EMBEDTEK

Vision system game changers: COTS and Open Source

How These Building Blocks to Innovation Make Vision Systems Accessible to All

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Executive Summary

Machine vision systems have historically required a large investment to be viable for many applications. The high price-per-unit in relation to the value of what was being manufactured typically limited their use to large manufacturers who needed to eliminate labor to ensure quality control and compliance on the production line. Now, consumer-driven advancements in sensor technology are driving lower cost and performance improvements in the broader supply chain. This is changing the way vision systems are developed and utilized.

Commercial-off-the-shelf (COTS) camera sensors, combined with open source software are being adapted to achieve the level of performance most would expect from an industry vision system but at a much lower cost. With advancements in technology such as a low-cost camera that can capture 240 frames per second, and configured software that provides a base for capturing and performing analytics, EmbedTek has leveraged cameras as optical sensors that are being used for data collection and real-time control, not just for their image capture function.

Camera sensors have been used to replace lasers for faster and more accurate object tracking, object feature recognition, character recognition, threat detection, and more. They've also enhanced mechanical intelligence on equipment to avoid collisions. Optical sensors allow us to collect more data and perform actions better, develop prototypes faster, and manufacture high volume end products cheaper.

Better, faster, cheaper vision systems. Now. In this white paper, we will show you how to:

- Determine how your application could benefit from a vision system
- Harness consumer-driven technology
- Modify COTS components and open source software for embedded device control
- Better understand when a custom camera solution makes sense

Better, faster, cheaper vision systems. Now.

The Systems We've Known

Machine vision systems have existed and evolved for decades as builders, engineers, and inventors looked to replace tedious and error-prone manual processes with the efficiency of automation. Today, they hold a prominent place in the manufacturing, medical and security industries, where machine vision is in many ways the eyes of an operation — spotting defects, predicting failures, ensuring accuracy, detecting anomalies, and sorting products. All at extremely high speeds.

Manufacturing environments are constantly under pressure to improve accuracy, quality, and reduce operating costs. To accomplish this, most manufacturers have turned to companies like Wisconsin-based Cognex for custom programmable logic controller (PLC) solutions in their production lines. Cognex is the world's leading supplier of machine vision systems, software, sensors, and ID readers. It has spent the last 30 years building its reputation and has the market share to prove it.

But there are three main barriers to innovation with proprietary systems like Cognex.

1. **They are price-prohibitive for high volumes.** A custom application can cost $5,000 to $10,000 per unit, plus software licensing fees.
2. **The short, consumer-like lifecycle of machine vision components** makes it difficult for niche applications to upgrade proprietary technology when new generations are available.
3. **Cognex solutions are high performance with a general purpose,** and a lot of time has been put into their development. While large manufacturing operations can afford the high cost and low volume, smaller operations don't have the means to invest what is needed to make the solutions a perfect fit for their application. So they either don't invest, or they invest in a solution that isn't perfect for them and make it work.

Today's low-cost, off-the-shelf camera components and open source software solutions make these barriers irrelevant.

1. **They cost hundreds of dollars per unit** and a few thousand dollars for the complete application with no software licensing fees.
2. **Upgrade and migration plans are built-in** at the beginning through a lifecycle management program that accommodates the entire supply chain, especially for niche and high volume applications.
3. **Custom innovation opportunities are endless.** COTS and open source have the unique ability to serve as building blocks to innovation. Cameras and components are purchased and adapted, not built from scratch. Analytics are developed by leveraging the shared successes and learnings from an open source community made up of thousands of expert users.

COTS and open source have dramatically shifted the playing field, opening up opportunities for nearly any OEM in any industry to improve equipment design, device control, and operational outcomes. At EmbedTek, we take advantage of this technology by looking at applications where optical sensors haven't traditionally been viable.

See the High-Speed Counter case study as an example. Disrupting the use of lasers is just the beginning of what open source and COTS-based vision systems can accomplish.

