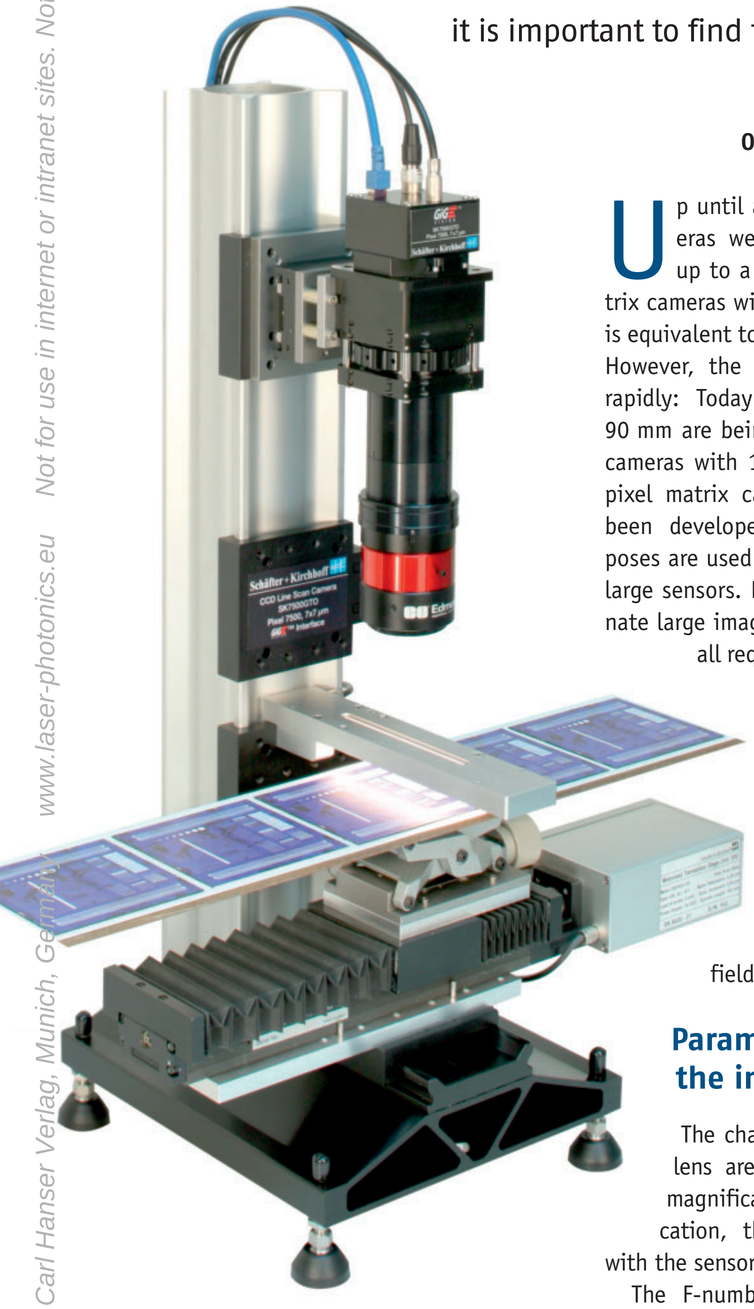
The Bigger the Better

LENSES FOR LARGE-FORMAT IMAGE SENSORS

High resolution matrix and line sensors are getting bigger – and the demands for lenses in machine vision systems are increasing. Depending on the purpose of use, the size of the sensor, the focal length, magnification, operating distance, resolution, intensity and the mechanical dimensions all play a role. As these characteristics influence each other, it is important to find the most suitable compromise for each application.



1 Solar inspection using a high-performance line scan camera system

OLIVER BARZ

Up until a few years ago, line cameras were equipped with sensors up to a length of 20 mm and matrix cameras with sensors up to 2/3" that is equivalent to an image circle of 11 mm. However, the sensor format has grown rapidly: Today sensors with a size of 90 mm are being used, e.g. for line scan cameras with 12,000 pixels or 16 megapixel matrix cameras. Lenses that have been developed for photographic purposes are used in many applications with large sensors. However, these can illuminate large image circles but do not fulfill all requirements of industrial image processing. During the development of the ›Large Format Lens‹ (Figure 2), the engineers from Edmund Optics (EO) have optimized the characteristics especially for this field of application.

Parameters that define the image quality

The characteristic parameters of a lens are the focal length, or the magnification. At constant magnification, the focal length increases with the sensor size.

The F-number (or relative aperture) designates the light intensity of a lens: It is the ratio between focal length and entrance pupil diameter – therefore the lens gathers more light the smaller the F-number is. On the other hand, the depth of focus rises with increasing F-number. Thus the F-number is an important feature of machine vision systems as it influences the operating speed and distance tolerance. Whereas an aperture of 1.4 is common in CCTV, most large-format lenses start from an aperture of 5.6. Edmund Optics' Large Format Lens opens to aperture 4.

The resolution designates the smallest image details that can still be separated at high-contrast. Typically it is measured in line pairs (one white and one black line) per millimeter: lp/mm. In the best case, such a line pair covers two pixels precisely. Then the lens is exactly as good as the sensor. Large-format sensors usually have a pixel size of 5 or 7 µm. For this purpose, a suitable lens such as the EO Large Format Lens has a sensor resolution of 100 or 72 lp/mm.

