KEYENCE

IMAGE PROCESSING USEFUL TIPS

Compilation

Lenses #1

Lenses #2

Image Capture

Lighting

Color

Communication (RS-232C)

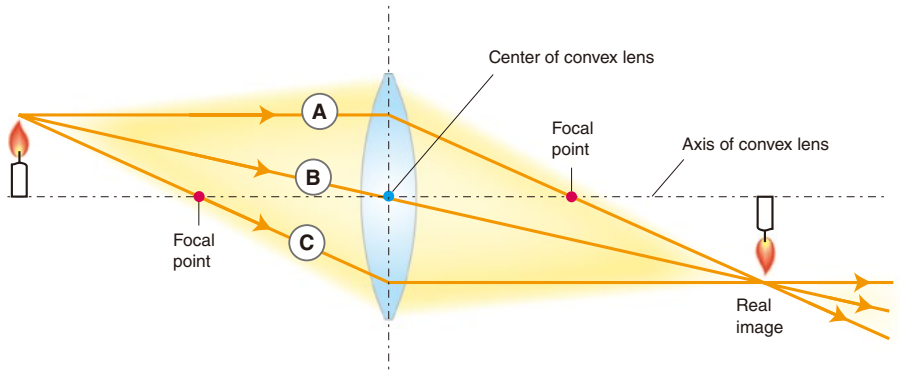
Preprocessing

Communication (Ethernet)

Image processing is an essential technology that raises the accuracy and efficiency of product defect inspection. Recently, technology in this area has seen significant advances and is producing results in on-site manufacturing. In order to correctly perform on-site image processing, it is essential to acquire a basic knowledge on the subject.
In this chapter we will explain basic knowledge regarding image processing.

01 The Role of the Lens

In image processing, light that has entered into the image receiving element (CCD) is transformed into electronic signals and used as data. For this process, it is important to have a lens that gathers light into the image receiving element. Based on the principle of refraction, the lens gathers light from the target into a single point, forming an image. During this process, the single point to which the light has been focused is called the focal point and the distance from the center of the lens to the focal point is called the focal length. When using a convex lens, the focal length will differ depending on the degree of thickness (bulge) of the lens. The larger the degree of bulge, the shorter the focal length.



[How light passing through a convex lens advances]

A. Light that has entered the lens parallel to the axis passes through the focal point after being refracted.
B. Light that has entered the center advances through directly, with no changes.
C. Light that has passed the focal point before entering the lens advances parallel to the axis after being refracted.

When seen through the mechanism of a camera, light that is emitted from a target which is outside of the focal point of a convex lens, is refracted on the lens, drawing an image whose vertical and horizontal planes have been reversed. This image is called a real image and if an image receiving element is placed here, a real image will be projected.

02

Types of Lenses Used in Image Processing

CCTV Lens

These lenses are for Close Circuit TVs, and are primarily used in inspection applications in the area of FA (factory automation) and surveillance applications in the areas of crime and fire prevention. Due to their limited number of lens elements and relative simplicity, these lenses are compact and low-cost. In general, these lenses can perform uniform aberration correction regardless of distance from the target.

CV-L Series general CCTV lens

CA-LHR Series low-distortion lens

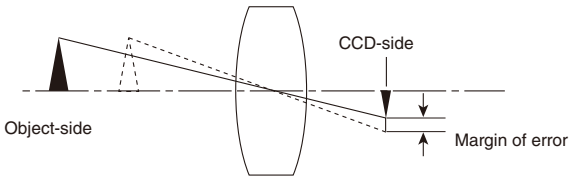
What makes us different

KEYENCE image processing lenses internally use eight layers of low-scattering glass and in comparison to normal CCTV lenses, utilize an optical design that limits distortion and chromatic aberration to a minimum.

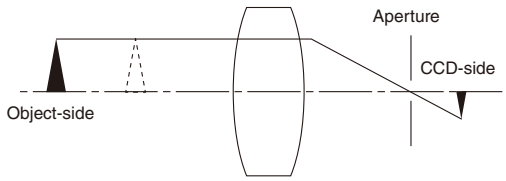
Telecentric Lenses

These are lenses that have been arranged to pass principal light through the focal point at a 0° angle of view. In other words, these lenses have been designed to have principal light advance parallel to the optical axis of the lens. Because the optical axis is parallel, distortion is difficult to generate and it is possible to acquire the size and position of the target with high-accuracy. Telecentric lenses demonstrate their true value in cases where high-magnification, low-distortion, and a deeper depth of field are required for image processing.

▶ **Normal Lens**



▶ **Object-Side Telecentric Lens**



The Efficacy of Telecentric Lenses

Original image

When the distance between the camera and target has shifted by 3 mm 0.12"

Telecentric Lenses

The image is in focus, leaving the size of the target unchanged.

Normal CCTV Lenses

The focus is blurred, changing the size of the target.

03 Structure of a CCTV Lens (CA-LH/LHR Series)

Floating Structure

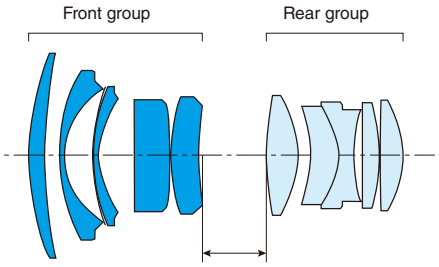
Floating structure is a function that separately moves the front and rear groups of a multi-lens assembly. Through this, it is possible to obtain high-resolution and contrast from close-distances to infinity.

[An optical design optimized via multiple lenses and floating structure]

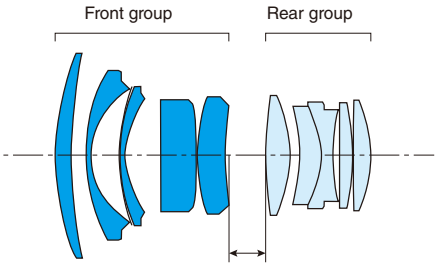
In order to bring out the best performance of multiple lenses, a floating structure that independently moves each internal lens group (front and rear groups) is used. When the front group of the lens assembly is moved during focus adjustment, the structure moves the rear group to the best position in order to optimize distortion correction. High performance is achieved by constantly maintaining the positional relationship of the lens groups in optimal condition between ranges from close proximity to infinity.

[Illustration of lens structure]

▶ Infinity



▶ Close Proximity



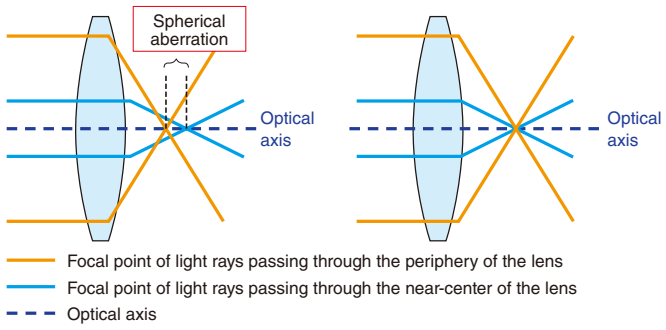
The rear group is moved during focus adjustment, correcting distortion.

Adopting Aspherical Lenses

Through the adoption of aspherical lenses, which possess a shape that is non-spherical, it is possible to limit optical aberration and obtain clearer images.

[Spherical lenses and aspherical lenses]

▶ Spherical Lenses ▶ Aspherical Lenses



Lens Mounts

Lens mounts, which act as joints between the CCD camera and the lens, come in a variety of types and if the pre-existing requirements of each side of the lens mount are not met together, it is not possible to maintain compatibility between the CCD camera and lens. Due to the occurrence of mechanical issues that include joint structure and dimension, and optical issues related to the CCD-side flange focus, it is necessary to confirm the mount of the CCD camera that will be used when selecting lenses. A mount for CCD cameras that is often used in the FA industry is called a C-mount. This type of mount has a 25.4 mm (1 in.) inner-diameter, a 0.794 mm pitch (32 TPI).

04 Lens Characteristics

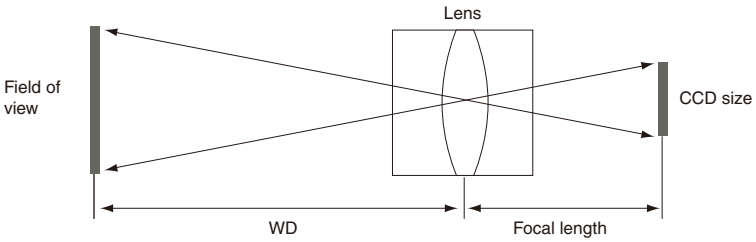
In the FA industry, the distance between the inspection target and the lens in image processing is generally called WD (working distance) and the image area is called the field of view. The field of view is determined by lens type and the size in inches, of the WD and CCD.

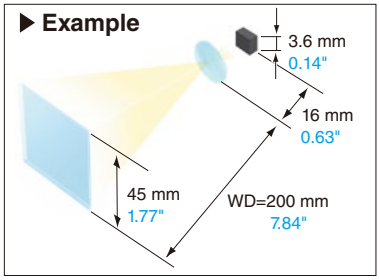
Working Distance (WD)

This signifies the distance from the end of the lens to the target when the focal point is in alignment with the target. This is also called operating distance. With a CCD, it forms a proportional expression that says Working Distance is to Field of View as Focal Length is to CCD Size (Working Distance : Field of View = Focal Length : CCD Size).

Focal Length

“Focal length” exists as one of the specifications of a lens. As representational models, lenses used for factory automation come in 8 mm 0.32", 16 mm 0.63", 25 mm 0.98", and 50 mm 1.97" specifications. The WD (working distance) can be equated to the position that aligns with the focal point from the field of view and focal length required for the target that you would like to capture.