CASE STUDY

High-Speed Counter

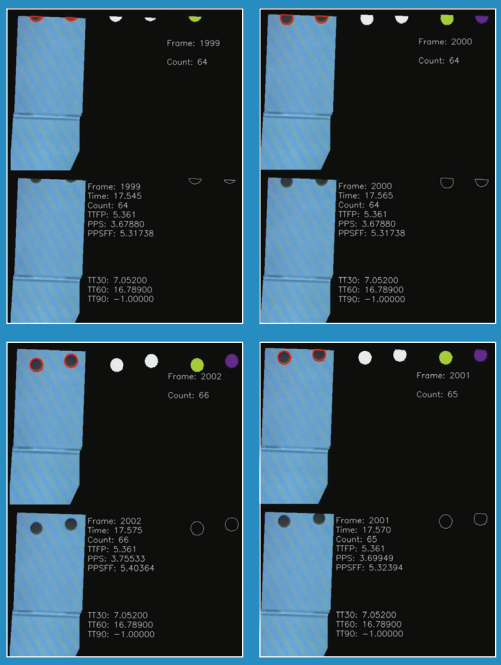
An OEM's existing object counter relied on the interruption of a laser beam to identify when an object was present to be counted. This forced the operator to hand-feed the objects into the machine and required one object to interrupt the laser beam at a time in order to be counted accurately. If two objects interrupt the laser beam at the same time, they would be counted as one.

A vision system immediately came to mind as a solution to increase speed, but the variability in size, shape, and rotation of the objects as they fell would compromise accuracy. The EmbedTek team used COTS camera sensors and components, open source software, and a few rounds of trial and error to design and optimize an entirely new environment inside of the counter. Transitioning to a camera sensor allowed not only counting the objects but also identifying and storing visual evidence of what was dispensed.

The process starts with an area for the operator to fill the counter, and then a feed mechanism manages the speed at which the objects are dropped through. The feed mechanism also triggers a motion-activated camera and lighting system. Polarization filters and strobe lighting synchronize with the camera frame speed to ensure brightness and clarity, which is necessary in order to distinguish objects as they present in a wide variety of ways. Once the image is captured, the software interprets the image and algorithms eliminate inaccuracies.

Our customer can now provide their customers who rely on quick, accurate, and verified counting with a solution that not only ensures quality but can record each counting session in the case they ever need to audit inventory or production processes. The vision system and specialized lighting environment make a next-generation technology possible without compromising manufacturing costs or drastically increasing the end-user investment.

The object counter system individually identifies each object and color codes it. This color code persists until the object goes beyond the view of the camera. The view in the following pictures is used for diagnostics. Each image is a collection of five different phases of the processing pipeline.



In each image:

- *The lower left frame is the raw image seen by the camera*
- *The upper left frame is the raw image with red circles drawn around the objects*
- *The middle top frame is a binary view of the objects*
- *The upper right frame is the color-coded view*
- *The lower left frame is the outline of the objects*

Where We're Headed

Just about every 18 months, a new generation of consumer applications electronics is introduced in the market. They continue to drive rapid improvement in COTS camera sensor quality, speed, and resolution. At the same time, the cost of manufacturing and purchasing the technology is reduced.

Not only are COTS camera sensors and components high-quality and affordable, they also are significantly smaller than less powerful camera systems 10 years ago. For example, the first cell phone with a built-in camera was the Sharp SCH-V200 flip phone, which came out in 2000 with an image resolution of 0.35 MP. The average smartphone today has a 12 MP resolution.

When integrated into medical devices, COTS camera sensors can improve patient outcomes. When monitoring a production line, they can prevent unplanned downtime, saving hundreds of thousands of dollars per year. With high-performance image processing and advanced analytics software, embedded camera systems can determine speed, improve accuracy, and select products based on shape or color.

EmbedTek leverages COTS camera sensors and components in conjunction with our established product line of computers and integrated displays. We've been able to change a year-long research and development process into a six to eight-week rapid prototyping process. This solves customer design challenges faster and helps their products stay in market longer.

For example, EmbedTek is currently working on a project that uses thermal imaging infrared cameras combined with a vision system with sensor fusion to distinguish human figures from inanimate objects. When integrated into its end product, the software will trigger a warning alarm or shut a machine down if a human is too close and in potential danger of injury.

Another example is a finished product that improved an existing OCR application while creating a path for a future migration and extending the overall life of the product.

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CASE STUDY

High-Performance In-Vehicle Camera System

An OEM partnered with EmbedTek to improve their existing high-performance image processor, which lived and operated inside the trunk of an active work vehicle. The manufacturer needed a flexible platform that could be updated to accommodate for the ongoing advancements in camera technology.

EmbedTek identified that migrations from one camera to the next would only be possible if the processor could remain and handle the upgrades. Can you guess what was holding them back from this approach in their current system? Proprietary data capture components, cables, and connectors. These proprietary components would require the OEM to replace the entire system to support future cameras.

Our team of engineers developed a custom printed circuit board (PCB) with complex software that eliminated the need for proprietary… anything. It allowed us to replace just the processor module with the existing, already deployed cameras, so field retrofits could begin immediately without changing the nature of the video stream. When the next generation cameras and interfaces are available, a simple change can be made to the manufacturing process to adopt the future architecture.

