INTRODUCTION TO INDUSTRIAL BARCODE READING

Understand the inner workings of 1D and 2D codes, printing and marking methods, and types of barcode readers

COGNEX

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WHAT IS A BARCODE

A ***barcode*** is a machine-readable pattern applied to products, packages, or parts. Barcodes contain data used for informational and marketing purposes as well as for tracking products throughout their lifecycle. Barcodes are read by using a special reader or scanner with lights and lenses that decodes the data in the codes. The information is then transferred to a database where it can be logged and tracked.

Although barcode technology was originally patented in 1952, it wasn't until 1974 that the first product—a package of Wrigley's gum—was scanned at a Marsh® supermarket in Ohio. Today, barcodes come in dozens of different formats, from a row of simple lines called a ***1D (one-dimensional) barcode*** to dots and squares that form a ***2D (two-dimensional) code***; ***QR (Quick Response)*** and ***Data Matrix*** codes are among the most popular 2D codes. The more advanced 2D code allows users to store and retrieve significantly more data than they could with a 1D code. This is because 1D codes only contain data in the horizontal direction whereas 2D codes contain information both vertically and horizontally.

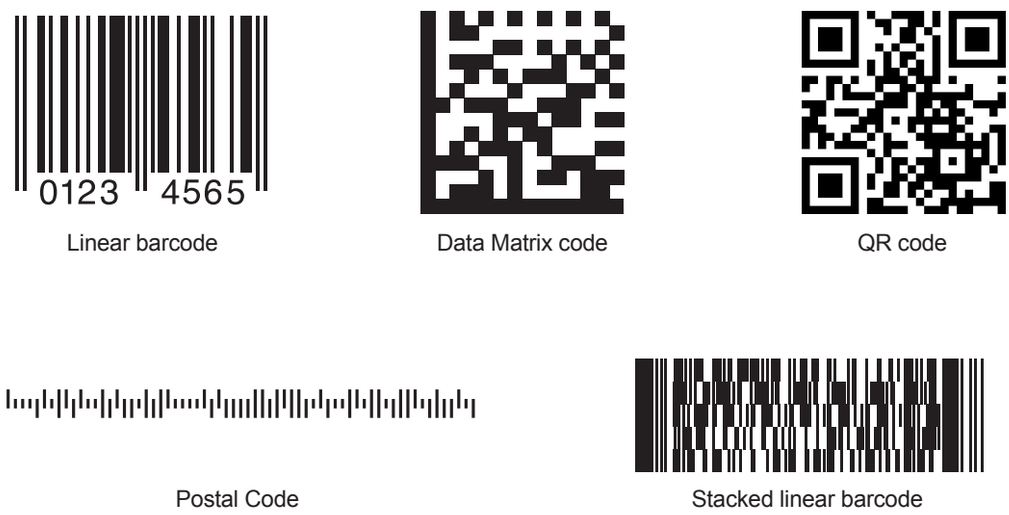


Figure 1: *1D and 2D code formats*

HOW BARCODES ARE USED

Barcodes are used as a means of quick identification. Nearly every industry uses barcodes to automate and simplify traceability by tracking everything from where something was produced and when it was shipped, to which retailer sold the product, at what time, and for how much. Overall, barcodes provide better accuracy, traceability, and sorting abilities than relying on manually-entered data.

Figure 2: *Barcodes are used in almost every industry*

Safety and liability are also drivers behind industry adoption of barcodes. In recent years, governments around the world have started to require medical devices and pharmaceutical manufacturers to apply machine-readable codes on every package down to individual medicine containers. Should a defective product reach a store shelf, automated tracking of every package will accelerate safety recalls while making quality-control data available to the entire supply chain.

TYPES OF BARCODES

1D barcodes

The first barcodes implemented worldwide were 1D barcodes. These linear codes only contain alphanumeric data. Each character in the code represents something different about the product and a database provides information on what each character means.

In most cases, 1D barcodes are read from left to right. The widths of the spaces and bars relate to a specific character in the barcode. A ***quiet zone*** or ***margin*** is the white space to the left and the right of the barcode; this helps the reader to locate the barcode. As a general rule, the margins should be at least seven to ten times the narrowest bar width in the barcode.

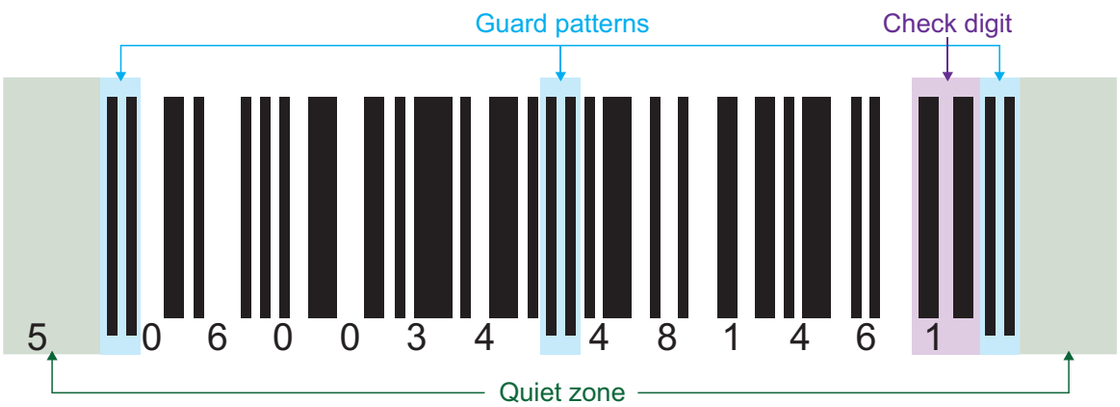


Figure 3: *Structure of a 1D code*

All the other bars in the code are based off a ratio of the narrow bar width. For example, 2:1, 3:1 and 2.5:1 are common ratios that describe the width of white spaces and black bars based on the starting point of the narrowest black bar. Some barcodes also have a ***guard pattern***. The guard pattern is at the beginning and end of the barcode; this pattern tells the reader where the barcode starts and ends.

