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Machine Vision Powers Robotic Bin Picking

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How 3D vision and deep learning are advancing robotic bin picking

Thanks to the combination of 3D machine vision and deep learning, the types of use cases in robotic bin picking are becoming more diverse.

Bin picking, which involves picking up an object from a bin or tote and moving it to another bin or surface, is a mind-numbing and muscle-fatiguing job for humans. However, automating it reliably and efficiently with robots can be challenging.

But that's changing. The combination of 3D vision and neural networks is expanding the possibilities of automated bin picking, allowing robots to pick and place a wide range of parts, including those that are shiny or irregularly shaped.

3D cameras are crucial components in bin picking because they provide depth data, which helps deep learning algorithms (possibly in combination with rule-based models) recognize objects including their orientation. Engineers then combine object recognition with sophisticated motion planning routines to guide a robot precisely, allowing it to pick up an object, grasp it securely, and place it somewhere else in a collision-free manner.

One example is a use case involving a leaf spring support arm, a large, heavy, and irregularly shaped steel component in a vehicle suspension system. Penna Flame Industries (Zeilenople, PA, USA), which hardens steel components with either flame or electromagnetic induction, developed an automated process to pack these parts for shipment.

Have you developed similar projects in bin picking? We'd love to hear about them. Reach out and let us know.

Linda Wilson
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Cover credit: Courtesy of Catalyst Connection

Robotic bin picking system at Penna Flame picks large, heavy industrial parts

With assistance from CapSen Robotics, the company integrated 3D vision and machine learning and hard-coded algorithms with a FANUC robot to automate the handling and packing of cumbersome components.

LINDA WILSON

Everyone at Penna Flame Industries (Zeilenople, PA, USA) agrees on one point: The worst job at the plant is packing leaf spring support arms.

A steel component in vehicle suspension systems, each support arm weighs 37 pounds, has dimensions of 18 × 12 in, semi-sharp edges, and is irregularly shaped.

Packing industrial parts for shipment is a common activity at Penna Flame. Launched in 1968, the family-owned business hardens steel components for its customers with either flame or electromagnetic induction processes. In either case, the goal is to increase the wear resistance and longevity of a variety of parts, such as gears, shafts, and axles.

FIGURE 1. A steel component in vehicle suspension systems, each leaf spring support arm weighs 37 pounds, has dimensions of 18 × 12 in. and semi-sharp edges, and is irregularly shaped. *Courtesy of Catalyst Connection*

Manual packaging processes

But packing the leaf spring support arms is no fun. “People quit over this stuff,” explains Michael Orr, vice president of operations at Penna Flame and grandson of the founder.

This is not hard to understand; the process is grueling. These are the steps:

- Wearing extra-thick work gloves because the pieces have sharp spurs, an employee picks up each piece from a 4-ft square wire bin that holds 110 pieces.
- The employee lays the part flat at the bottom of a plastic bin.
- Once there are eight pieces in the bin, the employee sprays them with oil-based rust preventative, flips them over, sprays them again,

and then flips them up and shakes them to remove the excess oil.
- In the last step, the employee picks up each part and packs it in a wooden shipping box.

Once the box is full, he or she puts the lid on the box and bands the lid and box together with metal binding.

Each wooden box holds a maximum of 23 parts if they are crammed together.

The same two employees typically pack these parts because most people at the plant don't want to do it. Orr says they are "tough and strong" and possess a good work ethic and competitive spirit. They race to see who can pack more parts, and the winner gets a company-funded reward. "We had to turn it into a game, basically," Orr says.

FIGURE 2. Michael Orr, vice president of operations at Penna Flame Industries, says packing leaf spring support arms is the least popular job at the plant.
Michael Orr, Penna Flame Industries

Developing an automated 3D bin picking system

Because of the challenges with manually packing these parts, Penna Flame in 2021 decided to pursue robotic bin picking. The company already had four FANUC (Yamanashi, Japan) robots deployed in other areas at the plant. Why not buy another one for packaging?

Orr approached the Catalyst Connection (Pittsburgh, PA, USA), a private nonprofit organization that helps small- and medium-sized manufacturers adopt advanced technologies. The organization helped 26-employee Penna Flame secure two grants totaling $15,000. The Catalyst Connection also engaged the ARM Institute (Pittsburgh, PA, USA), which specializes in integrating AI-enabled robotics into manufacturing processes.

The ARM Institute developed a conceptual plan for packaging the support arms using a robot. Its experts also reached out to CapSen Robotics (Pittsburgh, PA, USA), which develops and markets AI-enabled 3D machine vision and motion planning software for robots.

Software engineers at CapSen Robotics worked with Penna Flame to develop algorithms customized for the company's project.

How the robotic bin picking system works

With the new robotic bin picking process, a FANUC R 2000/165F robot, with a 165 kg payload and 2,655 mm reach, handles most of the work. Humans still put the lid on the wooden shipping boxes and band them.

To kick off the process, employees load the skid and drive it over to the packaging robot cell with a forklift.

The robot picks up each part with a magnetized end effector. There is a flat spot on each part where the magnet needs to connect with the part to hold it securely.

The robot manages the parts in a specific order. This is important: If parts are removed from the skid in the incorrect order, it could lead to instability in the entire stack of parts, explains Prajwal Poojari, robotic software engineer at CapSen Robotics, and a key member of the project team.

And to work best, Orr adds, the robot also needs a well-defined and consistent spot for each part, "so it can grab the flat part, and it is sturdy."

However, the wire basket did not work for the robot because it could not dislodge parts if they got stuck in the wire mesh. So, Orr designed a skid that holds 72 parts in six layers.

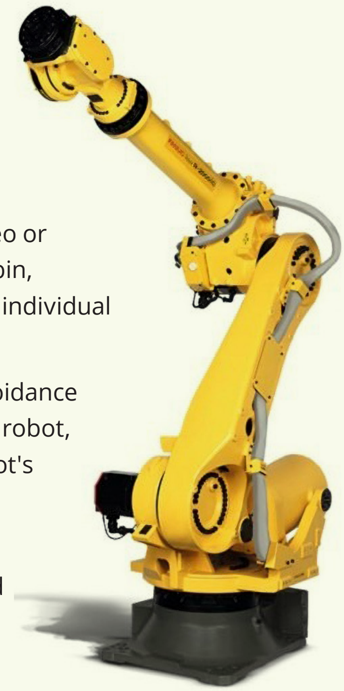
The steel skid has a divider down the middle and four posts, one in each corner, for stability. The parts are divided between layers: 16, 16, 14, 14, 12. For each layer, an equal number of support arms are placed on each half of the skid.

Automating the bin picking sequence

Once the robot picks up the part, it dips the part in the oil and then rotates the part slowly to dislodge the excess oil. Finally, the part is placed in a precise location within one of four wooden boxes lined up near the robot. It packs 18 pieces per box as the last step in the process, meaning each of the 72 pieces has a predefined destination within one of the four boxes.

It takes the robot 1.5 hours to complete the process for all pieces. "That's running at 80% speed. We like speeds that aren't crazy fast," Orr says.

Bin Picking Challenges Solved With Vision



High Part Variation (Clutter). 3D Vision (stereo or structured light) creates a point cloud of the bin, allowing the system to differentiate between individual overlapping parts.

Deep Bin Access & Obstruction. Collision avoidance planning uses real time 3D data to model the robot, gripper, and bin, dynamically guiding the robot's path to avoid obstacles as it dives deep into the container.

Cycle Time and Processing Speed. Optimized software and AI process the complex 3D data rapidly, ensuring minimal latency between scene capture and robot movement.

Reflective/Shiny Surfaces. (Partially Solved) Advanced algorithms and specialized lighting (polarization or diffused) are used the mitigate the glare, allowing the vision system to capture clean, accurate data on difficult surfaces.

Source: CapSen Robotics (Image: FANUC)

Directing the robot's movements with 3D imaging and machine learning

CapSen Robotics uses a combination of rules-based programming and machine learning methods to guide the robot, based on input from a vision system.

The machine vision hardware consists of a 3D camera (Zivid 2+LR110) from Zivid (Oslo, Norway), which is installed 10 feet above the robot cell, pointing down on the skid. The process also uses a proximity sensor, which is secured near the robot's magnetic end effector.

The Zivid camera uses a type of 3D imaging called structured light—a process in which a pattern of light is projected on an object or scene, and then the reflections are captured in images taken by a 2D sensor. The camera produces a 3D point cloud by analyzing the distortions in the patterns of light.

CapSen Robotics' algorithm uses point cloud information to determine an object's location and orientation. "The point cloud has the color information in the form of RGB and the depth information in the form of XYZ," says Poojari.

Based on that information, another algorithm generates a motion plan, "so that the robot can go towards the part in a collision free motion," says Poojari.

Important verification step in the robotic bin picking process

Once the robot picks up the part off the skid, the robot moves the part to a predetermined spot, so it can isolate the part from the clutter on the skid. The camera then snaps a second image for a verification step in which the software uses just RGB information to ensure that the support arm is stuck to the magnetic end effector within acceptable parameters. If the robot is not holding the part correctly, it puts the part in a reject bin.

Verification is a key step in the process, Poojari says. If the part is not oriented correctly, the part may collide with the bin holding the oil, potentially damaging the robot. But if it is positioned correctly on the end effector, the robot proceeds with the rest of the process.

The bin picking system does not need a third image or second verification step to place the part in the assigned position in one of the wooden packing boxes. That's because the positions in the packing bins are fixed. "We have that functionality, but we have not used it," Poojari says.

The software is loaded on a standard PC, and the processing occurs locally. "And then towards the end,

FIGURE 3. Penna Flame Industries purchased a FANUC R 2000/165F robot to automate the process of packaging leaf spring support arms. *Courtesy of Catalyst Connection*

the final information is sent to the robot's controller so that the robot can execute the motion," Poojari says.

The application communicates with the robot's controller via TCP/IP. The camera communicates with the PC using 10 Gbps Ethernet.

Because the parts are not shiny or reflective, the application only needs ambient light, Poojari says. Orr notes that Penna Flame redid the ceiling lights in this part of the operation recently.

Programming challenges abound for picking large, heavy parts

Developing the bin picking system was not easy. There were several challenges to overcome because the support arms are large and asymmetrical and placed side-by-side on the skid, leading to occlusions in the camera's field of view (FOV). The combination made detecting the part and its pose challenging. "We had to develop new algorithms and be smart enough to combine the rules-based approach and the learning-based approach together," Poojari says.

And because the part is large with a correspondingly large amount of CAD data, there are a lot more calculations involved than would be the case for a smaller object, Poojari adds.

The fact that the application is an "ordered picking application" also adds a layer of complexity. "We had to make sure that the camera is looking at the right area and not skipping a part or skipping two or three parts down the line," he explains. Otherwise, the robot may not pick up the parts in the correct order. "We have to detect the specific object that we want to pick next," Poojari adds.

Designing the placement scheme for parts on the skid

For his part, Orr worked through an unexpected challenge: Configuring the leaf spring support arms on the skid. The parts come in a left-side and right-side version—essentially mirror images of each other.

The Penna Flame team started with the left-side version and got the robot to pick up the parts from the skid securely and then run through the remainder of the process without issue.

That was not the case for the right side. "It was less stable with the same sequence," Orr says. "We had to reengineer how we stack them."

To solve the problem, Orr configured the layout on the skid with 0.25 in of space between the parts in the first layer. "We just widened the base," he says.

Developing safety measures

The robot works in an area surrounded by physical safety fencing and safety laser scanners—Keyence (Osaka, Japan) SZ04M—that the Penna Flame team configured and installed.

The cell has 7-ft physical fencing along both sides and safety scanners mounted vertically at the front and back of the space. Each one scans up to 14-ft high and in a 14-ft semicircle.

For added safety, the robot has force sensing, and Orr says they set the sensitivity percentage high. In addition, if the robot can't pick up a part correctly in three consecutive tries, it stops.

Timeline for lights-out use of AI-enabled 3D machine vision process

As of early October, the system was running autonomously with a human operator in the vicinity working on other tasks but also monitoring the robot.

