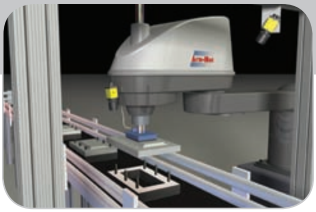
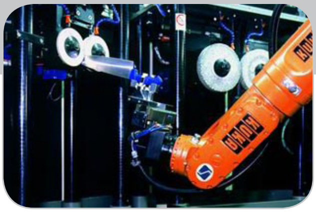
COGNEX vision

Expert Guide

Using Vision Systems for Robot Guidance





Introduction

In today's globalized marketplace, automation plays critical roles in maintaining quality in emerging markets while allowing developed countries to manage rising labor costs.

Originally, machines were built to automate specific manufacturing, assembly, and material handling tasks. Today, industrial robots have replaced dedicated machines for many automation tasks because they can be programmed to handle new products and even repurposed for new tasks in new locations.

However, like their predecessors, robots still couldn't think on the fly or react to unexpected conditions. Product needed to be presented to the robot in the same position and orientation every time, or the robot would fail to complete its task.

More recently, machine vision has given robots the power to "see" and react to changing conditions. Now, vision-guided robots can "feed" themselves using two-dimensional (2D) machine vision to locate and guide the robot arm to loosely positioned parts on a conveyor, for example. As long as the parts were positioned on a flat surface—and were not too large or tall to exceed the field of view (FoV) and focal depth of the machine vision cameras—2D vision-guided robots could free humans from repetitive and potentially dangerous tasks. Plus, they could do so at much higher speed and with far greater accuracy than any human.

Today, three-dimensional (3D) machine vision technology is taking robotic manufacturing to the next level of efficiency and productivity. With a variety of 3D machine vision technologies at their disposal, vision-guided robots can manipulate and assemble products of virtually any size and shape on a conveyor, rack, or bin, and even work right alongside humans without posing a serious safety threat. Tasks once thought beyond the ability of automation—such as processing beef, precision welding, and painting cars—can all be accomplished quicker, faster and cheaper than ever before with 3D vision-guided robotics.

2D vs. 3D: Moving Into the Real World

A conveyor or index table is essentially a 2D space. When the part is relatively small and laying on a flat surface, 2D vision-guided robotic solutions are the most cost-effective. These systems usually include overhead mounted camera(s) connected to a machine vision processing system. The camera looks down on the workspace, which includes either a Cartesian or Selective Compliant Articulated Robot Arm (SCARA) robot. These robots offer between two and four degrees of freedom, which makes them well-suited for 2D vision-guided applications.

The first step in installing and operating a vision-guided robotics application is to calibrate the vision system's visual coordinate system with the robot's physical coordinate system. It would be easy if these two coordinate systems were the same, but lens distortion, changes in illumination, and other factors can affect how the vision system sees the "real world," potentially introducing error into the vision-guided robot program.

By placing a camera directly above and perpendicular to the conveyor's surface and using a calibration routine—usually including a calibration "target" of known dimensions—a 2D vision system can align its visual coordinate system with the robot's physical coordinate system. Now, the machine vision system can extract meaningful position data from images of parts placed on the conveyor's surface.

To create a 2D map from the robot's center or starting point to the target object, images are sent from the overhead camera to a PC or embedded computer running image-processing software. (If the work area is large enough compared to the spatial resolution requirements for the cameras, the workcell may need multiple overhead cameras—one for where the robot picks up the object; another in front of the welding station, for example; and another camera for the outgoing conveyor.)

In each case, machine vision algorithms such as geometric pattern matching analyze images from each camera and locate object features in the image, such as a corner, screw, or some other obvious surface feature. Then, by measuring the distance from that object and a known point on the

Soot Particle Filter, 2D Robot Guidance

Engelhard Technologies GmbH uses robots to handle materials during production of soot particle filters for the automotive industry. Robot supplier Staübli suggested they consider vision systems from vision-guided robotics (VGR) specialist Cognex. Thanks to the efficient development environment of Cognex's In-Sight® Explorer smart camera software, the "pick-and-place" vision-guided robotics solution was up and running in less than four weeks.

The In-Sight vision system used in the robot cell must recognize each of the 25 filter variants, determine their exact position and provide that data to the robot as precise data, and read 2-D codes on each product. Using the PatMax® algorithm integrated with the In-Sight software for geometric pattern recognition, the 2D VGR solution was able to achieve 99.9 % accuracy.

By using an In-Sight color vision sensor, the workcell could also verify the presence of a green quality label on each filter and verify the number of parts in a container. By continuously checking the number of packed parts and by comparing the number actually produced, Engelhard Technologies determined the amount of rejects/loss after just two days of system development.

conveyor's surface, the vision system can create a 2D map or program path for the robot, including distance and direction from the center point. This location, often referred to as an "offset," is then sent to the robot controller, which will use the distance and direction information to direct the robot to the object. This is 2D vision-guided robotics.