Symbologies

Common 1D barcodes include but are not limited to: the ***GS1***; ***UPC (Universal Product Code)***, which is common in retail and consumer goods; ***EAN*** in the European Union; and ***Code 128***, which can describe any ASCII 128 character and is commonly used in logistics. Most of these barcodes include a ***check digit*** as part of its standard. The check digit is used to verify that the code is complete and not damaged or otherwise missing information; it does this by performing a mathematical operation on the data within the code.

Other 1D codes, such as ***Code 39*** (widely used by the military), ***POSTNET*** (used by the United States Postal Service®), ***Codabar***, and ***Interleaved 2 of 5*** offer optional check digits. ***Pharmacode***, which is used for the pharmaceutical industry, can be read both forward and backward. The drawback of this code is that it must be positioned the same way each time it is read.

Code 128

Typical usage:
Logistics

UPC-A

Typical usage:
Retail & Supermarkets in United States

EAN-13

Typical usage:
Retail & Supermarkets in Europe

Code 39

Typical usage:
Military & Automotive

Code 93

Typical usage:
Military, Automotive & Healthcare

Codabar

Typical usage:
U.S. Blood Banks, Photo Labs, FedEx® Airbills and Libraries

Interleaved 2 of 5

Typical usage:
Distribution & Warehousing

MSI/Plessy

Typical usage:
Supermarkets

POSTNET

Typical usage:
United States Postal Service (USPS®)

Intelligent Mail Barcode

Typical usage:
Some United States Postal Service (USPS)

Figure 4: *Types of 1D codes*

2D codes

Unlike 1D barcodes, 2D codes contain information both horizontally and vertically, allowing them to store much more data. For example, a single 2D code can hold up to 3,116 numeric characters or 2,335 alphanumeric characters, compared to the 39 characters that Code 39 can hold.

Unlike 1D barcodes, all 2D codes have built-in error correction, similar to the check digits in some 1D codes, which effectively eliminates misreads. Within a single 2D Data Matrix code, the data is typically encoded three times, which significantly increases the chances the code will be read correctly.

While 1D codes have quiet zones and guard patterns to identify where the code starts and stops, a 2D code has a quiet zone, a ***finder pattern***, and a ***clocking pattern***. The finder pattern is the L-shaped pattern located around the outside edge of two sides of the 2D code. This is used to ensure proper orientation during decoding. Opposite the finder pattern is the clocking pattern, a series of alternating black and white modules (or cells) that defines how big a single cell is and the size of the code (number of rows and columns) for decoding. The quiet zone is similar to that of 1D barcodes; however, it must surround the entire code.

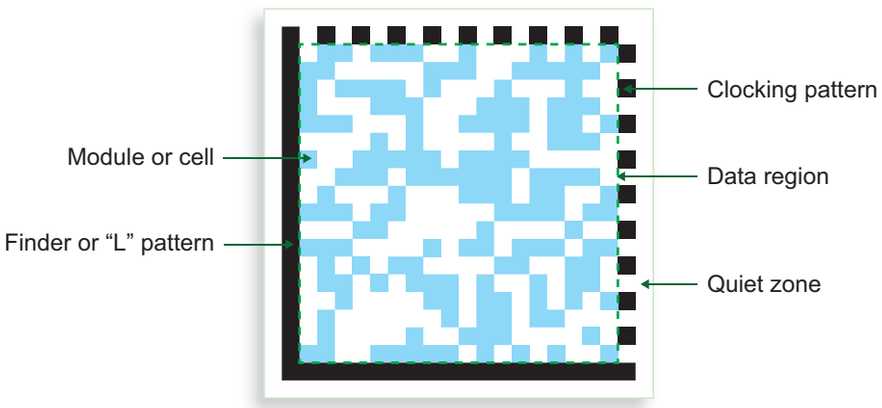
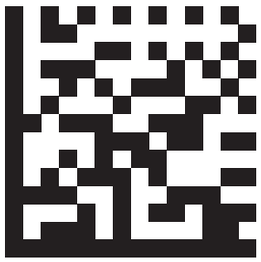


Figure 5: *Structure of a 2D code*

Symbologies

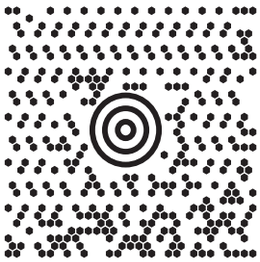
Common 2D codes include: Data Matrix, used by aerospace, defense, printed media and the U.S. Postal Service; ***MaxiCode***, a dot-based code that is used in logistics applications; QR codes, used in automotive and commercial marketing applications; and ***Aztec*** codes, used by ticket agencies and rental car companies.

Data Matrix



Typical Usage:
Aerospace, Automotive, Electronics, United States Postal Service (USPS)

MaxiCode



Typical Usage:
Logistics

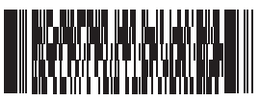
QR

Typical Usage:
Automotive Parts & Commercial Marketing

Aztec

Typical Usage:
Travel Tickets & Car Registration Documents

PDF417

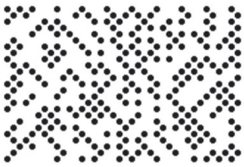


Typical Usage:
U.S. Driver's Licenses & Logistics

GS1 DataBar Stacked

Typical Usage:
Supermarkets

DotCode



Typical Usage:
Packaging, Logistics & Anti-theft Initiatives

Figure 6: *Types of 2D codes*

BARCODE PRINTING AND MARKING METHODS

Every code application begins with collecting information from a central database, which often includes the origin and other manufacturing data, and then applying that data to an object. The application of the code is usually accomplished in one of two ways: by applying the code to a package or label, usually using inkjet or thermal printing methods, or by permanently marking the code directly on a part via ***direct part marking (DPM)*** methods such as ***dot peen***, ***chemical etching***, or ***laser marking***.

