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Deep learning drives industrial automation forward

Do you want to incorporate deep learning models into your machine vision systems?

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Deep learning is based on multi-layered neural networks that can identify patterns by analyzing data. Integrators, machine builders, and end users are building deep learning algorithms into machine vision systems to help automate such processes as inspection, sorting, and assembly.

For example, determining whether an apple passes inspection is challenging because there are so many naturally occuring variations size, shape, and surface color and texture. It would be nearly impossible to write code that covers all of the possiblities. However, deep learning models learn to predict what variations are acceptable even if they haven't confronted the exact situation before.

As the application of deep learning to automation problems contiues to mature in the machine vision industry, *Vision Systems Design* will provide you with the latest information. The article on deep learning in this summer supplement is one example of our coverage on this important topic.

Linda Wilson
EDITOR IN CHIEF
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How to deploy deep learning algorithms in machine vision

There are numerous deep-learning methods available for developing machine vision systems or applications. Using commercial software tools, even non-experts can use deep learning.

ULF SCHULMEYER

In discussions of artificial intelligence or deep learning, you'll often hear phrases such as neural networks, black box, labeling, etc. These concepts are often difficult for the layperson to understand. People also end up believing that they need solid programming skills to truly master the technology and use it sensibly. Unfortunately, this impression ignores the potential that the technology offers for machine vision, and thus for automating production. Deep learning is not reserved for computer scientists or programmers.

Let's start at the beginning: What is deep learning?

As a subset of machine learning, deep learning is based on multi-layered neural networks that are capable of realistically emulating complex structures and processes of the human brain and making independent decisions. During a comprehensive training process, deep learning models learn to identify certain patterns and relationships by analyzing data.

So much for the theoretical side. But why is the technology so successful in the area of machine vision? It's because machine vision produces an extremely large amount of image data. It forms the perfect basis for the effective training of neural networks. That's the technical side.

At the same time, users also benefit from the technology. The recognition rates that deep learning can deliver reach new levels of quality. This also allows entirely new applications to be automated based on machine vision. Deep learning is a development that gives new impetus to machine vision as a whole.

The number of people who find the use of deep learning worthwhile is therefore growing steadily. Many companies, both large and small, are considering the idea of introducing artificial intelligence or deep learning. Frequently, however, they have certain reservations that keep them from taking this step. But using the technology is not as complicated as they might think. There are also tools that make it easier to work with deep learning.

The right deep learning method for each application

When it comes to implementation, the most important question is this: What exactly do you want to automate? The range of deep learning methods available to integrators,

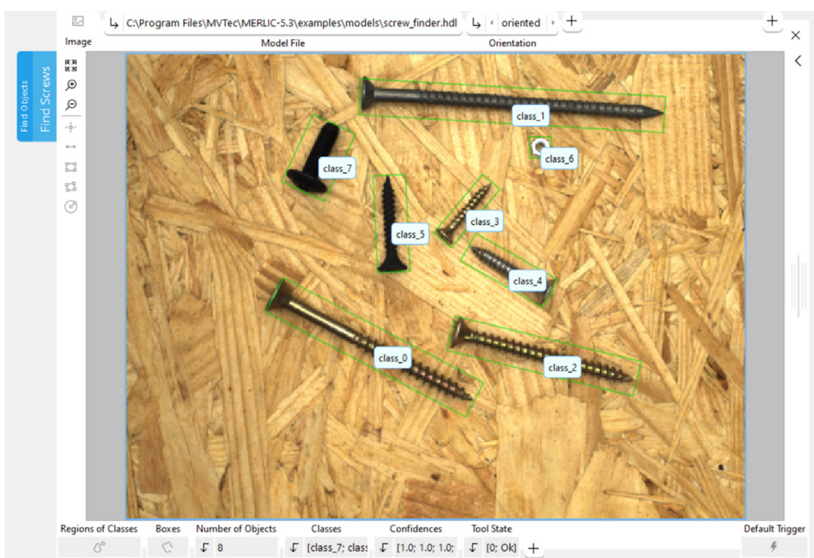

FIGURE 1. Deep-learning-based object detection localizes trained object classes and identifies them with a surrounding rectangle (bounding box). *Images courtesy of MVTec*

plant operators, and machine manufacturers—in short, to everyone who deals with this question—is growing all the time.

ANOMALY DETECTION

Anomaly detection allows defects to be recognized very quickly and easily, which makes fault inspection in the quality management process even more efficient. One particular advantage is that the technology requires much less training data compared to conventional deep learning methods. Indeed, 20 to 100 images are all you need for a complete training session. What's more, good images are sufficient for anomaly detection, enabling you to generate a training dataset much faster. An anomaly detection model trained on the basis of good images is then able to detect structural deviations from the training images, i.e., anomalies. This allows you to detect faults whose appearance was not previously apparent.

GLOBAL CONTEXT ANOMALY DETECTION

Global context anomaly detection goes one step further. It can recognize entirely new anomaly variants, such as missing, deformed, or incorrectly arranged components. As a result, fault detection is no longer limited to structural defects but also covers logical anomalies. This paves the way for entirely new possibilities, such as the inspection of printed circuit boards in semiconductor manufacturing or the verification of printing.

