Optics for electronic images

An extremely interesting White Paper by Schneider-Kreuznah engineers, it explains very nicely the limitations of human vision and the optics for digital photography. Exactly the same theory and conclusions can be applied to CCTV cameras. This is the first of two part article.

All illustrations by V.Damjanovski

The role of optics in conventional photography (with film materials) is very well known to professional photographers. They know how to correctly estimate the relative values of exposure, aperture, picture angle, perspective and its control, f stop, picture sharpness, depth of field, etc. The new CCD image storage medium (semiconductor image storage) has attributes that make many professional photographers feel insecure about their use:

- Which of the "old" rules still apply, what has to be re-thought?
- Is the quality of my equipment good enough to work with a digital body?
- Are my lenses suitable for use in digital photography?

To answer these questions, it is helpful to be able to evaluate picture quality, and especially image sharpness, by some repeatable measurement technique that can be documented.

What is "Picture Sharpness"?

Well, as an experienced photographer you will answer: the ability to resolve the finest details.

The measurement for this is a resolution test, consisting of alternating dark and bright bars of the same width and with varying patterns of smaller bars and spaces, such as seen in the following simplified illustration.

Fig. 1 : A Bar Test (Resolution Test)

The measurement for the fineness of structures in this example is the number of black/white line pairs per unit of length, thus for example 5 line pairs per centimeter. This totals 10 lines (black or white) per centimeter. Such a test pattern should be photographed with the highest resolution film possible. Then, by examining the developed film

with a powerful loupe or microscope, count the number of line pairs per unit of length that are just barely recognizable. If we take into account the scale of the image, this then provides a judgment for the picture sharpness of the optics used. Since the picture is usually minified, this limit of resolution on the film is usually expressed in line pairs per millimeter. Note that line pairs per millimeter (lp/mm) is the optics' industry's standard unit for expressing resolution.

Let us now carry out this experiment. The result is shown in Figure 2 on the next page. Our test object is, again, the resolution test pattern from Figure 1. The optics capture this pattern on the film and provide a result, as can be seen in Figure 2 under "picture." As the fineness of the test pattern increases (line pairs per millimeter increases), the picture becomes "flatter and flatter," until the finest structures are barely recognizable, at which point we have reached the limit of resolution.

If we designate the brightness of pure white paper with a value equal to "1" and the darkness of black printer's ink with value equal to "0" then the difference in brightness between light and dark bars becomes smaller and smaller as the number of line pairs increase. This is illustrated in Figure 2 by the diagram below it:

For the coarse structures, the difference between bright and dark is still equal to 1. For the medium structures the difference drops to 0.65-0.35 = 0.3, therefore 30%. And for the very fine structures, the difference is only 5%!

Actually, however, the goal is to capture the very finest patterns with a great amount of bright/ dark difference (high contrast or modulation) so that they remain easily visible!

The limit of resolution alone is therefore not an adequate measurement of picture sharpness; the modulation with which the pattern is reproduced (in line pairs per millimeter) must also be considered.

The higher the modulation, the better the optics!

We must therefore indicate the modulation of the reproduction as a function of the fineness of the pattern (in line pairs per millimeter) in a diagram. This is shown in Figure 2, down the bottom, where the modulation reproduced for the three line pairs per millimeter shown in the example is represented by circles. The result of our recognition is the **modulation transfer function**, abbreviated "MTF".

The MTF represents the relationship between the fineness of the pattern (in Lp/mm) and their reproduced modulation.

Now, a very important question must be clarified: up to what pattern fineness does a modulation transfer make sense at all, because what the eye can no longer see does not need to be transferred (imaged).

In this connection, we start from the assumption that the formation of an image does not exceed the printed format DIN A4 (210 x 297 mm or 8.27 x 11.69 inches), and that a picture recording format in a somewhat small size (24 x 36 mm) is used. This means a magnification of the picture format of about 7-7.5 times.