Thermal transfer or inkjet printing

Inkjet printers are most commonly used for printing the code on a package, label or other material. Inkjet printers create the barcode by propelling droplets of ink onto a substrate such as paper or plastic. Thermal transfer technology is typically used for printing labels. This process heats up the print head and applies ink directly to the label. Inkjet and thermal printing are often used to print 1D barcodes.

Figure 7: *Inkjet-printed code on pharmaceutical bottles*

Direct part marking

For many applications, such as medical devices, automotive parts, and other durable goods where traceability and liability protection at the component level are important, DPM methods offer a longer-lasting alternative compared to printing methods. DPM codes will typically include more data than just a part index number; therefore, they often use 2D codes instead of lower-bandwidth 1D barcodes.

Laser

Laser marking systems typically use fiber lasers to engrave Data Matrix codes or other 2D code symbologies on the part.

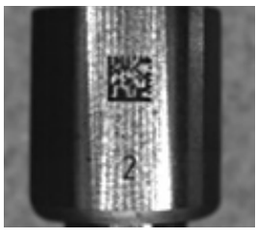


Figure 8: *Laser-marked code on a metal cylinder*

Dot peen

Dot peen marking systems, generally considered the most cost-effective option, use an oscillating stylus to press into the metal, creating a divot.

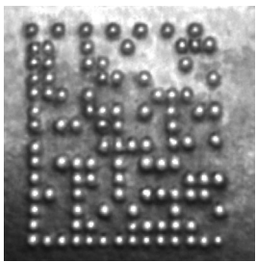


Figure 9: *Dot peen-marked code on an automotive part*

Chemical etching

Electrical chemical etching uses a sodium-based solution combined with a pulsing low-voltage electrical current. The charged solution dissolves the metal, which is then extracted through a special stencil.

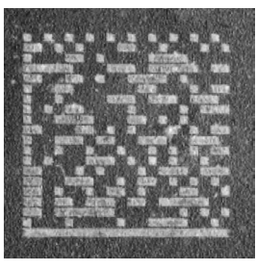


Figure 10: *Chemically-etched code on metal*

Depending on the material being marked, each method has its own strengths and weaknesses. For metal parts, laser-marking systems offer high-throughput permanent marks but are costly to install. Dot peen marking heads are less expensive but they wear down, which can compromise the mark.

TYPES OF BARCODE READERS

Laser scanners

A ***barcode scanner***, or barcode reader, is a device with lights, lenses, and a sensor that decodes and captures the information contained in barcodes. In the early days of 1D codes, codes could only be read by lasers. ***Laser scanners*** use a laser beam as a light source and typically employ oscillating mirrors or rotating prisms to scan the laser beam back and forth across the barcode. A photodiode then measures the reflected light from the barcode. An analog signal is created from the photodiode, and is then converted into a digital signal.

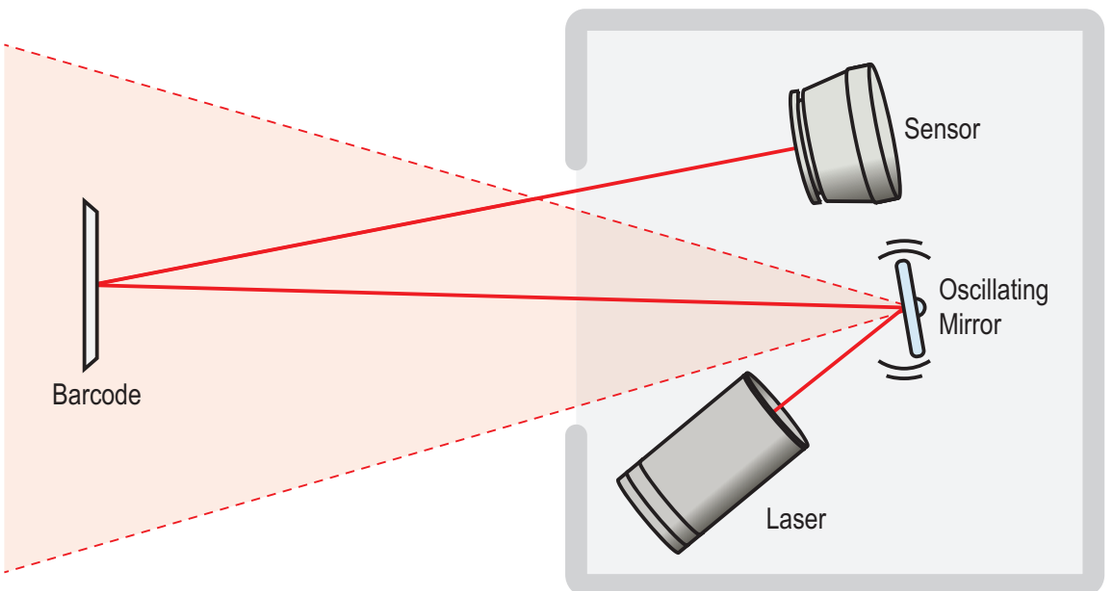


Figure 11: *Laser scanner*

Despite being an older technology, laser scanners still offer some operational benefits. Laser scanners do not require an image processor. They are also fast, capable of conducting up to 1,300 scans per second. Finally, because they use lasers—collimated beams of light that essentially do not diverge no matter how far the light travels from the source—they can read 1D barcodes from relatively long distances with the use of special optics.

