v).du.dv \qquad (5)$$

where we assume that the peak temperature occurs at the coordinates $x=0$, $y=0$

For a slit (which is a one dimensional object) we have $FTobj(u) = \sin(\pi.a.u)/\pi.a.u$, where a is the angular width of the slit and u is spatial frequency in angular units.
Using equation (5), we have:

$$\Delta/Timg/\Delta Tobj =$$

$$\int_{-\infty}^{\infty} OTFcam(u).[\sin(\pi.a.u)/\pi.a.u]du / \int_{-\infty}^{\infty} [\sin(\pi.a.u)/\pi.a.u]du \qquad (6)$$

Figure 3(a) shows a typical MTF curve for an industrial thermal imager, whilst *Figure 3(b)* shows values of $\Delta Timg/\Delta Tobj$ plotted against the angular width of the target, calculated using equation (6).

Figure 3(b) also shows a plot of $\Delta Timg/\Delta Tobj$ as a function of a for a square object. The assumption has been made that the MTF is the same along both axes.

4. Measurement of OTF/MTF of thermal imager cameras

The OTF/MTF of a camera can be measured either off the display, or from the video signal output of the camera. In the former case the effect of the MTF of the display is included in the measurement, in the latter case it is not. Although temperature information about a scene usually appears on the display, the actual process of temperature measurement is done on the video signal. It is therefore more appropriate to measure the OTF/MTF of the camera from the video signal and this paper deals mainly with such techniques.

Figure 4 illustrates an arrangement for measuring the OTF/MTF of thermal imaging cameras, which has been developed over several years by the author and colleagues [1, 2].

The test target is a narrow slit placed in front of a uniform thermal source whose temperature difference relative to the slit can be controlled.

http://dx.doi.org/10.21611/qirt.1992.009

The test target is shown at the focus of a collimator in *figure 4*, the purpose of this being to make the slit appear to be at infinity. If measurements are required in different parts of the field of view of the camera, the latter can be mounted on a goniometer table giving angular movement about one or two axes. Measurements may be made without a collimator (i.e. with the camera viewing the test target directly) provided the camera can focus down to a convenient distance.

It is convenient to use off-axis paraboloid mirror collimators for testing thermal imagers since they do not suffer from chromatic aberration and can be used over a wide range of wavelengths covering the visible and the thermal IR. Refracting collimators may also be used, but are usually restricted to working over a limited wavelength range (e.g. the 3 to 5 μm or the 8 to 12 μm bands).

The video signal from the camera goes to both a *digital transient recorder* and to a *line selector*. The first of these is able to capture one video line (or part of a video line) at a very high sampling rate, digitise it and transmit it at a controlled rate to the computer. The purpose of the line selector is to provide the recorder with a trigger pulse at the start of an appropriate video line (i.e. one which contains the signal generated by the slit target). The transient recorder has a signal sampling rate of up to 100 M samples/s and a storage capacity of up to 1024 samples and is therefore suitable for testing devices with video bandwidths of 10 MHz or more.

The computer and transient recorder communicate via an IEEE 488 interface which allows the computer to control such variables as the sampling rate, the time delay between the start of a video line and the start of sampling, etc., as well as controlling the transmission of the measured data between the two.

The equipment functions by measuring the LSF (line spread function) and then doing a discrete Fourier transform to obtain the MTF.

The software which processed the signal has several features which are necessary when measuring MTF from a video signal. These are the followings one's.

- The ability to average the result of measurements of the LSF over a number of video frames. Averaging is important if repeatable MTF measurements are to be obtained in the presence of noise.

- A facility for removing (if required) the effects of *jitter* when averaging several frames. Jitter is the small shifts in position of the image along the video line from one frame to the next.

Jitter removal is done by determining the mean centre of each LSF and applying appropriate shifts before averaging, so that all the centres coincide.

- A facility to remove *flicker*, i.e. the small vertical shifts in the video base-level from one frame to the next.

The correction is applied after the process of averaging together measurements from several frames. It consists of generating a new base level by finding the mean signal level at the two extremes of the LSF and joining them by a straight line. This also serves to remove a uniform background pedestals or one with a linear slope.

The software quite separately allows a non-uniform background pedestal to be measured and removed.

- The SiTF (signal transfer function) can be measured and plotted in order to check that the camera is operating in its linear range.

