Camera Selection –
How can I find the right camera for my image processing system?

Welcome back to Basler’s series of introductory lessons on image processing systems! The first installment in our series of white papers took an in-depth look at the basic principles of image processing systems. Now it’s time for your first concrete decision on the road to designing a real-life system: Which camera do you need? The best way to start is with a clear-eyed self-assessment. The first question is ultimately the most important: What do I really want to be able to see with the camera? Once you’ve figured this out, you can move on: What characteristics are necessary for my camera to deliver precisely what I defined above? Answering these two questions provides a strong start to the process.

Unless you have some idea of what you’re looking for, browsing through catalogs from camera manufacturers can be a daunting experience. There is a dizzying range of models, relevant properties, helpful features and potential applications. What’s really needed is a filter. Let’s start with the most sensible starting spot: Your application.

The sensor, shutter type and interface are selected next. Join us in this second part of our series of white papers for a step-by-step exploration of these and other stages of the overall decision. By the end of the paper you’ll have gained an overview of the various camera models and a well-grounded understanding of the key aspects of relevance to image processing systems.

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The decision to implement an image processing system is generally based on a concrete need. The basic requirements for your system will already point in the direction of one of the two major camera technologies used in industrial machine vision:

1. Network or Industrial Camera?

Cameras for image processing systems are categorized either as industrial/machine vision (MV) or network/IP (Internet Protocol) cameras.

Network cameras, also known as IP (Internet Protocol) cameras, record videos. They are frequently used in classical surveillance applications and in combination with industrial cameras. They are typically placed within robust housings designed to be resistant to jolts and harsh weather, making them suited for use indoors or out. A variety of functions, including day/night modes and special infrared filters (blocking or pass filters), have been engineered to deliver outstanding image quality even under extremely poor lighting and weather conditions. Network cameras acquire the images and compress them. This reduces the volume of data to such a degree that it can be stored in the camera. By connecting to a network, a theoretically unlimited number of users can also access the camera.

Industrial cameras by contrast send the images as uncompressed (‘raw’) data directly to the PC; The PC is then responsible for processing the relatively large volume of data. The benefit of this method is that no image information is lost.

There are two further subdivisions within the world of industrial cameras: Area scan and line scan cameras. They differ in the manner in which they capture an
image. An image is composed of a specific number of lines. Area scan cameras are equipped with a rectangular sensor featuring numerous lines of pixels that are exposed at the same time. The image data is thus recorded in one single step, and is also processed in the same way.

Line scan cameras by contrast use one sensor comprised of just 1, 2 or 3 lines of pixels. The image data is captured line by line, with the individual lines then reconstructed into an entire image during the processing stage. The question of whether an area or line scan camera should be used is a question of your applications and its requirements.

**Area scan cameras** are typically used in a variety of industrial applications as found in many different industries:

- In the automotive industry for inspection of individual parts, in control engineering and robotics for the positioning of components and code identification. Image processing systems are used along the entire value chain: from manufacturers to suppliers to machine shops.
- In electronics for inspection of components such as circuit boards, soldering checks and pick & place processes.
- In the pharmaceutical and packaging industries for checks of production steps and inspection for completeness, compliance with dimensional requirements and detection of material flaws, as well as assessment of bar codes, texts or matrix codes.
- In photovoltaics for inspections of geometry and saw marks, or for electroluminescence testing of solar cells, stringers and modules.
- In robotics for pick & place applications for gripping and positioning during the manufacturing process, such as for mechanical engineering.
- In sports for movement and technical analyses, as well as to support therapeutic measures.
- In industrial microscopy for detailed reviews of materials, microstructures and welding seams.

They also handle numerous tasks outside industrial settings:

- In biomedical microscopy, in medicine and the medical life sciences in machines such as dental scanners, eyeground checks and in many lab applications.
- In the fields of traffic and transportation, cameras serve as an optimized eye in a variety of intelligent traffic systems to regulate traffic flows, in toll systems and in traffic monitoring.
- For security and surveillance, often as a supplement to network cameras.

**Line scan cameras** are used universally when products must be inspected as they pass by on conveyor belts – at times at extremely fast speeds. Typical applications include:

- Checks of printed images in newspaper and magazine printing, where the printed products are moving at up to 100km/h.
- Millions of letters and packages run through the sorting facilities at logistics companies each day. Each individual shipment is identified and sorted at lightning speeds using line scan cameras to ensure quick and smooth delivery.
- In the food industry, they are used to inspect food products for geometry, damaged spots and particles. They inspect packaging and check the seals and caps on bottles.
- They control the surfaces of various materials, from plastic films and paper to steel and textiles, not to mention the wafers and coated surfaces used in the electronics and photovoltaic branches.