This does not mean that laser scanners do not have limitations. Among their crucial limitations is that they cannot read 2D codes, which are becoming increasingly more prevalent. Laser scanners also have trouble with 1D barcodes that are poorly printed, low-contrast, distorted, or damaged. Because the environment for code reading is rarely perfect, the number of misreads and no-reads are typically too high. The combination of highly reflective parts and light sources often create ***hotspots*** that confound laser scanners.

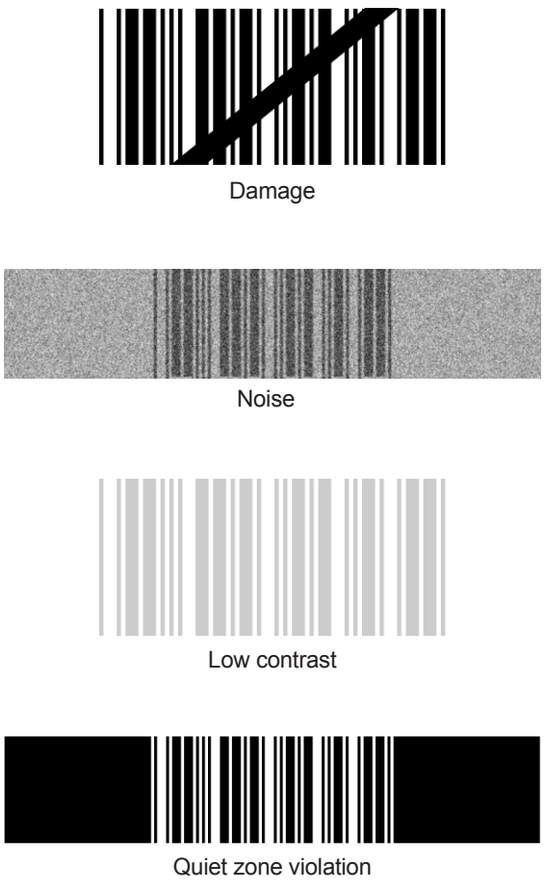


Figure 12: *Codes that can be hard to read with a laser scanner*

Code position is also critical to laser scanners because, with few exceptions, 1D codes must be scanned from left to right. This can require additional fixturing or mechanical systems to make sure an object's barcode is consistently oriented in a single direction. Laser scanners also have an oscillating mirror, and moving parts can break, resulting in additional costs and time required to repair or replace. Finally, due to eye safety concerns, laser scanners must be shielded to protect nearby workers.

Image-based barcode readers

Image-based barcode readers use an area array sensor similar to those found in digital cameras to acquire a picture of 1D and 2D barcodes. Then a ***microprocessor***, running special image-processing software, locates and decodes the code before distributing the resulting data across a network.

Image resolution

One of the biggest differentiators for choosing an image sensor, or camera, is resolution. Image resolution refers to how many individual pixels make up each image.

When it comes to matching an image-based reader's resolution to an application, one of the most common criteria is ***pixels per module (PPM)***. PPM refers to how many pixels it will take to cover one cell or module of the code, and will confirm whether the camera has enough resolution to read the code. PPM is calculated by dividing the camera's resolution in one direction (for example, 752 pixels for a standard resolution reader) by the Y-field of view in millimeters (78 mm), and then dividing the code size in millimeters by the modules (12 mm/22 modules). Finally, multiply these numbers together (5.26 PPM). It may sound complicated, but a configurator app or image-processing software running on these readers can quickly calculate PPM.

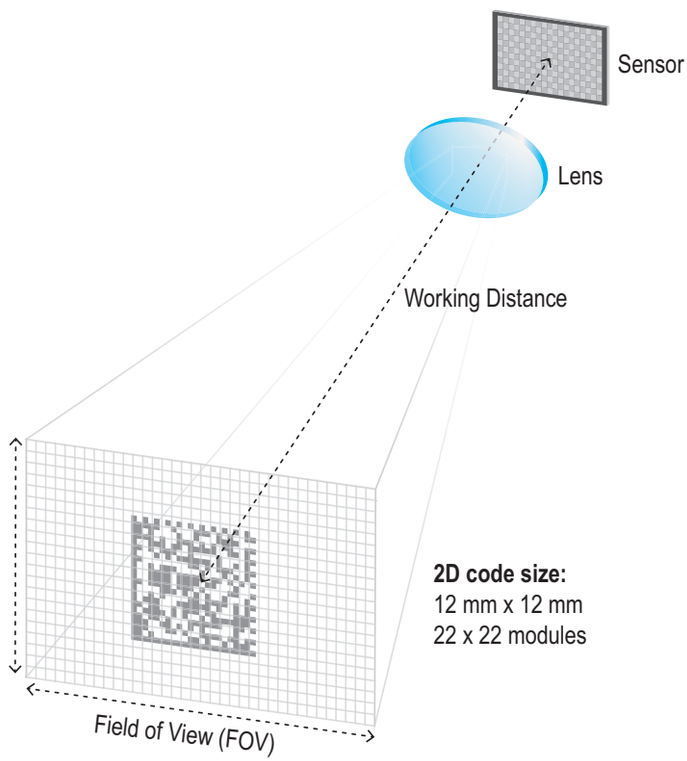


Figure 13: *Pixel grid showing PPM on a Data Matrix code using an image-based reader*

Lenses

An image-based barcode reader's optics are key for acquiring a good image of the code. Quality readers offer both ***S- and C-mount lens*** options, depending on the amount of resolution required at a given working distance to acquire an image of the code. The latest readers offer autofocus or ***liquid lens technology***, which allows the reader to adapt to changes in working distances. It works in the same way as the human eye, reshaping and bending in order to focus. This refocus is also accomplished through software, thus avoiding an operator manually adjusting the lens in the field or on the line.