The new image processor was designed using field-tested COTS components as building blocks, drastically reducing the time needed for the invention process.

Our product outperforms the OEM's previous processor in many ways:

- Balances the protection and durability required for the brutal in-vehicle environment with the high-performance quality required for the processor to capture images.
- Can withstand weather and climate anywhere in the world — from near Arctic in winter to Saudi Arabia in summer.
- Reduction in overall volume of the processor by 50 percent.
- Longer, simpler cable runs and connectors that provide better power distribution, reduce noise and signal loss, and lower manufacturing costs.
- Higher performance image processing and analytics capture more accurate information at faster vehicle speeds.

Our customer is happier with a less expensive, more reliable and durable design that is equipped to adapt to the fast pace of innovation in camera technology. Their end users are happier with a lower failure rate of image captures that can be critical to their jobs.

To achieve the level of performance you would expect from a Cognex-like system at a cost low enough to embed inside of an OEM solution takes a special skill set. Our mechanical, electrical, and software engineers bring their diverse backgrounds to the table when they work together to adopt open source technologies and leverage off-the-shelf products.

What to Look For

Vision systems are half about the camera sensors, and half about the software to support and interpret data the sensors capture. COTS and open source easily work together to make an extremely powerful tool for OEM equipment in every industry. The exciting part is that every application is truly different than the next. But, that's the challenging part, too.

There are hundreds of ways to approach a vision system challenge and thousands of options for COTS component configurations to develop a solution. Take the following factors into account when selecting parts and approaches for a new vision system platform.

Cameras

COTS camera sensors literally come in all shapes, sizes, and speeds. Start by thinking about the data you plan to collect from the camera and the minimum requirements needed in order to capture what you need. Following are considerations for lens selection and methods of illumination.

Feature	Why it's important	How to decide
Resolution	The resolution is the size of the image you can capture with the camera. This includes the amount of detail, which is measured in pixels (2048 x 1536 or 3 megapixels, for example). And how large an image can be blown up before becoming grainy. Camera technology has advanced and evolved to offer a range from sub-Megapixels to over 24, where the image is so detailed the human eye might not know if it is looking at a photo or real life.	This choice rests solely on how the images will be used. Higher megapixels are needed if a vision system will zoom in to analyze facial features or text at far distances. Lower megapixels can be considered for identifying general shapes and are better where storage or image processing speeds are important.
Shutter Speed	Shutter speed is the speed at which the camera shutter opens and closes to allow light in and capture the image, resulting in different levels of color penetration, depth and contrast. A fast shutter speed (up to 1/4000th of a second) will let in less light and capture images in bright light and can freeze a fast-moving object. Slower shutter speeds (down to 30 seconds) are helpful in very low light and when achieving the desired effect of motion blur or when artificial lighting is impractical.	Higher shutter speeds are ideal for vision systems working with objects in motion. Combine a high shutter speed with a series of high-resolution images and you could have crisp detail ideal for object identification in an industrial setting or surveillance application. Strobes at slower shutter speeds can be also be used if there is no other ambient light affecting the scene.

Feature	Why it's important	How to decide
Frame Rate	This pertains to the number of frames a video camera or screen can display per second. In the example of the object counter, a high-speed camera (240 frames per second) was not needed since the strobe lighting was used to freeze the objects. We used a 120 fps camera which reduced processing requirements.	The higher the frames per second, the more the motion can be slowed down, and detailed imagery of an event can be captured.
Lighting	Whether lighting is an internal or external camera component, it goes hand-in-hand with the camera selection because it is used in conjunction with resolution and shutter speed to capture the desired image. Proper use of strobing allows crisp capture of images and the elimination of glare.	S Electronic lighting allows a camera system to achieve the best combination of freezing an image and required frame rate. LED backlighting illuminates specific parts of an object that are being inspected.
Filters	Filters are placed on camera lenses or within the optical path to augment light, color, glare, and saturation in a final image.	Use a polarizing filter to eliminate reflected light and improve saturation. UV filters cut through the atmospheric haze that degrades image quality in photos taken outdoors. IR filters eliminate the IR spectrum of light that can affect color accuracy.
High Dynamic Range (HDR)	An HDR camera feature takes multiple photos at different exposures so that when the images are edited, they can be combined to compensate for the oversaturation of light and render darker images in the background to create the best final image possible.	HDR is ideal for security camera applications. New sensor technologies allow the different portions of an image to be exposed at different levels to prevent under/over pixel saturation.