The software also includes options for making measurements of other performance parameters. Some of the most important are:

- noise related parameters including RMS noise, noise power spectrum (NPS) and noise equivalent temperature difference (NETD) [1];

http://dx.doi.org/10.21611/qirt.1992.009

- from values of MTF, NETD and NPS the software can compute a curve for the minimum resolvable temperature difference (MRTD) and the minimum detectable temperature difference (MDTD) [3]; These can include the effect of the MTF of the display.

The discussion so far has concerned MTF measurements made with the object slit perpendicular to the TV scan lines. This is usually referred to as the LSF/MTF in the horizontal direction. Measurements are also sometimes required in the other direction, i.e. with the slit parallel to the lines. This can be done by using a line-selector which can be controlled by the computer. The measurement procedure is for the computer to sequentially select a number of video lines, covering the vertical extent of the image of a horizontal slit (i.e. the full LSF). The signal from the appropriate portion of each video line provides one point on the LSF curve.

Strictly speaking the device under test produces a sampled image in this direction and the LSF and MTF measured in this way will depend on the exact position of the slit image with respect to the TV scan lines. More appropriate measurement techniques are described in [4].

An example of an LSF curve and the associated MTF curve, measured using the equipment described above is shown in *figure 5*.

5. MTF of staring array imagers

Several thermal imagers are now available which do not use a scanning mechanism but simply have a large array of detectors, where each detector element generates one image pixel. Examples of these are the current range of imagers using PtSi or InSb detector arrays.

A problem arises in measuring the MTF of these imagers since they are sampled systems and the measured MTF will depend on the exact position of the image of the test object (e.g. the slit) relative to the detector elements.

The equipment and software described above has been modified to allow measurement of a unique MTF to be made on such thermal imagers. Additional hardware is required in the form of one or two motorised stages to allow the slit test object to be scanned across the detector array.

A full description of the technique will be found in [4].

REFERENCES

[1] WILLIAMS (T.L.), DAVIDSON (N.T.) and WOCIAL (S.), *Objective measurement of MRTD*. SPIE, Vol. 916, 1988, p. 92-98.

[2] WILLIAMS (T.L.) and DAVIDSON (N.T.), *Recent advances in testing of thermal imagers*. SPIE, Vol. 1110, 1989, p. 220-231.

[3] WILLIAMS (T.L.), *Objective MRTD measurement - an update*. SPIE, Vol. 1320, 1990, p. 420-430.

[4] WILLIAMS (T.L.) and DAVIDSON (N.T.), *Measurement of the MTF of IR staring array imaging systems*. SPIE, Vol. 1689, 1992.