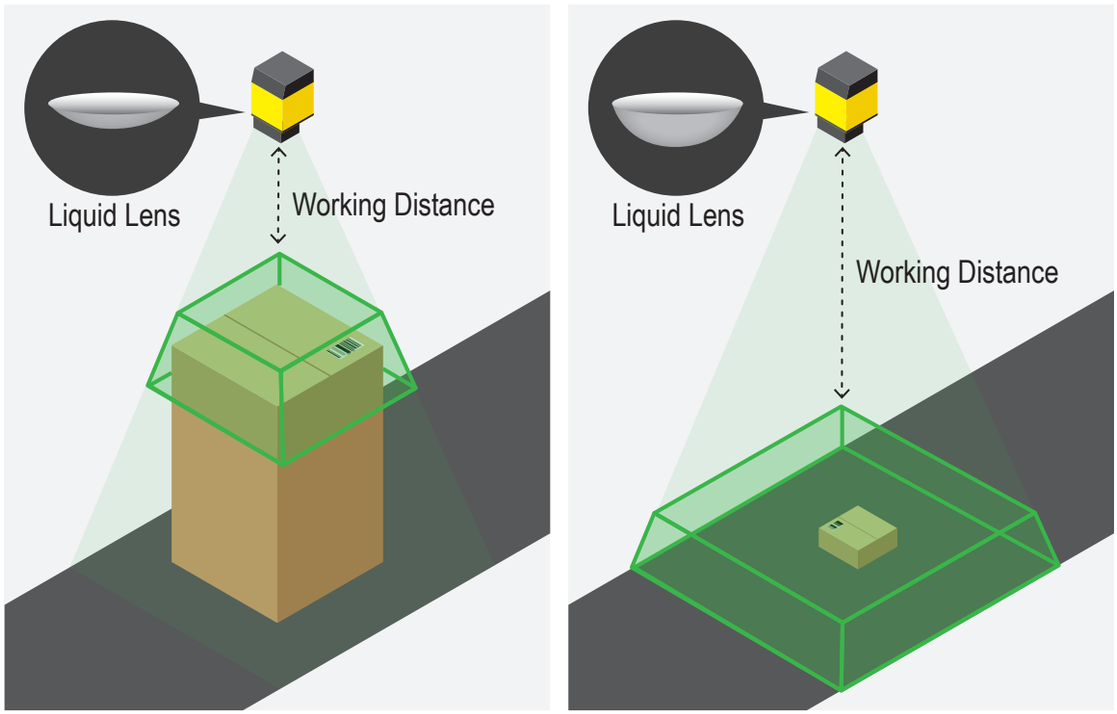


Figure 14: *Liquid lens technology*

Lighting

Lighting also has an important part to play in acquiring a good code image. A lighting technique involves a light source and its placement with respect to the code and the reader. Industrial barcode readers offer various combinations of integrated and external lighting options based on the environment and application. Some examples of lighting types include: ***bright field***, ***dark field***, and ***diffuse dome lighting***. Bright field highlights the marks that make up the code, while dark field refers to low-angle light that highlights the areas around the code marking, and is best for reading dot peen and recessed codes. Diffuse dome light is best used on reflective and curved parts, as it reduces hotspots and generates a high-contrast image. There are many other lighting options available, including advanced high-powered integrated lighting. Consult the Cognex Lighting Advisor (www.cognex.com/lightingadvisor) to explore the effects of different lighting techniques and positions.

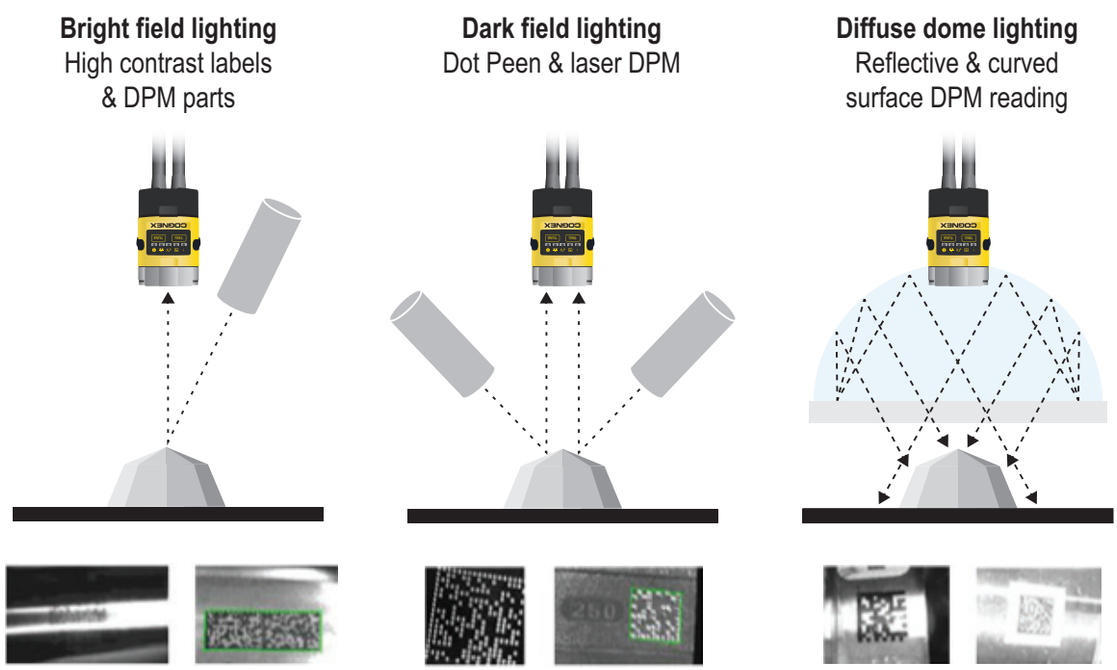


Figure 15: *Lighting technology*

HOW TO SELECT A BARCODE READER

Selecting the perfect barcode reader starts with a careful examination of your code-reading application. What types of codes are you reading, how fast is the line, and how durable do you want the solution? Where will the reader be located, and with what physical restrictions? How will the reader communicate?