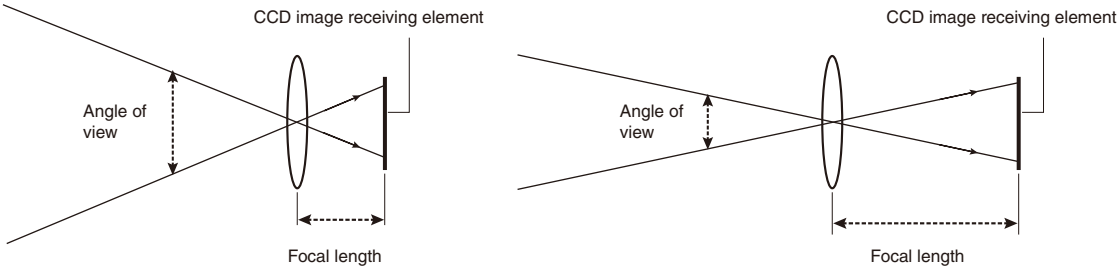
The size of the WD and the field of view is determined by the focal length of the lens along with the size of the CCD, and in ranges that are at the closest possible distance, where a close-up ring is not required, or at distances above this, the relationship can be represented with the following proportional expression.

WD : Field of View = Focal Length : CCD size

▶ **Example:** Using a lens with a 16 mm 0.63" focal length and CCD with a size of 3.6 mm 0.14", selecting a 45 mm 1.77" field of view will yield a WD of 200 mm 7.84".

Field of View

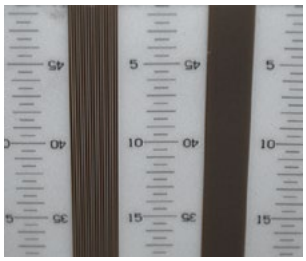
This is the image area within the range of the working distance. In general, the longer the working distance between the target and lens is, the wider the field of view (view angle). Additionally, the width of the field of view is determined according to the focal length of the lens. The angle of the range in which the lens can be used to capture images in regard to the field of view is called the angle of view or the view angle. Because the angle of view becomes larger as the focal length of the lens becomes shorter, the field of view will widen. Conversely, it’s possible to enlarge distant targets when the focal length is long.



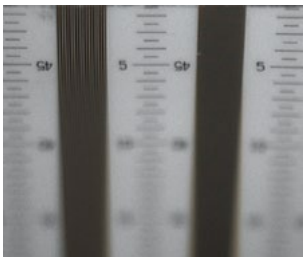
05

Depth of Field

Depth of field means the range that appears in focus through the lens (target-side distance). When the range is wide, it is called a “deep depth of field”. Conversely, when the range is narrow, it is called a “shallow depth of field”. Strictly speaking, though only one area can be in focus, to the human eye, images in a certain range appear to form clearly. This range is called depth of field.

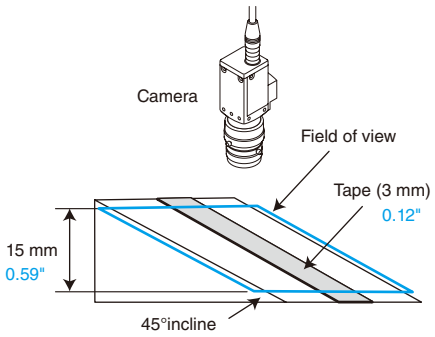


When aperture is reduced
(CA-LH25)



When aperture is open
(CA-LH25)

In the image below, an inclined surface that has been affixed with tape displaying height is shown. To the left of this image, is a comparison between an instance where the aperture has been reduced and an instance where it has been opened.



COLUMN 1

Does a CCD whose size per pixel (cell size) is large have a deep depth of field?

The logic behind depth of field

An explanation will be given using an instance where a CCD is used as an image receiving element. It is easy to know if an image is blurred by the size of individual pixels (unit cell size) on the CCD. Image 1 shows a state in which it is optically most in-focus. The apex of the light refracted with the lens matches perfectly with the top of the CCD, making it an ideal state.

So what about Image 2 and 3?

The position of the light apex is misaligned with the position of the CCD, but it does not overlap with neighboring CCDs.

Images 1 through 3 are actually all in focus.

This is because even if the size of the focal point within in the range of a single CCD pixel has fluctuated, images that have been output through electronic signals will not be reflected at all (won’t be understood). In this way, the changing range of the working distance, which limits the size of the focal point in a defined range, is called depth of field.

In other words, when using the same size and same optical magnification, because the allowable range in which CCDs with larger per pixel sizes is wide, it has a deep depth of field.

S1= Focal length + Thickness of close-up ring
S2= Working distance

Image 1

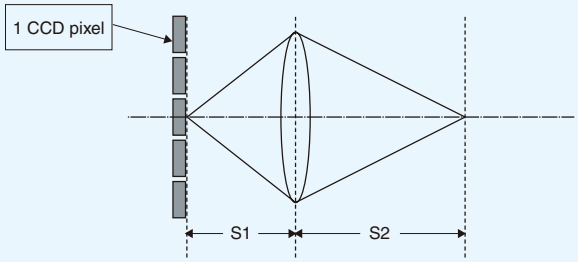


Image 2 A: State in which the target is misaligned in a far direction

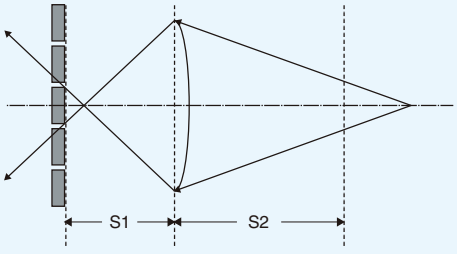
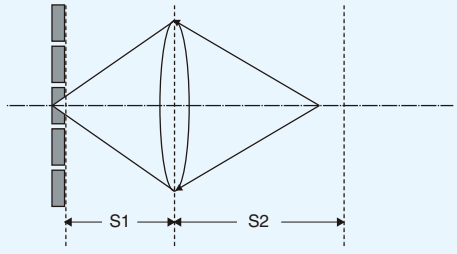


Image 3 B: State in which the target is misaligned in a close direction

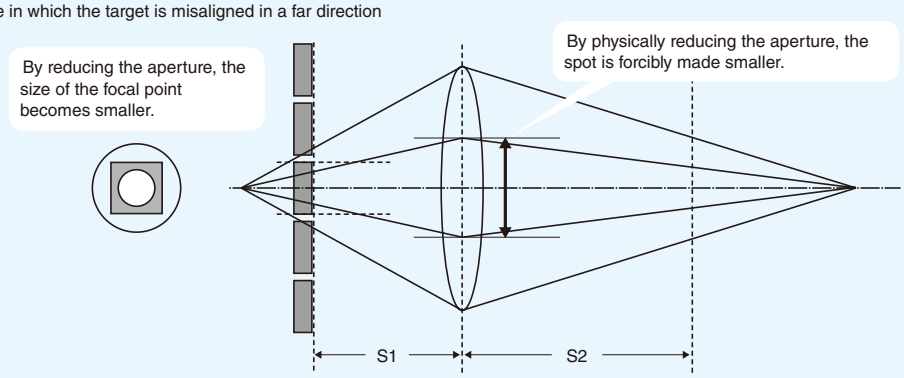


COLUMN 2

The reason why depth of field changes with aperture and focal length

Considering the principles that were explained in column 1, the answer is easy. No matter which lens, as the aperture is reduced, depth of field becomes deeper. This is because the aperture mechanism can make the angle smaller while maintaining the values for S1, and S2. This makes the size of the focal point smaller and widens the focus range.

A: State in which the target is misaligned in a far direction



06 Lens Resolution

Not limited to image processing, lens resolution is used in lenses for all optical measurement devices and it signifies the minimum interval in which observation is possible. A lens with a resolution of 10 µm 0.39 Mil can soundly observe striped lines that have been arranged in 10 µm 0.39 Mil line widths and 10 µm 0.39 Mil pitches. When the resolution is insufficient, 2 lines will appear as if they are stuck together, making the resolution unsuitable for an inspection that requires accuracy. Lens resolution is expressed in the formula for the Rayleigh limit*1 listed below.

$$\varepsilon = 0.61 \times \frac{\lambda}{\text{N.A.}^{*2}} \quad \text{(Rayleigh's equation)}$$

λ: Operating wavelength
(For visible rays, this is generally calculated with λ as 0.55 µm 0.02 Mil)

N.A.: The numerical aperture of the target lens

$$\text{N.A.} = \frac{\beta}{2F}$$

β: Optical magnification F: Effective No.

To improve resolution, it is important to raise the numerical aperture (N.A.) of the target lens.

***1 Rayleigh limit**
An evaluative standard for lenses. This was defined by the English physicist, Lord Rayleigh.

***2 Numerical aperture (N.A.)**
An index for the purpose of calculating the performance of a lens, including resolution. Brighter images can be obtained as the numerical aperture increases in size.

07 Lens Magnification

Magnification is a ratio between the actual size of the measurement target and the size that can be seen through an optical measurement device. Conventionally, optical magnification was used when observing through the eyepiece of a microscope, but recently, the idea of monitor magnification is spreading from the increase of systems that display observation targets on an LCD monitor.

[Optical magnification]

With a digital camera, optical magnification is calculated by dividing the dimensions of the effective camera elements by the field of view.

[Monitor magnification]

Monitor magnification is calculated by dividing the diagonal length of the monitor by the diagonal length of the camera elements, and then multiplying that by the optical magnification.

08 F-Stop

This value (also called F-number) signifies a standard that displays the brightness of a lens. Accurately speaking, it is a value that divides the focal length of the lens by its diameter (gauge). F: The “F” in F-stop derives from the word focal.

$$F = \frac{f}{D}$$

F : F-stop
D : Lens diameter
f : Lens focal length

In practice, the lens won’t transmit all the light; part of it will be reflected by the lens. Additionally, in order to reduce optical aberration, multiple lenses are used, reducing the amount of transmitted light. Through this, lenses that have a large amount of light transmission obtain bright images and are said to be “bright” and lenses that have a small amount of light transmission are said to be “dark”.
The relationship between lens focal length and diameter, or in other words, the F-stop, is one element that greatly influences the brightness and darkness of a lens. A lens with a small F-stop value will be a “bright lens” and one with a large value will be a “dark lens”. With a general compact camera, the side of the lens will be marked with something like “F=2.5” or “1:2.5”. This means that the F-stop is 2.5. For the performance of the camera lens, if the F-stop is around 2.0, it can be said that its class is rather bright.

09 Mount

A mount is a mechanism that secures the lens for image processing equipment that can replace the lens. It is also called a lens mount and in general, lens mounts for SLR cameras are well known. In image processing, C-mounts and CS-mounts are often used.