Orr hired an outside integration firm to complete an independent safety assessment. Once that step is complete, the goal is for the robot to pack the parts overnight while the plant is closed. "It should be able to pack without anyone here," Orr says. "That's exciting." ◎

Effective lighting design strategies for reliable machine vision applications

Industry expert Perry West explains how to solve key challenges in machine vision lighting, such as dealing with specular surfaces, ambient light, and complex defect requirements.

PERRY WEST

The design of lighting for machine vision applications has challenged machine vision system designers since the birth of machine vision around 1980. It continues to challenge system designers today and will likely challenge vision systems designers for years to come.

There are many challenges in lighting design for machine vision. This article covers five of these. Your experience will likely reveal additional challenges.

Optics expertise

Most machine vision developers are not experts in optical physics. More likely they are experts in software development, mechanical engineering, controls engineering, or some other discipline useful in the design of machine vision systems. When it comes to lighting, it's all about optical physics: how light interacts with objects and how to provide light that will give the highest contrast.

Starting in machine vision, my expertise was electronics, not optics. As I have worked in machine vision, I am fortunate to have mentors including Hal Schroeder (retired, EG&G Reticon; Salem, MA, USA), Ken Womak (retired, Eastman Kodak; Rochester, NY, USA), Matt Young (retired, National Institute of Standards and Technology; Gaithersburg, MD, USA) Kevin Harding (Optical Metrology Solutions; Niskayuna, NY, USA), Greg Hollows (Edmund Optics; Barrington, NJ, USA), Nitan Sampat (Edmund Optics; Barrington, NJ, USA), Stuart Singer (Schneider Optics; Hauppauge, NY, USA), Nick Sischka (Edmund Optics; Barrington, NJ, USA), and others.

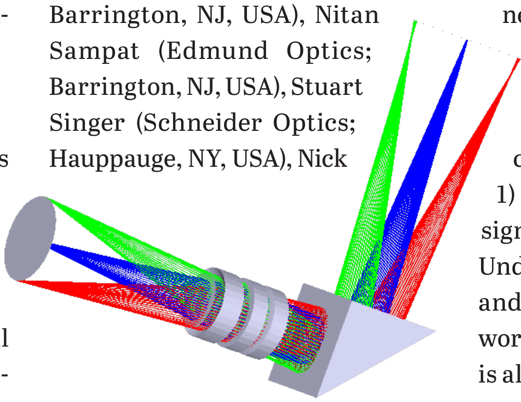


FIGURE 1. To develop the illumination for a machine vision application, a basic understanding of optical physics helps. Example: Optical Design Ray Trace (a computational method to simulate the path of light rays as they travel through a lens). *Courtesy of Automated Vision Systems*

In addition to the insight and advice from these experts, I also needed to investigate and study many aspects of optics that apply to machine vision. I am still learning today.

What every machine vision developer needs to do is to cultivate mentors who will help them gain an understanding of how to apply optical principles to machine vision. Along with advisors, a healthy curiosity and independent study are needed. A starting point could be the online courses on optics for machine vision at https://www.autovis.com/resources/videos/optics.

The good news is that you don't need to become an optical physicist, you don't need to run complex equations, and you don't need to have specialized software (See Figure 1) to succeed with lighting design for almost every application. Understanding optical principles and recognizing how they are at work in the scene you are imaging is almost always sufficient.

Complex requirements

One challenge to machine vision systems and lighting is dealing with a complex requirement. Often, this is for the inspection of cosmetic defects (See Figure 2). Normally, the requirement is not to detect just one type of defect, but a list of different defects such as scratches, dents, chips, stains, etc. Creating contrast for each of these defects can require different lighting solutions. Each lighting solution requires a separate lighting technique, camera exposure, and image to process.

The normal tendency is to try to find a compromise solution that will provide some contrast for each of the different defects using just one lighting technique. That means the software must deal with low-contrast and often somewhat noisy images. The accuracy of the vision system in detecting defects is compromised. The larger the number of defects to detect, the greater the compromise.

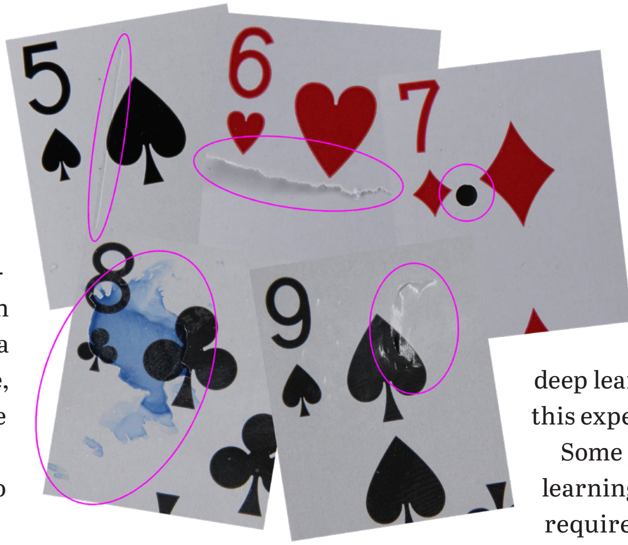


FIGURE 2. Several different defects. *Courtesy of Perry West, Automated Vision Systems*

Take, for example, a vision system that must detect scratches and discoloration on a part's surface. Scratches are mechanical changes to the surface and can often be detected best with dark field illumination. Discoloration does not change the surface mechanically and will likely require bright field illumination to detect. It is possible to have both bright field and dark field light sources for one camera. Two very rapidly acquired images with the two light sources strobed as required can solve the application.

However, what happens as the list of defects increases? The number of lighting solutions to cover the list of defects grows, and the vision system solution becomes cumbersome.

The path to simplifying the vision system's design is to limit the number of defects the vision system is expected to detect. Start with a Pareto chart listing each defect ranked by its frequency of occurrence. Usually, there is a clear break between more frequent and less frequent defects. Focus the vision system on detecting only those defects that occur frequently and set aside the infrequent defects. Usually, manufacturing and quality control departments resist this approach because a human inspection is believed to be able to find any and all defects.

The software non-solution

It happens every day, people expect a clever application of image processing algorithms to mitigate any shortcoming in optics and illumination. With the advent of deep learning for image processing, this expectation has exploded.

Some people suggest that AI/deep learning will lead to solutions that require less attention to lighting. Clearly, AI/deep learning can cope with changes in an image that would be difficult with traditional rule-based programming. However, what does and does not show up in an image will affect the results of AI/deep learning just as it does for rule-based programming. Researchers in deep learning feel satisfied with 90% accuracy and extremely satisfied with 98% accuracy. However, industry typically wants Six Sigma performance. So, 99.9% is a better target for vision system accuracy.

FIGURE 3. Part with a shiny (specular) finish. *Courtesy of Perry West, Automated Vision Systems*

So, what about self-driving cars? They need to be extremely reliable without engineered lighting. The vision application for self-driving cars has several attributes that are not available in most machine vision systems. First is sensor fusion. Self-driving cars do not rely just on vision; they have data from radar and often lidar sensors to combine with vision data.

Second is time series. Vision systems for self-driving cars bring in and analyze image data as a continuous video stream. Something that appears in one image but not the next is still relevant because of the short time interval.

Third is driving policy. Self-driving cars have a driving policy that compensates for errors in the analyzed vision stream to prevent problems. Machine vision systems installed in a manufacturing environment have none of these attributes and must rely on a single image from just one or a group of cameras.

From the very earliest days of computing, the phrase "garbage in, garbage out" has stood as a beacon to anyone willing to pay attention. Poor image quality is garbage and will always challenge image processing and lead to less accurate results than good image quality.

The need for well-engineered lighting for machine vision applications will not go away.

Ambient light

Ambient light is whatever light exists in the vicinity of the vision system excluding light that was engineered specifically for the vision system application.

There are three truths about ambient light:

- It virtually always exists.
- It is not under the control of the vision system developer.
- It will change unpredictably.

What are the sources of ambient light? One is the area lighting for human workers. This often leads to glare and glint if not anticipated and mitigated. Also, lamps and fixtures for area lighting do fail and repairing them may take hours to days in some cases. The vision system must continue to operate reliably during the outage. Other variables can be a flashing light on a forklift or even a person walking by wearing a white shirt or smock that reflects ambient light onto the scene.

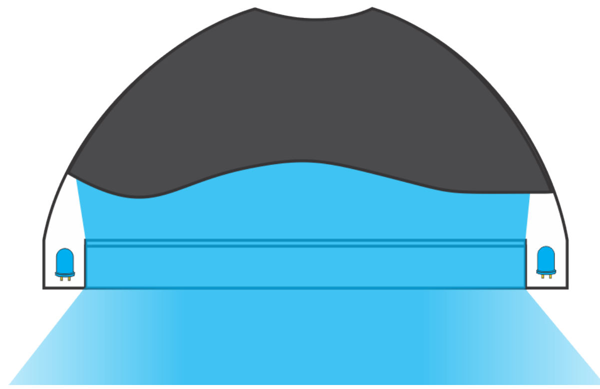


FIGURE 4. Example of a dome light. *Courtesy of Perry West, Automated Vision Systems*

Exterior light, often from the sun, is especially challenging because of its high intensity and its variability depending on time of day, season, and weather. Windows, skylights, and doors that may be opened or closed are sources of exterior light. The only practical way to deal with direct sunlight is to block it from the scene and from the camera.

Always keep in mind that a vision system may work reliably for an extended period of time. Then, if the vision system is relocated, the ambient light environment will be different, and the vision system's performance might degrade. Rarely is the vision engineer called in advance of the move to assess what measures need to be taken to keep the vision system operation reliable. However, when the vision system performance is less than acceptable, the vision engineer must respond with a rapid fix.

There are established techniques for mitigating the effect of ambient light. The first of these is to block ambient light with an enclosure or shroud. Some vision engineers dislike this approach since it impedes access to the area where the vision system is installed and makes maintenance more difficult.

A second very common approach is to use lighting with a narrow spectral band and a matching filter over the camera. The filter lets through most of the engineered light energy while suppressing a large percentage of ambient light, which is usually broad spectrum. This approach works extremely well except where color imaging is required.

A third approach is to overpower ambient light with a very bright light source. With LEDs that can be pulsed and over driven, this approach is very practical. Consider using two or three techniques for any vision system design.

Specular surfaces

There is nothing harder to image than a mirror or any surface that is specular with the properties of a mirror (See Figure 3). Specular surfaces present two challenges:

- When a surface should appear bright, lighting it to give a uniformly lit surface.
- When the surface should appear dark, preventing any glint or glare from either ambient light or engineered light from reaching the camera's lens.

FIGURE 5. Example of a flat dome light. *Courtesy of Metaphase Technologies via Perry West, Automated Vision Systems*

For the specular surface to appear bright in the image, the most common technique is to use a highly diffuse light source like a dome (See Figure 4) or flat dome light (See Figure 5). While every point on the specular surface will be illuminated by light through a wide range of angles, only a small percentage of those light rays from any point on the object will reflect into the camera lens' entrance pupil.

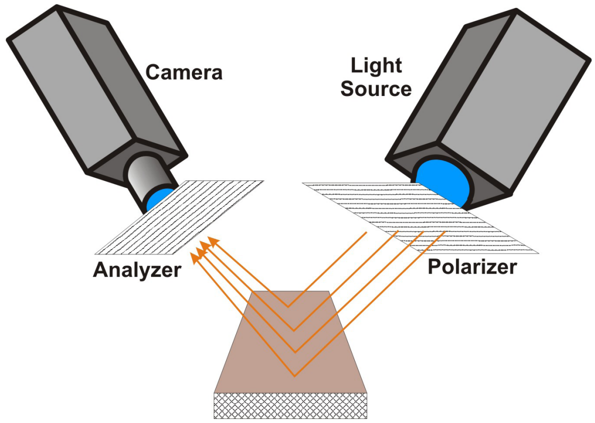


FIGURE 6. A polarizer-analyzer pair is used to image specular surfaces or eliminate glare from engineered lighting. *Courtesy of Perry West, Automated Vision Systems*

Another approach to imaging specular surfaces and eliminating glare from the engineered lighting is to use a polarizer-analyzer pair (See Figure 6). The polarizer is a linear polarizer placed over the light source. The analyzer is also a linear polarizer placed over the camera's lens. The scene is illuminated with polarized light. Specular reflection preserves the polarization of the light while the scattering of the light by diffuse reflection eliminates polarization. The analyzer is rotated to eliminate the specularly reflected light. A good portion of the diffusely reflected light passes through the analyzer to form an image in the camera.