CLASSIFICATION

Classification uses image data to assign objects to a specific category or class, such as a good part or a bad part. This makes it possible to determine a class with a certain degree of probability for each individual image.

OBJECT DETECTION

Object detection, a deep-learning-based technology, localizes the position and class of objects. The process is able to recognize various object entities of different object classes and object instances, including their positions in the image.

SEGMENTATION

There are two types of segmentation based on deep learning: semantic segmentation and instance segmentation.

Semantic segmentation categorizes the pixel-precise localization of trained objects, structures, and faults. During this process, a certain class is assigned to each pixel in the image. By teaching the model based on

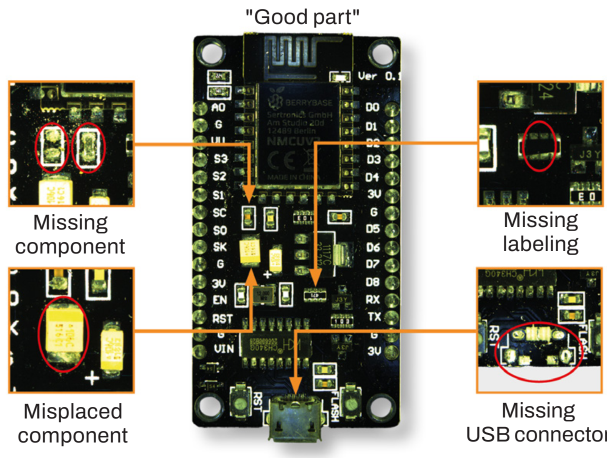

FIGURE 2. Deep-learning-based object detection localizes trained object classes and identifies them with a surrounding rectangle (bounding box).

training data, a specific class can be predicted with a high degree of probability for each pixel in a new image. This approach makes it possible to perform inspection tasks that were previously impossible or only feasible with considerable programming effort.

Instance segmentation combines the benefits of semantic segmentation with those of object detection. This type of segmentation enables objects to be assigned to different classes in a pixel-precise manner. The technology is particularly helpful in applications where objects are very close together, touch each other, or overlap. Typical applications include gripping randomly arranged objects from bins (random bin picking) and identifying and measuring naturally grown structures.

EDGE EXTRACTION

This technology is a relatively new and unique method for robustly extracting edges with the aid of deep learning. It reliably extracts only the desired edge from a large number of edges visible in an image. It's also able to robustly recognize edges in low-contrast and noisy situations, which permits the extraction of edges that cannot be identified with conventional edge recognition filters. The technology is generally used in combination with rule-based machine vision approaches.

DEEP OCR

OCR (optical character recognition) can be used to identify and classify text. When based on deep learning algorithms, the technology is also known as deep OCR. It can deliver robust results, even under challenging conditions, such as when identifying slanted text, distorted letters or characters printed on or etched into reflective surfaces, or highly textured colored backgrounds. With deep OCR, characters are grouped automatically, enabling words to be identified. This increases recognition performance, for example by avoiding misinterpretations of characters with a similar appearance.

DEEP COUNTING

With deep counting, you can localize and count a large number of objects very quickly. The technology is not only guided by the shape of the parts, but it also incorporates other distinctive features, such as color, pattern, or texture, using the deep learning approach. One particular benefit is that deep counting achieves very robust results even when objects are made from highly reflective and amorphous material. It can also be used to reliably record a vast quantity of objects that touch each other or partially overlap. The technology is therefore an excellent choice for counting a wide range of products in the food and beverage industry as well as for the correct and complete packaging of small items such as nuts or bolts.

Where does deep learning make the most sense?

Deep learning opens up entirely new fields of application and makes machine vision accessible to more people, including those who are not very familiar with machine vision or who do not wish to program algorithms themselves. AI systems can generally be set up with their own image files. The advantage is that by training the neural networks, AI often delivers more robust results than classic algorithms. For example, traditional matching works very well when all objects look exactly the same. But AI really shines when the data has a lot of variation, as can happen when changes occur naturally, such as in fruit and vegetables. In such cases, it's difficult to clearly define the classic features ahead of time: When is a surface good, and when is it not? Another use case applies to manufacturers in production who have very high-quality standards.

Some companies have virtually no production errors and therefore also no error images that could be supplied to a rule-based system. It's possible for a defect to occur only once out of every ten thousand objects. But companies don't know exactly how this will work beforehand. AI-based anomaly detection can help. The technology doesn't have to know what a bad part looks like ahead of time, since it's trained only on the basis of good parts. Such applications would not have been possible in the past with rule-based programming.