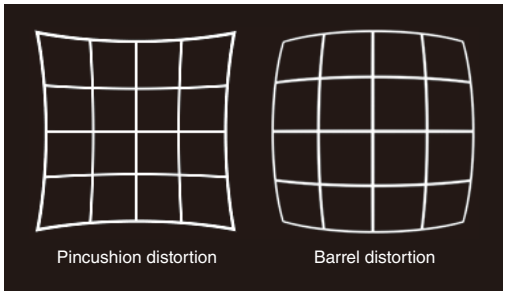
10 Distortion

Distortion signifies a state where an image reflected through the lens is deformed. In truth, a perfectly-shaped lens does not exist. Due to this, ideally, direct light that has passed through the lens should advance unaltered, however the light that has passed through the lens will distort along the outer or inner areas. The former is called “barrel distortion”, while the latter is called “pincushion distortion”.

Distortion will appear as barrel distortion with a wide-angle lens and will appear as pincushion distortion with a zoom lens. In order to correct distortion, an aspherical lens is used.

What makes us different

With original optical design, KEYENCE lenses drastically reduce distortion when compared to standard lenses.
The CA-LH Series uses a floating structure, and the CA-LHR Series uses a floating structure and aspherical lens* to correct distortion.



* For information on aspherical lenses, refer to "Lenses #1".

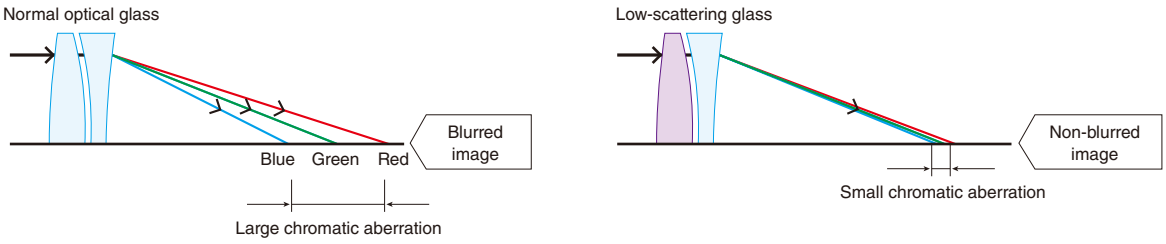
11

Chromatic Aberration

Principles of Chromatic Aberration

Chromatic aberration signifies when the refractive index differs depending on the wavelength of the visible beam, causing the image that is generated after being transmitted through the lens to be misaligned. A differing refractive index means a differing focal length. So, the colors of each wavelength each, individually form an image and reflect an image that looks blurred.

▶ **The mechanism of chromatic aberration (axial chromatic aberration)**



Types of Chromatic Aberration

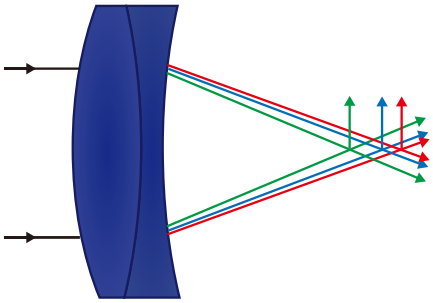
There are two types of chromatic aberration: axial and transverse.

Axial chromatic aberration:
A state in which the refractive index differs by wavelength of light, which then changes each focal point, resulting in an image that is entirely blurred.

Transverse chromatic aberration:
A state in which the magnification of the image differs by color, causing colors to bleed as you approach the edges of the lens.

How to Prevent Chromatic Aberration

A method used to resolve the problem of chromatic aberration involves utilizing a lens with a different refractive index, called an achromatic lens. Other methods include using lens materials that have low dispersion such as fluorite (calcium fluoride crystal) or ED glass.

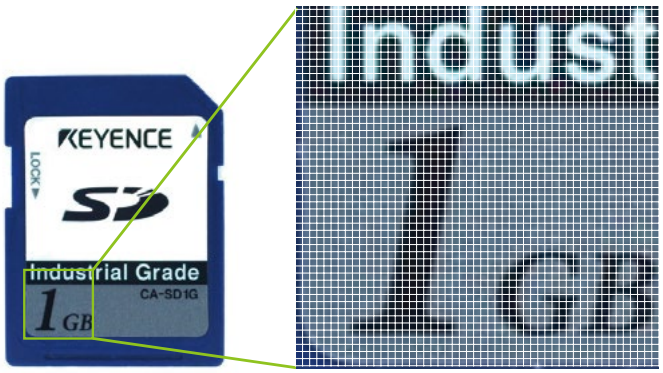


Chromatic aberration correction with an achromatic lens

12 What is a Pixel?

A pixel signifies the smallest structural unit of a digital image. An image on a computer is rendered in pixels, a collection of points that have been aligned in an orderly fashion. Every single point possesses color information called hue or tone and through this, it's possible to draw a color image.

For example, with an LCD, "resolution: 1280 × 1024" is displayed. This indicates that the amount of pixels lined-up horizontally is 1280 and vertically it's 1024. With this display, the total amount of pixels comes to 1280 × 1024 = 1,310,720. Images can render more details as the pixel amount increases, so from this we can say that an image has "high resolution".



13 How Pixels Work

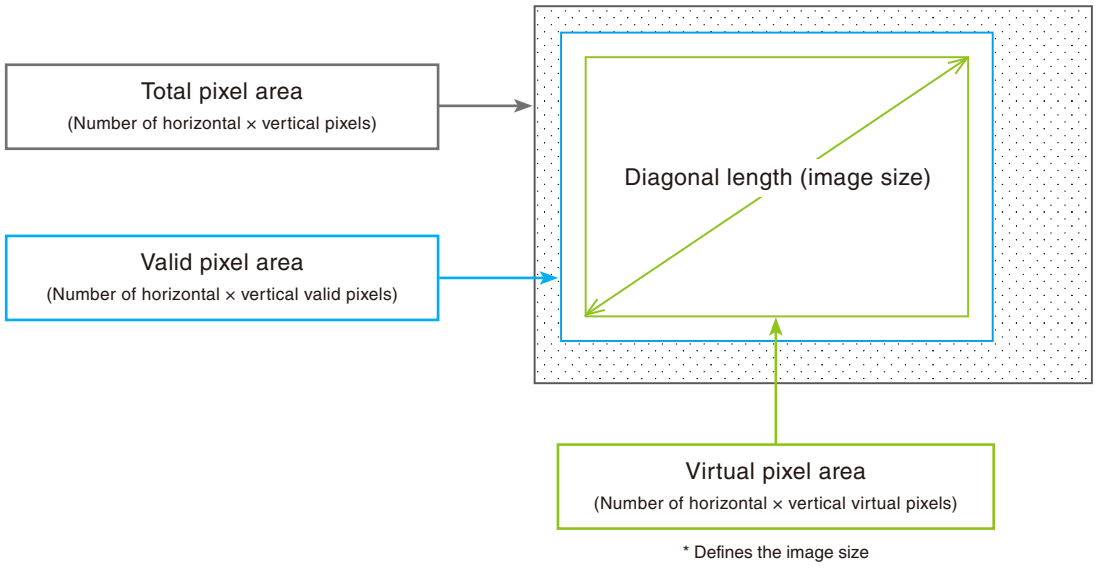
All pixels for the image sensor (image receiving element), which is represented by the CCD, do not function to output image signals. There are total pixels, which signify the pixels of the entire image sensor, in addition to valid pixels and virtual pixels, which are the actual functioning pixels.

Valid pixels:

The pixels amongst the total pixels that handle image signals. When showing the performance of a digital camera, its performance is determined by guidelines that ask you to use the number of valid pixels.

Virtual pixels:

The pixels amongst the valid pixels that guarantee the performance of the product.



14 Shutter Speed

This signifies the period of time in which a charge is accumulated in the image sensor of a CCD or CMOS. If the shutter speed is 1/250, then period of time in which it will gather light is 1/250 seconds. When the shutter speed is fast, the amount of light that hits the sensor is small. Conversely, when it is slow, the amount of light that hits is large. In other words, it can be said that shutter speed serves as a function that adjusts the amount of light. Shutter speed and the amount of received light (accurately speaking, the amount of accumulated charge) have the following relationship.

[EXAMPLE] When a shutter speed of 1/1000 sec. (1 ms) is considered standard...
- When the shutter speed is 1/500 sec. (2 ms), the amount of light that will hit will double.
- When the shutter speed is 1/2000 sec. (0.5 ms), the amount of light that will hit will be halved.

15 What is Gain?

Gain signifies the electrical amplification of image signals. CCD cameras for image processing have a built-in function that amplifies signals when capture has been performed in dark areas, making it so that they appear bright. They also have a gain control function, which automatically adjusts the gain in response to the brightness of the target.

The effect of increased sensitivity

Before increasing sensitivity

After increasing sensitivity

A comparison of images at 1/10000 shutter speed

* A comparison on a like-for-like basis with fluorescent lighting.

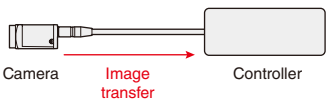
What makes us different

All of our CCD cameras for image processing use KEYENCE developed cameras.

Our cameras have built-in specialized integrated circuits called ASIC (See below), and it's possible to freely set items such as image area, process area, shutter speed, and transfer system from the controller side. These functions are not implemented with support from the controller side, but with support from the camera-side only. As a result, there is no added processing time even if the settings are changed. This is also the effect of having the specialized ASIC built-in.