**Network cameras** are used for a variety of surveillance tasks, from process controls in shipping lines and packaging systems to building and traffic surveillance systems. Among the places where they are used are:

- Banks
- Casinos
- Company campuses and public buildings (stadiums, train stations, airports, container ports)
- Logistics and transportation (freight centers, access controls)
Extensive information and camera recommendations for specific applications can be found at the Basler website.

2. Monochrome or Color Camera?

This decision is relatively simple. It depends entirely on the nature of the application requiring image processing. In defining precisely what results you need from the camera system, you’re also in effect defining whether the image captures require color for proper analysis/ongoing processing or whether black and white is sufficient. If color isn’t mandatory, then a monochrome camera is typically the better choice. Because they do not need a color filter, they are more sensitive than color cameras and deliver more detailed images. For many applications, such as intelligent traffic systems, a combination of black and white and color cameras are also frequently used to satisfy the specific national legal requirements for evidence-grade images.

3. Sensor Types, Shutter Technique, Frame Rates

The next important step involves picking a suitable sensor, built either around CMOS or CCD sensor technology. The choice of shutter type must also be taken into consideration at this point. There are two options: Global or rolling shutter. Once the sensor type and shutter have been defined, then the next consideration is of the frame rate, meaning the number of images that a camera must deliver per second to handle its task seamlessly. While this topic seems somewhat complex at first glance, the decisions are actually quite clear cut once the requirements on the image processing system are known.

Sensor types
The fundamental difference between the two sensor technologies is in their technical structure.

In CMOS (Complementary Metal-Oxide-Semiconductor) chips, the electronics to convert the light (and specifically: the photons) into electronic signals (electrons) are integrated directly into the surface of the sensor. This makes them especially quick since they can read the image data more rapidly and allow the user to address the image range flexibly. CMOS sensors are heavily used in the consumer market, such as in SLR cameras.

Pros:
- High resolution (number of pixels)
- Low power consumption
- Strong quantum efficiency

These properties have helped CMOS chips gain a foothold in areas previously dominated by CCD sensors. The technology has progressed so far over the years that it is now suitable for almost any image processing applications. The high image rates without compromising in image quality are one especially strong selling point for the current generation of CMOS sensors.

Unlike the CMOS sensor, the pixels on a CCD (Charge Coupled Device) sensor use the entire sensor surface to capture the light, with no conversion electronics placed on the sensor’s surface. This leaves more space for pixels on the surface, which in turn means more light is captured. Sensors of this type are thus extra light-sensitive, a major benefit in low-light applications like astronomy. CCD sensors deliver outstanding image quality in slower applications, although their architecture and the way in which they transport and process image data has increasingly brought them to the limits of their speed.

In light of the many technological improvements in recent years, the trend on the sensor market is increasingly pointed toward CMOS technology.

Shutter
The shutter type may not seem important at first blush when choosing a sensor, but don’t be fooled: It is of crucial importance that the shutter matches the application. The two options are global and rolling shutters. The shutter protects the sensor within the camera against incoming light, opening only at the moment of exposure. The selected shutter or exposure time provides the right ‘dose’ of light and determines how long the shutter remains open. The difference between the two shutter variants is in the way they handle exposure to light:

The global shutter approach opens to allow the light to strike the entire sensor surface all at once. Depending on the frame rate (typically cited in fps), a moving object is thus exposed in a rapid succession. Global
shutter is the optimal choice for applications where very fast moving objects must be captured, such as in the traffic and transportation fields, in logistics and in inspections of printed materials.

Rolling shutter by contrast exposes the image line-by-line. In a nutshell, each image is comprised of horizontal rows. Each line in turn is made of some number of pixels. The type of pixel depends on the resolution (more on this can be found in the chapter “Resolution, Sensor and Pixel Size”). In short: high resolution = many pixels, low resolution = fewer pixels. Line-by-line exposure occurs in stages.

Once the last line in image 1 has been completely captured, then the recording of the next shot starts anew with the first line. Depending on which exposure time is selected and the speed of the object, distortions can occur when photographing objects moving during the exposure process. This makes the method unsuitable for some applications. The distortions occur when the individually captured lines are recomposed into one single image and are known as the rolling shutter effect.

CCD sensors always use global shutter, while CMOS sensors offer both model variants. As described in the section on “sensor type,” both sensor technologies have their pros and cons. These should be used to form the basis for a decision. In many cases, the problems related to the rolling shutter effect can be circumvented through proper configuration of the exposure times and the use of an external flash. In other words there’s no need to abandon the possibility of a rolling shutter just because the objects are moving.

The following example illuminates this using a model from the Basler ace series:

The Basler ace acA2500-14gm has 1944 lines. The delay between two lines totals 35 μs, or 0.000035 s. The sensor requires 70 milliseconds to capture all 1944 lines once. Once that figure is applied to the speed of the moving object, it becomes clear that any shutter speed of 1/14 second will thus avoid the rolling shutter effect. As long as the object does not shift significantly within those 70 milliseconds, then the rolling shutter technique delivers the same quality images as a global shutter.