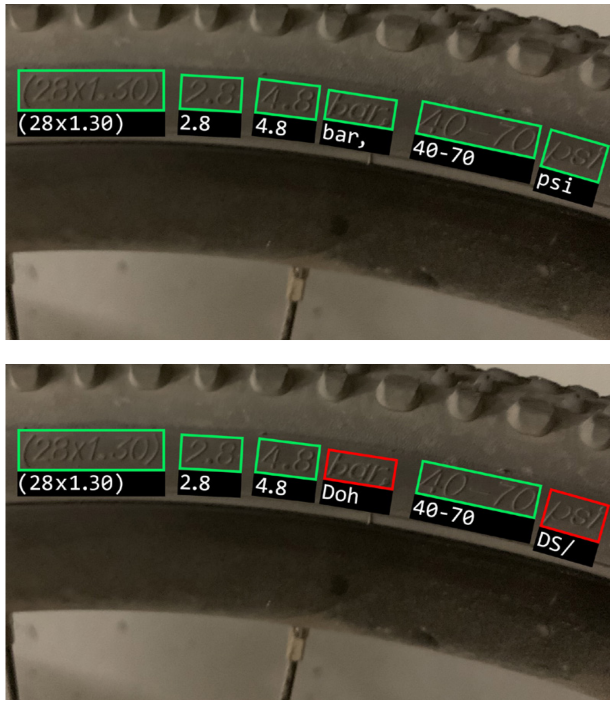

FIGURE 3. Top: An example OCR using deep learning, which is known as deep OCR. Bottom: Without the use of deep learning, the OCR application produced results that were less accurate than with the deep learning OCR.

However, the ideal way to achieve the perfect machine vision application is to combine deep learning algorithms with rule-based machine vision techniques. One such application would look something like this: Companies use AI for pre-classification in order to identify a point region of interest, within which a highly precise measurement can be taken using traditional methods. This makes the application as a whole faster and the results more accurate.

How to get started with using deep learning in machine vision

To run an application, you first need to have a classic machine vision setup consisting of a camera, appropriate illumination, and suitable computer hardware, such as an industrial PC equipped with a high-performance CPU or (even better) a GPU. But at the heart of any machine vision setup lies powerful machine vision software available from a variety of companies.

Optimal image data preparation for training

To use deep learning applications, you first have to label the training images. The goal of labeling is to note the desired output of the AI model in the image. Such

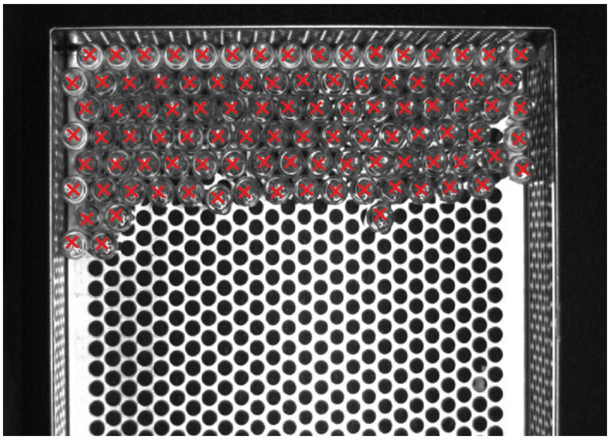

FIGURE 4. Deep counting can be used to count a large number of objects, like glass bottles, quickly and robustly.

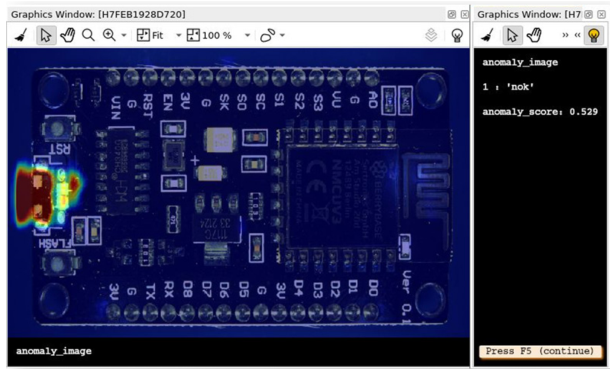

FIGURE 5. A heat map increases the transparency of deep learning inferences by highlighting the part of the image on which the decision is based.

information can be the image class or the object's position within the image. Software that provides an intuitive user interface makes labeling very easy even for beginners and can be used without any programming skills. When taking the next step (preparing the data), keep in mind that the image data must be available in an optimally prepared form.

A particularly practical aspect is that good images are all that is needed to train certain deep learning technologies, so-called "unsupervised" methods such as anomaly detection. These are easy to obtain. Moreover, the number of these image datasets required is from 20 to 100 good images, depending on the condition of the object to be inspected. The training process itself takes place at the press of a button.

A glimpse into the deep learning black box

One criticism of deep learning is the lack of transparency in the decision-making processes. While the latest developments, described below, can't completely illuminate what goes on inside this black box, they do provide certain insights into the inner workings of the neural networks. There are tools that use a heat map to highlight the image areas relevant for decision-making. This is a way to track or influence the behavior of the deep learning algorithms.

Thanks to the Out-of-Distribution Detection (OOD) technology you can identify unforeseen behavior caused by incorrect classifications during operation and take the appropriate measures. When using a deep learning classifier, the system generally assigns unknown objects to a learned class. This can lead to problems, for example, when dealing with error types or foreign bodies that have never been encountered before. The new deep learning feature alerts the user when an object is classified that was not included in the training data. This could be a bottle with a green label, for example, if the system has only been trained on bottles with red or yellow labels. In this case, the message "Out of Distribution" is displayed along with an OOD score indicating how much the object deviates from the trained classes.