The sensor size tells the maximum image circle, where the specified resolution is reached. If the sensor is too large for the lens then vignetting occurs (edge shading). Generally the image quality close to the optical axis is better than at full field. Light beams that strike the edge

CONTACT

Edmund Optics GmbH,
D-76227 Karlsruhe/Germany,
Tel. +49 (0) 7 21 /6 27 37 -30,
Fax +49 (0) 7 21 /6 27 37 -33,
www.edmundoptics.de

2 **The Large Format Lens from Edmund Optics has been optimized for industrial image processing using large format sensors**

of the image under a larger angle of incidence lead to natural vignetting: The relative illumination is reduced by a factor that corresponds to the cosine of the fourth power of the angle of incidence (›cos4 law‹, see also *http://de.wikipedia.org/wiki/Cos4-Gesetz*, only in German). For example, with an angle of 30°, the intensity drops down to 56 percent in comparison to an angle of 0°. For photography, the natural vignetting is not relevant for the image impression and is usually not specially corrected. In machine vision, however, measurements have to supply exact values even close to the edge of the image. In these cases, this loss in quality must be kept to a minimum.

Geometric considerations concern the operating conditions, the total track from object to sensor and the size of the lens. The developers of machine vision systems with large-format sensors have to synchronize the individual parameters and components with each other so that these achieve an optimum combination between the camera, lens and illumination. When Edmund Optics is commissioned with custom made products for special applications, there are strict requirements for the magnification, resolution and light intensity as well as for the room that has been provided for the machine vision system itself. The developers in the EO Optical Design Center are looking for a cost effective solution that can be implemented in the serial production.

The EO Large Format Lens

The EO Large Format Lens that can be purchased from the shelf today originated from a custom made product. A system integrator searched for a suitable lens for inspecting LCD panels during the production. Key sizes are the 5 µm large LCD pixels of the panel and the 7 µm large CCD pixels of a 12k line scan camera. The magnification (1.4x) and the resolution of 100 lp/mm in the object space have resulted from this. The lens has been chromatically corrected as the red, green and blue LCD pixels have to be equally mapped. Originally designed with an aperture of 5.6, the customer's demands have led to an aperture of 4 to double the inspection speed. However, without additional effort these changes made to the aperture would have reduced the image quality. The image quality could be returned to the original image quality after numerous optimization sequences. In the meantime the lens is used in many different processes, such as for inspecting ceramic printed conductor boards or solar cells (see the **INFO** box).

The bandwidth of the different lens connections with large-format cameras range from the established Nikon-F-Mount (**Figure 4**) to different screw threads (such as M42, M72) up to manufacturer-specific objective connections. The flange back distance has also not been standardized and therefore, care should be taken to obtain the correct extension tube and the correct working distance when positioning the object to the sensor. The F-Mount is widely used in industrial image processing but is not free of play in comparison to the screw thread. Next to the fixing that is free from play, the M72 adapter of the EO Large For- ▶

3 **1.4x lens in an M72-Mount with axis adjustment (Tip-Tilt)**

INFO: Solar cell inspection

When manufacturing solar cells, the manufacturer monitors all stages of the production to ensure a consistent high standard of quality. An important process is the attachment and the subsequent inspection of the electric contacts, the so-called grid fingers. Surface defects are an indication for problems in the production process where the manufacturer has to counteract immediately. Solar cells of the newest generation have a grid finger of 100 µm in width with a required accuracy of 10 µm. In the production, 30 solar cells with a size of 150 x 150 mm² are hanging together in strips of 4.5 m.

High resolution cameras with 7000 to 12,000 pixels are used for inspecting in real time. The line read-out is synchronized with the feed of the solar cell line using an encoder so that varying transporting speeds do not cause any distortions. The strips are detected in approximately 9 seconds thanks to the large aperture of the Large Format Lens. The combination of the EO Large Format Lens and the line scan camera ›SK7500‹ from Schäfter+Kirchhoff is suitable for this measuring task (**Figure 1**). The lens maps the grid fingers with 1.4x magnification to 7 x 7µm² pixels. Two camera systems, each with 7500 pixels operate in parallel to achieve the required resolution of 10 µm.

Thanks to the field flattening and the high resolution of the lens of 100 lp/mm, no image details get lost. The solar cells are equally mapped with sharp images from the center up to the full field. The drop in brightness to the full field that exists with all lenses has been reduced to the theoretical minimum by Edmund Optics. With their 660 MB, the two images of the solar cell lines, each with 7500 x 46200 pixels almost correspond to the capacity of a Compact Disk. A high performance computer evaluates this enormous volume of data.

mat Lens offers additional possibilities to adjust the position of the optical axis to the sensor (**Figure 4**). Modular systems with interchangeable tubes and mounts are an advantage. They usually consist of one or more basic lenses, a focusing tube and the corresponding lens mount. The flange back distance can be additionally aligned using extension tubes. At present, for large-format sensors, efforts are also being made defining a standard for the connection between lens and camera. ■

4 **0.7x lens in an F-Mount**

Summary: Detects all details

With the EO Large Format Lens, Edmund Optics has begun to develop a series of lenses that can cope with the versatile applications when using large format cameras. The real-time solar cell inspection is used as an example for the performance capability of the lens. Two high-resolution line scan cameras that each have 7500 pixels detect details with a resolution of 10 µm in parallel operation. Thanks to the Large Format Lens, solar cells can be mapped with sharp images up to the image border.

AUTHOR

Dipl.-Phys. OLIVER BARZ (sales@edmundoptics.de) is employed in the sales department for machine vision components of Edmund Optics in Karlsruhe/Germany.