18 years into the new millennium, there are a number of exciting and evolving electronic innovations taking place. Among them is the development of ‘intelligent’ robots for industry, especially in smart factories (see The role of Sensors in the Industrial IoT (IIoT)).

The advent of 5G communications will enable factories to take data from the production floor that will improve quality and enable increased automation. 5G low latency with accelerated edge computing, coupled with fast sampling capability, will give rise to higher speeds in manufacturing and enable closed-loop inline inspection of manufactured components.

Editor’s Note: This article is part of an AspenCore Special Project on vision guided robots. With the cost and size of cameras dropping and the power of image processing software increasing, robotic systems are seeing a surge in new vision-guided applications, especially those using 3D. This Special Project explores hardware, software, and business issues surrounding this technology through a collection of interrelated articles, listed at the end of this one.

Hewlett-Packard Enterprises says, "Edge computing is a distributed, open IT architecture that features decentralized processing power, enabling mobile computing and Internet of Things (IoT) technologies. In edge computing, the device processes data itself, or by local computer or server, rather than being transmitted to a data center" (Figure 1).
Machine vision

A critical component in the performance of intelligent robotics is machine vision (MV) technology. This uses computers coupled with high-speed cameras. By combining these two technologies, complex inspection tasks can be performed as well as digital image acquisition and analysis. That data can control a robotic arm, sort objects, recognize patterns, and so much more that we have not even conceived yet.

An alliance

First, we need to begin with the Embedded Vision Alliance, which defines embedded vision as the practical use of computer vision in machines that understand their environment through visual means.

Next, let’s look at industrial applications of a robot’s vision sensing architecture. One of the best and most complex aspects of MV is 3D imaging. Cameras, combined with other support equipment perform many tasks including image signal processing (ISP), video transport, format conversion, compression, and analytics.

Some 3D camera imaging technologies from Microsoft, Intel, and Occipital follow.

Microsoft

Microsoft Azure has a neat computer vision offering via cloud computing. They are bringing the intelligent edge to robotics via this platform. See an example of how well they can analyze an image
here. Their Computer Vision API is pretty remarkable. One of their customers, Jabil Circuit, Inc connected their factory floor to the cloud; see how they integrated predictive analytics with real-time manufacturing here. Jabil uses sensors, wireless, precision machines, optics, automation, and mechatronics in their manufacturing.

In late, 2018, Microsoft announced that they are bringing the Robotic Operating System (ROS) to Windows 10, working with Open Robotics and the ROS Industrial Consortium (ROS-I).

Intel

Intel is taking a hardware approach to accelerate intelligent vision with the use of FPGA-based accelerator solution technology as a result of their 2015 acquisition of Altera combined with Intel CPUs for next-gen vision-based systems.

Camera sensor technology is ever being improved, so there is a trend to replace analog cameras with smart Internet Protocol (IP) cameras. Also, in the new mix with IP cameras comes artificial deep-learning-based video analytics. FPGAs are right for the needs of vision-based systems since they have high performance/watt, low latency, and flexibility (Figure 2).

Figure 2

The flexibility that FPGAs have in supporting different sensor and MV interfaces (Image courtesy of Intel)

MV technology is enhanced via the use of FPGAs because they enable MV camera designs with different image sensors and MV-specific interfaces. An FPGA also has use as a vision-processing accelerator inside the edge computing platform that can capture the power of artificial intelligence (AI) deep learning to analyze the MV data outputs.

Other areas that are enhanced and enabled by the use of FPGAs in robotic vision cameras are: use of multiple GigE cameras where one FPGA can integrate image capture, camera interface, communications, and preprocessing; a frame grabber link between MV cameras and the host PC running the algorithms; the use of Camera Link using TI’s Channel Link interface; USB 3 vision; CoaxPress; and Thunderbolt.