It's also possible to influence the deep learning results with the help of the threshold value. For example, the threshold value can be set very high for the purpose of anomaly detection, in which case you get only OK results. If you set a lower threshold value, the system correspondingly delivers fewer and fewer OK results and thus no "false negatives." This allows you to flexibly and individually adjust how sensitively the model responds to irregularities.

Starting with deep learning: Best with machine vision

If companies want to take advantage of the many benefits of deep learning, they need well-thought-out strategies for the targeted implementation and long-term use of the technology. However, like all AI methodologies, the topic is associated with a certain degree of complexity. Machine vision is proving to be a key technology in this context, in which proven deep learning methods can be used efficiently and profitably. ◎

Ulf Schulmeyer is the product manager for MERLIC at MVTec Software GmbH (Munich, Germany).

Tell us what you think about this article. Send an e-mail to lwilson@endeavorb2b.com.

How TI Fluid Systems improved its steel strip inspections

The integrators opted for a contact image sensor system, providing higher resolution and fewer false positives than an earlier camera-based solution.

DEBORAH ABRAMS KAPLAN

TI Fluid Systems had a problem. The company produces automotive fluid storage, carrying and delivery systems. That includes steel coils to fabricate pipes for brake and fuel supply circuits. Any perforations in the steel, no matter how tiny, can cause safety issues. TI Fluid (Liège, Belgium) had a camera-based inspection system in place, 3 meters above the steel strips on a production line. However, this system required complex calibration and had frequent operational failures and false hole detections. The company needed a dependable and highly precise inspection and detection system to conform to the automotive industry's stringent safety standards.

The steel coil producer sought help in developing and implementing an inspection system to detect every potential hole at least 1 mm in size. It needed to do so on steel strips moving at 95 meters per minute, or 1,580 mm per second.

The inspection follows a copper or nickel electrodepositing coating process on the original steel strip. "After inspection, the coil is rewound before being sent to the pipe production line. If a defect is detected, the steel strip is automatically marked at the right position," says Arnaud Philippart, CEO of InDeep-solutions (Ferrières, Région Wallonne, Belgium), the company that spearheaded the development of the new inspection process.

The holes might have different origins, says Philippart. The defects could be present on the coil when delivered to TI Fluid Systems. Or they could be generated during

FIGURE 1. The integrators chose a contact image sensor because it acquires high-resolution images at high frequency.
Images courtesy of InDeep-solutions

FIGURE 2. At TI Fluid Systems, steel strips move on a production line at a rate of 95 meters per minute, or 1,580 mm per second.

the trimming process. It's also possible a metallic foreign body, such as screws or iron shavings, could impact the production line and cause the holes.

Developing a new inspection process

InDeep-solutions specializes in industrial process monitoring and production quality inspection. The company initially tested a laser profiler for the role, but there was not sufficient frequency and resolution to identify the holes. InDeep brought phil-vision GmbH (Puccheim, Germany) in as a partner to select the optimal camera technology to use. phil-vision specializes in machine and computer vision, distributing image processing components and integrating them. The phil-vision experts recommended Teledyne DALSA's mono compact image sensor AxCIS (AX-FM-08B12H-00). This technology was originally developed to inspect printed materials and batteries. The small, quasi-telecentric line scan cameras are often used for highly precise measurements.

In addition to recommending components, the phil-vision team provided feasibility testing and software integration.

The team integrated the AxCIS sensor into compact housing, minimizing alignment complexities. They paired it with an Xtium2 CameraLink HS frame grabber, also from Teledyne DALSA (Waterloo, ON, Canada), for a short working distance, which also simplified installation. The setup did not require complicated cabling, complex alignment or calibration.

Developers fixed the sensor at a minimum acquisition frequency of 10kHz for a 0.15 mm resolution in the direction of travel, though they received a higher 0.022 mm resolution along the steel strip's width. These resolutions were effective for detecting defects.

The settings allowed the sensor to gather and measure in 4,000 line batches, using a reduced CPU load during continuous monitoring. The system maintained a 0.4 second response time. The software analyzed