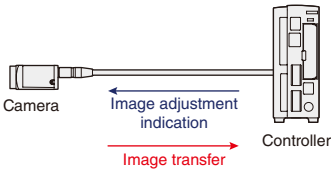
Conventional

Only processes images from the camera



ASIC built-in

Processes received images after indicating optimized images



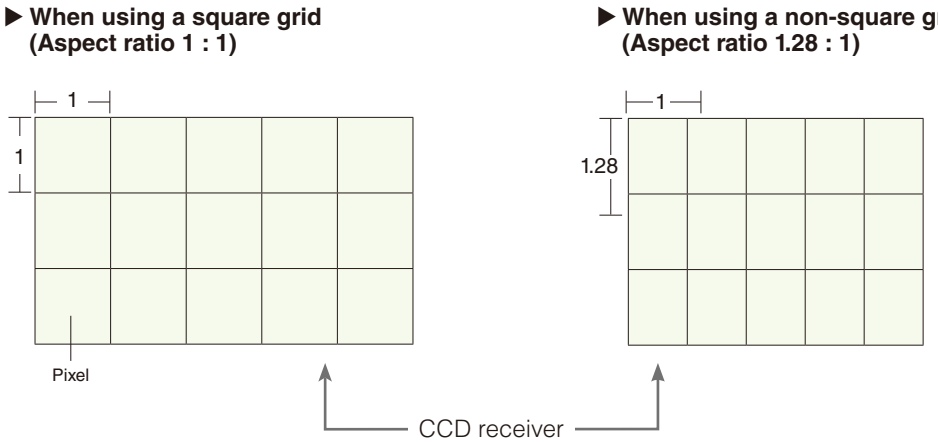
COLUMN 3

What is ASIC?

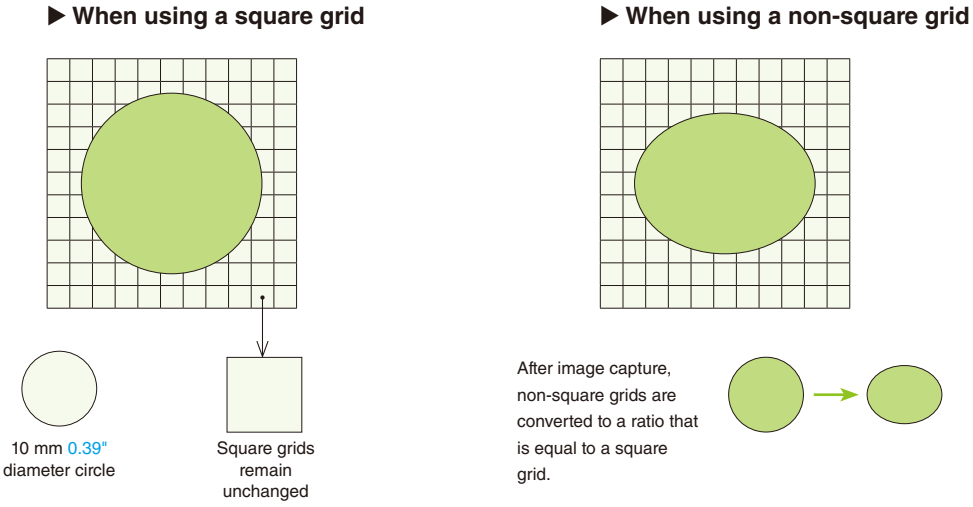
It is an abbreviation of Application Specific Integrated Circuit. It is a general customized LSI (large scale integration), and signifies an integrated circuit that was created for the purpose of being used for specific operating applications.

16 Square Grids and Non-square Grids

A square grid (array) indicates that the vertical and horizontal pixels of the unit cell are in equal proportion. Because it is a 1 : 1 ratio, it has the benefit of being able to maintain high-accuracy without adjusting the image.



[Case study] What happens when a circle 10 mm 0.39" in diameter is captured?



When image data that has been captured with a non-square grid CCD is displayed in direct image processing pixels (1 : 1), circles will appear horizontally elongated, making it necessary to correct the image.

Many different kinds of lighting are used in factory automation (FA) for positioning, inspections, and other applications.
When selecting appropriate lighting for each application, it is necessary to understand the characteristics of light sources.

17 Light Sources – Types and Characteristics

LED

"LED" stands for "light-emitting diode" and describes a diode (an elemental semiconductor) that emits light. While fluorescent lights use discharge phenomena to convert electrical energy into light indirectly, LEDs convert electrons into light directly. Thus, they are highly efficient at converting energy and are energy-saving light sources. Moreover, LEDs have long lifespans, emit an abundance of wavelengths (colors) and have many other advantages, so they have been widely used in image processing in recent years.

Fluorescent Lights

Fluorescent lights emit visible light when ultraviolet rays generated by arc discharge phenomena hit the fluorescent substance inside of their glass tubes. Typically, the insides of the tubes are coated with the fluorescent substance and contain encapsulated mercury. The tubes are then sealed and electrodes for discharging electricity are placed at each end.
Fluorescent lights have been widely used in the past because they last longer than incandescent bulbs. They emit white light and daylight colors, and there are three-wavelength fluorescent lights that emit colors very similar to natural light. They come in various shapes such as bulbs and straight or circular tubes.

Halogen Lamps

Halogen lamps feature bulbs with inactive gases, such as nitrogen, and halogen gases, such as iodine, enclosed inside. They emit light using the same principle as incandescent bulbs but shine brighter and last longer. They are used in car headlights, spotlights at commercial facilities and photography studio lights. The light is limited to the color of the bulb.

Xenon Lamps

Xenon lamps are gas discharge lamps that emit light similar to natural light. Xenon gas is enclosed inside of silica tubes. Compared to incandescent bulbs, xenon lamps are brighter, consume less energy, and last longer. They are mainly used as light sources for projection devices and projectors.
Xenon lamps include short-arc lamps, long-arc lamps, and flash lamps.

Metal Halide Lamps

Metal halide lamps are a type of high-intensity discharge (HID). A mixed vapor consisting of metal halide (halogenated metal) and mercury is enclosed inside the lamps, and they emit light from arc discharge. Advantages of metal halide lamps include high intensity, low energy consumption and long lifespans. Metal halide lamps have long been used on roadways and in tunnels, and are used to light the insides of large architectural structures, aquariums for ornamental fish, and night games at athletic facilities.

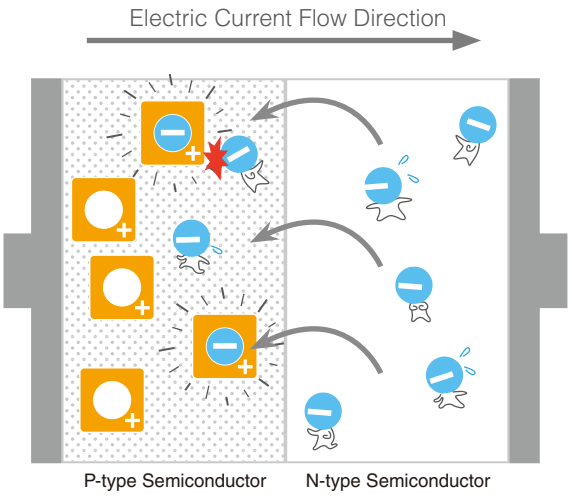
Relative Characteristics of Different Types of Lighting

	Brightness	Lamp Lifespan	Colors	Power consumption
LED	Somewhat inferior	Long	Abundant	Conserves energy
Fluorescent Lights	Somewhat inferior	Somewhat short	Few	Conserves a bit of energy
Halogen	Bright	Somewhat short	Few	Many
Xenon	Bright	Long	Few	Conserves a bit of energy
Metal Halide	Bright	Long	Few	Conserves energy

18 LED

Basic Structure

LEDs emit light when electrons collide with positive holes inside of joined N-type and P-type semiconductors with electricity flowing through them.
The wavelength (color) of the light depends on the size of the bandgap of the semiconductor (the region where electrons cannot exist).
Thus, many different semiconductor materials for many different wavelengths have been created.
Applications in display, lighting and other areas have increased greatly in recent years thanks to the invention of blue LEDs that use gallium nitride as well as white LEDs.



Light resulting from the collision of electrons and positive holes.

Why are LEDs used so heavily in image processing?

Compared to fluorescent, halogen, and other lighting, LEDs are better at switching, last longer, and have better shapes.
Their main characteristics are as follows:

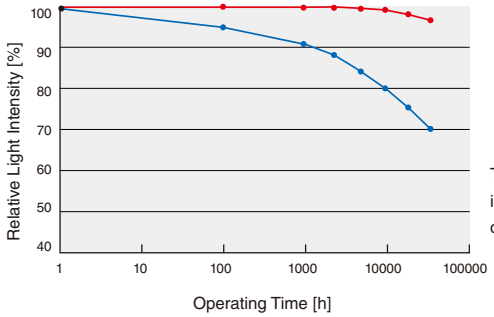
Fast Response Speed

LEDs use elemental semiconductors and have superior switching capabilities. Thus, the response speed of single elements is characteristically on the order of a nanosecond.

Long Lifespan

With half-lives of tens of thousands of hours, LEDs last tens to hundreds of times longer than fluorescent lights, and, unlike fluorescent lights, repeated switching does not shorten their lifespans. This long lifespan makes it possible to save on costs and on the bother of replacing lamps.

Continuous Lighting (Blue Line) vs Intermittent Lighting (Red Line) (Representative Example)



This figure represents the change in relative light intensity when lights are on for one unit of time and off for four units (ON:OFF = 1:4).

Shape Advantages in Image Processing

The small size of LEDs enables creation of highly-flexible lighting fit to production lines.

Range of Colors and Homogeneity of Light

LEDs are known for their abundance of wavelengths. In addition to visible blue, white, and red, they can also emit ultraviolet and infrared light, allowing for the selection of any color to suit the workpiece. And with no irregularity in intensity, the homogeneity is superb.

19 Diffusion Plates and Polarizing Plates

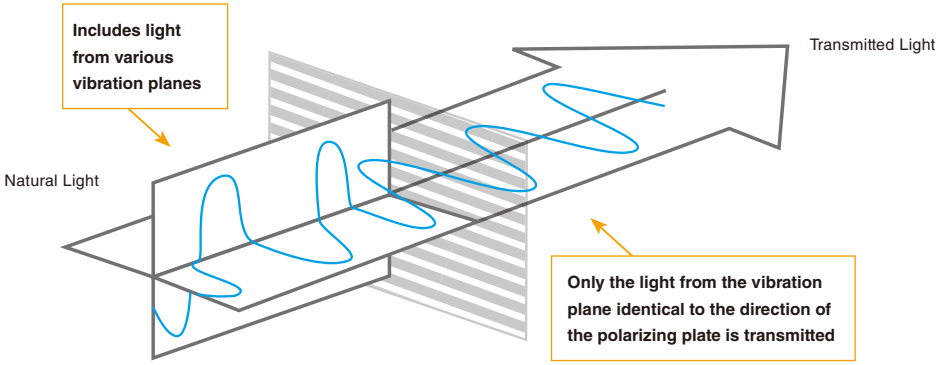
Diffusion plates and polarizing plates are used in order to make lighting fit the objective and for efficient application.