Occipital

This company has Occipital Tracking technology for MV with 6-degree of freedom (6-DoF) positional tracking, mapping and obstacle awareness, and more. They also have Structure sensor and Structure Core for robotics.

With Structure Core, Occipital has created a pocket-sized computer vision device with onboard wide-vision camera, stereo infrared capability, an on-board DSP, and a color module. Figure 3 shows
three cameras: A wide-vision camera with 160 degree field-of-view and two infrared cameras. There is an on-board inertial measurement unit (IMU) and a NU3000 processor that computes depth and also has a programmable DSP.

Figure 3 Occipital Structure Core is an advanced depth sensor (Image courtesy of Occipital)

Advanced MV and 3D displacement sensing

Advanced MV and 3D displacement sensing

Cognex

Cognex has solutions for 3D laser profilers, including 3D displacement sensors typically used for 3D inspection of a product (Figure 4). Learn more by watching this Cognex video.

Figure 4 Cognex DS1000 and DS925B 3D laser displacement sensors (Image courtesy of Cognex)

Cognex also has their VISIONPRO VIDI deep-learning-based software for industrial image analysis in factory automation applications. This software handles defect detection, texture and material
classification, assembly verification as well as deformed part location, and character reading, including distorted print by combining artificial intelligence (AI), VisionPro, and Cognex Designer Software.

**Semiconductor solutions**

Next, thinking like a designer, we will go to some of the semiconductor experts to see what kind of solutions they can provide for custom and/or proprietary hardware and software designs.

**Texas Instruments**

TI has some really neat reference designs for machine vision cameras. One unique solution that TI has for 3D MV is with the use of their Digital Light Processor (DLP) technology. The following is a great example of how DLP can be used in a 3D MV application (**Figure 5**).

**Figure 5** A DLP solution for 3D MV

In addition to the hardware, TI has a DLP structured light software development kit (SDK) and a complete reference design for 3D MV with their [TIDA-00254](#).

**Analog Devices**

Analog Devices has chosen to develop solutions for barcode scanners. These kinds of image-based systems are being designed into MV systems because of the need to identify and read a large variety of labels regardless of their size, shape, color, or condition. They feel that the barcode scanner market is currently undergoing a shift from laser-based systems to imaging solutions to obtain greater scanning resolution, throughput, and specificity. To do this, embedded processors are tasked
with edge detection and classification, erosion, dilation, reorientation, and return of interest selection, along with color and template matching portions of the scanning algorithm.

In the area of MV cameras, where defects or anomalies can be detected in real-time within the camera itself, analysis processing by a Blackfin DSP can deliver increased efficiency and more cost-effective line scan and failure detection solutions. Learn more about the ADSP-BF70x series for portable bar code scanning in this video.

Analog Devices also enabled a six-legged robotic spider, which could be deployed in a rugged environment that is too dangerous for humans, like areas with earthquakes or other natural disasters.

**Cobots**

Robots will be working alongside humans in smart factories and in space. These collaborative robots are called cobots. New technology advances in computer vision and image recognition will help enable these cobots to avoid contact with their human co-workers. VEO Robotics is an excellent example of a company developing perception and intelligence for industrial cobots. Visit their website to view a neat video introduction.

**NASA MV for robotics**

Now let’s look at a NASA technology for autonomous rover MV. Their latest rover is the Mars 2020 Rover that has a very unique ‘SuperCam’ that does not see images like most other MV cameras, but instead uses infrared and green laser beams to remotely analyze the chemistry of materials such as soil and rock. The technique used is laser-induced breakdown spectroscopy (LIBS) and mineral analysis with a remote RAMAN spectroscopy system based on the rover (Figure 6). See this article for more details.

![Figure 6 The Mars 2020 Rover using its SuperCam (Image courtesy of NASA)](image-url)
Wheelchair with robotic arm

This example is a bit more complex than the previous one. The design will help patients with medical movement disorders to perform daily tasks. Patients with upper-body extremity disorders, such as Parkinson’s Disease, can benefit from this design since manual control of a robotic arm will be challenging to these people. An autonomous arm, mounted onto a wheelchair, using computer vision is the basic idea.