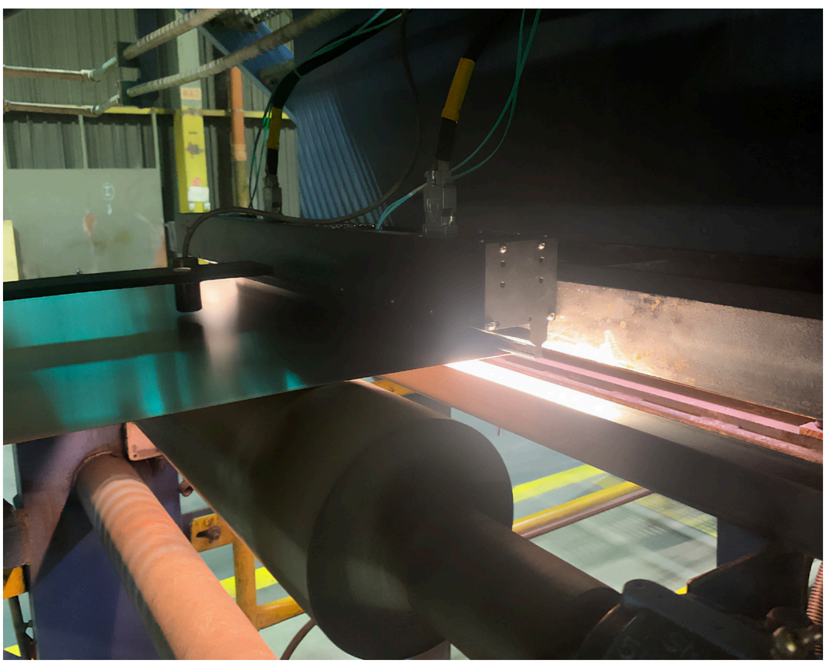

FIGURE 3. The engineers integrated a compact image sensor into housing and positioned it above the steel strip on the production line. They installed a ribbon light at the bottom of the steel strip, maximizing image contrast.

each image immediately upon release, building the next image in parallel during processing.

"Although the AxCIS contact image sensor is primarily designed to capture clean images in printing production lines, it possesses many characteristics that extend its functionality to include small hole detection," says Philippart. That includes a "very high resolution and very high acquisition frequency," he adds.

"Thanks to the back light, the edges and holes are clearly visible," Philippart says. Contact image sensors already have lighting built in, though it isn't always useful for each application. For the TI Fluid Systems project, the developers used a simple LED ribbon for lighting, says Philippart. "The light source must be positioned at the bottom of the steel strip with the sensor situated above it. This configuration enables a substantial contrast. Consequently, the built-in light is not interesting for this particular application."

FIGURE 4. InDeep-solutions created customized software to highlight the defects, such as tiny holes in a steel strip, with a red square.

Customized software designed to minimize human intervention

As part of the process, InDeep created customized software, which runs on a rugged PC, to provide high-resolution images and highlight the defects with a red square. It can display the last 10 detected holes while archiving the data for six months. This assists with traceability and quality audits. The testing found that the new system identifies fewer false positives, while not missing any holes.

Another benefit is that the system is already calibrated. "The software only needs to be configured during the commissioning," Philippart says, and it is designed to be easy to use. Developers set sensor properties, such as exposure time and frequency, along with the communications and processing parameters, such as threshold and buffer size. Then the software is fully autonomous. "It starts automatically on boot, loads the configuration and starts doing its job. There is also a windows service checking that the inspection software is running," he adds.

> Another benefit is that the system is already calibrated.

After the solution powers on, it auto-launches the software. It then detects the hardware and begins acquiring data. The system begins image buffering, temporarily storing image data before processing it. The image analysis occurs next, including edge detection, width measurements and hole detection. These results are communicated to the programmable logic controller, and the image is recorded in case of a detected defect.

While InDeep created the software, phil-vision supported driver development, sensor timing, programming and software integration, "thus contributing to the successful implementation of the inspection system," Philippart says.

The end results and next steps

TI Fluid's inspection system has been running online for months now, says Philippart. In-Deep solutions says it is reliable, accurate and user-friendly, meeting the highest industry standards. TI Fluid ordered a second sensor as a spare part, "proving the importance of the system for their production," he says. The repurposing of the AxCIS sensor and this setup could be interesting for other companies, he adds, and he'd like to duplicate this system elsewhere, in the future. ◎

Deborah Abrams Kaplan is a freelance journalist and author who covers covers tech topics and manufacturing/supply chain.

How to design custom microscope objectives for imaging applications

When designing a custom microscope objective, it is important to consider the relationship among numerical aperture, angular field of view, and waveband.

REBECCA CHARBONEAU

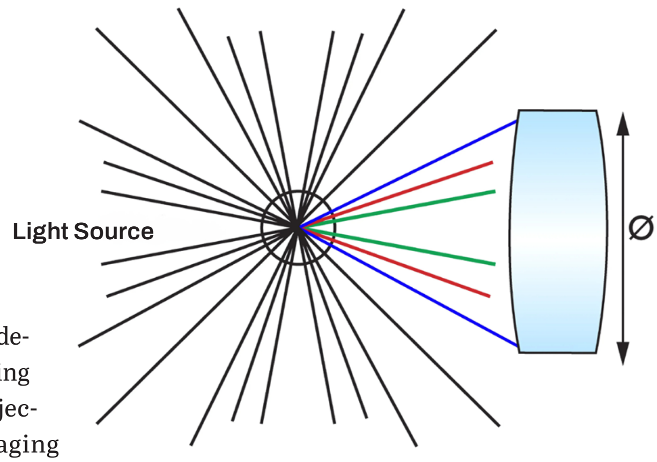

FIGURE 1. System throughput. *All images/figures courtesy of Edmund Optics*

In microscopy, infinite conjugate microscope objectives have become the industry standard, offering enhanced flexibility and compatibility with supporting optical components such as filters, beamsplitters, and fluorescence cubes. However, while these objectives enable sophisticated optical designs, they also introduce a layer of complexity—particularly when integrating them into custom imaging systems. The reality is that there is no "one-size-fits-all" solution; system requirements vary widely across applications, from biomedical imaging to industrial inspection, each imposing unique constraints on angular field of view, numerical aperture, and chromatic correction. This article will discuss these specifications when designing a custom microscope objective and how to determine what trade-offs to make.

