Does imaging system MTF affects classification accuracy?

Abstract

Application scientists selecting remote sensing data from an electro-optical camera for a specific study generally consider the spatial resolution and the spectral bands. Usually, the application scientist is not aware of other sensor characteristics that could have a bearing on the accuracy of analysis he is doing. This paper highlights how the modulation transfer function affects the classification accuracy.

Key words: - Remote sensing, MTF, Classification, Contrast, Spatial frequency

1. Inroduction

Remote sensing application scientists can currently access data from various sources that are operating earth observation system. However, earth observation camera specifications are not well understood by the end-users, so that they can choose data from the best/optimum sensors for their specific application. Even the terminologies used to characterize the sensor are not unambiguously defined. Joseph 2020 has highlighted these issues and made some specific recommendations to have a standard set of specifications to be provided by all electro-optical camera manufacturers. Application scientists selecting remote sensing data from an electro-optical camera for a specific study generally consider the spatial resolution and the spectral bands. Usually, the application scientist is not aware of other sensor characteristics that could have a bearing on the accuracy of analysis he is doing. This paper highlights how the modulation transfer function affects the classification accuracy.

1. Modulation Transfer Function

How does one distinguishes an object from its surrounding? In visual perception one distinguishes two objects only if there is a difference in the radiance (brightness)/colour between the target of interest and the surroundings. This difference is called contrast; that is the difference in the radiance that makes an object distinguishable from its surroundings. To understand the contrast consider a target with a series of equally spaced, alternating white and dark bars as shown in figure 1(a). The radiance emanating from the bars is shown in figure 1(b). If Lmax and Lmin corresponds to the radiance from the white and black pixels respectively then contrast is given by

$$Contrast = L_{max} - L_{min}$$

To compare targets with different illumination levels the contrast is normalized with total illumination and the term is called contrast modulation C_M .

$$C_M = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

The contrast modulation is always positive with values ranging between zero and one.

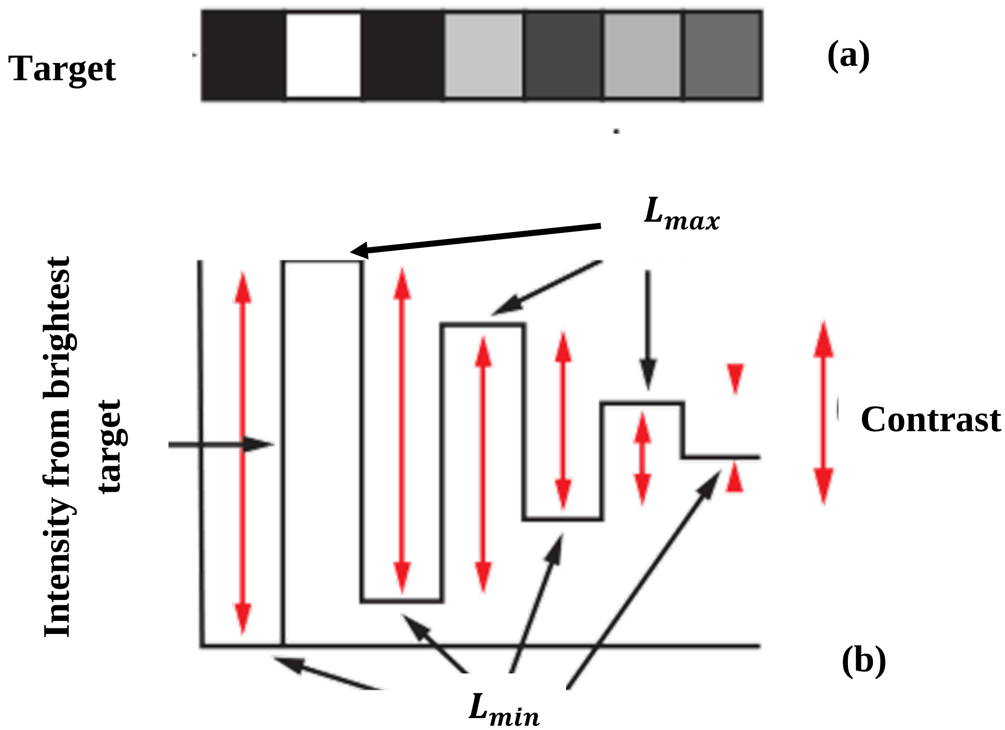

Figure.1.Concept of Contrast (a) Target (b) The intensity distribution

Adapted from https://www.edmundoptics.com/knowledge-center/application-notes/optics/introduction-to-modulation-transfer-function/