The robotic arm has six-degrees of freedom and is mounted onto an electric wheelchair with a computer system and two vision sensors. One sensor detects the coarse position of colored objects, positioned randomly on a shelf, using a computer vision algorithm. The second sensor gives a fine location of the object by making sure it is correctly positioned in the front of the gripper. The arm will automatically grasp and pick up the colored object and give it to the user (Figure 8).

![Electric Wheelchair](image1)

**Figure 8** A robot arm mounted to an electric wheelchair (Image courtesy of Reference 10)

The robotic arm is a Trossen Robotics PhantomX Reactor Robot Arm Kit that uses an Arduino-compatible microcontroller, Arbotix-M robocontroller, also from Trossen. In order to communicate with the arm via computer, designers used PySerial, a python serial port access library.

Vision sensors

Two USB webcam vision sensors were employed for object detection. Vision sensor 1, a Logitech HD c920 webcam, is mounted above the robotic arm facing the shelf. This captures the video of the arm and the shelf for coarse positioning in real time so that the video frames are processed to locate the X and Y position of the target object. Vision sensor 2 is a robot VGA webcam mounted above the gripper using a 200 mm gooseneck. That vision sensor captures the close-up video of the target object. The computer vision algorithm takes over to find and grasp the object and move it in front of the user to deliver the object.

Cartman

The Amazon Robotics Challenge 2018 winner, Team Australian Centre for Robotic Vision (ACRV),
successfully designed a pick-and-place robot for autonomous warehousing. See Cartman, the Cartesian Robot, in action below.

It is a difficult job for a robot to select specific objects from a cluttered pile of random objects. This is a more advanced project that can operate in household cleaning chores or in advanced space-related sample return. Figure 9 shows the parts of Cartman.

Figure 9 Cartman is designed with two 6-DoF manipulators. A camera is mounted on the wrist with two effector tools (a suction tool and parallel gripping mechanism). There is a second camera mounted on the frame that takes a secondary image of picked items with a red backdrop curtain area. (Image courtesy of Reference 11)

The cameras

An Intel RealSense SR300 RGB-D camera was selected because of its small size and light weight, since it is mounted on the robot’s wrist. This camera uses an infrared projector in the camera to determine depth. Another RealSense camera is mounted on the robot’s frame for a second classification check of the item picked.
An interesting challenge in this contest was that the set of items from which the robots had to choose were only provided to teams 45 minutes before each competitive run. This made for deep-learning challenges. This winning team chose to fine-tune their base RefineNet network on a minimal dataset of the unseen items. The team developed a semi-automated data collection process that enabled them to collect images of each unseen item in seven unique poses, create a labelled dataset, and begin fine-tuning of the network within only 7 minutes. During the competition fine-tuning was performed on an Intel Core i5-7600 and four NVIDIA GTX1080Ti graphics cards.

The team realized that the performance of robotic systems, as seen during the challenge, still has a long way to go to achieve human levels of performance (approximately 400 picks/hour, while Cartman can perform about 120 picks/hour). They feel that the following two attributes were critical to winning the challenge and more generally for designing autonomous robotic systems capable of operating in the real world:

- A design methodology focused on system-level integration and testing to help optimize competition performance,
- High-level logic designed to be robust, and able deal with errors.

**Machine vision challenges in textile inspection**

Teledyne Dalsa has a really neat line of area scan, line scan, TDI line scan, smart, and infrared cameras. They have accepted the challenge of using MV in the very demanding textile industry that requires finished goods to be free of structural and surface defects. This is a daunting and complex task.

MV uses mostly industrial cameras in harsh industrial environments. In the textile industry, materials may move at speeds of up to 120m/minute in a production line that is able to operate 24 hours a day, while maintaining a high consistency and quality of the product, which will improve the bottom line.