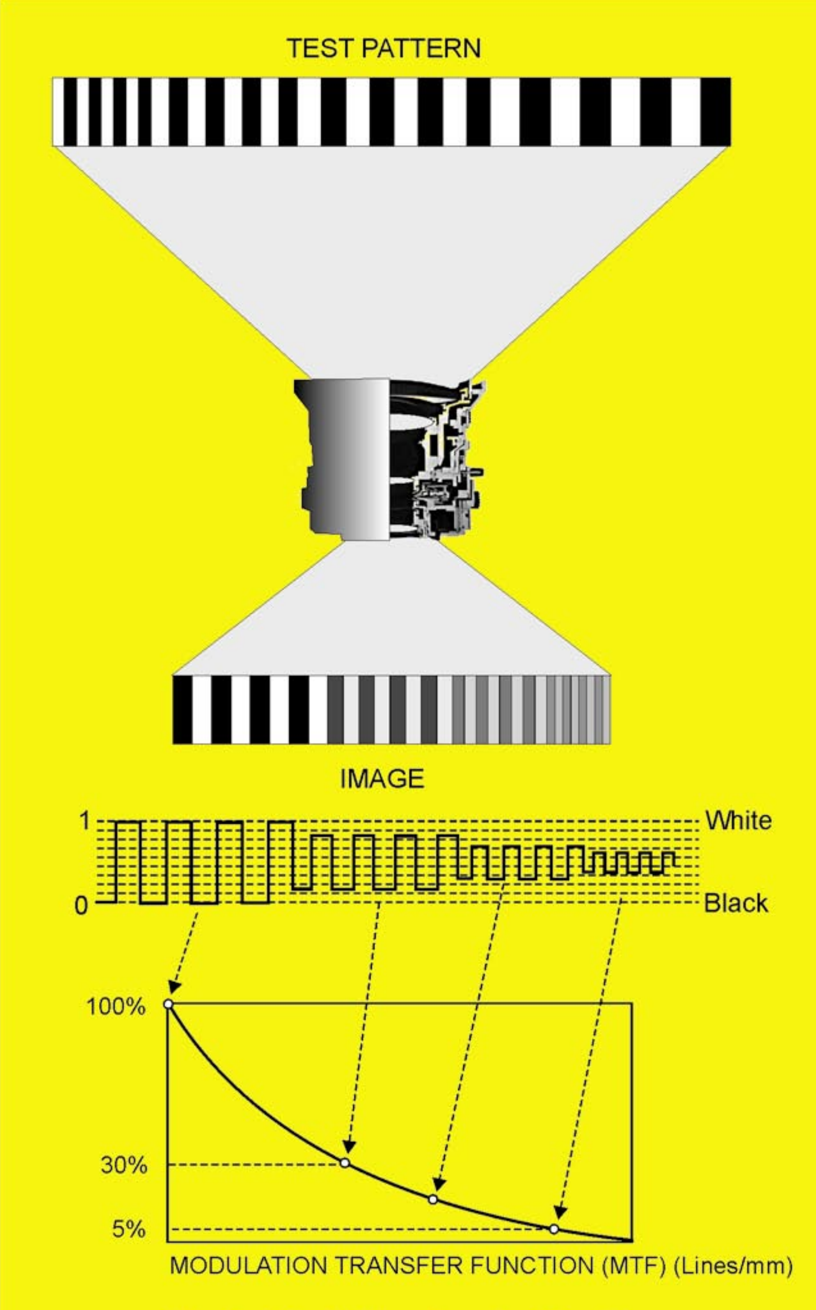

Fig. 2 : Modulation Transfer Function

The usual distance for viewing a DIN A4 document will be about 25 cm ("clear seeing distance").

What details can the human eye still recognize?

The answer from many practical experiments is: **a maximum of 6 line pairs per millimeter** (6 Lp/mm).

Converted to the photograph format, this means approximately 7 x 6 = 42 lp/mm, expressed when rounding the numbers as 40 lp/mm.

In the case of high-quality printing on art printing papers (glossy coated papers), printing is usually done with a raster width of 150 lines per inch up to a maximum of 200 lines per inch (with 256 shades of gray and 45° angling). This is therefore about 6-8 lines/mm and therefore 3-4 line **pairs**/mm. Consequently, even from this point of view, the 6 lp/mm is a reasonable upper limit. Anything above that is neither resolved nor recognized by the human eye. However, the highest possible modulation transfer (MTF) is definitely desirable and may be perceived with this line pair number!

A very clear representation of these facts was given as early as 1976 by Heynacher and Köber[1], whose explanation with sample images is highly recom-

Figure 3: Different MTF Characteristics

mended for reading.

In order to carry the pure indication of a resolution value completely to the limit, a simple calculation example can be considered:

Assume that we use the highest resolution film with excellent optics, which together can reproduce about 75 lp/mm. Enlarged by a factor of 7.5, this results in the resolution limit in the image of 10 Lp/mm, which the eye can no longer resolve!

Decisively more important is the degree of the modulation reproduced up to the resolution limit of the eye; that is 6 Lp/mm in the magnification or 6 x 7.5 = 45 Lp/mm on the film!

This example can also easily be transferred to other film formats. Thus, for the format of 9 x 12 cm (4 x 5 inches), the line pair number limit to be considered is at about 20 lp/mm, even with a substantially larger final format.

You may now wonder what these tests with simple bar grids and patterns have to do with reality, where complicated structures having soft tone transitions and fine surface details occur simultaneously, such as on a sand surface lit from the side. If we are to be scientifically accurate, the answer is fairly complicated, but it can be reduced to a simple denominator. Every brightness and pattern distribution in the test subject can be thought of as being composed of a sum of periodic structures of different fineness and orientation. The bar tests are only a simple example. Under actual photographic conditions, instead of the abrupt bright/dark transitions of our test patterns, only softer transitions have to be considered, with a "more harmonic" progress and more precisely sinusoidal changes.

The sum of all these lines (line pairs/mm) of different orientation comprise the object structure. The object is then offered to the lens for portrayal in the image plane. The lens weakens the contrast of the individual components according to its modulation transfer function and produces an image, which corresponds more or less well to the object.

In this regard, the answer to the question posed at the beginning, "What actually is picture sharpness?" becomes apparent. Picture sharpness is:

- The highest possible modulation reproduction for coarse and fine object structures (expressed in line pairs per mm), up to a maximum line pair number dependent on the application.
- This limit depends on the format of the photograph and the intended final enlargement and is decisively affected by the highest line pair number that the eye can recognize in the final enlargement (about 6 lp/mm).

Figure 3 summarizes this again graphically:

1. low modulation, high resolution Lp/mm
2. high modulation, less resolution = better quality
3. high modulation, high resolution = no improvement in quality

(In the next issue - Sensor related constraints in electronic imaging)