Design considerations

NUMERICAL APERTURE

Numerical aperture (NA) is arguably one of the most important specifications to define when designing a microscope objective into an imaging system. NA defines an objective's ability to gather light at a given working distance (Figure 1). It describes the acceptance cone of an objective defined by the angle ∅ and relates to the objective's diffraction limit or resolution.

Equation 1 below establishes the relationship between NA and system resolution:

$$\text{Resolution} = \lambda/(2{*}\text{NA}) \quad [1]$$

Where:
λ = wavelength

The relationship of resolution and NA can be used to understand what the system diffraction limit is, or what minimum distance at which two distinct point sources of light can be distinguished. This defines what the system resolution is in object space and drives the complexity of a microscope objective design. As the NA grows, the rays (∅) entering the objective become steeper and require more optical elements and advanced assembly techniques to keep aberrations controlled. In a large NA design, the objective will have higher resolving power and can be used for high-end microscopy applications in electronics inspection and life sciences applications.

The angular field of view (AFoV) of a microscope objective describes the maximum viewable area when looking through an eyepiece or with a camera (Figure 2). The AFoV is typically specified as the full angle (in degrees) associated with the horizontal dimension of the imaging sensor the objective is being used with. A standard microscope objective typically has an AFoV of ~4° and increases with sensor coverage. Inversely, shorter focal length objectives will have a larger AFoV, but this introduces challenges with optical design to correct for aberrations such as spherical, which cause the rays to defocus causing image blur.

WAVEBAND

Similar to a machine vision imaging lens, the design waveband is an important consideration for a custom microscope objective as it impacts the system resolution. These effects from polychromatic light induce chromatic aberrations, which are deviations from "perfect" theoretical performance. While a "perfect" lens does not exist, chromatic aberrations can be minimized to reduce changes to image quality. It is important to understand which wavelengths of light are required for the application when designing a custom microscope objective. For example, the design requirements for an objective to transmit compared to image ultraviolet light are very different. Fluorescence microscopy is a great example application

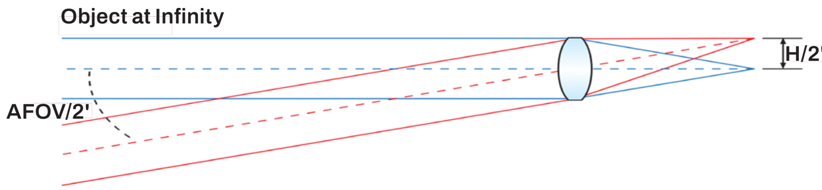

FIGURE 2. Angular field of view (AFoV).

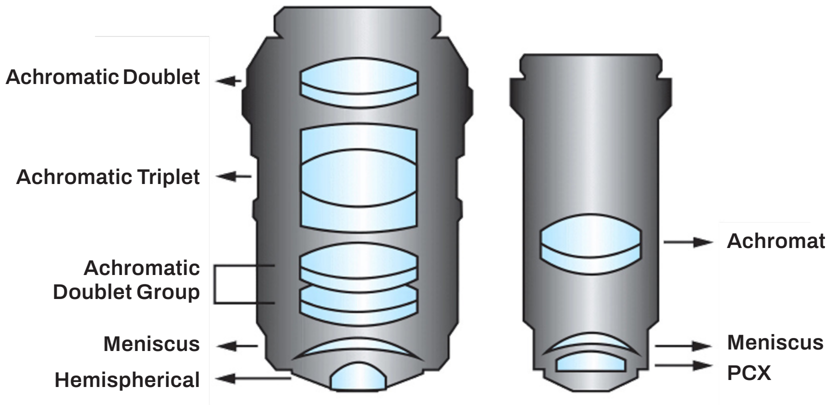

FIGURE 3. Microscope objective cross-sections.