In visual perception one can distinguish two objects only if there is a brightness/colour difference between them, which is referred to as contrast. Greater the contrast it is easier to distinguish; that is why a white ball in a lawn can be easily discriminated compared to a green ball in the same place. There has to be a minimum contrast at the eye of the observer, below which an object cannot be detected, called contrast threshold. There is a similar concept in the digital analysis of an image. In a hypothetical ideal system with no noise, in principle one can distinguish a difference of one DN value. However in an actual camera system the difference in DN value that can be unambiguously distinguished will depend on the system noise, that is, the contrast in the image has to be large enough to overcome the random noise. For the present discussion the details of this is not considered. The interested readers can refer to Joseph 2020.

In summary, in the process of imaging the camera system reduces the contrast of the object in the recorded data. This reduction in contrast from object space to image space is represented by Modulation Transfer Function (MTF). That is

$$MTF = \frac{Contrast\ modulation\ in\ image\ space}{Contrast\ modulation\ in\ object\ space}$$

Figure 2. Schematics showing the contrast reduction in the image compared to the object

Since there has to be a minimum contrast to distinguish an object from it's surrounding, *MTF is a critical performance parameter of the imaging system*. (The MTF of the data product depends on many other factors such as platform jitter, atmosphere, and so on. The MTF in the along-track direction is also affected by the 'smear' produced by the motion of the spacecraft during the integration time.).Figure 2 shows the contrast reduction in the image compared to the object being imaged. From the image one can make two inferences. At the first look, one realizes the boundary between the black and white strips is not as sharp as in the object, which is important when one carries out visual interpretation. The other issue that normally goes un noticed is radiometric fidelity-that is how faithfully the contrast in the object space is represented in the image. For digital classification what is of concern is how this affects the accuracy.

2. MTF and spatial frequency

Since MTF is a function of spatial frequency, we shall first try to understand the concept of spatial frequency. In an image captured by a remote sensing camera the DN value changes depending on how heterogeneous the terrain is. The change of DN value will be frequent over a distance if the terrain contains objects with varying reflection/emission as in imagery over an urban area. While imagery taken over an area containing relatively large patches of uniform surface the DN value changes over a distance will be less frequent (Figure 3). In remote sensing spatial frequency refers to *the frequency of change of DN value per unit distance across an image.*