Conclusion

The design of lighting for reliable machine vision system performance is critical. It poses unique challenges. Yet most of these challenges have been faced and successfully solved. Do not underestimate the lighting design process in your projects. If you face challenges in your project that seem difficult to you, reach out to lighting companies or consultants with experience. They can usually guide you through the challenges, leading to a successful project. However, reach out earlier in the project rather than later. Addressing lighting challenges later in the project usually leads to more constraints in the types of solutions you can implement. ◎

Perry West is founder and president of Automated Vision Systems Inc.; www.autovis.com.

Harnessing UV-C LEDs for advanced inspection and quality control

UV-C LED technology enables precise fluorescence-based automated inspection in such disciplines as food safety, adhesive quality control, and beverage authentication.

FABIEN DUBOIS

Countries around the world are banning mercury-based illuminators. Mercury lamps are used in many machine vision applications such as inspecting currency for evidence of counterfeiting or sorting vegetables using chlorophyll fluorescence. Indeed, these broadband ultraviolet sources based on mercury have monopolized the market to the point where photoinitiators and fluorescent inks were developed to match the emission peaks of its spectrum.

With deadlines approaching, vision engineers are now starting to contemplate life without mercury, and in the very near future, a viable alternative will be required to replace these legacy fixtures.

LEDs are considered the natural successor. For every application that previously employed mercury, the question arises as to whether it can be achieved with an LED solution. However, this change can also be considered an opportunity to explore different technologies. LED solutions, for example, can potentially enable new applications that were previously unattainable.

Mercury bulbs are a great multi-wavelength source as they produce a set of discrete wavelength “lines.” These are generally high power, and a filter is used to selectively pass through the chosen wavelength, while blocking others when a single wavelength is required. This discrete nature leaves “dead zones” where mercury struggles. In the UV-C range, mercury has a predominant peak at 254 nm, but it struggles in the 265-285 nm range.

In response to this shortcoming of mercury, developers of LEDs have produced a series of LEDs with peaks in this range. This opens new applications where natural processes require light in this range (this could be a fluorescence or absorption feature).

In this article, we will discuss how fluorescence using the UV-C wavelengths works and some current and prospective use cases for UV-C LEDs.

What is fluorescence?

Fluorescence is the process where a sample is exposed to a specific wavelength (material dependent) that it absorbs, causing it to emit a longer wavelength. The absorbative/emissive properties depend on the chemical structure of the sample.

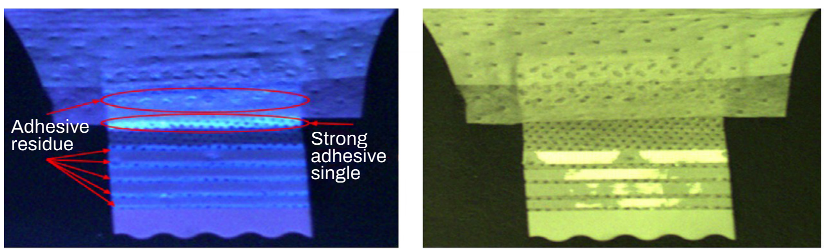


FIGURE 1. Image of a diaper tab under a 285 nm LED illuminator (left), compared with RGB image under ambient light (right). *Images courtesy of ProPhotonix*

These absorbing wavelengths usually have a spectral width, where they will absorb wavelengths close to the peak and emit, but this is usually a much less efficient process. Given that fluorescence is already a “lossy” process (i.e., the light intensity produced is only a tiny fraction of what is used to cause it), using a non-optimized wavelength accentuates this fact. UV-C

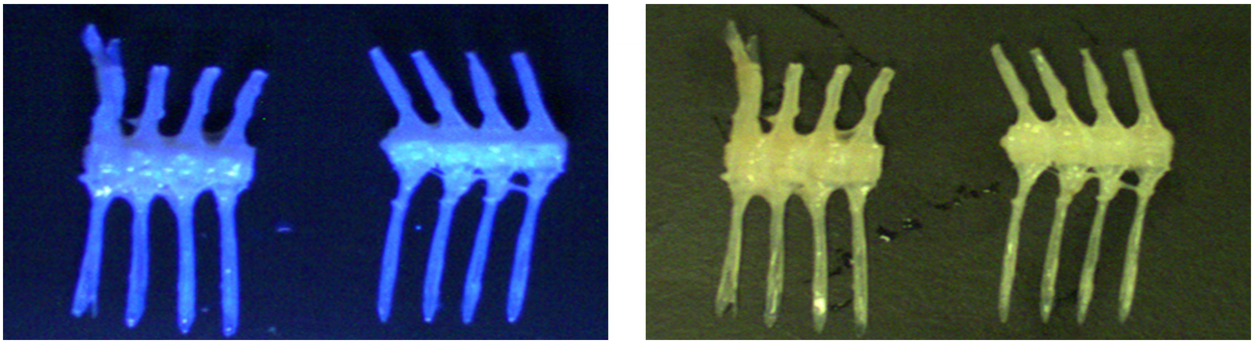


FIGURE 2. Image of fish bones under a 285 nm LED illuminator (left), compared with RGB image under ambient light (right).

LED technology excels at any fluorescence that occurs in the 265–285 nm range.

Inspecting adhesives with UV-C LEDs

Engineers are using UV-C LEDs to inspect adhesives in a variety of sanitary products, such as diapers. They will often have optical brighteners added to them; these absorb radiation in the 280–360 nm range while emitting a bright blue color in the 430–460 nm range. This can be exploited to inspect the adhesive. The images in Figure 1 show the adhesive tab of a diaper under ambient light and when illuminated by 285 nm LED light. In the fluorescence image, one can see the strong blue line at the hinge point of the tab and the residue where the tab was stuck down, and on the tab itself. Fluorescence can be used to inspect the deposition of this adhesive during production.

The fluorescent properties of UV-C also can be used to inspect food. In fish processing, bone removal is a key step to ensure consumer safety. The standard screening process for bones in processed meat and fish is to use X-ray technology. However, this is very expensive, and fish bones are so small they won't absorb enough X-rays to show up in scans. Because the bones are similar in color to the fish flesh in many instances, this can make visual inspection challenging.

Due to the collagen content in fish bones a fluorescence can be observed when using UV-C radiation. Collagen contains aromatic amino acids (mostly tryptophan, tyrosine, phenylalanine) with absorption maxima between 260 and 290 nm. These will fluoresce with a blue-violet color (380–400 nm) while the surrounding muscle will not fluoresce.[1] By using the appropriate filter, the bone can be highlighted, distinguishing it from the meat easily.

Absorbative spectral features

The advantage of fluorescent applications is that, despite requiring ultraviolet radiation, we observe the output in the visible range with a standard CMOS camera. However, along with UV LED development, advancements have also been made in ultraviolet camera technology.

Much like InGaAs cameras used in the SWIR vision sector, we can now target spectroscopic features in the UV range with the appropriate camera. Based on the material chemistry specific to the target application, we present case studies that would normally require a destructive lab-based test on a small sample. Instead, it is now possible to perform non-destructive techniques that can be applied to the entire batch of a product, ensuring 100% inspection within the process.

Inspecting decaffeinated coffee beans

Take, for example, the decaffeination of coffee. Once the beans have been put through their decaffeination process (such as the Swiss water process or the carbon dioxide process), a batch of the beans will be destructively tested to measure their caffeine concentration.

Once this batch is below a certain level it is assumed the entire batch is then appropriately decaffeinated. Studying the absorption spectrum of caffeine in the UV range, it can be found to have a peak at 272 nm. If illuminated with a 275 nm light and inspected with a UV-C-sensitive camera, the beans will reflect more light as the caffeine concentration decreases.

With careful training and development, a solution can be developed to inspect the caffeine content of every bean of a batch and remove any that have not been appropriately decaffeinated. Thus, ensuring 100% batch quality.[2]

Using UV and hyperspectral imaging to inspect whiskey

UV-C machine vision lighting need not be confined to single wavelength features. The world of hyperspectral imaging is now being extended to the UV side of the spectrum. Already extensively used in the SWIR

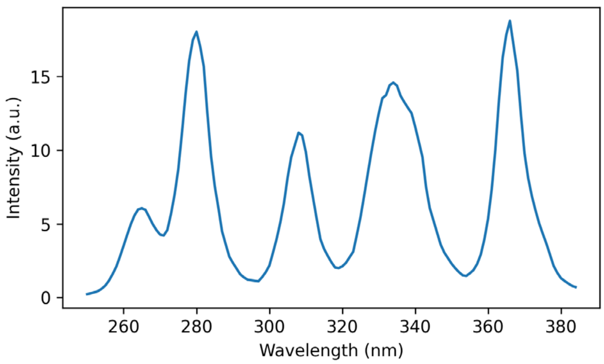


FIGURE 3. A hyperspectral light source can be made using a range of UV LEDs.

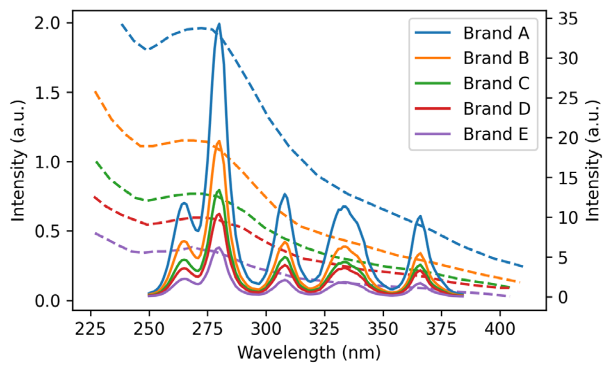


FIGURE 4. Simulated hyperspectral curves of various whiskey counterfeit samples.

region, this allows for the full chemometric analysis of samples similar to that of a spectrometer combined with the spatial feature analysis of a camera.

In SWIR absorption peaks associated with compounds like water, proteins or oils are usually tracked, building a unique spectral fingerprint for each pixel in the image.

This fingerprint can be used to identify defects or track chemometric properties of our product.

Studies have shown the possibility of detecting counterfeit whiskey using UV spectrometry.[3] The flavor profile of whiskey is complex and comes from a group of compounds known as congeners. Each whiskey will have its own unique congener profile based on the production process (what grain is used, the malting process, the distillation process and barrel aging process).

Examples of these include:

- Vanillin (vanilla type flavor, combined with a spiced note) which is typically linked to the barrel aging process, where the lignin of the wood barrel is broken down into vanillin.
- Ethyl acetate (fruity note, almost green apples) is a common ester continuously produced during barrel maturation through the interaction of acids and alcohol.

Counterfeit whiskey is made through the dilution of high value whiskey with less expensive, tasteless alcohol and adding coloring. While the alcohol-by-volume (ABV) is maintained, the congener profile cannot be faked easily.

This adulteration works due to the subjectivity of human taste, and the lack of experience with expensive whiskey. How many people have tasted a premium whiskey brand often enough to know what it should taste like? By recording a "golden reference" for each whiskey brand, we can test for major spectral differences in the UV spectrum, associated with counterfeiting.

While not an ideal broadband hyperspectral source (the full range of wavelengths availability in LEDs is still limited), the proposed spectrum above does cover the full wavelength band of interest. Each sample of interest can be scanned and instantaneously assessed for tampering. Drastically increasing throughput compared to using a spectrometer on one bottle sample at a time.

Here is the data (Figure 4) presented in the aforementioned publication in which a number of authentic and counterfeit whiskeys were tested with a UV spectrometer (solid curves). Using this we can also simulate what an arrangement of UV-C LEDs designed to simulate hyperspectral imaging would produce (dashed curves).

Using these curves we can train a rudimentary machine learning model. When tested, this model has the ability to correctly differentiate counterfeit from authentic samples 100% of the time. The caveat must be raised that this is simulated data on a small dataset. More widespread testing would be required to test this method's robustness and accuracy.