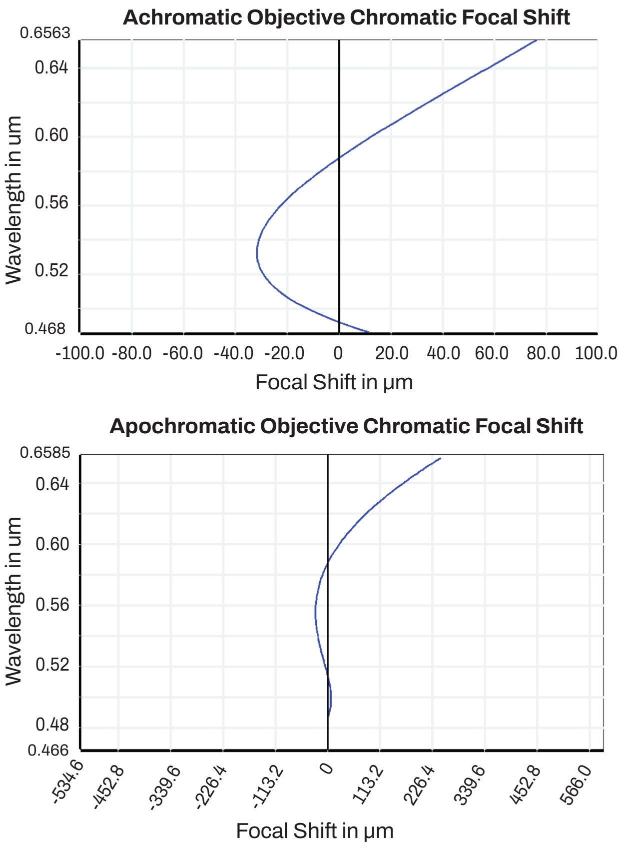

FIGURE 4. Chromatic focal shift of an achromatic (top) and apochromatic (bottom) microscope objective.

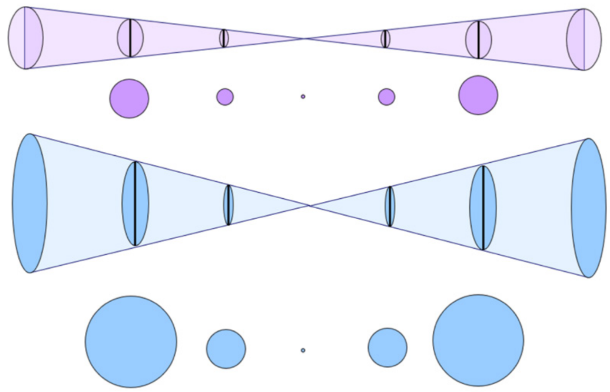

FIGURE 5. Depth of field.

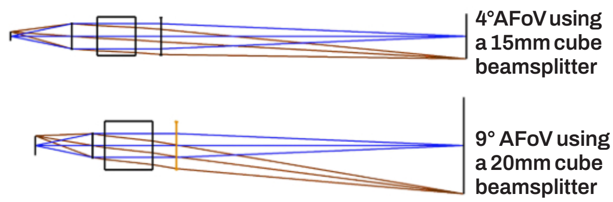

FIGURE 6. Angular field of view (AFoV) comparisons.

where shorter wavelengths only need to be transmitted to excite a specific fluorophore. This puts less of a constraint on the design as any chromatic aberrations induced by the shorter wavelengths will not be what is imaged on the sensor.

Figure 3 shows the cross-section for an apochromatic (left) and achromatic (right) objective. The apochromatic design has triple the number of elements compared to an achromatic objective. Per ISO 19012-2:2013(E), achromat objectives only consider the focal shift between red and blue wavebands whereas apochromats consider the focal shift between red, blue, and the reference wavelength (typically green for an objective designed for visible light). This difference in design requirements can be related to the chromatic color correction each objective has. Figure 4 compares the degree of color correction between the two designs.

Manufacturing considerations

NUMERICAL APERTURE

Large numerical apertures demand a lot from the optical design to correct for off-axis aberrations like coma, astigmatism, and lateral color. This results in increased complexity for the assembly and manufacturing of optical and metal components. The typical assembly procedure for a high NA objective involves active alignment where the wavefront of the objective is measured as the optical elements are aligned in the optical cell. This type of assembly requires skilled operators and an increased production time.

Besides challenges with assembly, the optical design itself has the potential to require lens elements with sharp curvatures or very short radii. This makes manufacturing these elements more difficult, requiring longer machining times. Aspheres are sometimes used in very complex designs to reduce the number of optical elements but also requires specific manufacturing techniques.

ANGULAR FIELD OF VIEW

Designing for a large angular field of view requires the same precision manufacturing and assembly techniques that a large NA objective entail. Active alignment and increased processing time are needed to achieve lens positioning with single-digit micron precision. Similar to large NA, the glass types used in the design of a larger AFoV objective can have high indexes, making them more difficult to manufacture. There is also the potential for supply chain challenges when sourcing materials that are more exotic in the optical glass catalog.

WAVEBAND

When the design waveband of a microscope objective is very broad, this can exponentially increase the complexity of the design compared to a narrowband objective. For example, a design that is optimized to cover 400-1000nm (VIS-NIR) compared to a design that only covers 400-700nm (VIS) will likely be available at very different price points. This is due to specialized glass being required to transmit different wavebands, especially in the ultraviolet and infrared bands. Chromatic aberrations, known as axial and lateral color, are also affected by the waveband and require different considerations for the glass type and lens geometry.