Software

Open source software is emerging as an important building block for engineers developing embedded camera systems. The source code is available to the public so successful platforms can be modified and further developed collaboratively by independent users. This saves product developers hours of work and weeks off of a timeline. And by building off of each other, together the entire industry can rapidly advance sensor technology software. Oh, and by the way, it's free!

One open source platform the EmbedTek engineers favor is OpenCV. OpenCV is an open source computer vision and machine learning software library built to provide a common infrastructure for complex image sensor-related processing. Its international community of more than 47,000 people has downloaded the software more than 14 million times.

Feature	Why it's important	How to decide
Background Subtraction	A widely used technique for generating a foreground mask by using static cameras.	Often used when tracking or identifying moving objects, where the object is in focus and the background is blurred or irrelevant to the data collection.
Object Detection	Classify images to know what an image is, and obtain the bounding box coordinates to know where the object is as well.	Necessary for applications that involve counting or tracking. The object counter example used object detection and background subtraction.
Object Tracking	Object detection in a real-time video stream.	Real-time tracking is essential in surveillance applications for tracking people, vehicles, or other objects.
Attribute Measurement	Attributes can refer to size, area, contour, shape, color, reflectivity… any parameter that would describe an object from a software perspective.	Most common across industries and applications. Important for quality control, for example, when a system is meant to confirm the end product matches the design.
Distance Measurement	The distance to an object in an image, calculated by the distance of the camera from an object and the width of the object.	Used to detect edges with or without ideal light, inspect an object for accurate production, or perform a function such as lifting inventory.

OpenCV was built for computational adeptness with multi-core processing. Its heterogeneous compute platform allows it to be used for everything from graphic design to military operations and robotics.

Software developers write complex image processing algorithms in order for their system to capture data through the camera, analyze it to identify trends, and report out on a record, perform a function, or make a logic decision. A vision system is only as good as its data so the analytics function is a critical piece to making a successful application. Here are some of the tools readily available through open source software.

OpenCV provides the methods for doing the above actions, but in many cases, on their own, they are inadequate to achieve high speed, high reliability needed for a high-performance machine. So the EmbedTek team uses the pieces as building blocks, modifying them to achieve the results we are looking for. In some cases, we use them as the foundation of a software process. In others, we learn from how they are developed and then rewrite the method to work more effectively in our application.

About 80 percent of the work is done for us with open source software. As the community continues to grow and develop, it provides more mechanisms that give us, engineers, access to better algorithms, faster performance, and more tools at our disposal. Then we spend the remaining 20 percent refactoring, redesigning, and honing different aspects to customize the software for our use.

Next Steps

Historically in the machine vision industry, the development of low-cost, long-life light sources, imaging devices, interfaces, computers, and software have driven significant innovation. That time is now for off-the-shelf camera sensors and open source software platforms. COTS components and open source software applications are rapidly evolving the capabilities of vision systems while driving down the cost per unit, making vision systems accessible to any manufacturer in any industry. Embedded machine vision systems also play an important role in improving accuracy, quality, and operating costs for OEMs.

When the sky is the limit, OEMs need an embedded technology partner they can work with to create a solution that has their customer's best interest in mind, for today and throughout the lifetime of the product. Select a partner who is knowledgeable in your industry, understands how a new solution will impact the manufacturing supply chain and has the skill to develop a truly unique and innovative solution.

About EmbedTek

EmbedTek creates, designs, and builds computers, custom software, sensors, cameras, and displays for original equipment manufacturers. We make it as easy as possible for OEMs to leverage and embed superior technology for truly differentiated products. Our mission is to create the platform that best serves our customer's business.

Our first engagement with customers is often designing a purpose-specific computer, display, or camera system for an existing product. We see and feel production pain points that we work to identify, carefully evaluate, and solve. The more we get to know our customers, we can design additional features and functions for their product lines to improve reliability, cost, and performance in a new way. Then, when market needs arise that can be solved through technology, we work with customers to create entirely new products, equipment, and solutions that put them miles ahead of their competition.

Few things are more disruptive or costly to an OEM than unexpected changes to their platform. All aspects of EmbedTek's process are organized around the need to provide our customers with proactive product transitions as opposed to reactive transitions. We take on the toughest technology, manufacturing, and integration challenges, evaluate them carefully and solve them. Check out our products and case studies at www.embedtek.net.

If you would like more information about our vision system component suppliers, please go to www.embedtek.net