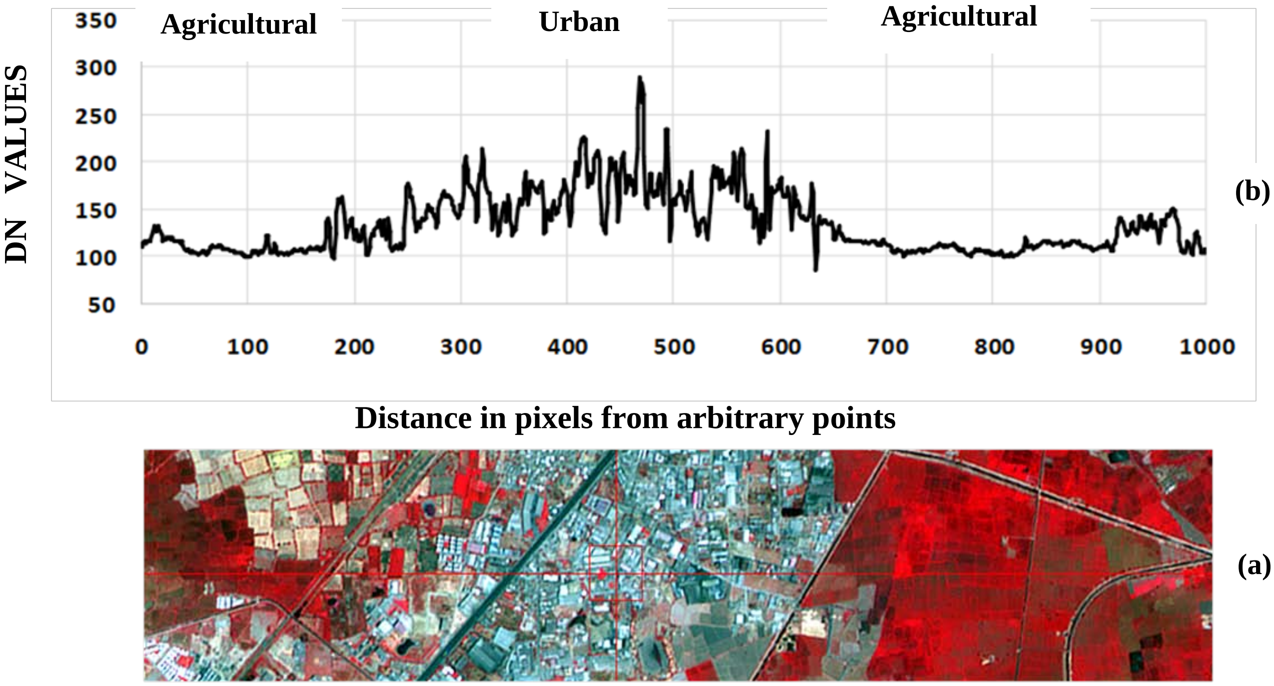

Fig. 3 (a) FCC of Resourcesat-2A LISS-IV data (b) Variability of Green band DN values along a transect

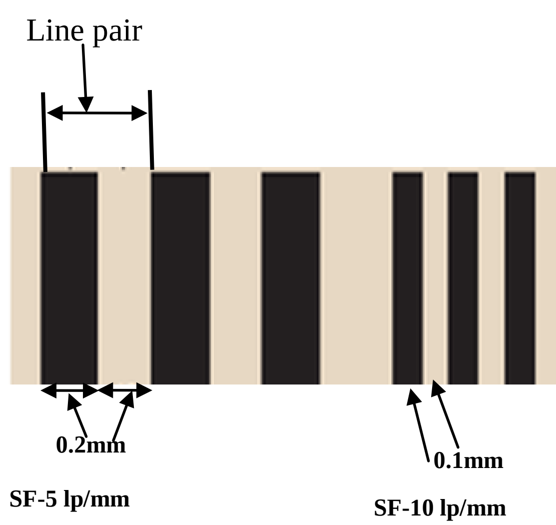

Figure 4. Concept of line pair (lp) and spatial frequency (SF)

Though generally there are no periodic structures in a remote sensing image the concept can be understood by considering an alternating periodic bright and dark target as in figure 4. In sound and in electromagnetic radiation we talk about the intensity variation in cycles per second. Analogous to cycles we have *line pair (lp)* which consists of one dark and one bright target. How often the line pair varies over a distance is called spatial frequency and is specified as line pair per unit distance. The units of the distance will depend on the type of system being dealt with. Normally one refers to spatial frequency with respect to image space and the unit of distance used is mille meter (mm). If we have bright and dark lines of 0, 02 mm each, the line pair has a width of 0.04mm, which corresponds to 25 lp/mm.