Symbologies

Data requirements for your inventory or track and trace application may be only a few kilobytes today, which may make a 1D barcode seem the most logical choice. But data requirements are likely to grow along with the size and complexity of your operation. It is worthwhile to anticipate future requirements that would benefit from a 2D code or the ability to read compromised barcodes. You may own your distribution channels today, but growth or new clients in remote locations may necessitate a third-party logistics company, leaving you no longer in control of the code-marking quality. Investing in better technology today may minimize future equipment upgrades.

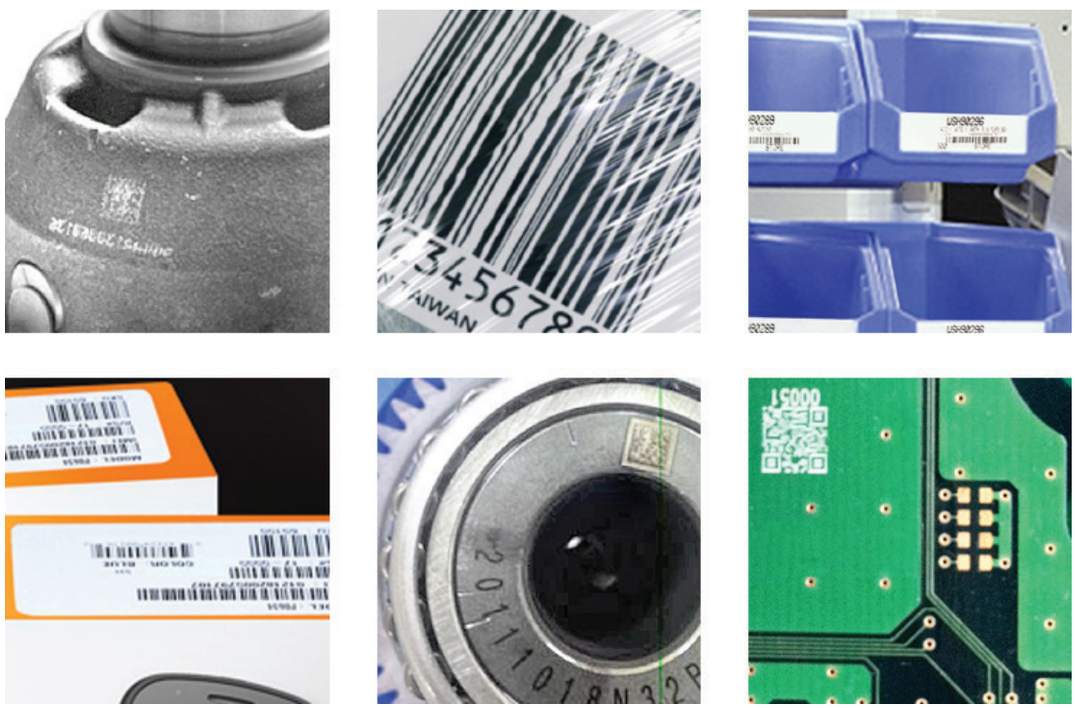


Figure 16: *Barcode symbologies*

Read rates

Read rate is the number of successfully read barcodes divided by the number of attempts. The read rate is usually expressed as a percentage and the closer to 100%, the better. Every time a machine or person handles your products there is a chance that the machine-readable code could be damaged.

Calculating Read Rate

If 9,900 barcodes are successfully read in 10,000 attempts, the read rate is calculated:
9,900 ÷ 10,000 = .99 or 99%.

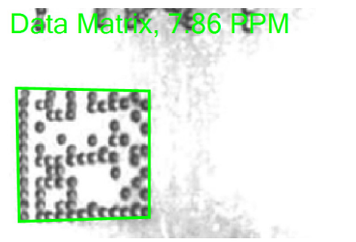
This problem isn't limited to paper and plastic packages. Even codes etched into metal can be distorted or damaged. So if supply chain accuracy is important to your business, make sure your reader can read noisy codes—such as those that are printed on cardboard or are scratched, deformed or low contrast—not just perfect codes fresh off the printer.

Low resolution

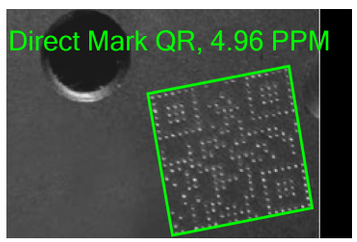
Missing perimeter features

Specularity

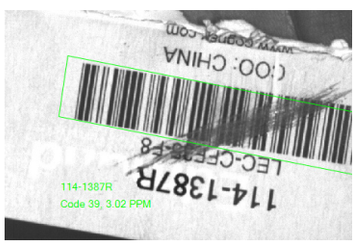

Warped



Poorly marked



Small modules



Scratched

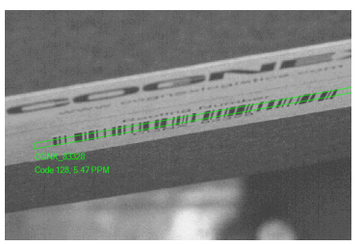

Extreme perspective

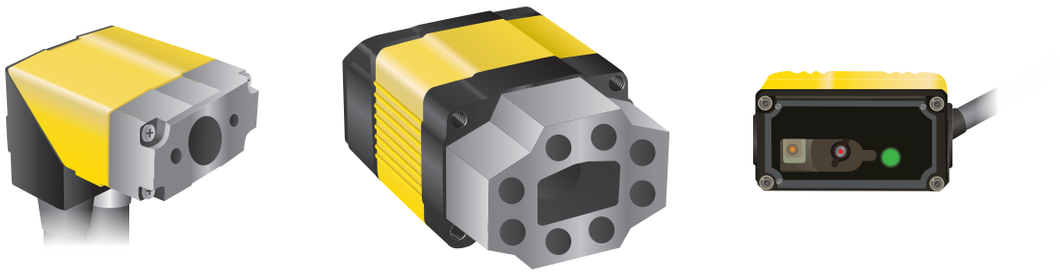
Figure 17: *Types of hard to read barcodes*