Now assume the object on the table isn't small like a microchip that extends only a few millimeters on the conveyor table and, therefore, cannot be treated as part of the 2D space. What if the object was a car fender that has to be grabbed from a rack that hangs in free space?

In this case, the vision-guided robot workcell designer cannot depend on the racked panels being in the same position or in the same orientation every time. In an autoracking application like this, each panel is slightly farther away than the previous one. Therefore, each panel has a different location in 3D space (translation) and likely has different orientations (rotation) to each axis compared to the previous part. In the most challenging "bin picking" applications, the parts may be placed loosely in a bin, with no structured packing or dunnage. In both cases, the vision system must locate the part in 3D space, including both translation and rotation, to correctly adjust the programmed movements of an articulated robot with 6 degrees of freedom to the racked part.

Working with 3D Vision-Guided Robotics (VGR)

Machine vision offers four main techniques for providing 3D robot guidance:

- Single-camera triangulation
- Stereoscopic or multi-camera triangulation
- Structured light
- Time of flight (ToF)

Designers need to understand the pros and cons of each solution and how they align with industrial applications.

SINGLE- AND MULTI-CAMERA TRIANGULATION: Both single-camera and multi-camera triangulation start with multiple images of the same FoV taken from different perspectives. Often a single camera is mounted on a the robotic arm so that the robot can move the camera around to take multiple pictures, which takes more time but costs less than multi-camera 3D VGR systems.

Again, geometric pattern search algorithms locate key features in each image. Because each image represents a different perspective, the key features change location, shape, and size. By numerically analyzing how the features are different in each image and comparing those changes in location, shape, and size to similar measurements of a calibration target taken during the calibration set-up routine, the machine vision system can accurately calculate the part's 3D location and orientation. The more images the system compares, the more accurate the 3D data. However, the more pictures are taken, the slower the throughput.

Single- and multi-camera triangulation 3D VGR systems can provide highly accurate 3D position data across a large area, which is why this technique is often used in the automotive and other durable-goods industries for assembly, dispensing, and painting applications.

STRUCTURED LIGHT: Structured-light solutions also use triangulation and can provide additional accuracy to conventionally lit single- and multi-camera triangulation 3D VGR systems. Structured-light solutions use either standard lamp with periodic line filter or laser light to project lines onto a surface. The lines give the light "structure" rather than even illumination across the entire area.

By analyzing images showing the lines projected onto the target object's surface and measuring how the lines change shape, the 3D vision system can create a 3D map of the surface of the target object. This technique can also generate 3D data from a single image from a single camera. The accuracy of structured-light 3D VGR increases as the spatial resolution of the camera increases and as the projected line pattern increases in density, and decreases as the size of the work area grows.

Structured-light 3D VGR solutions are excellent choices for smooth and reflective parts that do not have easy-to-find surface features for a geometric pattern search algorithm. The specialized lighting adds to the cost and accuracy of the overall systems, and if the light is coherent, it can add to safety concerns. But for sheet metal and polished metal parts, for example, structured light may be the most cost-effective solution.

TIME OF FLIGHT: Time-of-flight (ToF) cameras are relatively new to the world of commercial industrial cameras, although the technology has been around for many years. These specialized cameras use a variety of optical, non-contact methods to measure how long it takes light to travel from the illuminator, off the target part, and back to the camera. Each pixel can yield a specific 3D data point. However, these specialized cameras typically have a limited number of pixels—and therefore spatial resolution—compared to conventional CCD and CMOS industrial cameras.

For large workspaces where required accuracies are measured in millimeters or centimeters, ToF cameras can be an attractive solution to 3D VGR applications.

Getting Started with 3D VGR

Every vision-guided robot application starts at the same place: the target part. Users should ask a number of questions, including but not limited to:

- What is my part and how will it appear to the vision system? (Big vs. small; reflective vs. dull; fragile vs. robust)
- Is the application essentially 2D or 3D?
- What sort of robot does that application require? (Wash-down or cleanroom-ready SCARA? Large payload Cartesian? Articulated robot for 3D manufacturing or material handling?)
- Will you quality inspect or track-and-trade the part at the same time you assemble it? (Task a dedicated smart camera to inspection and defect classification or add an autoID camera in addition to VGR solution.)
- What sort of machine vision system do I need? (Smart camera for 2D VGR? Single-camera structured-light solution with PC host for moderate throughput? Multi-camera stereoscopic for high-resolution or large-area 3D VGR?)
- What cameras will I need to generate a 2D or 3D offset for the robot and to possibly inspect the part for defects, depending on user needs? (Smart camera, high-resolution CCD, high-frame-rate CMOS, overhead mount, robot mount, etc.)
- What does the machine vision system need to accomplish, how will that affect image-processing software selection, and what computer hardware do I need to make sure the VGR system doesn't slow down production? (Do you need a specialized 3D VGR algorithm? Application programming interfaces (APIs) for specific robot controller manufacturers? Smart camera vs. PC host?)
- What sort of light or combination thereof will work best for your VGR application? (Strobe, color, laser, etc.?)
- What network connectivity do I need between the robot, vision system, and plant network? (Will the system be connected to a manufacturing execution system (MES)? Will images be archived for later analysis?)
- How will operators interact with the VGR solution? (Touchscreen, HMI on robot controller or vision system?)