Regardless of when the obsolescence of mercury lamps is actually enforced in various regions worldwide, it is clear that UV LED technology will, at some point, replace them. With efficiencies improving and prices dropping, UV-C LEDs are becoming a viable alternative, while also unlocking new applications that the fixed spectra of the mercury option does not allow. ◎

References

1. Ł. Saletnik, W. Szczęsny, J. Szmytkowski, and J. J. Fisz, *Int. J. Mol. Sci.*, 24, 8, 7631 (2023); https://doi.org/10.3390/ijms24087631.

2. Gayathri G., J. Q. D'Souza, and N. G. Sundaram, *Minerals*, 13, 4, 465 (2023); https://doi.org/10.3390/min13040465.

3. R. I. Aylott, A. H. Clyne, A. P. Fox, and D. A. Walker, *Analyst*, 119, 1741–1746 (1994); https://doi.org/10.1039/an9941901741.

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CAMERA MANUFACTURERS

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Active Silicon Ltd Iver, UK; 44-1753-650600; www.activesilicon.com; sales@activesilicon.com								
Harrier 10x AF-Zoom Camera	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, 3G/HD-SDI, USB/HDMI, HDMI, IP H.264	60	—
Harrier 36x AF-Zoom Camera Global Shutter	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, HD-SDI, USB/ HDMI, HDMI, IP H.264	30, 60	—
Harrier 55x AF-Zoom Camera	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, 3G/HD-SDI, USB/HDMI, HDMI, IP H.264	30	—
Harrier 18x AF-Zoom HDMI 4K Camera	CMOS	C+M	Area array	4K (3840 × 2160), 1920 × 1080	VIS	HDMI, CVBS	30 (4K), 60 (Full HD)	—
Harrier 23x AF-Zoom IP 4K Camera	CMOS	C+M	Area array	4K (3840 × 2160), 1920 × 1080	VIS	IP H.265/H.264	30 (4K), 60 (Full HD)	—
Tamron MP3010M-EV	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, HDMI, USB 3, 3G/HD-SDI, HD-VLC, CVBS, H.264	60	—
Sony FCB-EV9500L	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, USB 3, HDMI, 3G/HD-SDI, HD-VLC, CVBS, H.264	60	—
Sony FCB-EV9520L	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS , USB 3, HDMI, 3G/HD-SDI, HD-VLC, CVBS, H.264	60	—
Alkeria Srl Cascina, (PI), Italy; 39-050-778-060; www.alkeria.com; sales@alkeria.com								
CELERA One	CMOS	C+M	Area array	2–12 MPixels	NIR, VIS	USB3	175	—
NOTA	CMOS	C+M	Area array	2–12 MPixels	VIS	USB3	161	—
CELERA P	CMOS	M	Area array	5–12 MPixels	VIS	Dual-USB3	154	—
NECTA	CMOS	C+M	Line scan	2–8K	VIS	USB3	—	95 kHz
NECTA X	CMOS	C+M	Line scan	4–16K	VIS	USB3.1 Gen2	—	95 kHz
Basler AG Ahrensburg, Germany; 49-4102-463-500; www.baslerweb.com; sales.europe@baslerweb.com								
Basler ace 2	CMOS	C+M	Area array	640 × 512–5328 × 4608	SWIR, VIS, UV	GigE, 5GigE, USB3, CXP-12	≤240	—
Basler racer 2	CMOS	C+M	Line scan	—	VIS	GigE, 5GigE, CXP-12	—	≤240 kHz
Basler dart	CMOS	C+M	Area array	720 × 540- 4208 × 3120	VIS	GigE, USB3, BCON for MIPI	≤523	—
Basler boost	CMOS	C+M	Area array	1936 × 1464–13376 × 9528	VIS	CXP-12	≤400	—
Basler ToF Camera	CMOS	M	Area array	640 × 480	NIR	GigE	30	—
Baumer Optronic GmbH Radeberg, Germany; 49-3528-4386-0; www.baumer.com/vision; sales.cc-vt@baumer.com								
CX/CX.I cameras	CMOS	C+M	Area array	720 × 540–5312 × 4592	SWIR, UV, VIS	GigE, USB3, Digital I/O, power outputs	≤318	—
CX.XC cameras	CMOS	C+M	Area array	656 × 520–5312 × 4600	SWIR, VIS	GigE, Digital I/O	≤237	—
LX series	CMOS	C+M	Area array	800 × 608–9344 × 7000	NIR, UV, VIS	10GigE, Dual GigE, GigE, Camera Link, Digital I/O, power outputs	≤1622	—
IX series	CMOS	C+M	Area array	1280 × 800	VIS	GigE, Digital I/O	≤50	—
QX series	CMOS	M	Area array	5328 × 4608	VIS	50GigE, Digital I/O, power outputs	≤101	—
BGFRM Technology (Imalligent) Shanghai, China; 86-4001828892; www.imalligent.com; info@imalligent.com								
VRD-1200B	—	C+M	Area array	2448 × 2048	VIS	GigE	8	—
VRD-600B	—	C+M	Area array	2448 × 2048	VIS	GigE	8	—
VRH9-120B	—	M	Area array	4200 × 2160	VIS	GigE	11.6	—
VRH9-040B	—	M	Area array	4200 × 2160	VIS	GigE	11.6	—
VRH9-020B	—	M	Area array	4200 × 2160	VIS	GigE	11.6	—

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Canon Medical Components USA Inc Irvine, CA, USA; 810-357-5022; https://mcu.canon/vsd; vsd-sales@mcu.canon								
SV-2000 Video Borescope Tablet Console or CCU	CMOS	C	Area array	400 × 400, 720 × 720	VIS	HDMI, USB 3.0	—	30 Hz
JCS-HR5U One-piece 1080p with USB	CMOS	C	Area array	1920 × 1080	VIS	HDMI, USB 3.0	—	59.94 Hz
IK-HD5UM 3CMOS, 1080p 2-Piece Remote Head	CMOS	C+M	Area array	1920 × 1080	NIR, VIS	3G-SDI, DVI, USB 3.0, RS-232	—	50, 59.94 Hz
Ultra HD IK-4K, 3-Chip Ultra HD 4K Video Camera (2-Piece Remote Head)	CMOS	C	Area array	3840 × 2160, 1920 × 1080	VIS	4- 3G-SDI, RS-232	—	59.94 Hz
JCT-TF5G/7G	CMOS	C	Area array	728 × 544, 1456 × 1088	VIS	Camera Link, PoCL	—	59.4 MHz
Chromasens GmbH Konstanz, Baden Wurttemberg, Germany; 49-7531-876-0; www.chromasens.de; info@chromasens.de								
allPIXA evo 16k CXP	CMOS	C+M	Line scan	16,384 × 3	VIS	CoaXPress	—	73 kHz
allPIXA evo 32k CXP	CMOS	M	Line scan	32,768 × 1	VIS	CoaXPress	—	80 kHz
allPIXA pro 7.3k	CCD	C	Line scan	7300 × 3	VIS	Camera Link	—	29.7 kHz
allPIXA neo 6k 10GigE Color-NIR	CMOS	C	Line scan	6144 × 4	NIR, VIS	10GigE	—	45 kHz
allPIXA neo 4k 10GigE Color	CMOS	C	Line scan	4096 × 3	VIS	10GigE	—	90 kHz
CMICRO Corp Takamatsu, Kagawa, Japan; 81-87-869-8310; www.cmicro.co.jp/en; support@cmicro.co.jp								
RSB400H	CMOS	C	Line scan	4096 × 3	VIS	Camera Link, CoaXPress	—	21.4 kHz
HOB200H	CMOS	M	Line scan	2048 (10 × 180 µm pixels)	VIS	Camera Link	—	69.9 kHz
FXS800A	CMOS	M	Line scan	8192	VIS	CoaXPress	—	72.4 kHz
NDB100H	InGaAs	M	Line scan	1024 × 2	SWIR	Camera Link, GigE	—	40 kHz
HMM16KP-X9	CMOS	C+M	Line scan	16384 × 3	VIS, NIR	CoaXPress	—	61 kHz
Cognex Natick, MA, USA; 508-650-3000; www.cognex.com; news@cognex.com								
In-Sight 3800 Vision System	CMOS	C+M	Area array	≤5MP (2448 × 2048)	VIS	Ethernet	200	—
In-Sight 2800 Vision System	CMOS	C+M	Area array	≤2MP (1920 × 1080)	VIS	Ethernet	—	≤45 Hz
Cubert GmbH Ulm, Germany, 49-177-788636-9, https://cubert-hyperspectral.com/en; sales@cubert-gmbh.de								
ULTRIS X20	CMOS	C	Area array	410 × 410	Hyperspectral, NIR, VIS, UV	GigE	8	—
ULTRIS X20 Plus	CMOS	C+M	Area array	1886 × 1886	Hyperspectral, NIR, VIS, UV	Dual GigE	4	—
ULTRIS 5	CMOS	C	Area array	290 × 275	Hyperspectral, NIR, VIS	GigE	45	—
ULTRIS SWIR 1	InGaAs	C	Area array	200 × 200	Hyperspectral, SWIR	USB3	80	—
ULTRIS XMR	CMOS	C	Area array	1000 × 1000	Hyperspectral, NIR, VIS	USB3	17	—
e-con Systems Fremont, CA, USA; 408-766-7503; www.e-consystems.com; camerasolutions@e-consystems.com								
e-CAM85_CUHSB	CMOS	C	—	—	VIS	GigE	60	—
RouteCAM_CU86	CMOS	C	—	—	VIS	GigE	30	—
STURDeCAM88_ CUOAGX	CMOS	C	—	—	VIS	GMSL2	30	—
See3CAM_ 37CUGM	CMOS	C	—	—	VIS	USB 3.2/2.0	72	—
See3CAM_CU83	CMOS	C	—	—	VIS	USB 3.2/2.0	30	—
Emergent Vision Technologies Inc Port Coquitlam, BC, Canada; 866-780-6082; www.emergentvisiontec.com; sales@emergentvisiontec.com								
EROS 10GigE	CMOS	C+M	Area array	0.33–24.5 MP	VIS, SWIR, UV	10GigE	30–711	—
BOLT 25GigE	CMOS	C+M	Area array	0.5–127.4 MP	VIS, NIR, UV	25GigE	17–1594	—