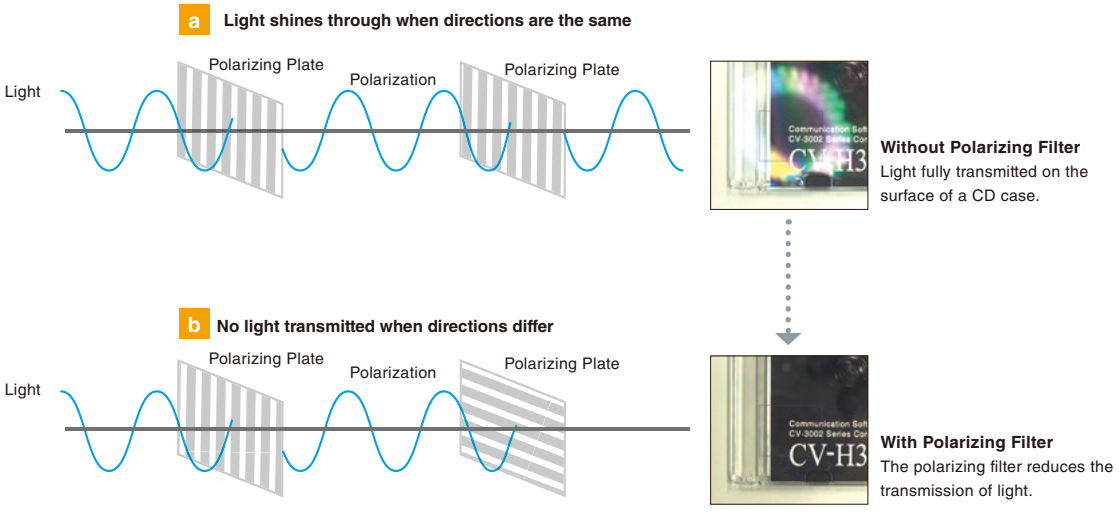
Diffusion Plates

Diffusion plates are sheets or films that diffuse light evenly across entire surfaces. Polished glass filled this role in the past. Nowadays, diffusion plates are used as part of the backlights fitted into the back of LCD panels.

Polarizing Plates

Natural light includes many vibration planes facing in different directions. This is where polarizing plates are used to produce light only from a given plane. Polarizing plates have extremely thin slits cut into them, and light shone through one polarizing plate produces only the ray on the same vibration plane as the slit. When two polarizing plates are used together, sometimes light will not shine through.
The display boards on LCDs make use of this phenomenon that helps display images depending on whether or not light is transmitted.

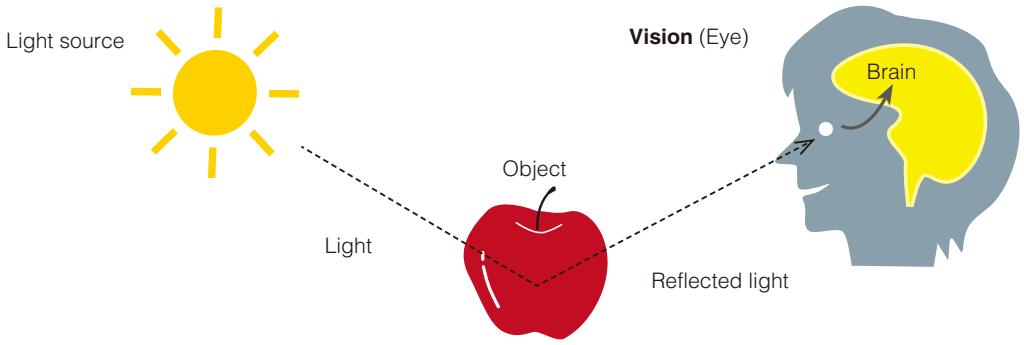




How do human eyes and cameras recognize color?
This chapter provides an explanation of important color concepts that affect image processing.

20 What is Color?

All objects have color. However, in order to recognize that color, two other elements are essential: light and an eye that can recognize that color. In short, 'color' is perceived visual stimuli, specifically the light reflecting off an object, received through the eye and transmitted to the brain.



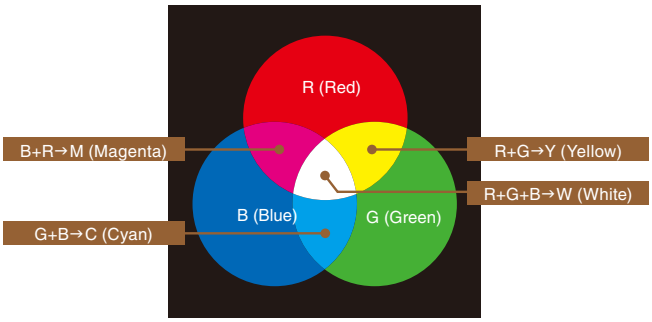
21 Three Primary Colors

Color is defined on the basis of the three primary colors. The primary colors are colors that cannot be produced by mixing other colors.
The three primary colors are the source of all other colors.

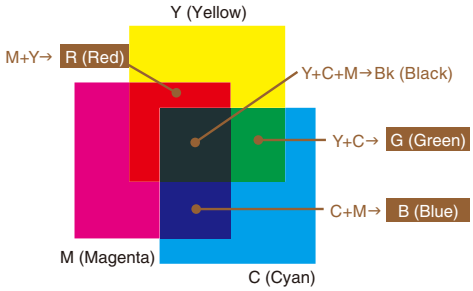
The difference between RGB and CMY

The three primary colors of light are red, green, and blue. Taking the first letter of each color, the three primary colors of light are collectively called "RGB." When all three colors of light are mixed, white is produced.
On the other hand, the three primary colors of pigment are cyan, magenta, and yellow, which are collectively referred to as CMY, from the first letters of the colors. Mixing the three colors of pigment will give you any tone and/or shade between (and including) white and black depending on the brightness of the introduced pigments.

Three Primary Colors of Light



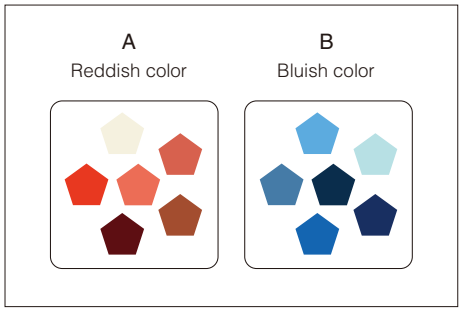
Three Primary Colors of Pigment



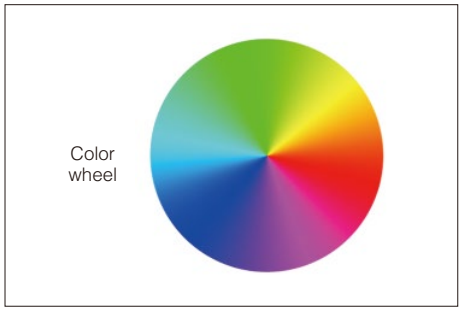
22 Three Properties of Color

Color can be defined using a number of different schemes, and one of them is by using the three attributes of color: Hue, saturation, and brightness (value). The individual colors can be identified using these attributes.

Hue



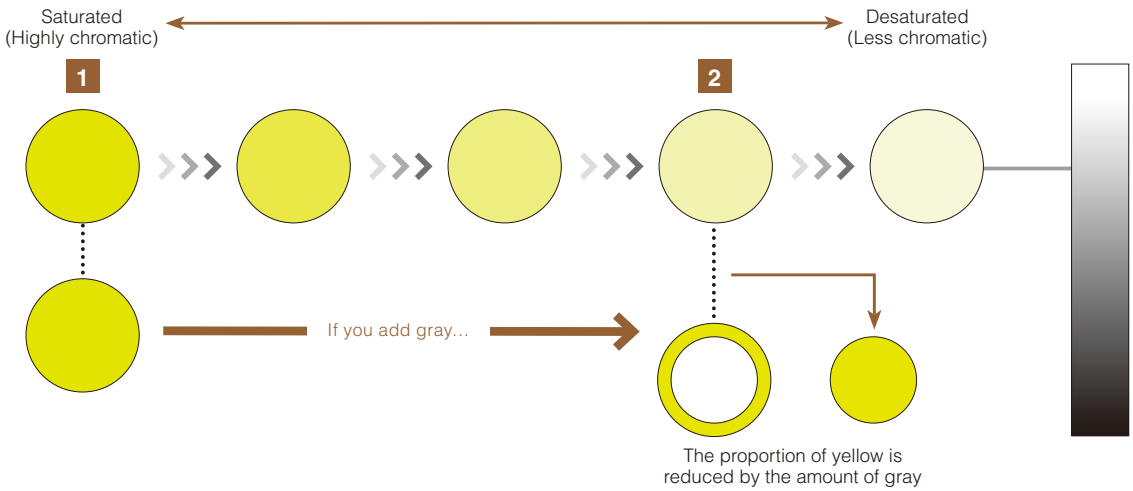
Color can be classified into a group of chromatic colors, or colors that have a hue, or a group of achromatic colors (white, black, pure grays), or colors that do not have a hue.
Among chromatic colors, the color variation (red, blue, and yellow) is called a “hue.”



Major hues include red, yellow, green, blue, and purple. A circular arrangement of hues based on the color spectrum that centers on these hues is called a “color wheel.” By using a color wheel, you can create intermediate colors and complementary colors.

Saturation

Saturation is the level of vividness of a color and indicates chromatic purity. A highly chromatic, vivid color is described as “saturated” while a less chromatic, pastel color is described as “desaturated.”
The most saturated colors are the “pure colors” while the most desaturated colors (colors with no vividness) are neutral colors.