For more information and additional technical details on this topic please see our white paper “Global Shutter, Rolling Shutter — Functionality and Characteristics of Two Exposure Methods (Shutter Variants).”

Frame Rate
This term is synonymous with ‘frames per second’ or ‘fps’. For line scan cameras, the terms ‘line rate’ or ‘line frequency’ are used. It describes the number of images that the sensor can capture and transmit per second.

The higher the frame rate, the quicker the sensor, meaning more captured images per second and with it higher data volumes. For area scan cameras like the Basler ace, these volumes can vary greatly depending on the interface and whether a low rate of 10 fps or a high (fast) speed of 340 fps is being used. Just which frame rates are possible or even necessary depends on what the cameras in the image processing system must record. For fast-moving applications like inspections of printed images, with newspapers moving at high speeds past the camera inspection point, the cameras must be able to ‘shoot’ in milliseconds. This is a far cry from some microscopic inspections used in medicine and industry, which typically require only low frame rates.

4. Resolution, Sensor and Pixel Sizes

The relationship between these three factors has already been explored in depth in Part 1 of this White Paper series. Here’s a brief review of the key points:

Resolution
In practice, resolution describes a measurement of the smallest possible distance between two lines or points such that they can still be perceived as separate from one another within the image. So what is meant when you’re looking at a camera’s spec sheet and it says:
“2048x1088”? That number describes the number of pixels (the dots that form the image) per line, in this case 2048 pixels for the horizontal lines and 1088 pixels in the vertical lines. Multiplied together, the numbers indicate a resolution of 2,228,224 pixels, or 2.2 megapixels (million pixels, or ‘MP’ for short).

A simple formula is used to determine which resolution is required for your application:

\[
\text{Resolution} = \frac{\text{Object Size}}{\text{Size of the detail to be inspected}}
\]

While it may seem abstract at first blush, it’s actually very easy to comprehend:

**Example 1:**

You’d like to capture a precision image of the eye color of a roughly 2m tall person standing at a specific point:

\[
\text{Resolution} = \frac{\text{Height}}{\text{Eye detail}} = \frac{2 \text{ m}}{1 \text{ mm}} = 2,000 \text{ pxl in x and y}=4 \text{ MP}
\]

→ A resolution of 4 megapixels is required to ensure that the 1 mm large detail for the eye is clearly recognizable.

**Example 2:**

Your application should identify the license plates on vehicles. You’ll need at least 200 pixels to identify the license plate.

\[
\text{Resolution} = \frac{\text{Lane width}}{\text{Plate width}} = \frac{4 \text{ m} \times 200}{0.4 \text{ m}} = 2,000 \text{ pxl in x}=2 \text{ MP}
\]

→ You thus need 2 megapixel resolution to ensure doubt-free identification of the license plate.

**Sensor and Pixel Size**

Large surfaces, both on the sensor and the individual pixels themselves, offer more space to capture incoming light. Light is the signal used by the sensor to generate and process the image data. The greater the available surface, the better the Signal-to-Noise Ratio (SNR), especially for large pixels measuring 3.5 μm or greater. A higher SNR translates into better image quality. A measurement of 42 dB is considered a solid result.

Another benefit of a large sensor is the larger space onto which more pixels can fit, which produces a higher resolution. The real benefit here is that the individual pixels are still large enough to ensure a good SNR – unlike on smaller sensors, where there is less space available and thus smaller pixels must be used.

And yet large sensors and a large number of large pixels won’t achieve much unless the right optics are in place. They can only achieve their full potential when combined with a suitable lens also capable of depicting such high levels of detail. Large sensors are also always more cost intensive, since more space means more silicon.

**5. Interfaces and Housing Size**

These are two more topics that you’ll always confront when designing an image processing system. We’ll provide a brief bit of detail on each:

**Interfaces**

The next step on the path to a finished image processing system is selecting the interface. The objective here is to weight a series of different factors against one another to find the optimal balance of performance, costs and reliability.

The interface serves as the liaison between the camera and PC, forwarding image data from the camera sensor to the components that process the images, i.e. the hardware and software. The choice is available between a variety of modern, widely available technologies

- Camera Link (CL)
- Gigabit Ethernet (GigE)
- USB 3.0
- USB 2.0
- FireWire

as well as older technologies which, due to their limitations, are not recommended for general use.

- USB 2.0
Depending on what your application demands in terms of cable length, bandwidth, plug & play compatibility, number of cameras per system, real-time compatibility and budget, you can select between Camera Link, GigE or USB 3.0 to find the best set of properties to transmit image data from the camera to the PC quickly, cleanly and securely.