Usage

The scanning environment will also indicate which type of reader you need. If your application calls for reading cartons of various sizes traveling at high speed down a conveyor, then a small fixed reader will be the best choice. ***Fixed-mount barcode readers*** enable automated, hands-free scanning of codes from a mounted position, usually on a production line.

If the reader is the final inventory check for dock workers loading incoming materials or outgoing product, a handheld barcode reader will be ideal. ***Handheld barcode readers*** are held in the hand of an operator and can be corded or wireless.

If it's a courier or technician working in the field, a mobile barcode reader with built-in code reading capability will help quickly scan packages or check equipment specifications. ***Mobile barcode readers*** are also held in the hand of an operator and can be purpose-built for a particular application or smartphone-based with a rugged mobile terminal enclosure.



Fixed-mount barcode readers

Handheld barcode readers

Mobile barcode readers

Figure 18: *Types of image-based barcode readers*

Communications

After marking the part or product and reading the code, the data is stored or used within a plant or distribution center network. Image-based barcode readers offer a full range of industrial communication protocols including ***Ethernet***, ***USB***, ***RS-232, discrete I/O, Ethernet/IP, PROFINET*** and ***Modbus TCP/IP***. This simplifies integration between reader and network, which is critical not only for reading and sending product tracking information, but also for storing archived images in the event of a no-read or misread.

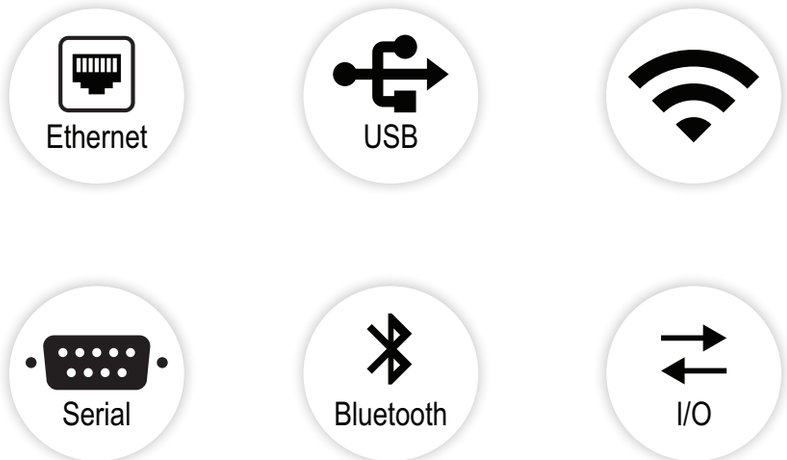


Figure 19: *Communication protocols*

Cost of ownership

With the additional power and flexibility of image-based barcode readers, you might expect the cost to be considerably more than laser scanners. While that was true in the past, the latest image-based readers cost about the same as industrial laser scanners that have far less functionality. New microprocessors and CMOS digital sensor chips also mean image-based systems can be nearly as fast as the fastest laser scanner. And these developments come in addition to the traditional benefits of image-based readers: no moving parts, resulting in a longer life than laser scanners; ability to read 2D codes as well as damaged and omnidirectional codes; and the ability to store images for audits and tracking.

To learn more about image-based barcode readers, visit cognex.com/barcodereaders or cognex.com/blogs.

GLOSSARY

1D barcode Also known as a linear barcode, a machine-readable code representing data in the widths and spacings of parallel lines. Examples include: Aztec, Codabar, Code128, Code 39, EAN, Interleafed 2 of 5, Pharmacode, POSTNET, and UPC.

2D barcode A machine-readable code that stores data both horizontally and vertically. Examples include: Data Matrix, MaxiCode, and QR code.

Aztec code A type of 2D barcode also published as ISO/IEC 24778:2008 standard, named after the resemblance of the central finder pattern to an Aztec pyramid. Has the potential to use less space than other matrix barcodes because it does not require a surrounding blank “quiet zone.”

Barcode scanner An electronic device that decodes and captures the information in a barcode.

Bright field Producing or using a strongly lighted background.

C-mount lens A type of lens mount commonly found on 16 mm movie cameras, closed-circuit television cameras, machine vision cameras, and microscope phototubes.

Check digits A form of redundancy check used for error detection on identification numbers that is analogous to a binary parity bit used to check for errors in computer-generated data. Consists of a single digit (sometimes more than one) computed by an algorithm from the other digits (or letters) in the sequence input.

Chemical etching A form of direct part marking; the subtractive manufacturing process of using baths of temperature-regulated etching chemicals to remove material to create an object with the desired shape.

Clocking pattern Provides a count of the number of rows and columns in a 2D barcode.

Codabar A discrete, self-checking 1D barcode that allows encoding of up to 16 different characters, plus an additional four special start and stop characters, which include A, B, C, and D.

Code 128 The most robust 1D barcode type. The number 128 refers to the ability to hold any character of the ASCII 128 character set. Includes all digits, characters, and punctuation marks, making it compact and powerful as it enables diverse storage of data.