CAMERA MANUFACTURERS

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Emergent Vision Technologies Inc Port Coquitlam, BC, Canada; 866-780-6082; www.emergentvisiontec.com; sales@emergentvisiontec.com								
ZENITH 100GigE	CMOS	C+M	Area array	2.5–152 MP	VIS	100GigE	14–3462	—
PACE 10GigE	CMOS	C+M	Line array	4K × 2, 8K × 4, 8K × 16, 16K × 2, 16K × 16, 9K 256 TDI	VIS	10GigE	—	70–172 kHz (single line), 23–57 kHz (tri-rate)
ACCEL 25GigE	CMOS	C+M	Line array	8K × 4, 8K × 16, 9K 256 TDI, 16K × 2, 16K × 16	VIS	25GigE	—	120–304 kH (single line), 60–100 kHz (tri-rate)
PINNACLE 100GigE	CMOS	C+M	Line array	8K 256 TDI, 9K 256 TDI, 16K 256 TDI, 16K × 16	VIS	100GigE	—	70–172 kHz (single line), 23–57 kHz (tri-rate)
EVK DI Kerschhaggl GmbH Raaba, Austria, 43-316-461-664, www.evk.biz; office@evk.biz								
EVK HELIOS EQ32	InGaAs	C+M	Line Scan	—	Hyperspectral	GigE	—	446 Hz (@ full/248 bands)–3.8 kHz (ROI)
EVK HELIOS EC32	InGaAs	C+M	Line Scan	—	Hyperspectral	GigE	—	447 Hz (@ full/248 bands)–3.8 kHz (ROI)
EVK HELIOS EC64	InGaAs	C+M	Line Scan	—	Hyperspectral	GigE	—	>700 Hz @full (248 bands)
Hamamatsu Corp Bridgewater, NJ, USA; 908-231-0960; www.hamamatsu.com; photonics@hamamatsu.com								
High Speed InGaAs Camera (C15333-10E)	InGaAs	M	Line scan	1024 × 1	SWIR	GigE	40 klps	40 kHz
VGA InGaAs Camera (C12741-03)	InGaAs	M	Area array	320 × 256	SWIR	USB3	216	—
RGBNIR multiline Camera (C16006)	CMOS	C+M	Line scan	8192 × 4	NIR, VIS	Camera Link	20 × 4 klps	—
Compact InGaAs Camera (C15853-02)	InGaAs	M	Line scan	1024 × 1	SWIR	USB 3.1 Gen1	40k lps	15 MHz
ORCA-Fusion (C14440-20UP)	CMOS	M	Area array	2304 × 2304	VIS	CoaXPress, Digital I/O, USB3	100	—
QVGA Standard/ ex-tended InGaAs Camera (C16090 series)	InGaAs	M	Area array	320 × 256	SWIR	USB 3.1 Gen1	500	—
Headwall Photonics Inc Bolton, MA, USA; 978-353-4100; www.headwallphotonics.com; sales@headwallphotonics.com								
Hyperspec SWIR 640	MCT	C+M	Line Scan	—	Hyperspectral, SWIR	CameraLink	—	—
Hyperspec MV.C VNIR	CMOS	C+M	Line Scan	—	Hyperspectral, NIR, VIS	USB 3.1	—	—
Hyperspec MV.C NIR Imaging System	InGaAs	C+M	Line scan	—	Hyperspectral, NIR	Ethernet	—	—
HySpex by NEO Oslo, Norway; 47-40-00-18-58; www.hyspex.com; hyspexsales@neo.no								
Baldur S-384N	MCT	M	Line scan	—	Hyperspectral, SWIR	Camera Link, LVDS, 5V/12V/24V TTL	650	—
Baldur S-640iN	InGaAs	M	Line scan	—	Hyperspectral, NIR, SWIR	GigE, LVDS, 5V/12V/24V TTL	500	—
Baldur V-1024N	CMOS	M	Line scan	—	Hyperspectral, NIR, VIS	Camera Link	1000	—
IDS Imaging Development Systems GmbH Obersulm, Germany; 49-7134-96196-0; www.ids-imaging.com; info@ids-imaging.com								
uEye CP camera series	CMOS	C+M	Area array	800 × 600–5328 × 4608	NIR, VIS	Digital I/O, GigE, USB3	≤410	—
uEye LE camera series	CMOS	C+M	Area array	1280 × 1024–3552 × 3552	NIR, VIS	Digital I/O, GigE, USB3	≤235	—
uEye XCP-E camera series	Event Based	M	Area array	1280 × 720	VIS	Digital I/O, USB3	>10,000	—

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
IDS Imaging Development Systems GmbH Obersulm, Germany; 49-7134-96196-0; www.ids-imaging.com; info@ids-imaging.com								
uEye Warp10 camera series	CMOS	C+M	Area array	4112 × 3008–8200 × 5468	NIR, UV	Digital I/O, 10 GigE	≤100	—
Nion 3D Time of Flight camera	ToF	M	Area array	1280 × 960	VIS	GigE	30	—
IMPERX Boca Raton, FL, USA; 561-989-0006; www.imperx.com; sales@imperx.com								
AI1-P1911 CMOS Cheetah Camera	CMOS	C	Area array	—	NIR	GigE Vision w/ PoE	—	—
P67-C1911 Cheetah Camera	CMOS	C+M	Area array	1944 x 1472	NIR	GigE Vision w/ PoE	40	—
2.86 MP CLF-C1921 CMOS Cheetah Camera	CMOS	C+M	Area array	1944 x 1472	NIR	Camera Link Full	174	—
P67-C2010 Cheetah Camera	CMOS	C+M	Area array	2064 x 1544	NIR	GigE Vision PoE	36	—
P67-C2820 Cheetah Camera	CMOS	C+M	Area array	2856 x 2848	NIR	GigE Vision PoE	14.8	—
inno-spec GmbH Nürnberg, Germany; 49-911-3766910; www.inno-spec.de; info@inno-spec.de								
BlackEye	InSb	C+M	Line scan	640 × 200/300	Hyperspectral, MWIR	2.5 Gigabit Ethernet	—	0.52 kHz
BlueEye Gen.2	CMOS	C+M	Line scan	1650 × 1750	Hyperspectral, UV	USB 3.1 type C	—	0.04 kHz
RedEye 1.7	InGaAs	C+M	Line scan	320 × 256	Hyperspectral, NIR	GigE	—	0.34 kHz
Instrument Systems GmbH Munich, Germany; 49-8945-4943-0; www.instrumentsystems.com; sales@instrumentsystems.com								
LumiTop X150 Imaging Colorimeter	CMOS	C	Area array	150 Mpixel(≤600 MP per color channel)	VIS	CoaXPress	—	—
LumiTop X30 Low Luminance Imaging Colorimeter	CMOS	C	Area array	31 Mpixel	VIS	GigE	—	—
LumiTop 5300 Imaging Colorimeter	CMOS	C	Area array	24 Mpixel	VIS	GigE	—	—
VTC 4000 IR Nearfield Camera	CMOS	M	Area array	12 Mpixel	IR	Ethernet	—	—
VTC 2400 IR Farfield Camera	CMOS	M	Area array	5 Mpixel	IR	Ethernet	—	—
IO Industries Inc London, ON, Canada; 519-663-9570; www.ioindustries.com; sales@ioindustries.com								
Victorem 4KSDI-Mini	CMOS	C+M	Area array	4096 × 2160	VIS	HD-SDI	60	—
Victorem 120B68-CV	CMOS	C+M	Area array	4096 × 3008	VIS	CoaXPress	68	—
Redwood 654G71-CX	CMOS	C+M	Area array	9344 × 7000	VIS	CoaXPress	71	—
Volucam 120B68-V	CMOS	C+M	Area array	4096 × 3008	VIS	10GigE, HD-SDI	68	—
8KSDI	CMOS	C+M	Area array	8192 × 4320	VIS	HD-SDI	60	—
iX Cameras Ltd Woburn, MA, USA; 339-645-0778; www.ix-cameras.com; info@ix-cameras.com								
i-SPEED 511	CMOS	C+M	Area array	1920 × 1080	NIR, UV, VIS	Ethernet, GigE, HDMI, HD-SDI, Proprietary, USB3	100–1,000,000	10 GPx/s
i-SPEED 514	CMOS	C+M	Area array	1920 × 1080	NIR, UV, VIS	Ethernet, GigE, HDMI, HD-SDI, Proprietary, USB3	100–1,000,000	13 GPx/s
i-SPEED 717	CMOS	C+M	Area array	2072 × 1536	NIR, UV, VIS	Proprietary	2.45 million	17 GPx/s
i-SPEED 721	CMOS	C+M	Area array	2072 × 1536	NIR, UV, VIS	Proprietary	2.45 million	21 GPx/s
i-SPEED 727	CMOS	C+M	Area array	2072 × 1536	NIR, UV, VIS	Proprietary	2.45 million	27 GPx/s
JADAK, a Novanta Co North Syracuse, NY, USA; 315-701-0678; www.jadaktech.com; info@jadaktech.com								
Allegro LW-AL-CMV2000	CMOS	C+M	Area array	2048 × 1024	NIR, VIS	GigE, USB3	300	—
Allegro LW-AL-CMV12000	CMOS	C+M	Area array	4096 × 3072	NIR, VIS	GigE, USB3	50	—
Allegro LW-AL-IMX172	CMOS	C+M	Area array	4000 × 3000	VIS	GigE, USB3	35	—
Mini Camera	CMOS	C+M	Area array	1280 × 800	VIS	USB2, RS-232	60	—

CAMERA MANUFACTURERS

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
KEYENCE Corp of America Itasca, IL, USA; 888-539-3623; www.keyence.com/usa; marketing@keyence.com								
VS-C2500X	CMOS	C+M	Area array	5120 × 5120	VIS	Proprietary	35	—
VS-L1500X	CMOS	C+M	Area array	4400 × 3296	VIS	Proprietary	44	—
CA-HF6400	CMOS	C+M	Area array	8192 × 7808	VIS	Proprietary	17.4	—
CA-HL08MX	CMOS	M	Line scan	1 × 8192	VIS	Proprietary	—	97.7 kHz
XT-060	CMOS	C+M	—	3072 × 3072	VIS	Proprietary	—	—
LUCID Vision Labs, Inc. Burnaby, BC, Canada; www.thinklucid.com; sales@thinklucid.com								
Helios2+ ToF 3D Camera High-Speed/HDR Mode	ToF	M	Area array	640 × 480	3D	GigE, PoE+	30	125 MB/s
Helios2 Narrow 31° × 24° Field of View ToF Camera	ToF	M	Area array	640 × 480	3D	GigE, PoE+	30	125 MB/s
Helios2 Wide 108° × 78° Field of View ToF Camera	ToF	M	Area array	640 × 480	3D	GigE, PoE+	30	125 MB/s
Helios2 Ray ToF Camera (940nm)	ToF	M	Area array	640 × 480	3D	GigE, PoE+	30	125 MB/s
Atlas 5GBASE-T Camera	CMOS	C+M	Area array	≤6464 × 4852	NIR, VIS	5GigE, PoE	≤173	600 MB/s
Atlas 5GBASE-T IP67 Camera	CMOS	C+M	Area array	≤5320 × 4600	NIR, VIS	5GigE, PoE	≤173	600 MB/s
Phoenix Camera	CMOS	C+M	Area array	≤5472 × 3648	NIR, VIS	GigE PoE	≤286	125 MB/s
Triton IP67 Camera	CMOS	C+M	Area array	≤5300 × 4600	NIR, VIS	GigE PoE	≤286	125 MB/s
Triton2 IP67 2.5 GigE Camera	CMOS	C+M	Area array	≤5300 × 4600	NIR, VIS	GigE, 2.5GigE, PoE	≤166	312 MB/s
Triton2 SWIR IP67 Camera	CMOS	M	Area array	2560 × 2048	SWIR	2.5GigE, PoE	≤85	125 MB/s
Triton10 - 10GigE Camera with RDMA	CMOS	C+M	Area array	≤5320 × 4600	NIR, VIS	10GigE	≤216	1.2 GB/s
Atlas SWIR IP67 Camera	CMOS	M	Area array	1280 × 1024	SWIR	GigE, PoE	≤257	1 Gbps
Atlas10 UV Camera	CMOS	M	Area array	2840 × 2840	UV	GigE, PoE	126	1.2 GB/s
Atlas 10GBASE-T Camera	CMOS	C+M	Area array	<9344 × 7000	NIR, VIS	GigE, 10GigE, PoE+	≤205	1.2 GB/s
Triton2 4K Line Scan Camera	CMOS	C+M	Line scan	4096 × 2 px	NIR, VIS	2.5GigE, PoE	60 kHz	312 MB/s
Triton2 EVS Event-Based Camera	Event based	—	Area array	1280 × 720	VIS	2.5GigE	>10k	312 MB/s
Triton Smart with On-Sensor AI for Edge Inference	CMOS	C+M	Area array	4056 × 3040	AI camera	GigE	30	125 MB/s
Mega Speed Corp Minnedosa, MB, Canada; 204-867-3767; www.megaspeedusa.com; sales@megaspeedusa.com								
Mega Speed MS140K	CMOS	C+M	Area array	1920 × 1080– 64 × 16	VIS	GigE	35–225,000	—
Mega Speed MAX V1	CMOS	C+M	Area array	1920 × 1080– 640 × 16	VIS	GigE	2400	—
Mega Speed MAX V3	CMOS	C+M	Area array	1920 × 1080 640 × 16	VIS	GigE	35–200,000	—
Mega Speed X8 PRO	CMOS	C+M	Area array	1280 × 800– 640 × 16	VIS	GigE	4000– 512,000	—
Mega Speed MS35K PRO Cart	CMOS	C+M	Area array	1920 × 1080– 640 × 480	VIS	GigE	3000	—
Opto Engineering Mantova, (MN), Italy; 39-0376-699111; www.opto-e.com; press@opto-e.com								
ITALA G.EL series	CMOS	C+M	Area array	1456 × 1088– 5328 × 4608	VIS	GigE	4.8–74.2	—
ITALA G.SWIR series	CMOS	M	Area array	1296 × 1032	SIR, VIS	GigE	87.8	—
ITALA G.IP series	CMOS	C+M	Area array	728 × 544– 5328 × 4608	VIS	GigE	4.8–296.5	—
ITALA 10G series	CMOS	C+M	Area array	2472 × 2064– 6480 × 4860	VIS	10GigE	21.7–231.2	—

This table is published as a service. The publisher does not assume liabilities for errors or omissions.
Please visit www.vision-systems.com/directory for the comprehensive online company listings.