**Camera Link** is a high-performance interface that can be used easily and securely with industrial cameras of all performance classes. Its distinguishing characteristic is its versatility: From cameras in ultra-compact formats to megapixel resolutions and frame rates of several hundred fps.

But remember one thing: System costs are always higher for Camera Link since a frame grabber is inherently required. In many cases this component is more expensive than the camera itself. Camera Link is nevertheless the interface of choice for applications requiring very high data rates.

**GigE and USB 3.0** by contrast work with existing PC technology, which has a positive impact not just on system costs, but on the complexity of configuration as well thanks to its plug & play compatibility.

GigE and USB 3.0 also fall under the aegis of the GigE Vision and USB3 Vision, respectively, industrial certification standard. It ensures smooth interplay between all components when the cameras are combined with standard accessories.

For those interested in a more comprehensive exploration of the subject, the pros and cons of the individual interfaces can be found in the Basler white paper “Comparison of the Most Common Digital Interface Technologies in Industrial Machine Vision.” Click here to download it!

**Housing Size**

The size of the camera housing is tied directly to the choice of interface. While not inherently one of the core criteria for camera selection, it nevertheless can impact the overall integration into the system. In applications where cameras are organized next to one another (known as multicamera setups) to better record the entire width of a material web, each millimeter of space matters.

At Basler for example the portfolio of available models ranges from the 29 mm x 29 mm of the Basler ace to the larger dimensions of individual cameras with very large (line scan) sensors, such as the Basler sprint series.

**6. Useful Camera Features**

All Basler cameras come equipped with a core of helpful features to improve image quality, assess image data more effectively or control processes with greater precision. A comprehensive listing of all features for each camera model is beyond the scope of this white paper; Our Features Check List provides a more detailed review.

Let’s instead take three features as examples here, given their potential importance for the design of your image processing system:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Cable Lengths</th>
<th>Bandwidth max. in MB/s.</th>
<th>Multi-Camera Costs</th>
<th>“Real-time”</th>
<th>“Plug &amp; Play”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>USB 2.0</strong></td>
<td>5m</td>
<td>40</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>4.5m</td>
<td>64</td>
<td></td>
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<tr>
<td><strong>GigE Vision</strong></td>
<td>100 m</td>
<td>100</td>
<td></td>
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<tr>
<td><strong>USB 3 Vision</strong></td>
<td>8 m</td>
<td>350</td>
<td></td>
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<tr>
<td></td>
<td>10 m</td>
<td>850</td>
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</tr>
</tbody>
</table>

**Comparison of Interfaces**

Housing sizes play a crucial role in multicamera setups.

Camera housings can vary significantly in size.
AOI (Area of Interest)
Basler cameras always provide the option of selecting specific individual areas of interest within the frame, or multiple different AOIs at once. Those sections of the frame, and those sections alone, are then processed and output. The benefit here is that only those parts of the frame are processed that are of relevance for assessment of the image. Above and beyond this, individual AOIs are often used to read out camera data more quickly, because the lower data volume leads to a higher frame rate.

“Autofeatures”
Basler cameras offer a series of so-called “Autofeatures.” Examples of this are automatic exposure adjustment and automatic gain, which together ensure that the exposure time and gain parameters adapt automatically to changing ambient conditions to keep the image brightness constant.

Sequencer
The sequencer is used to read out specific image sequences. This means for example that various AOIs can be programmed and then automatically read out sequentially by the sequencer.

8. Summary and Outlook
The selection of the camera is the first step toward the overall system. In this way the first two parts of our white paper series have put you into a strong starting position. You can choose from a broad product portfolio encompassing both monochrome and color models featuring various resolutions, frame rates and sensor technologies.

All Basler cameras possess standard interfaces that are the perfect choice for a variety of applications and which offer you the greatest possible flexibility during integration into an image processing system.

As the series continues, we’ll explore in depth the topics of image quality, lens selection, lighting, hardware and software and key camera functions.

7. Basler Camera Selector
You’ve now become familiar with the most important factors to help define your image processing system to meet your application’s precise requirements. You’ve informed yourself about the relationship between sensor types, frame rates and various resolutions, and you understand the pros and cons for different interfaces. Now all that’s missing is the right camera! How can you put your newfound knowledge to work in selecting a suitable model?

Quite simply: The Basler Camera Selector for area scan, line scan and network cameras supports your decision by filtering using specific selection criteria, including the resolution or frame/line rate, to find which camera best fulfills your requirements.
Basler AG

Basler is a leading global manufacturer of digital cameras for industrial and video surveillance applications, medical devices, and traffic systems. Product designs are driven by industry requirements and offer easy integration, compact size, excellent image quality, and a very strong price/performance ratio. Founded in 1988, Basler has more than 25 years of experience in vision technologies. The company employs over 400 people at its headquarters in Ahrensburg, Germany, as well as in international subsidiaries and offices in the U.S., Singapore, Taiwan, Japan, and Korea.

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