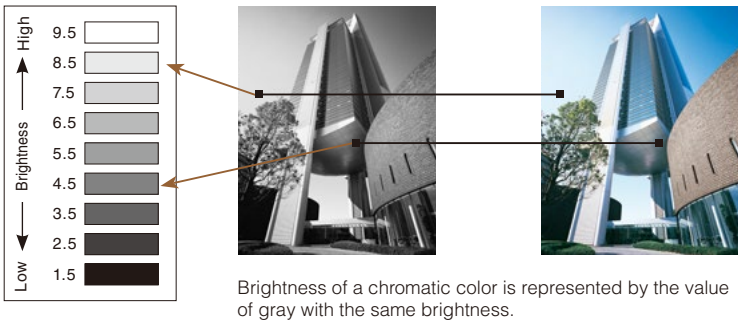


Brightness

Brightness (also called “Value”) represents the brightness or darkness of color. Both chromatic and achromatic colors have brightness.

Bright colors are described as “bright” while darker colors are described as “dark.”

The brightest color is white and the darkest color is black, and this applies to both the chromatic color group and achromatic color group. In other words, the brightness of a chromatic color can be expressed by the level of neutral color that corresponds to that brightness.



Brightness of a chromatic color is represented by the value of gray with the same brightness.

23 Complementary Colors

Complementary colors are any two colors on opposite sides of the color wheel, such as red and green, blue and orange.

Mixing the complementary colors will produce a neutral color. When complementary colors of pigment are mixed (subtractive color mixing), you will get black. When complementary colors of light are mixed (additive color mixing), you will get white.

Complementary colors are two colors on opposite sides of the color wheel

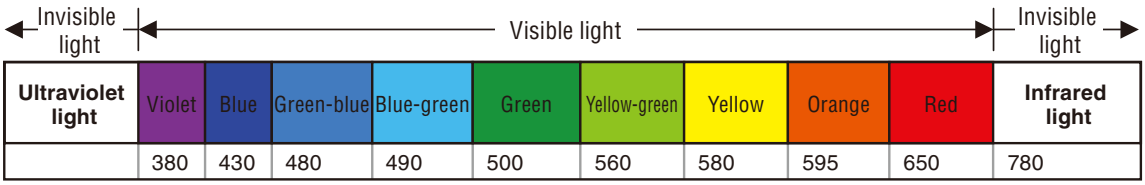
The two colors on the color wheel opposite one another are called “physical complementary colors.” In addition to “physical complementary colors,” there are “psychological complementary colors”, which are the colors that appear as an afterimage caused by the visual system of the human eye. For example, if you stare at a red color for an extended period of time and then look at something white, you will ‘see’ a light afterimage of cyan.

24 Relationship Between Wavelength and Color

When natural light is split by a prism, the 'white' light appears to be seven different colors of light. The difference in the color of light varies depending on its wavelength. As the wavelength gets longer, the color changes from violet to blue, then green and yellow, before finally hitting red. The wavelength of each color is shown below.

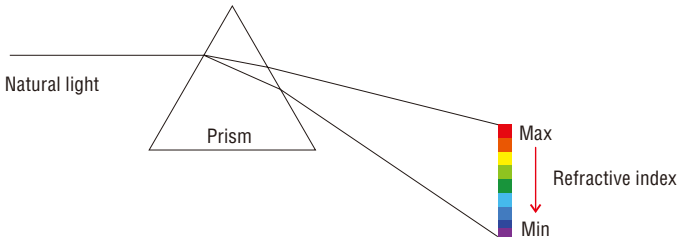
nm = nanometer

Violet	400 to 435 nm
Blue	435 to 480 nm
Green-blue	480 to 490 nm
Blue-green	490 to 500 nm
Green	500 to 560 nm
Yellow-green	560 to 580 nm
Yellow	580 to 595 nm
Orange	595 to 610 nm
Red	610 to 750 nm
Red-violet	750 to 800 nm



(Unit: nm)

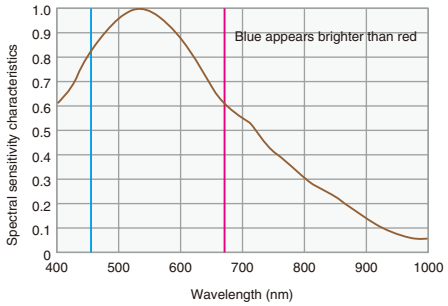
Image of optical refractive index (natural light)



When natural light travels through a prism, the refractive index of light closer to violet is greater while the refractive index of light closer to red is smaller. That is, the shorter the light's wavelength is, the greater its refractive index.

25 Sensitivity Characteristics (Spectral Characteristics)

The wavelengths of light that a camera or image sensor can respond to are defined by its sensitivity characteristics or spectral characteristics.
For example, the human eye is sensitive to light with a wavelength between 380 and 760 nm, peaking at 560 nm. This indicates that the human eye is most sensitive to the color green, which is at the center of the visible spectrum.
In general, CCD cameras are made based on the sensitivity characteristics of the human eye. There are also CCD cameras that have sensitivity characteristics that support ultraviolet light and infrared light.



The figure shows an example of sensitivity characteristics of a CCD camera if 560 nm, the wavelength the human eye is most sensitive to, is '1.'
Here, you can see that blue (460 nm) appears approximately 1.3 times brighter than red (660 nm).

RS-232C is a communication method used to output the result of image processing, or to control an image processing instrument from a PC or PLC. The following describes details of the RS-232C communication.

26 What is RS-232C?

Communication protocol for serial type transmission

RS-232C is a type of serial transmission used for communication between computers (or PLCs) and sensors or other peripheral devices. Another serial type communication protocol is USB. This type is generally incorporated into personal computers.

RS-232C is an abbreviation for “Recommended Standard 232 version C.” It is a designation of the communication protocol used to transmit digital signals and is standardized by Electronic Industries Alliance (EIA) in the United States. The maximum communication speed is 115.2 kbps.

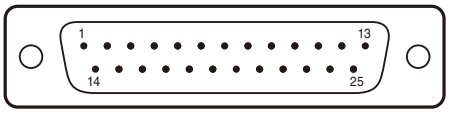
There are two types of digital signal transmission: Parallel and serial.

The former transmits data of 8 or 16 bits simultaneously through multiple lines. The latter transmits one bit of data at a time through two lines, one for sending and the other for receiving. Consequently, it is noticeable that the parallel transmission is faster in terms of communication speed.

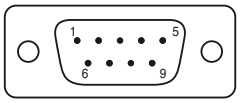
However, the parallel transmission involves complicated wiring. The serial transmission is slower in terms of communication speed, but its wiring is far simpler.

At present, parallel transmission is used for signal transmission inside a device, such as internal transmission inside a computer; and serial transmission is used for transmission between devices.

RS-232C terminal pins (D-sub 25-pin)



RS-232C terminal pins (D-sub 9-pin)



27 Points for Setting RS-232C

RS-232C communication specifications

RS-232C communication requires setting of the following specifications.

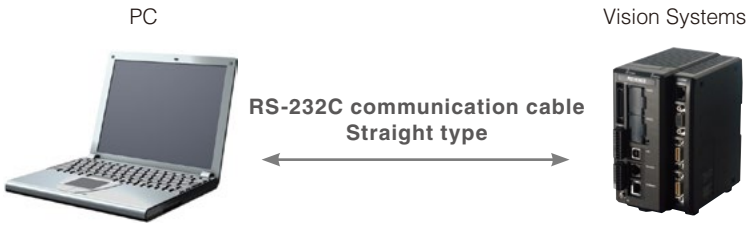
Specifications	Setting description
Baud rate	Number of bits transmitted in one second
Data bit length	Number of bits of data
Parity check	Setting for communication error detection
Stop bit length	Number of stop bits
Data delimiter	Symbol used to separate data

RS-232C communication cable

There are two types of RS-232C communication cables: Straight type and cross type. In general, a straight type is used for connecting a computer (or PLC) and peripheral devices (including sensors). A cross type is used for connecting computers.

The most common way to distinguish between these cable types is a straight type cable has “male and female connectors” at the ends, and a cross type cable has “female connectors” at both ends. The maximum length of an RS-232C communication cable is 15 m 49.21'.

<To connect an image processing instrument and a PC>



<To connect an image processing instrument and a PLC link unit>

To establish RS-232C communication between an image processing instrument and a PLC, connect a “straight type” communication cable to the “PLC link unit”.

Gender changer

When a PC (or PLC) and a peripheral device are connected with more than one cable for extension, an “extension adapter” is used to connect the cables.
Normally, the RS-232C connector on the device is “female”, and the connectors at both ends of the cable are “male”.
Therefore, a “female-to-female” gender changer (device to change between male and female) is required to connect two cables.

Gender changer to convert from D-sub 9-pin female to D-sub 9-pin female

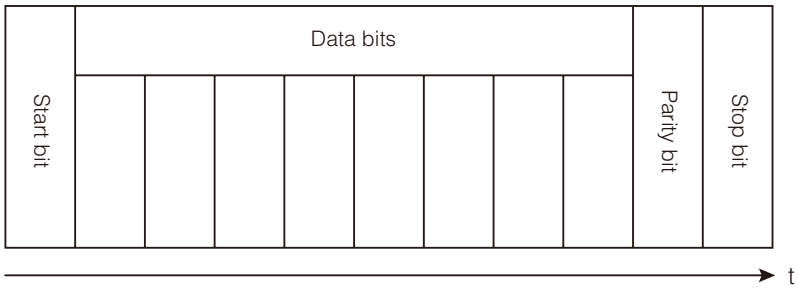
28 Communication Speed

Baud rate and bps

Although both the baud rate and bps (bit per second) are used as the unit to transmit digital signals, the baud rate does not equal the bps rate. The Baud rate is a unit to express the number of modulation/demodulation actions which a modem or other device can make in one second. On the other hand, bps is a unit to express the amount of signals which can be transmitted in one second.
The unit to express communication speed is bps.
For example when a modem can make 2400 modulation/demodulation actions in one second and can transmit a signal of 2 bits in one modulation/demodulation, its baud rate is 2400 and communication speed is 4800 bps.

29 Outline of Communication Specifications

The RS-232C communication starts with a start bit and outputs other items in the order of data bits, a parity bit, and a stop bit. One byte of signal can be sent in this process.



Start bit

This bit notifies that communication will start from now. The start bit is always fixed to 0 (zero).

Data bits

The data bits normally consist of 7 or 8 bits. The number of bits can be specified as desired.

Parity bit

This bit is used to check whether the sent data is correct or not. The setting can be selected from “Odd”, “Even”, or “None”.

Stop bit

This bit notifies that one byte of communication has finished. One (1) is always sent as a stop bit.