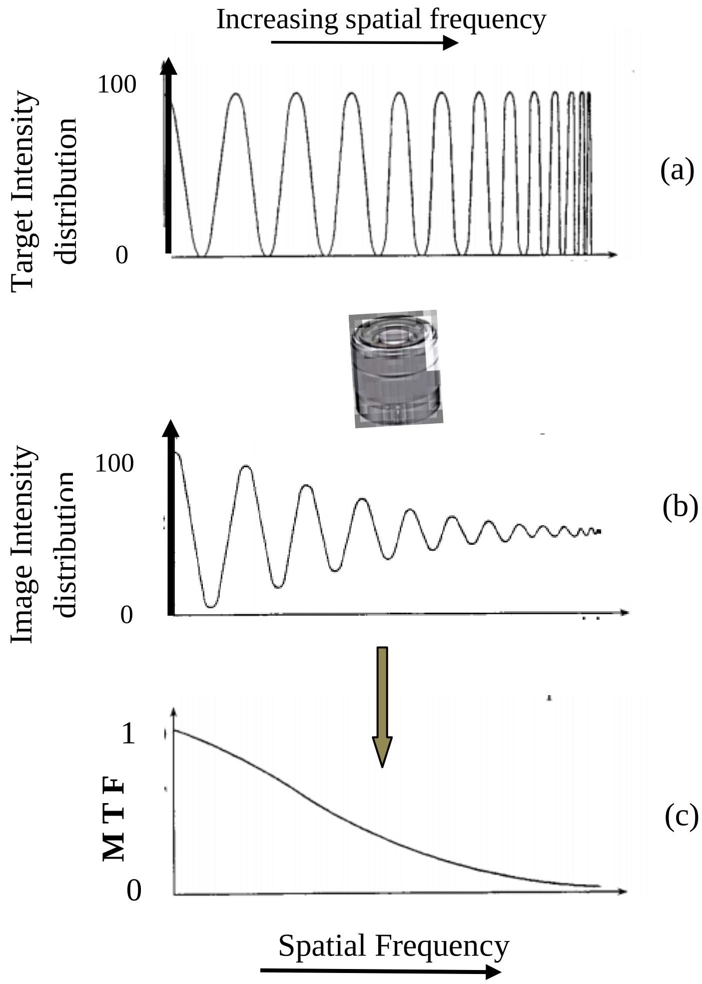

Fig.5 MTF variation with spatial frequency. (a) Target with varying spatial frequency having 100% contrast (b) The image , the contrast reduces as spatial frequency increases. (c) Gives the MTF corresponding to various frequencies.

Figure 5 shows how the MTF varies with spatial frequency. As the spatial frequency increases the contrast reduces (Figure 5b).Thus the imaging system acts as a ‘low pass filter’ – preferentially transmitting low spatial frequency information with minimal reduction in contrast. MTF is represented graphically as a function of spatial frequency with a maximum value of one- i.e. no change in the contrast compared to the object and zero-i.e. the image contrast is zero. In practical terms when analyzing objects much larger than the Instantaneous Geometric Field of View (IGFOV) the effect of system MTF is negligible

3. MTF and radiometric accuracy

One also notices from Figure 2 that the black strip has become ‘less black’ and the white strip ‘less white’. Figure 6 shows the radiance of a target recorded by a remote sensing instrument is dependent on surrounding objects. The target under consideration (Mildewed Barley) when