Working with an integrator who is familiar with vision-guided robotic applications can make it easier to answer these questions and help you avoid common pitfalls.

Vision-Guided Robotics for Any Industry

Italy's Tiesse Robot is a leader in industrial automation and vision-guided robotic solutions that have produced vision-guided robotic workcells for hundreds of industries, including durable goods and iron cast parts, among many others.

One solution for the durable-goods industry included a robotic workcell for assembling washing machines that includes two robots guided by a machine vision system running Cognex VisionPro® software. The cell consists of a pallet store for components, a measuring station with remote camera for the hole centers, a station for fitting the caps, a turntable for fitting and riveting the roller bolts, and two Kawasaki vision-guided robots that move the parts between the various stations and prepare the preassembly of the roller on the turntable.

To overcome common challenges for vision-guided robotics such as changes in ambient lighting while maintaining operational simplicity, Tiesse used a number of Cognex vision tools that include PatMax, PatFlex®, PatInspect®, non-linear calibration and measuring tools, and VisionPro 3D.

The special features of the cell include production in random mode and on-the-fly robot path correction of errors to adjust to changes in hole spacing for roller mounting bolts.

Another interesting application uses a vision-equipped robot to refine and finish medium and large iron castings that can weigh up to 500 kg. Cognex VisionPro software determines the orientation of the arriving part, while a second vision system defines the exact position of the castings in three dimensions.

In a similar application, Tiesse Robot engineers developed a vision-guided robot workcell to finish office chair plastic backrests and fit them with metal inserts to attach the seat to the chair frame.

The inspection cell is located downstream of a press that stamps eight different product codes at random. To handle random production, Cognex VisionPro software was incorporated in the island that makes it possible to handle up to 32 different product codes without changing speed or flexibility.

The cycle of each robot includes locating the backrest on the conveyor, guiding the robot in three dimensions to pick up the part, visual inspection to verify part dimensions and identify any upstream production equipment errors, sequential placement of all the inserts according to the position measured by the vision system, and depositing the finished product on the removal transporter.

For example, robot-mounted cameras need cables to carry data from the camera to the vision system. The robot's constant repetitive motion can stress cables, while the wrong cable can restrict a robot's movement. Many companies offer special "flex" cables designed specifically for VGR applications that avoid these problems. Machine vision suppliers can make it easier on the integrator by offering Power over Ethernet (PoE) solutions that combine both the data cable and power cable into one, reducing the amount of cable that has to be fixed to the robot.

Integrators can also help users select quality machine vision software solutions that simplify the all-important calibration and communication requirements between robot and vision system. For instance, Cognex's VisionPro calibration routine not only corrects for lens distortions and roll-off common to all industrial cameras, but it can also expedite aligning the vision coordinate system to the robot coordinate system.

And while most robots communicate with a vision system using either serial or Ethernet communication, every robot controller has unique requirements for how that data is communicated. Cognex overcomes this by offering drivers for both robots that use standard serial communication and specialized serial communications, including:

Pre-configured (built-in) serial communications for:

- Motoman
- Kuka
- ABB
- Fanuc
- Denso
- Staübli
- Kawasaki

Robots that use standard serial communications (no special drivers):

- Adept
- Epson
- IAI
- Mitsubishi
- Nachi
- Yamaha
- ...among others

The VGR Competitive Advantage

Companies that effectively utilize robotic systems can increase throughput and lower production costs; improve product quality and reduce rework and waste; normalize product quality across geographic regions; move production closer to end markets regardless of the availability of low-cost labor; reduce existing labor costs; add production shifts without incurring additional hiring, training, and overtime costs; and protect workers from hazardous and repetitive tasks.

By adding machine vision technology, these companies now have the ability to track product, reduce liability, improve supply chain management, improve quality and troubleshoot challenging lines and processes, and greatly expand their use of robotic automation by adding 2D or 3D machine vision guidance. Taken together, the advantages of vision-guided robotics can significantly improve a company's bottom line, saving time, money and resources.

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