Code 39

Also known as “3 of 9 Code,” was the first 1D barcode symbol to use numbers and letters. This variable-length barcode is self-checking, so a check digit normally is not necessary, but recommended. It gained popularity due to its ability to encode up to 43 numbers, letters, and other characters and is still widely used, especially in non-retail environments.

Dark field

Illumination of the field of view from the side so that the object is viewed against a dark background.

Data Matrix

A 2D code that can encode large amounts of data (up to 2,335 alphanumeric or 3,116 numerical characters) and use an error-correction system to read codes that are as much as 40% damaged. It is made up of black and white cells in a square or rectangular pattern, and includes a finder and clocking pattern.

Diffuse dome lighting

A lighting arrangement where the light is directed into a hemispherical, usually white, enclosure that reflects the light backwards on an object without bright spots, or hot spots, common to direct bright field lighting.

Direct part marking (DPM)

A process to permanently mark parts with product information including serial numbers, part numbers, date codes, and barcodes. This is done to allow the tracking of parts through their full life cycle. Examples include: chemical etching, dot peen, and laser marking.

Discrete I/O

Refers to a wiring method where the conductor directly connects a transmitter to a receiver without encoding, protocols, or other common methods used to create digital networks.

Dot peen

A direct part-marking method composed of a carbide or diamond stylus that rapidly actuates and makes a series of small dots on a material’s surface. The stylus moves along the surface and forms marks including alphanumeric characters and machine-readable codes and logos.

EAN

Standing for International Article Number (EAN), EAN-8 is the European counterpart of the UPC-A symbol. The main difference between them is that the EAN-13 encodes an extra digit of data to make a total of 13. The first two digits of the barcode identify a specific country, and the check digit is the last number of the second group of six digits. This is primarily used on small packaging where space is limited.

Ethernet

A system for connecting a number of computer systems to form a local-area network, with protocols to control the passing of information and to avoid simultaneous transmission by two or more systems.

Ethernet/IP

An Industrial Ethernet network that combines standard Ethernet technologies with the media-independent Common Industrial Protocol (CIP).

Finder pattern

Also called a locator or L pattern, it lies along two sides of a 2D code and helps the reader to locate and determine the orientation of the machine-readable code.

Fixed-mount barcode reader	Enable automated, hands-free scanning of codes from a mounted position, usually on a production line.
GS1	Global Standards One (GS1) develops the global standards for business communication, most notably the barcode.
Guard pattern	Usually a pair of bars in a 1D barcode that indicate the beginning and end of specific data strings.
Handheld barcode reader	Scans codes from the hand of an operator and can be corded or wireless.
Hotspot	A bloom or section of an image where all pixels in that area have maximum intensity values, hiding any image data that may have otherwise been found in that area of the image; usually caused by lights reflecting off shiny surfaces during imaging.
Image-based barcode reader	Uses an area array sensor similar to those found in digital cameras to read both 1D and 2D barcodes.
Inkjet printer	A computer peripheral that sprays ink onto paper, labels, boxes, and other media.
Interleaved 2 of 5	A continuous two-width 1D barcode symbology commercially used on 135 film, for ITF-14 barcodes, and on cartons of some products, while the products inside are labeled with UPC or EAN.
Laser marking	A direct part-marking method that labels materials with a laser beam by engraving, removing, staining, annealing, and foaming an object's surface.
Laser scanner	1D barcode reader that directs a laser point source across the code by passing the beam through a rotating prism or mirror.
Liquid lens technology	Allows the reader to adapt to changes in working distances. Liquid lenses do not move or use motors and therefore are much more robust than mechanical or spinning optics.
Margin	The margin is a blank space around a barcode that separates the barcode from neighboring graphics, shapes and textures. Also see quiet zone.
MaxiCode	A fixed-size 2D code that holds up to 93 data characters composed of a central bulls-eye locator and offset rows of hexagonal elements. It was created by United Parcel Service to allow quick, automated scanning of packages on high-speed conveyor lines.
Microprocessor	An integrated circuit that contains all the functions of a central processing unit of a computer.

Mobile barcode reader	Scans codes from the hand of an operator and can be purpose-built for a particular application or smartphone-based with a rugged mobile terminal enclosure.
Modbus TCP/IP	A serial communication protocol published by Schneider Electric®. Each device on a Modbus network is given a unique address (similar to Ethernet/IP) and as long as the devices are on the Ethernet network they are able to send Modbus commands.
Pixels per module (PPM)	Determines how many pixels are in one cell or module of the code.
Pharmacode	Also known as Pharmaceutical Binary Code, a barcode standard used in the pharmaceutical industry as a packing control system.
Postal Numeric Encoding Technique (POSTNET)	Barcode used by the United States Postal Service to automatically sort mail. Unlike most other barcodes in which data is encoded in the width of the bars and spaces, this 1D barcode encodes data in the height of the bars.
PROFINET (Process Field Net)	An standard for industrial automation using a computer network. Typically used with Siemens® PLCs.
Quick Response (QR) code	Codes containing square blocks of black cells on a white background with finder patterns in the top left, top right, and bottom left corners. It was developed to track parts during vehicle assembly but is now commonly used in printed marketing materials.
Quiet zone	A blank space around a barcode that separates the barcode from neighboring graphics, shapes, and textures. See also margin.
Read rate	Number of successfully read barcodes divided by the number of attempts.
RS-232	A standard for serial communication transmission of data.
S-mount lens	A standard lens mount that uses a male metric M12 thread with 0.5 mm pitch on the lens and a corresponding female thread on the lens mount; thus an S-mount lens is sometimes called an M12 lens.
Universal Product Code (UPC)	A variety of 1D barcodes widely used in the United States for tracking trade items.
Universal Serial Bus (USB)	A common interface that enables communication between devices and a host controller, such as a personal computer (PC).

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