Delimiter

To send a communication command from the RS-232C port of a PC (or PLC), you need to set a symbol to separate each command between the PC (or PLC) and peripheral device. This separating symbol is called a delimiter. In most cases, “CR (Carriage Return)” or “CR + LF (Carriage Return + Line Feed)” is used.

30 Handshake

To enable the RS-232C type communication, the terminals at both of the sender and receiver sides need to read/write signals at the same communication speed. However, if the signal processing on the receiver side delays, the sent signals may be lost. Handshake is a mechanism to prevent this problem, where the terminals on both sides confirm the communication status of each other. If the processing in the receiver terminal delays, the sender temporarily stops sending signals and resumes sending when the receiver can accept signals.

There are three types of handshake: Hardware handshake, software handshake, and Xmodem.

31 Communication Protocol and Script

The communication protocol is the “conventions” or “procedures” used when a PC (or PLC) and peripheral devices communicate.

Modem definition file

Modem settings used for the RS-232C communication are described. Using the file containing the definition enables smooth communication.

Communication command

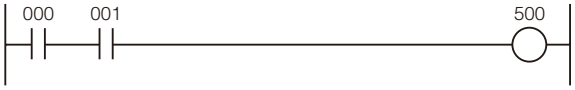
The commands for executing communication through the RS-232C port.

Script

A series of commands used when communication is made through the RS-232C port. A script is written in a more simplified language than programming languages.

Ladder language

A programming language used to write a logical circuit used by a PLC. Since the program is written based on two rails and rungs between them, the written program is called a “ladder diagram”. This programming language provides visually recognizable relationships between the input conditions and outputs.

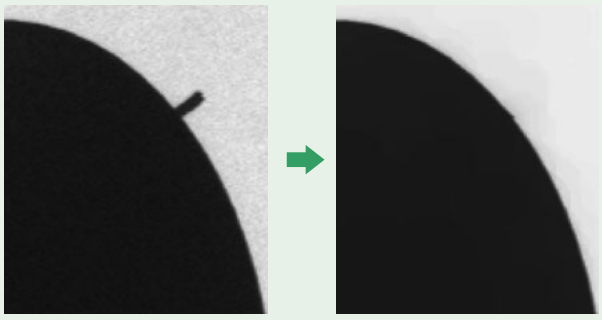


Ladder example: “AND circuit” which turns on output relay 500 when both input relays 000 and 001 are ON

To allow stable inspections using image processing technology, it is crucial to minimize noise in images. This chapter introduces preprocessing filters which reduce noise which cannot be eliminated only by improving optical conditions.

32 What is Preprocessing?

To perform quality inspections or measurements using image processing, it is essential to first obtain images of a high enough quality for their respective purposes. Images simply captured by a camera are not always suitable for these purposes due to the type of light source, material of workpiece or image capturing environment, which may result in an inconsistency in inspection results.
To avoid this problem, the captured images are sometimes processed (converted) using image filters in accordance with the intended use of images. This processing procedure is called image preprocessing. Image preprocessing can enhance the clarity of captured images, make the elements required for applications (shapes, colors, etc.) more distinct or eliminate undesirable components (noise). When preprocessing with filters, materials such as image processing devices and PC photo retouch software are used. There are many different types of filters, and it is important to understand their characteristics to select the optimum filter for the respective applications.



Example of image preprocessing
Filters eliminate noise to provide a clear image.

33 Filter Processing Area

When an original image is preprocessed with filters, a large image could require long processing time. For this reason, it is important to specify the areas to filter.

34 Filter Coefficients

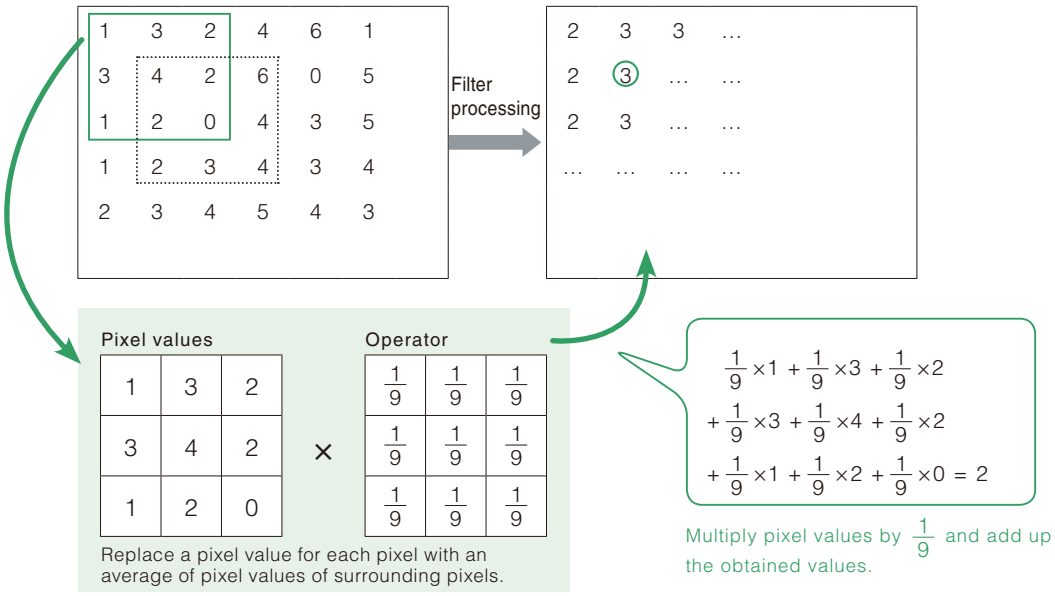
The typical filters used for preprocessing consist of filter coefficients of “3 × 3”, “9 × 9”, “16 × 16”, etc. With the “3 × 3” type, which is the most commonly used, the image data for 3 horizontal and vertical pixels are referenced, and the filter is applied to the pixel in the center.
For example, if an image is composed of 320 horizontal pixels and 240 vertical pixels, the image is filtered 76,800 times (320 × 240).

Example of filter coefficient
Filter coefficient used for averaging of an image

$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$

When the filter coefficient in the below figure is used, a preprocessed pixel value for each 3 × 3 area is obtained by multiplying respective pixel values of nine pixels in the original image by 1/9 and then adding them up. The filtered image can be obtained by repeating this calculation for each 3 × 3 area by shifting one column at a time.

Example of calculation using filter coefficient



35 Typical Filters

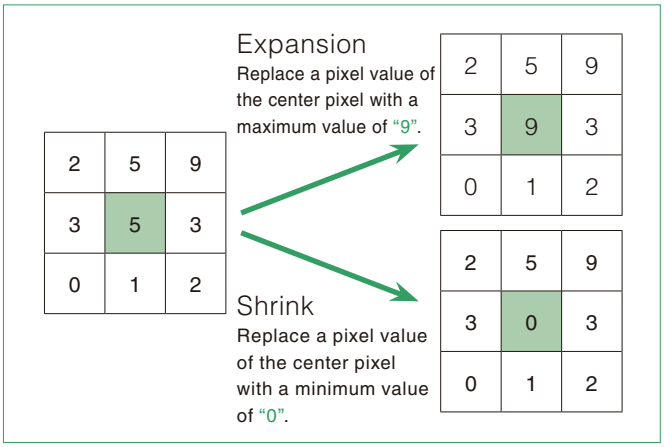
The following section introduces major filters typically used for image preprocessing. In actual applications, the combined use of multiple filters to obtain images which meet application needs has become a mainstream method.

Expansion filter

This filter eliminates noise components (dirt) which are undesirable for image processing. It replaces the pixel value of the center pixel in the 3 × 3 area with that of the highest value among nine pixels.
When an expansion filter is applied to a monochrome image, it will make all nine pixels white if any one of pixels surrounding the center pixel in the 3 × 3 area is white.

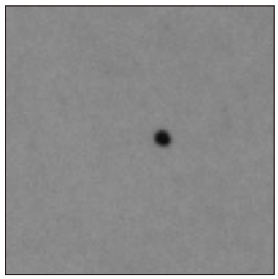
Shrink filter

A shrink filter is also effective to eliminate noise components. In contrast to the expansion filter, the shrink filter replaces the pixel value of the center pixel in the 3 × 3 area with that of the lowest value among nine pixels.
When the shrink filter is applied to a monochrome image, it will make all nine pixels black if any one of pixels surrounding the center pixel in the 3 × 3 area is black.



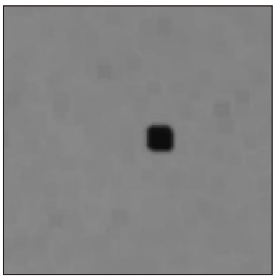
Even if fine noise components such as dirt are captured as part of an image, an expansion or shrink filter can remove them to make the image clearer.

Example of filter processing



Original image

After applying an expansion filter

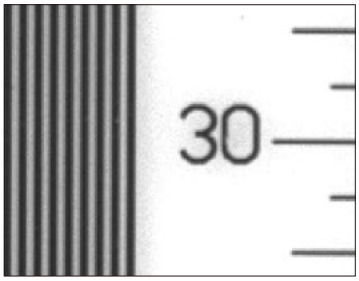


After applying a shrink filter

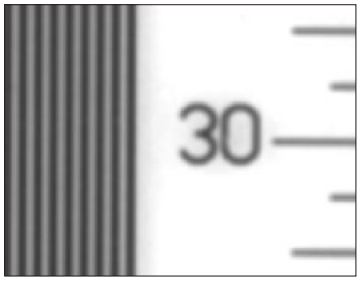
Averaging filter

The filter improves image quality by smoothing (softening) shading on them. It averages pixel values of all nine pixels including the one in the center. The impact of noise components can be also reduced by softening images. The filter also helps position measurements such as the edge detection of workpieces or pattern search stable.

To provide more natural smoothing, a weighted average filter can be used.