http://dx.doi.org/10.21611/qirt.1992.009

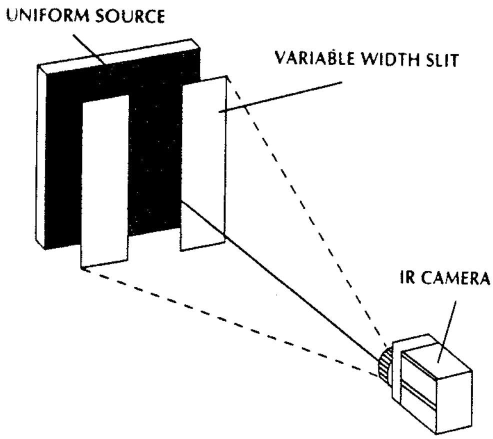


Fig. 1. - SRF measurement

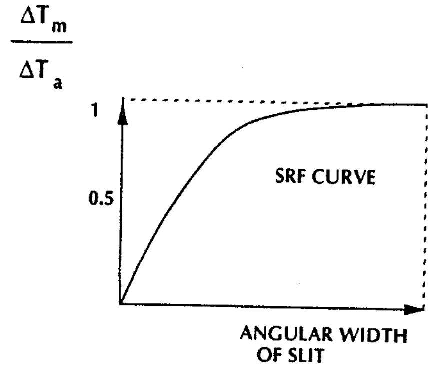


Fig. 2. - SRF curve

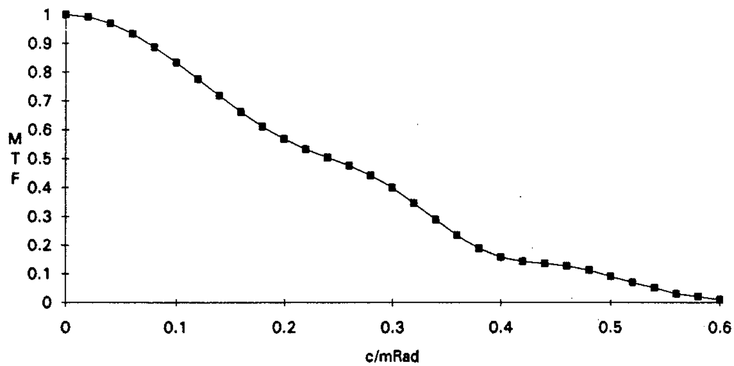


Fig. 3(a). - MTF of thermal camera

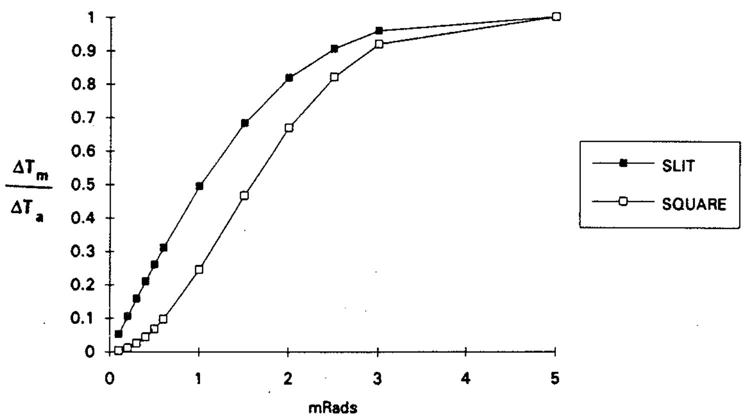


Fig. 3(b). - Temperature correction calculated from MTF

http://dx.doi.org/10.21611/qirt.1992.009

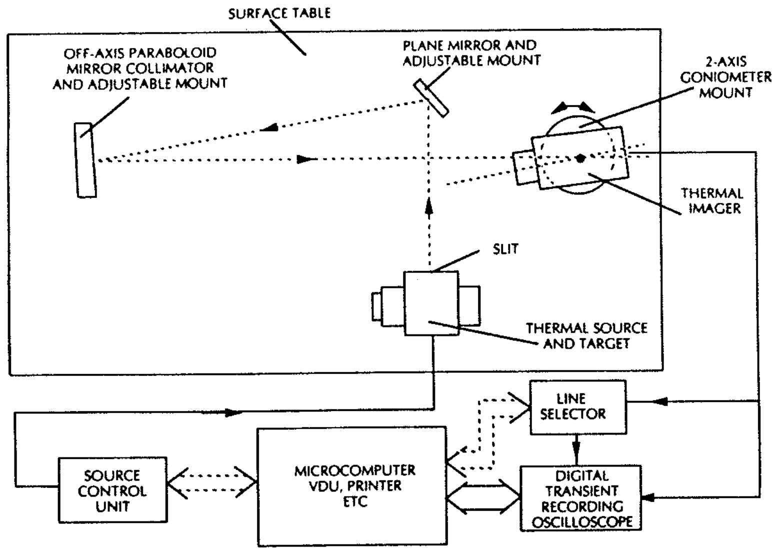
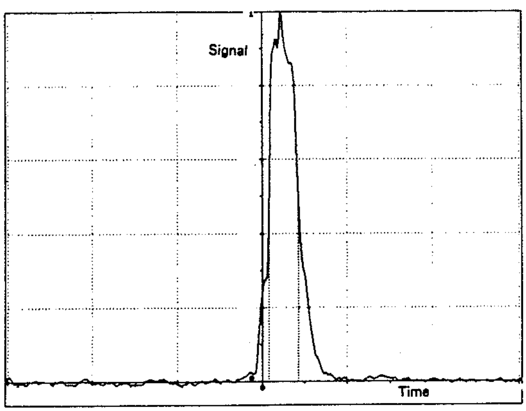


Fig. 4. - Thermal imager OTF/MTF test facility

LSF



MTF

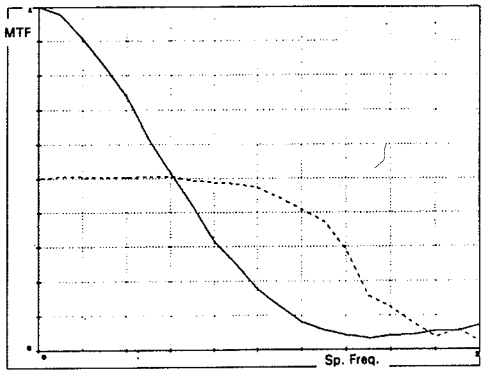


Fig. 5. - LSF and MTF curves for a thermal imager