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Opto Engineering Mantova, (MN), Italy; 39-0376-699111; www.opto-e.com; press@opto-e.com								
COE-U series	CMOS	C+M	Area array	1280 × 1024–5472 × 3648	VIS	USB 3.0	6.4–201	—
COE LS-X series	CMOS	C+M	Line scan	4K	VIS	GigE	19–28	—
Percipio Technology Ltd Shanghai, China; 86-218-015-8012; www.percipio.xyz; info@percipio.xyz								
GM465-E1	3D	C	Area array	1280 × 960	IR	100GigE	10	—
PMD03-E1	3D	C	Area array	2048 × 1536	IR	GigE	1.57	—
FM815-IX-E1	3D	C	Area array	1280 × 960	IR	GigE	5	—
VMD03-8521C	3D	C	Area array	2048 × 1536	VIS	GigE	0.76	—
TM421-E1	3D	C	Area array	640 × 480	IR	GigE	10	—
Photron USA Inc San Diego, CA, USA; 858-684-3555; www.photron.com; image@photron.com								
FASTCAM NOVA R3-4K	CMOS	C+M	Area array	4096 × 2304	VIS	1GigE/10GigE	750–150,000	—
FASTCAM MH6	CMOS	C+M	Area array	1920 × 1400	VIS	GigE	750–5000	—
Pharsighted E9•150S	CMOS	C+M	Area array	640 × 480	VIS	1GigE/10GigE	489,000–2,720,00	—
Pharsighted E9•100S	CMOS	C+M	Area array	640 × 480	VIS	1GigE/10GigE	326,000–2,720,000	—
Pharsighted E9•80S	CMOS	C+M	Area array	640 × 480	VIS	1GigE/10GigE	272,000–2,457,000	—
PHYTEC Messtechnik GmbH Mainz, Germany; 49-6131-9221-0; www.phytec.de; contact@phytec.de								
VM-016-M	CMOS	C+M	Area array	1280 × 800	VIS	MIPI CSI-2	60	—
VM-017-L	CMOS	C+M	Area array	2592 × 1944	VIS	FPD-Link III	60	—
VM-017-M	CMOS	C+M	Area array	2592 × 1944	VIS	MIPI CSI-2	60	—
VM-020-L	CMOS	C+M	Area array	1920 × 1200	VIS	FPD-Link III	96	—
VM-020-M	CMOS	C+M	Area array	1920 × 1200	VIS	MIPI CSI-2	120	—

CAMERA MANUFACTURERS

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Pixelink Ottawa, ON, Canada; 613-247-1211; www.navitar.com/product/pixelink-cameras; sales.pixelink@ametek.com								
PL-X9524	CMOS	C+M	Area array	5328 × 4608	VIS	10GigE	44	—
PL-X9520	CMOS	C+M	Area array	4512 × 4512	VIS	10GigE	52	—
PL-D757	CMOS	C+M	Area array	3208 × 2200	VIS	USB3	57	—
PL-D753	CMOS	C+M	Area array	1936 × 1464	VIS	USB3	141	—
PL-D782	CMOS	C+M	Area array	2048 × 1200	VIS	USB3	159	
Radiant Vision Systems Redmond, WA, USA; 425-844-0152; www.radiantvisionsystems.com; info@radiantvs.com								
ProMetric I61 Imaging Colorimeter	CMOS	C+M	Area array	9568 × 6380	NIR, VIS	GigE, 10 GigE	—	—
ProMetric I16-G Imaging Colorimeter	CMOS	C+M	Area array	5312 × 3032	NIR, VIS	Ethernet 1000	—	—
ProMetric Y61 Imaging Photometer	CMOS	M	Area array	9568 × 6380	NIR, VIS	10 GigE	—	—
ProMetric Y16-G Imaging Photometer	CMOS	M	Area array	5312 × 3032	NIR, VIS	Ethernet 1000	—	—
Schäfter+Kirchhoff GmbH Hamburg, Germany; 49-40-853-997-0; www.sukhamburg.com; info@sukhamburg.de								
SK4k-U3DR7C	CMOS	C	Line scan	4096 × 2 Bayer Pattern	VIS	USB3	—	43.4 kHz
SK8k-U3DR4	CMOS	M	Line scan	8192 × 1	VIS	USB3	—	43.4 kHz
SK2048_HA	CCD	M	Line scan	2048 × 1	VIS	USB3, GigE Vision, Camera Link	—	52.63 kHz
SK2048U3HU	CMOS	M	Line scan	2048 × 1, 12.5 × 500 μm²	VIS	USB3	—	7.14 kHz
SK4096U3HW	CMOS	M	Line scan	4096 × 1, 7 × 200 μm²	VIS	USB3	—	2.38 kHz
SK2048U3JR	CCD	M	Line scan	2048 × 1	VIS	USB3	—	4.69 kHz
SK1024_SH	CCD	M	Line scan	1024 × 1	VIS	USB3, GigE Vision, Camera Link	—	27 kHz
SK2048_SH	CCD	M	Line scan	2048 × 1	VIS	USB3, GigE Vision, Camera Link	—	14 kHz
SK22368GTFC-4L	CCD	C	Line scan	5400 × 3	VIS	GigE	—	5.1 kHz
SICK Inc Bloomington, MN, USA; 952-941-6780; www.sickusa.com; info@sick.com								
InspectorP61x	CMOS	M	Area array	1.2 Mpixel	NIR, VIS	Serial, Ethernet, Fieldbus	≤70	—
Inspector83x	CMOS	C	Area array	1.3- 5.1 Mpixel	NIR, VIS	Serial, Ethernet, Fieldbus	≤70	—
Inspector85x	0	M	Area array	5-12 Mpixel	NIR, VIS	Serial, Ethernet, Fieldbus	≤70	—
Ruler3000	CMOS	M	Line scan	3202, 560 × 832 px 0 datapoint/ profile	—	Ethernet, GigEvision	—	—
Visionary-B Two	ToF	C	Line Scan	1024 × 576	—	Ethernet, GigEvision	≤30	—
sensingCam - SEC100	CMOS	C+M	2D snapshot, stream-ing, event recording	2,880 x 1,616	—	REST API, Ethernet	—	—
SPECIM Spectral Imaging Ltd Oulu, Finland; 358-10-4244-400; www.specim.com; info@specim.com								
Specim FX10	CMOS	M	Line scan	1024 × 224	Hyperspectral, NIR, VIS	Camera Link / GigE Vision	330 (full), 9900 (1 band)	—
Specim FX17	InGaAs	M	Line scan	640 × 224	Hyperspectral, NIR	Camera Link / GigE Vision	670 (full), 15,000 (4 bands)	—
Specim FX50	InSb	M	Line scan	640 × 154	MWIR	GigE Vision	377	—
Specim FX120	MCT	M	Line scan	100 × 160	Hyperspectral, LWIR	GigE Vision	240 (full)	—
Specim SX25	MCT	M	Line scan	640 × 392	Hyperspectral, SWIR	GigE Vision	162 (full)	—

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
SWIR Vision Systems Inc Morrisville, NC, USA; 919-248-0032; www.swirvisionsystems.com; sales@swirvisionsystems.com								
Acuros CQD 1280 eSWIR Camera	CQD	M	Area array	1280 × 1024	IR, Multispectral, NIR, SWIR, VIS	GigE, USB3	90	—
Acuros CQD 1920 eSWIR Camera	CQD	M	Area array	1920 × 1080	IR, Multispectral, NIR, SWIR, VIS	GigE, USB3	60	—
Acuros CQD 640 SWIR Camera	CQD	M	Area array	640 × 512	IR, Multispectral, NIR, SWIR, VIS	GigE, USB3	280	—
Acuros CQD 1280 SWIR Camera	CQD	M	Area array	1280 × 1024	IR, Multispectral, NIR, SWIR, VIS	GigE, USB3	90	—
Acuros CQD 1920 SWIR Camera	CQD	M	Area array	1920 × 1080	IR, Multispectral, NIR, SWIR, VIS	GigE, USB3	60	—
Teledyne DALSA Waterloo, ON, Canada; 519-886-6000; www.teledynevisionsolutions.com; tdi_sales.americas@teledyne.com								
Calibir GX	Microbolometer	M	Area array	640 × 480	LWIR	GigE	30, 60	—
MicroCalibir	Microbolometer	M	Area array	640 × 480	LWIR	USB2	60	—
Falcon4-CLHS	CMOS	M	Area array	2240 × 1248, 4480 × 2496, 6144 × 6144, 8192 × 8192	VIS	Camera Link HS	1200, 609, 330, 120, 90	—
Genie Nano-CL	CMOS	C+M	Area array	2448 × 2048, 2464 × 2056, 4112 × 2176, 4096 × 4096, 5112 × 5112	NIR, VIS	Camera Link, Camera Link Full	35,141, 88, 64, 45, 30	—
Genie Nano-CXP	CMOS	C+M	Area array	4096 × 4096, 5120 × 5120, 6144 × 6144, 8192 × 8192	NIR, VIS	CoaXPress	120, 80, 40, 30	—
Genie Nano-1GigE	CMOS	C+M	Area array	640 × 480, 728 × 544, 800 × 600, 816 × 624, 1280 × 1024, 1456 × 1088, 1608 × 1104, 1632 × 1248, 1936 × 1216, 2048 × 1536, 2448 × 2048, 2592 × 2048, 4112 × 2176, 4112 × 3012, 4912 × 3684, 4096 × 4096, 5120 × 5120	NIR, VIS	GigE	862, 311, 566, 160, 83, 213, 90, 85, 39, 84, 116, 151, 55, 140, 35, 51, 56, 40, 30, 20, 13, 31, 34.4	—
Genie Nano-5GigE	CMOS	C+M	Area array	2064 × 1544, 2464 × 2056, 4112 × 3008, 4112 × 2176, 4500 × 4500, 5420 × 5420, 8192 × 5420	VIS	5GigE	190, 141, 64, 88, 64, 30, 19	—
Genie Nano-10GigE	CMOS	C+M	Area array	6144 × 6144, 8192 × 8192	VIS	10GigE	18,13	—
Linea	CMOS	M	Line scan	2048 × 1, 4096 × 1, 8192 × 1, 16,384 × 1	VIS	Camera Link, Camera Link HS, GigE	—	80, 71, 52
Linea Color	CMOS	C	Line scan	2048 × 2, 4096 × 2, 8192 × 2	VIS	Camera Link, GigE	—	48 × 3, 26 × 3