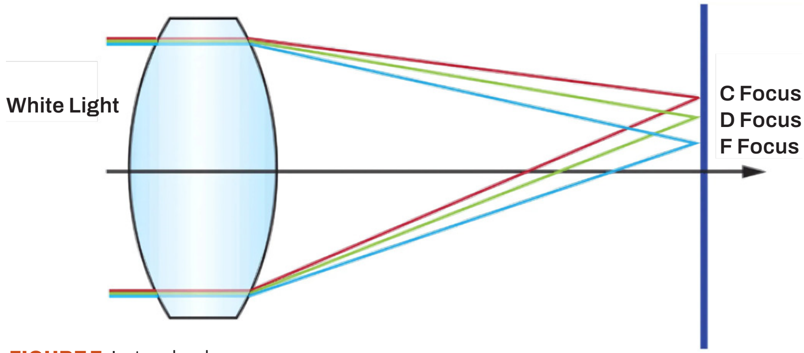

FIGURE 7. Lateral color.

Impact on application

NUMERICAL APERTURE

Using an objective with a smaller numerical aperture can be useful in applications that would benefit from a large depth of field. When the application involves inspecting an object that will have varying heights (semiconductor wafers, electronics pieces, biological samples, and microfluidic devices), having a large depth of field will alleviate the need for refocusing during sampling. Figure 5 shows a comparison of the depth of field of an objective with a small NA (top) versus a large NA (bottom). The center of each cone is representative of an object that is in focus and as the cones get larger, the image blurs faster.

When depth of field is not as critical as light throughput and resolution, using a large NA objective is the better solution. Large NA objectives will collect significantly more light and are ideal options for low-light applications like fluorescence microscopy. Referring back to equation 1, a larger NA will theoretically allow an imaging system to resolve smaller feature sizes on the object under observation. However, it is important to consider that the larger NA objectives come at a higher price point due to the design and manufacturing challenges that were previously discussed.

ANGULAR FIELD OF VIEW

If a compact system is ideal and additional optics like filters or beamsplitters are required, then using a large AFoV infinite conjugate objective could be a suitable option. The overall system length of a larger AFoV objective is shorter than that of a typical ~4° AFoV objective. As seen in Figure 6, the larger AFoV objective has a smaller system length, but at the cost of larger optics. The objective and tube lens will increase in size and, as a result, additional optics in the beam path must grow so no vignetting occurs.

WAVEBAND

Besides having an objective that is color corrected over the application waveband, using bandpass filters will improve the image quality of the system. When using polychromatic light, off-axis chromatic aberrations, like lateral color, are difficult to correct for. Figure 7 shows that when polychromatic light is used, lateral color causes different wavebands to focus at different points on the image plane. This type of aberration can be detrimental for life science applications where color is critical to identify a specific cell structure. When a bandpass filter is used, only a small waveband of light is imaged through the objective and lateral color will be significantly reduced.

Conclusion

Designing custom microscope objectives demands consideration of the tradeoffs between numerical aperture, waveband, and angular field of view. For example, increasing NA improves resolution and light-gathering capability but often comes at the cost of reduced AFoV and more complex chromatic correction across a given waveband. Similarly, broadening the spectral range can introduce significant chromatic aberrations if not controlled for in the optical lens design, while expanding AFoV may introduce off-axis aberrations that challenge conventional lens design strategies. Ultimately, optimizing a custom objective is an exercise in prioritization—matching the optical configuration to the specific application requirements while acknowledging that gains in one parameter often require compromises in another.

Rebecca Charboneau is an optical engineer at Edmund Optics (Barrington, NJ, USA).

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https://www.senswork.com

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https://www.shanghai-optics.com

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https://www.sisco.com/thermal-imaging-cameras

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Hong Kong,
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Wayne, NJ, United States
http://www.phantomhighspeed.com

Visionary.ai
Jerusalem, Israel
https://www.visionary.ai

Viztronics Technologies
Leixlip, Kildare, Ireland
https://viztronics.com

VS Technology Corp
Tokyo, Japan
https://vst.co.jp/en

VST America Inc
Arlington Heights, IL, United States
http://www.vstamerica.com

Vzense Technology Co
Newark, CA, United States
https://www.vzense.com

W3+ Fair/FLEET Events GmbH
Jena, Germany
https://w3-fair.com/en

Wavelength Electronics Inc
Bozeman, MT, United States
http://www.teamwavelength.com

Wavelength Opto-Electronic (S) Pte Ltd
Singapore
https://wavelength-oe.com

Westech Optical Corporation
1387 Fairport Rd, Bldg 900H, Fairport, NY, 14450, United States
TEL: 585-377-2490
jcarlino@westechoptical.com
https://westechoptical.com
With decades of collective experience in lens manufacturing, lens design, and opto-mechanical engineering, Westech offers a diverse range of precision optics and matching Q.C. solutions to help solve your imaging needs. Rapid prototyping to pre-production to high-volume production – Don't pay catalog prices for OEM optics.

Wireless CCTV LLC
Richardson, TX, United States
https://www.wcctv.com

XCEL Laser
Aurora, IL, United States
https://xcellaser.com

Xenics | Exosens
Leuven, Belgium
https://www.xenics.com

XIMEA
M√°nster, NRW, Germany
https://www.ximea.com

Zebra Technologies Inc
Lincolnshire, IL, United States
https://www.zebra.com

Zmation Inc
Portland, OR, United States
http://www.zmation.com

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