Original image

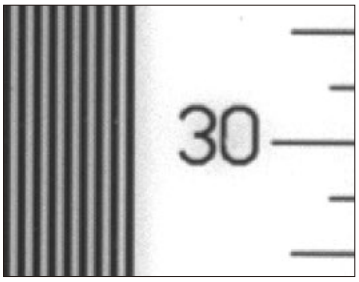


Averaging

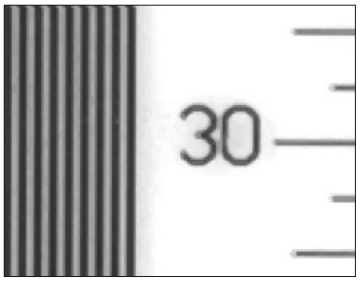
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$

Median filter

The filter sorts pixel values of nine pixels and then assigns their median to the center pixel as its pixel value. Unlike the averaging filter, it can reduce noise components without blurring images. The filter is effective especially for removing noise which is caused by pixels of very different color and intensity from those in their area.



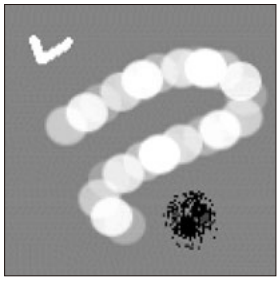
Original image



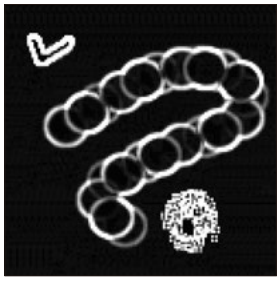
Median

Sobel filter

It is a type of filters which are effective for edge extraction. It emphasizes the edges on images with small contrast. In addition, the processed images look more natural.
Besides the Sobel filter, there are more filters used for the edge extraction, including Prewitt, Roberts and Laplacian filters.



Original image

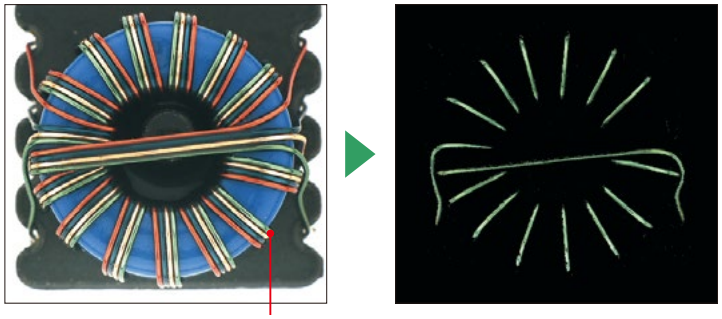


Sobel

36 Other Preprocessing

Color extraction

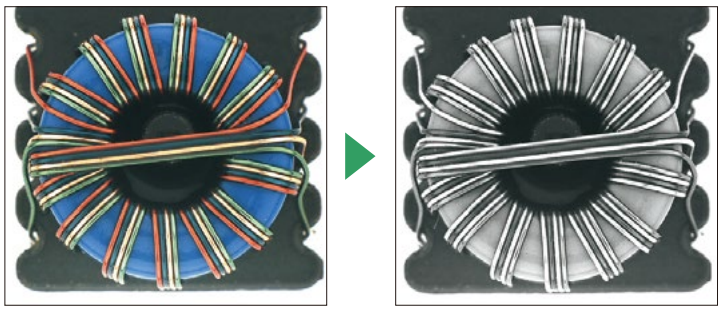
It is processing to extract specified color elements from a captured color image.
The color video signals are converted into R (Red), G (Green) and B (Blue) digital data. The color extraction is performed using these data.
This processing binary-converts each pixel into an extracted pixel or an unextracted one. For this reason, the process not only ensures a stable extraction even for dark colors but also diminishes the amount of color information data to be processed, eventually allowing high-speed post-processing.



Example of color extraction
Only the color element of green is extracted from the original image.

Gray-scale processing

The gray-scale processing, which is also known as shade-scale processing, is used to obtain the shade-scale information for an image captured with a camera. This processing divides the shade gradation of pixel into 8 bits (= 256 levels) and utilizes all of these 256-level shade data. Therefore, this processing significantly increases the accuracy in the detection of workpieces. It is very useful in the applications like the detection of workpieces which are difficult to detect with monochromatic binary processing.



In image processing applications, there is a growing need for data storage not only for measurement data but also images. This data is communicated between image processing devices and controllers to be stored in memory or on HDDs. Recently, Ethernet is more often used for this communication. Ethernet, which enables faster communication than RS-232C and USB, is suitable for the transmission of large volumes of data, and it is expected to have further widespread use.

37 What is Ethernet?

Overview of Ethernet

Many different types of communication functions are used for control systems. One of them is LAN (Local Area Network), which is the communications network connecting a group of computers to each other or a computer to other devices including measurement instruments and sensors.
LAN is a communications network used within a relatively limited area such as a office or factory, and Ethernet is widespread as major communication standard for LAN. In our daily life, Ethernet is used for the computer-to-computer or PC-to-Internet connections.

Positioning of Ethernet among communication standards

The forms of communications networks are roughly divided into two groups: wired communication and wireless communication. Ethernet is one of the wired communication technologies. The Ethernet network basically uses metal cables. However, in the standard with a transfer rate of 100 Mbps, fiber optic cables are used.
Wired communication is further categorized into serial communication and parallel communication according to the number of communication wire. Serial communication requires a single wire while parallel communication uses two or more. Ethernet is a type of serial communication like USB and IEEE1394 (FireWire).

Major communication standards by communication distance (Wired)

Very short distance (PAN)	RS-232C, USB, SCSI, IEEE1394
Short distance (LAN) Medium distance (MAN)	Ethernet, PLC, RS-422
Long distance (WAN)	FTTH, DSL

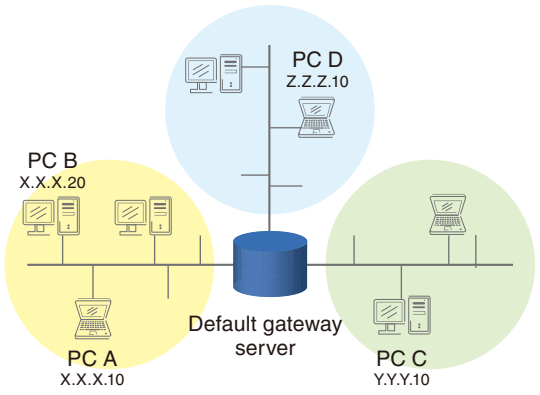
Communication standards categorized by communication wire type

	No. of communication wires	
	Serial communication	Parallel communication
Metal cable	Ethernet, USB, IEEE1394, RS-422	SCSI
Fiber optical cable	FTTH, GbitEther	

38 Default Gateway

LAN is a network built up with multiple computers and peripheral devices which are interconnected each other. In other words, it is a closed network since the devices on the network, which can communicate each other within the network, cannot connect to other networks or Internet. To communicate the devices on any other network beyond the boundary of its own LAN, the device must use a gateway, which means a “gate” or “entrance”. Among gateways, a default gateway is a typical “gate” used for the communication with external networks. Generally, a device called a router plays a role of default gateway.

Default gateway is a “gate” to connect different networks to each other.



39 Ethernet Communication Cable

Ethernet uses a communication cable called a twisted pair cable, which is generally known as LAN cable. There are roughly two types of LAN cables: straight cable and crossover cable. In addition, the cable specifications differ depending on the transfer speed and transmission band. When setting up a new network, it is necessary to select suitable LAN cables according to the types of devices to connect to each other and the communication conditions.
To distinguish a straight cable from a crossover cable, check the connectors with its both ends placed side by side. If the alignment of colors of jacketed wires is identical in both connectors, it is a straight cable.

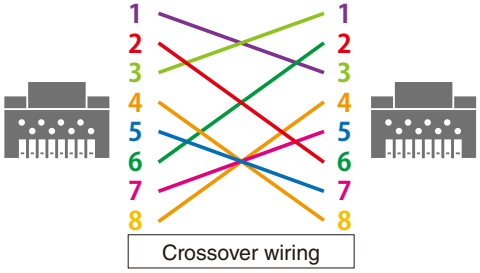
Straight cable

It is a LAN cable used to connect a computer to a switch (like a hub) , a hub to a router, and so on.

Wires are aligned in the same order at both ends. (Colors assigned to respective wires stay in the same order.)

Crossover cable

A crossover cable is used mainly for the following connections: computer to computer, hub to hub, router to router and computer to router.



Wires are aligned in different orders at both ends. (Colors assigned to respective wires are left-right reversed.)

40 IP Address

Overview of IP address

The devices on an Ethernet network communicate with each other using a protocol called TCP/IP. The same goes with the access to the Internet. In these communications, each computer or peripheral device is recognized with its IP address, which is an identification number assigned to each device. The IP address is unique to each device to represent its location on the network.
The IP address consists of four sets of numbers from 0 to 255; for example “192.168.36.91”. In an internet connection, no identical IP addresses can exist.
The total number of currently available IP addresses (IPv4) is approximately 4300 million, but the world is expected to run out of available IP addresses under IPv4 due to the global spread of the Internet. To cope with this problem, switching the protocol to IPv6 (340 trillion × 1 trillion × 1 trillion addresses) is now under discussion.

Global IP address

Among the IP addresses, a global IP address is a unique address assigned to a communication device such as a computer when it is connected to the Internet. The global IP address is assigned to devices to be connected to a LAN and/or WAN (Wide Area Network).
This was originally controlled by an organization called the IANA (Internet Assigned Number Authority), but now the actual control work is performed by the ICANN.

Private IP address

The global IP address is needed for the connection to the Internet, whilst a private IP address is an address assigned to a device on a LAN. The device uses the private IP address for the communication within the LAN, but when it accesses external networks like the Internet, the private IP address is converted into its global IP address.

41 UDP (User Datagram Protocol)

This is a part of TCP/IP suite, representing a protocol (communication procedure) used with the IP which defines an Internet address.
Although the UDP provides a high transfer speed, data sometimes goes missing during transfer since it does not confirm whether data transfer was successfully performed or not. For this reason, it is not suitable for data transmission, which requires high reliability. The UDP is used mainly for the streaming transmission of voices and videos, where the dropping of some data packets does not cause serious problems.

42 Applications of Ethernet Communication in Image Processing

Last years Ethernet communication is utilized in various ways in image processing. The application of ethernet is not limited only to the communication of measurement data between image processing devices and external control instruments such as PCs or PLCs, but nowadays is used for an increasing number of other applications such as the output of all captured images including NG images to an FTP or PC.

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