CAMERA MANUFACTURERS

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Teledyne DALSA Waterloo, ON, Canada; 519-886-6000; www.teledynevisionsolutions.com; tdi_sales.americas@teledyne.com								
Linea 2	CMOS	C	Line scan	4096 × 3, 4096 × 4	NIR, VIS	5GigE	—	40 × 3, 32 × 4
Linea HS	CMOS	M	TDI	4096 × 192, 8192 × 192, 13,056 × 192, 16,384 × 128, 16,384 × 192, 32,768 × 64	NIR, VIS	Camera Link HS	—	400
Linea HS2	CMOS	M	TDI	16,384 × 288	NIR, VIS	CameraLink HS	—	1000
Linea HS Color	CMOS	C	TDI	16,384 × 256	NIR, VIS	Camera Link HS	—	100 × 3
Linea HS Multifield	CMOS	C	TDI	16,384 × 256	NIR, VIS	Camera Link HS	—	133 × 3
Linea ML	CMOS	M	Line scan	8192 × 4, 16,384 × 4	NIR, VIS	Camera Link HS	—	300
Linea ML Color	CMOS	C	Line scan	8192 × 3, 16,384 × 3	VIS	Camera Link HS	—	100 × 3
Linea ML Multispectral	CMOS	C	Line scan	8192 × 4	NIR, VIS	Camera Link HS	—	75 × 4
Linea SWIR	InGaAs	M	Line scan	1024 × 1, 512 × 1	SWIR	GigE	—	40
Linea Lite	CMOS	M	Line scan	2048 × 2, 4096 × 2, 8192 × 2	VIS	Camera Link, GigE	—	120, 50
Linea Lite Color	CMOS	C	Line scan	2048 × 2, 4096 × 2	VIS	Camera Link, GigE	—	40 × 3, 25 × 3
Piranha4 Series	CMOS	M	Line scan	2048 × 2, 4096 × 2, 8192 × 2	VIS	Camera Link	—	200
Piranha4 Color	CMOS	C	Line scan	2048 × 3, 4096 × 3, 8192 × 3	VIS	Camera Link	—	70 × 3
AxCIS	CMOS	M	Line scan	14,304 × 2, 28,608 × 2	NIR, VIS	Camera Link HS	—	120
AxCIS Color	CMOS	C	Line scan	14,304 × 3, 28,608 × 3	NIR, VIS	Camera Link HS	—	150, 180
Teledyne e2v, a business unit of Teledyne Digital Imaging US Inc Chestnut Ridge, NJ, USA; 845-425-2000; teledynevisionsolutions.com; e2v-imaging.us@teledyne.com								
OctoPlus OCT	CMOS	M	Line scan	2048 × 1	NIR	Camera Link, USB3	—	20, 80, 130, 250 kHz
Teledyne FLIR LLC Wilsonville, OR, USA; 877-773-3547; www.flir.com; sales@flir.com								
FLIR A6260 SWIR	InGaAs	C+M	Area array	640 × 512	SWIR	GigE, SDI	0.0015–125 Hz (180 Hz burst)	125 Hz (full), 25,614 Hz (max)
FLIR A6750 Series	InSb or Strained-Layer Superlattice	C+M	Area array	640 × 512	LWIR, MWIR	GigE, SDI	0.0015–125 Hz	125 Hz (full), 4175 Hz (max)
FLIR A8580 Series	InSb or Strained-Layer Superlattice	C+M	Area array	1280 × 1024	LWIR, MWIR	GigE, CoaXPress, SDI	0.0015–45 Hz (GigE), 60 Hz (CXP)	60 Hz (full), 3709 Hz (max)
FLIR X6980 Series	InSb or Strained-Layer Superlattice	C+M	Area array	640 × 512	LWIR, MWIR	GigE, CoaXPress, Camera Link, SDI, HDMI	0.0015–1004 Hz	1004 Hz (full), 29,133 Hz (max)
FLIR X8580 Series	InSb or Strained-Layer Superlattice	C+M	Area array	1280 × 1024	LWIR, MWIR	GigE, CoaXPress, Camera Link, SDI, HDMI	~0.5–181 Hz	181 Hz (full), 6026 Hz (max)
FLIR Ax8	Microbolometer	C+M	Area array	80 × 60	LWIR	Ethernet	9 Hz	9 Hz
FLIR A400 Smart Sensor	Microbolometer	C+M	Area array	320 × 240	LWIR	Ethernet, Wi-Fi (optional)	30	30 Hz
FLIR A400 Image Streaming	Microbolometer	C+M	Area array	320 × 240	LWIR	GigE, Wi-Fi (optional)	30	30 Hz
FLIR A500 Smart Sensor	Microbolometer	C+M	Area array	464 × 348	LWIR	Ethernet, Wi-Fi (optional)	30	30 Hz

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Teledyne FLIR LLC Wilsonville, OR, USA; 877-773-3547; www.flir.com; sales@flir.com								
FLIR A500 Image Streaming	Microbolometer	C+M	Area array	464 × 348	LWIR	GigE, Wi-Fi (optional)	30	30 Hz
FLIR A700 Smart Sensor	Microbolometer	C+M	Area array	640 × 480	LWIR	Ethernet, Wi-Fi (optional)	30	30 Hz
FLIR A700 Image Streaming	Microbolometer	C+M	Area array	640 × 480	LWIR	GigE, Wi-Fi (optional)	30	30 Hz
FLIR Boson+	Microbolometer	M	Area array	640 × 512, 320 × 256	LWIR	USB, CMOS	60, 30	60, 30
FLIR Boson	Microbolometer	M	Area array	640 × 512, 320 × 256	LWIR	USB, CMOS	60, 30, 9	60, 30, 9
FLIR Lepton	Microbolometer	M	Area array	160 × 120, 80 × 60	LWIR	SPI	9	9
FLIR Neutrino SWaP	HOT MWIR	M	Area array	640 × 512, 1280 × 1024	MWIR	USB or UART (921.6k baud)	<60 Hz	<60 Hz
FLIR Neutrino Performance	HOT MWIR	M	Area array	1280 × 1024, 2048 × 1536	MWIR	RS-422, selectable BAUD rate	60 Hz, 120 Hz	60 Hz, 120 Hz
FLIR Neutrino IS	HOT MWIR	M	Area array	640 × 512, 1280 × 1024	MWIR	USB or UART (921.6k baud)	<60 Hz	<60 Hz
FLIR Neutrino Ground ISR	HOT MWIR	M	Area array	—	MWIR	RS-422 UART COM, up to 921,600 Baud	<120 Hz	<120 Hz
Teledyne FLIR ISS Richmond, BC, Canada; 604-242-9937; www.flir.com/mv; mv-sales@flir.com								
Blackfly S USB	CMOS	C+M	Area array	0.4–24.5 MPixels	VIS	USB3	15–522	—
Dragonfly S	CMOS	C+M	Area array	5 MPixels	VIS	USB3	49	—
LT Series	CMOS	C+M	Area array	1.7-31.4 MPixels	VIS	USB3	15–162	—
Firefly S	CMOS	C+M	Area array	0.4–1.6 MPixels	VIS	USB3	60–121	—
Blackfly S Board Level	CMOS	C+M	Area array	1.6–20 MPixels	VIS	USB3, GigE	10–226	—
Blackfly S GigE	CMOS	C+M	Area array	0.4–24.5 MPixels	VIS	GigE	5–291	—
Forge 1GigE IP67	CMOS	C+M	Area array	5 MPixels	VIS	GigE	24	—
Forge 1GigE SWIR	InGaAs	—	Area array	1.3 MPixels	SWIR, VIS	GigE	92	—
Forge 5GigE	CMOS	C+M	Area array	5–24.5 MPixels	VIS	5GigE	35–207	—
Oryx 10GigE	CMOS	C+M	Area array	3.2–31 MPixels	VIS	10GigE	26–216	—
Bumblebee × 5GigE	CMOS	C+M	—	3 MPixels	VIS	5GigE	16–20.8	—
Ladybug6	CMOS	C	—	72 MPixels	VIS	USB3	15	—
Ladybug5+	CMOS	C	—	30 MPixels	VIS	USB3	30	—
DDU2607M series | DDU1607M Series | DDU1207M series	CMOS	C+M	Area array	5120 × 5120, 4000 × 4000, 4096 × 3000	VIS	Dual USB3	28.3, 47, 62	742, 752, 750 MB/s
DU1207M Series | DU657M Series	CMOS	C+M	Area array	4096 × 3000, 2560 × 2560	VIS	USB3	32, 55	393, 360 MB/s
BU2409M Series | BU1206M Series | BU805M Series | BU502M Series	CMOS	C+M	Area array	5320 × 4600, 4096 × 3000, 2840 × 2840, 2448 × 2048	VIS	USB3	15, 31, 46, 75	367, 393, 371, 376 MB/s
BU1207M Series | BU505M Series | BU302M Series	CMOS	C+M	Area array	4096 × 3000, 2448 × 2048, 2048 × 1536	VIS	USB3	31, 75, 120	393, 376, 377 MB/s
Toshiba Teli Corp Tokyo, Japan; 81-42-589-8771; www.toshiba-teli.co.jp/en/; teli-global@toshiba-teli.co.jp								
EX670AM Series | EX370BMG-X	CMOS	C+M	Area array	8192 × 8192, 6144 × 6144	VIS	CoaXPress2 (CXP-12 Quad)	64.5, 120	4329, 4530 MB/s
DDU2607M series | DDU1607M Series | DDU1207M series	CMOS	C+M	Area array	5120 × 5120, 4000 × 4000, 4096 × 3000	VIS	Dual USB3	28.3, 47, 62	742, 752, 750 MB/s
DU1207M Series | DU657M Series	CMOS	C+M	Area array	4096 × 3000, 2560 × 2560	VIS	USB3	32, 55	393, 360 MB/s
BU2409M Series | BU1206M Series | BU805M Series | BU502M Series	CMOS	C+M	Area array	5320 × 4600, 4096 × 3000, 2840 × 2840, 2448 × 2048	VIS	USB3	15, 31, 46, 75	367, 393, 371, 376 MB/s

CAMERA MANUFACTURERS

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Toshiba Teli Corp Tokyo, Japan; 81-42-589-8771; www.toshiba-teli.co.jp/en/; teli-global@toshiba-teli.co.jp								
BU1207M Series | BU505M Series | BU302M Series	CMOS	C+M	Area array	4096 × 3000, 2448 × 2048, 2048 × 1536	VIS	USB3	31, 75, 120	393, 376, 377 MB/s
BU406M Series | BU205M	CMOS	C+M	Area array	2048 × 2048, 2048 × 1088	NIR, VIS	USB3	90, 170	377, 379 MB/s
BU238M Series	CMOS	C+M	Area array	1920 × 1200	VIS	USB3	165	380 MB/s
BU160M Series | BU040M Series	CMOS	C+M	Area array	1440 ×1080, 720 × 540	VIS	USB3	240, 523	373, 203 MB/s
BU132M | CSCS60BM18	CMOS	M	Area array	1280 × 1024	VIS	USB3, PoCL (Base)	61	80 MB/s
BU2006M Series | BU1203MC Series | BU602M Series	CMOS	C+M	Area array	5472 × 3648, 4000 × 3000, 3072 × 2048	VIS	USB3	19, 30, 60	379, 360, 384 MB/s
BG505LM Series | BG302LM Series	CMOS	C+M	Area array	2448 × 2048, 2048 × 1536	VIS	GigE	22, 36	110, 113 MB/s
BG160M Series | BG040M Series	CMOS	C+M	Area array	1440 × 1080, 720 × 540	VIS	GigE	72, 291	112, 113 MB/s
BC505LM Series | BC302LM Series	CMOS	C+M	Area array	2448 × 2048, 2048 × 1536	VIS	Camera Link, PoCL (Base|3taps)	36, 56	180, 177 MB/s
BC160M Series | BC040M Series	CMOS	C+M	Area array	1440 × 1080, 720 × 540	VIS	PoCL (Base|3taps)	148, 523	230, 203 MB/s
CSC6M100CMP11 | CSC6M100BMP11	CMOS	C+M	Area array	2560 × 2560	VIS	Camera Link, PoCL (Full)	99.2	650 MB/s
Vieworks Co., Ltd. Anyang-si, Gyeonggi-do, South Korea; 82-70-7011-6161; https://vision.vieworks.com; sales@vieworks.com								
VC Series	CMOS	C+M	Area array	2048 × 1088–14, 192 × 10,640	NIR, VIS	Camera Link, CoaXPress, CoaXPress 2.0, 10GigE, CoaXPress-over-Fiber	454	—
VP Series	CMOS	C+M	Area array	5120 × 5120–24,000 × 12,000	VIS	Camera Link, CoaXPress, CoaXPress 2.0	35.4	—
VN Series	CMOS	C+M	Area array	15,360 × 15,360–23,760 × 18,012	VIS	CoaXPress	72	—
VNP Series	CMOS	C+M	Area array	23,760 × 18,012–48,000 × 24,000	VIS	CoaXPress, CoaXPress 2.0	30	—
VX Series	CMOS	M	Area array	5120 × 5120	VIS	GigE	4.7	—
VZ Series	CMOS	C+M	Area array	720 × 540–5496 × 3672	NIR, SWIR, VIS	GigE, 2.5GigE, USB3	528	—
VT Series	—	M	TDI	3200 × 32–23,360 × 256	VIS	Camera Link, CoaXPress, CoaXPress 2.0, GigE	—	300 kHz
VT Sense Series	—	M	TDI	4640 × 256–16,384 × 256	VIS	CoaXPress, CoaXPress 2.0, CoaXPress-over-Fiber	—	543 kHz
VTC Series	—	C	TDI	2160 × 80	VIS	Camera Link, CoaXPress, GigE	—	140 kHz
VL Series	CMOS	C+M	Line scan	2048 × 2–16,384 × 2	VIS	Camera Link, CoaXPress 2.0, 5GigE, 10GigE,	—	200 kHz
Vision Components GmbH Ettlingen, Germany; 49-7-2432-16723; www.vision-components.com; sales@vision-components.com								
VC MIPI Camera Modules	CMOS	C+M	Area array	≤5496 × 3672	NIR, VIS	MIPI CSI-2 + trigger	≤530	6 Gbit
VCSBC Nano Z 00xx	CMOS	C+M	Area array	1600 × 1200	NIR, VIS	Digital I/O, Ethernet, GigE, RS-232	60–230	—
VC nano Z-LED Series	CMOS	C+M	Area array	≤1920 × 1200	NIR, VIS	Digital I/O, Ethernet, RS-422/LVDS	≤174	—
VC pro Z Series SoC Based Smart Camera Family	CMOS	C+M	Area array	≤1920 × 1200	NIR, VIS	Digital I/O, Ethernet, RS-232	≤174	—
VC MIPI Multiview Cam	CMOS	C+M	Area array	≤1280 × 800	NIR, VIS	MIPI CSI-2 + trigger	60–230	—