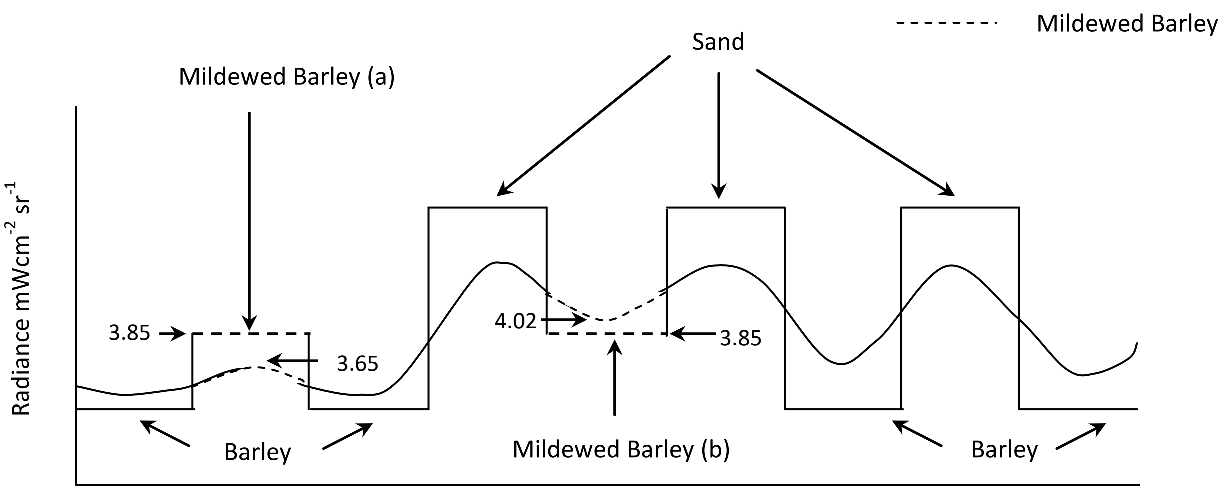

Figure 6. Example showing the MTF effect on radiometric accuracy. The `square wave’ pattern gives the actual radiance from three targets – Barley, mildewed barley (MB) and sand. There are two fields of mildewed barley – one amongst barley (a) and the other amongst sand (b). The ‘sine curve’ gives the radiance when the scene radiation is measured through a radiometer. The numbers represent the radiance values. The MTF of the radiometer modifies the radiance value. Mildewed barley both (a) and (b) have the same radiance (3.85). But due to the radiometer MTF, the MB at ‘a’ shows a lower value (3.6), while MB at ‘b’ shows a higher value (4.02). In the case of ‘b’ the higher radiance from the sand spills over to MB, while the reverse happens in the case ‘a’. Thus the redistribution of the radiance due to MTF can give erroneous radiance value compared to actual field value *(Adapted from Norwood, V.T.1974. Balance between resolution and signal-to-noise ratio in scanner design for earth resources systems. Proc. of SPIE 51: 37-42.).*

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surrounded by objects with higher radiance, then the remote sensing instrument measured radiance of the target is higher than the actual target radiance. Here, the higher radiance from the surrounding ‘spills over’ to the target under consideration. The reverse can happen if the surrounding has a lower value compared to the target radiance. Thus, the remote sensor measures *apparent* radiance depending on the surroundings. Hence the radiance of a target recorded by a remote sensing instrument is dependent on the surrounding objects. That is the radiance recorded

(DN value) in the image is different from the actual radiance emanating from the object. From a radiometric consideration, the effect of MTF is to 'spill' the energy to adjacent targets thereby affecting the radiometric fidelity—that is how well the image preserves the radiance distribution compared to what is in the scene imaged. This affects the classification accuracy when one carries out multispectral classification using per pixel classifier technique such as Maximum Likelihood Classifier.

The above discussions show that the radiometric error produced due to MTF of the imaging system diminishes as the target size increases from the Instantaneous Geometric Field Of View (IGFOV-that is the spatial resolution specified by the sensor manufacturer) and also as the difference between adjacent radiances decreases. To reduce the effect of MTF on classification accuracy due to target size Joseph (2000) introduced the term Radiometrically Accurate IFOV (RAIFOV)- IFOV at which MTF is 0.95. Radiometrically accurate minimum target size is given by RAIFOV projected on to the ground. Targets with dimension larger than this can be considered to have minimum radiometric error introduced due to MTF and hence MTF introduces negligible error in the classification To compare different imaging systems, one can consider RAIFOV as a parameter to determine how large a target must be to ensure that the radiometric errors caused by MTF are less than a specified value.

4. MTF and Classification accuracy.

Once proper bands are selected the classification accuracy depends on several factors such as contribution of boundary pixels, noise contribution, atmospheric effect, radiometric fidelity, and so on. Therefore to separate the contribution due to MTF alone is difficult. To investigate this effect one could consider two different systems having close spatial resolution with similar spectral bands and acquired under similar conditions but having different MTF. Then one could assess the effect of MTF by carrying out classification on an area having fields of the size of a few times the spatial resolution. The one with better MTF should give better classification accuracy. Whereas the classification carried out having a field size larger than RAIFOV there should not be any significant difference between the systems.

The application scientists should consider the MTF of the data they select for analysis. The unfortunate part is that this specification is rarely given by the data providers as part of the specification. The user should demand a minimum set of specifications such as MTF and signal-to-noise ratio (SNR) at a specified reference radiance to be made as part of the material they put out for their product and updated based on post launch assessment.

5. Conclusion

The Modulation Transfer Function (MTF) is an important imaging system parameter which affects the radiometric fidelity of the data generated by a remote sensing instrument. While deciding on to select the data for analysis MTF also should be considered in addition to other sensor parameters such as spatial resolution and spectral band details. More targeted study is required to assess the contribution of MTF on classification accuracy.

References

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