Line scan cameras are the ones typically used in this kind of operation with their single line of pixels used to create a continuous 2D image of the fast moving material. These cameras are particularly well suited for imaging continuous webs of material, while detecting changes in pattern, color, and texture, as well as defects in the material. These types of cameras do an excellent job in delivering smear-free images at high speeds with excellent processing efficiency and lower cost per pixel compared to area cameras. Learn more about color line scan cameras in the video below.

Newer multi-line scan cameras are now combined with different LED light sources that can detect a range of defects across the full length and width of a textile quickly moving along a production line. The illumination across the field of view should be uniform and of high-intensity.
Reference 12 states, "The data generated by the line scan camera is typically used to create two-dimensional images or automatically create a map which will show exactly where defects are located on the surface of the textile. A quality control inspector can then review the defect map to determine its validity. Some of the typical defects quality control inspectors look for are water damage, misprints, foreign fibers, oil spots, among others. Images processing software then analyzes the images or defect map to construct a virtual cutting plan for an inspected textile. This process will enable the manufacturer to virtually construct a cutting plan that will produce the greatest yield with minimal defects, before cutting the physical textile. After an ideal cutting plan is generated, the manufacturer can then implement the plan and prepare the textile for shipment."

Robots are among us, they see many things that humans cannot and process large amounts of data orders of magnitude faster than a human brain. They have eyes, ears, speech, and the capability to smell and sense. They can walk, talk, grasp, and perform complex functions. We are presently entering an area of AI that is the beginning of reasoning for robots. But we are the creators and masters of this technology. We have a responsibility to be sure that our creations are used for productive purposes, while re-training the people who may be losing jobs that technology does better. Technology is good, but we, as the guardians of that technology must preserve their place in society while ensuring a better and more successful world for everyone.

Steve Taranovich is a senior technical editor at EDN with 45 years of experience in the electronics industry.

References

1. The Four Key Trends Driving the Proliferation of Visual Perception, Jeff Bier, Embedded Vision Alliance, December 4, 2018
2. Eye Spy: The Basics of Robotic Vision Systems, Isaac Maw, engineering.com, July 16, 2018
3. Cognex
4. 3D Machine Vision Reference Design Based on AM572x With DLP Structured Light, Texas Instruments
5. Graphical Embedded System Design Empowers Life Saving Spider Robots, Pom Yuan Lam (BEng), Lecturer, Nanyang Polytechnic, Singapore on Analog Devices website
7. Mars 2020 Rover cameras, NASA
8. Trends in 3D Inspection: Edge Computing, Acceleration, and 3D Smart Sensors for IIoT, LMI Industries
9. Computer Vision Based Object Grasping 6DoF Robotic Arm Using Picamera, V. Kumar, Q. Wang, W. Minghua, S. Rizwan, SM Shaikh, X. Liu, 2018 4th International Conference on Control,
Want to learn more? Check out these other articles in AspenCore's Special Project on machine-vision-guided robots:

- **3D vision enhances robot opportunities**
  Vision guided robotics (VGR) has long used 2D imaging, but the advent of cost-effective 3D is opening new application opportunities.

- **Open-source software meets broad needs of robot-vision developers**
  Robot vision applications can bring a complex set of requirements, but open-source libraries are ready to provide solutions for nearly every need. Here are some of the many open-source packages that can help developers implement image processing capabilities for robotic systems.

- **Applications for Vision-Guided Robots**
  Perhaps the most significant recent developments regarding robotics have involved the combination of high-resolution imaging, artificial intelligence, and extreme processing capabilities.

- **Designer's Guide to Robot Vision Cameras**
  Giving a robotic system vision requires the right camera selection. Here's a guide to get you started.

- **3D vision gives robots guidance**
  Many options exist for 3D machine vision, each addressing different application needs.

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