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Xenics nv Leuven, Belgium; 32-16-38-99-00; www.exosens.com/brands/xenics; advancedimaging@exosens.com								
Manx series	InGaAs	M	Line scan	2048 × 1	SWIR	CoaXPress	256	—
Cheetah+ series	InGaAs	M	Area array	640 × 512	SWIR	CoaXPress	1700	—
Wildcat+ series	InGaAs	M	Area array	640 × 512	SWIR	Camera Link, USB3	220	—
Dione series	Microbolometer	M	Area array	320 × 240, 640 × 480, 1024 × 786, 1280 × 1024	LWIR	16bit DV/MIPI CSI-2/ USB/UVC	60	—
Crius series	Microbolometer	M	Area array	640 × 480, 1280 × 1024	LWIR	CL/SDI/DF40/MIPI CSI-2	60	—
XIMEA Münster, NRW, Germany; 49-251-202-408-0; www.ximea.com; info@ximea.com								
High-Speed Cameras with up to 3600 Fps	CMOS	C+M	Area array	1280 × 864	VIS	Digital I/O, Fiberoptic, PCIe, Proprietary	3500+	64 Gbps
Multiple Camera Platform	CMOS	C+M	Area array	1936 × 1216, 2064 × 1544, 2464 × 2056, 4112 × 2176, 4112 × 3008	NIR, VIS	PCIe, Proprietary, USB3	340	—
Embedded Vision Cameras	CMOS	C+M	Area array	1936 × 1216, 2064 × 1544, 2464 × 2056, 4112 × 2176, 4112 × 3008	Multispectral, NIR, VIS	Digital I/O, PCIe, Proprietary, USB3	166, 218, 165, 95, 69	20 Gbps
xiMU, MU196	CMOS	C+M	Area array	5120 × 3840	NIR, VIS	Digital I/O, USB3	30	5 Gbps
xiMU, MU050	CMOS	C+M	Area array	2608 × 1964	NIR, VIS	Digital I/O, USB3	14.5	5 Gbps
xiMU, MU051	CMOS	C+M	Area array	2472 × 2064	NIR, VIS	Digital I/O, USB3	49.5	5 Gbps
xiC, 2.3-24.5 Mpixel Camera	CMOS	C+M	Area array	1936 × 1216, 2064 × 1544, 2464 × 2056, 4112 × 2176, 4112 × 3008	NIR, VIS	Digital I/O, USB3	165, 122, 76, 43, 31	5 Gbps
xiX, small 2.3-24.5 Mpixel Camera	CMOS	C+M	Area array	1936 × 1216, 2064 × 1544, 2464 × 2056, 4112 × 2176, 4112 × 3008	Multispectral, NIR, VIS	Digital I/O, PCIe, Proprietary, USB3	166, 218, 165, 95, 69	20 Gbps
xiX, large with detached sensor heads	CMOS	C+M	Area array	1936 × 1216, 2064 × 1544, 2464 × 2056, 4112 × 2176, 4112 × 3008	Multispectral, NIR, VIS	Digital I/O, PCIe, Proprietary, USB3	166, 218, 165, 95, 69	20 Gbps
xiJ/xiRAY, Scientific	CMOS	C+M	Area array	2048 × 2048, 3296 × 2472, 4864 × 3232, 6576 × 4384	UV, VIS, X-ray	PCIe, Proprietary, USB3, Digital I/O, FireWire	<82	<20 Gbps
xiSPEC, Hyperspectral	CMOS	C	Line scan/Area array	2048 × 8, 2048 × 5, 512 × 272, 409 × 217	Hyperspectral, NIR, VIS	USB3	170 hypercubes	5 Gbps
Zhejiang MRDVS Technology Co., Ltd Hangzhou City, China; 86-13370882355; www.mrdvs.cn; service@mrdvs.com								
S10	3D	C	Area array	240 × 160	IR	Digtal I/O, Ethernet	20	—
S10 Ultra	3D	C	Area array	240 × 160	IR	Digtal I/O, Ethernet	20	—
M4 Mega	3D	C	Area array	640 × 480	IR	Digtal I/O, Ethernet	25	—
V2 Pro	3D	C	Area array	1920 × 1080	IR	Digtal I/O, Ethernet, CAN	20	—
Zivid Oslo, Norway; 47-21022472; www.zivid.com; marketing@zivid.com								
Zivid 2	3D	C+M	Area array	1944 × 1200	VIS	10GigE	10	—
Zivid 2+	3D	C+M	Area array	2448 × 2048	VIS	10GigE	10	—
Zivid 2+ R-series	3D	C+M	Area array	2448 × 2048	VIS	10GigE	10	—

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CAMERA DISTRIBUTORS

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
1stVision Inc Andover, MA, USA; 978-474-0044; www.1stvision.com; info@1stvision.com								
Allied Vision Goldeye SWIR GigE and Camera Link Series	InGaAs	M	Area array	320 × 256, 640 × 480	SWIR	Digital I/O, Ethernet, GigE, Camera Link	344	106 MB/s
Allied Vision Mako and Alvium GigE and USB3 Series	CMOS	C+M	Area array	VGA–31 MPixels	NIR, VIS	Digital I/O, Ethernet, GigE, USB3, MIPI-CSI2	≥1000	400 MB/s
IDS Imaging GigE, 5GigE, and USB3 Series	CMOS	C+M	Area array	VGA-45 MPixels	NIR, VIS	Digital I/O, Ethernet, GigE, 5 GigE, 10 GigE, USB3	396	500 MB/s
Teledyne Dalsa Linea GigE, 5GigE, and Camera Link Line Scan Series	CMOS	C+M	Line scan	2048 × 1–32, 768 × 1	NIR, SWIR, VIS	Digital I/O, Ethernet, GigE, 5 GigE, Camera Link	—	≥80 kHz
Teledyne Dalsa Genie Nano GigE, 5GigE, Camera Link, and CoaXpress Series	CMOS	C+M	Area array	VGA–67 MPixels	LWIR, NIR, VIS	Digital I/O,Ethernet, GigE, 5 GigE, 10 GigE	≥1000	1608 MB/s
Active Silicon Ltd Iver, UK; 44-1753-650600; www.activesilicon.com; sales@activesilicon.com								
Harrier 10x AF-Zoom Camera	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, 3G/ HD-SDI, USB/HDMI, HDMI, IP H.264	60	—
Harrier 36x AF-Zoom Camera Global Shutter	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, HD-SDI, USB/HDMI, HDMI, IP H.264	30, 60	—
Harrier 55x AF-Zoom Camera	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, 3G/HD-SDI, USB/HDMI, HDMI, IP H.264	30	—
Harrier 18x AF-Zoom HDMI 4K Camera	CMOS	C+M	Area array	4K (3840 × 2160), 1920 × 1080	VIS	HDMI, CVBS	30 (4K), 60 (Full HD)	—
Harrier 23x AF-Zoom IP 4K Camera	CMOS	C+M	Area array	4K (3840 × 2160), 1920 × 1080	VIS	IP H.265/H.264	30 (4K), 60 (Full HD)	—
Tamron MP3010M-EV	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, HDMI, USB 3, 3G/HD-SDI, HD-VLC, CVBS, H.264	60	—
Sony FCB-EV9500L	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, USB 3, HDMI, 3G/HD-SDI, HD-VLC, CVBS, H.264	60	—
Sony FCB-EV9520L	CMOS	C+M	Area array	1920 × 1080	VIS	LVDS, USB 3, HDMI, 3G/HD-SDI, HD-VLC, CVBS, H.264	60	—
Systematic Vision Corp Ashland, MA, USA; 508-532-1116; www.systematicvision.com; bill@systematicvision.com								
SVS-Vistek FXO Series	CMOS	C+M	Area array	5–24 MPixels	NIR, VIS	CoaXPress 2.0, 10 GigE	259	—
Princeton Infrared 1280MVCam	InGaAs	M	Area array	1280 × 1024	NIR, SWIR, VIS	Camera Link	100	—
Photonfocus MV8-D8424-G01-GT	CMOS	C+M	Area array	8424 × 6032	VIS	10GigE	24	—
Photonfocus MV4 Series	CMOS	C+M	Area array	1.3–65 MPixels	NIR, UV, VIS	GigE, 10GigE	80,000	—
Photonfocus MV3 Series	CMOS	C+M	Area array	0.1–0.3 MPixels	NIR, UV, VIS	Camera Link, GigE	344	—
Photonfocus MV2 Series	CMOS	C+M	Area array	1.3–5 MPixels	Multispectral, NIR, VIS	GigE	18,540	—

Product	Sensor type	Color/ Mono	Scan type	Image format	Spectrum digitized	Interface	Frame/s	Data rate
Systematic Vision Corp Ashland, MA, USA; 508-532-1116; www.systematicvision.com; bill@systematicvision.com								
Mikrotron EoSens 2.0CXP2	CMOS	C+M	Area array	1920 × 1080	VIS	CoaXPress 2.0	2220	—
Mikrotron EoSens 1.1CXP2	CMOS	C+M	Area array	1280 × 864	VIS	CoaXPress 2.0	3660	—
JAI FSFE-3200D-10GE Flex-Eye	CMOS	C+M	Area array	2048 × 1536	Multispectral, NIR, VIS	10GigE	123	—
JAI FSFE-1600T-10GE Flex-Eye	CMOS	C+M	Area array	1440 × 1080	Multispectral, NIR, VIS	10GigE	213	—
JAI SP-45000-CXP4	CMOS	C+M	Area array	8192 × 5460	NIR, VIS	CoaXPress	51	—
JAI GO-X Series	CMOS	C+M	Area array	3.2–45 MPixels	NIR, VIS	GigE, USB3, CoaXPress	162	—
IOI Victorem CX Series	CMOS	C+M	Area array	0.4–26.2 MPixels	VIS	CoaXPress	523	—
Emergent Vision HZ-100-G	CMOS	C+M	Area array	11,276 × 9200	VIS	100GigE	30	—
Emergent Vision HZ-65000-G	CMOS	C+M	Area array	9344 × 7000	VIS	100GigE	71	—
Emergent Vision HB-25000-SB	CMOS	C+M	Area array	5320 × 4600	VIS	25GigE	98	—
Allied Vision Goldeye G/CL-034 TEC1	InGaAs	M	Area array	636 × 508	SWIR	Camera Link, GigE	303	—
Allied Vision Goldeye G/CL-030 TEC1	InGaAs	M	Area array	1280 × 1024	NIR, SWIR, VIS	Camera Link, GigE	100	—
Allied Vision Alvium 1800 U/C-130 VSWIR	InGaAs	M	Area array	1296 × 1032	NIR, SWIR, VIS	USB3, MIPI CSI-2	130	—
Allied Vision Alvium G5-130 VSWIR	InGaAs	M	Area array	1296 × 1032	NIR, SWIR, VIS	5GigE	130	—

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