Technical White Paper

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Tech Trends in Machine Vision

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Machine vision has long been a mainstay of science fiction, so much so that many consumers may think that most of the industrial world is completely vision-enabled. That isn't quite true yet, but machine vision has actually played an important role in improving manufacturing operations since the 1980s.

As the technology progressed out of research laboratories and into practical implementations, and as hardware and software underpinnings have advanced, machine vision capabilities and applications have multiplied. The manufacturing marketplace continues to apply machine vision in new ways to improve performance and quality. In large part this is due to high-performance devices which can be economically applied to solve a variety of problems. Another major contributing factor to increased implementation is ease of use, as new solutions are much simpler to deploy and support than older vision hardware and software.

Some of the first machine vision applications involved rudimentary edge or spacing detection, but in the 1980s these evolved into systems that could read two-dimensional symbols and labels when properly presented to vision detection hardware. First generation "smart cameras" were limited and difficult to configure, but users were hungry for the flexibility this technology could offer over and above traditional sensors, so they put up with many initial implementation difficulties.

The latest generation of hardware and software can achieve high speed three-dimensional analysis. In many ways this drives a virtuous circle of improvements and adoption as *Forbes.com* (Reference 1) observes "the rapid advancement of machine vision technology as the main reason companies seem to be buying more equipment. Companies can now buy cameras the size of quarters that can capture and process high-quality footage that just three years ago wouldn't have been possible." Better vision systems increase use in manufacturing applications, and increased demand spurs vision system suppliers to improve their products.

Another newsworthy and relevant application of machine vision is for self-driving cars and unmanned vehicle (drone) operations. These represent a much more cutting-edge application of vision than is used by manufacturing industries, but the underlying principles and needs are the same. Although manufacturing applications aren't widespread just yet, drones are being used now to perform inspections of assets such as electrical transmission lines (Figure 1, Reference 2), and can be deployed for inspection of other assets such as pipelines, tank farms, and water/wastewater distribution and collection systems.

Figure 1

This White Paper will address the latest technology trends in machine vision and show how these trends are providing benefits to manufacturers worldwide. High performance hardware options are making it easier than ever to install vision systems and different networking architectures have emerged to best serve a wide variety of diverse applications. Standards are emerging to ease integration, and software is becoming easier to set up and use.

While no single approach is ideal for all needs, a fundamental objective is to reduce the development and deployment effort by end users. Advanced hardware and software deliver on this goal, minimizing life cycle support and the total cost of ownership.

Who's Looking at Machine Vision?
Understanding what types of companies are implementing machine vision and what they are looking for helps to define where the technology is moving. Any application involving detailed human inspection of finished products is a good candidate for upgrading to an automated vision inspection system (cover image). In the manufacturing space, some of the prominent vertical markets taking advantage of machine vision include the automotive, food and beverage, pharmaceutical and semiconductor sectors.

Since motor vehicles involve so many parts, the automotive arena naturally applies machine vision for tracking components by label or direct inspection. As the vehicles are assembled, vision guided robotics provide a speedy and repeatable manufacturing solution. Furthermore, vision systems become part of the quality process when used to inspect, gauge and verify dimensions, diameters, distances and alignment.

In food and beverage processes, especially where a wide variety of end products are produced, machine vision systems can verify that product packaging identifies all ingredients included in the product, which is critically important for foods containing known allergens. Pharmaceutical processes have an even greater criticality, as it's absolutely crucial to trace and trace all ingredients and finished products.

For both the food and beverage and pharmaceutical industries, label detection goes far beyond confirming simple placement and orientation, or precision artwork inspection. The presence and accuracy of date codes must be correct for perishable items, while lot codes are crucial should a product recall occur. On the process side, vision offers an accurate and sanitary non-contact sensing method for monitoring fill levels or extruded product dimensions to ensure they meet manufacturer quality requirements.

Some industries have specific sensing needs in locations where it is best to keep personnel away for safety or cleanliness reasons. For instance, semiconductor fabrication plants use vision systems in clean rooms to inspect marks and die attachment, applications where high accuracy and fast response is crucial. They also measure ball grid arrays and perform alignment and location inspections for wafers, integrated circuits and other parts.

Watching Out For Pain Points
End users implementing machine vision systems anytime before the mid-2000s likely experienced some pain and suffering during implementation. The less-capable hardware of the time may have been overloaded to an extent that caused frame and image losses, leading to unreliable image acquisition. Perhaps there were unique connection requirements, or even if Ethernet was used it was challenging to perform the IP configuration. On the software side,

proprietary protocols and software development kits (SDKs) required extensive custom coding, and this steep learning curve eroded the chances of success.

There have been many trends on both hardware and software fronts which have resulted in increasingly capable platforms using more standardized elements. These technical developments mean users can expect reduced development and deployment time, solid platform performance, a lower total cost of ownership (TCO), and an overall more productive life cycle.

Many Hardware Flavors

There is no “one size fits all” solution when it comes to machine vision hardware, which complicates hardware and software specification. However, there are a manageable number of options and combinations which users can select from to best meet their needs, and each solution has its place.

The primary brain for any machine vision architecture is the central processing unit (CPU). Of course, CPUs are generically applied in many types of digital devices. Today’s multiple core CPUs offer exceptional performance and ease of programming. However, the particular nature of vision systems means that they can benefit from the application of specific CPUs and related components optimized for the task.

Various co-processors are available to improve system performance. Graphics processing units (GPUs) are specialized circuits designed to offer massive floating-point computing power which can be harnessed to accelerate image handling, and they are able to rapidly manipulate the associated data defining such images. GPUs can apply common instructions simultaneously on all the elements of large data sets, like the ones making up an image.

Field-programmable gate arrays (FPGAs) are another form of integrated circuit which can be optimized to quickly perform multiple instructions. FPGAs excel at direct hardware access, and can be applied to swiftly execute complex functions and calculations.

Processors and co-processors can be combined to form CPU+GPU, CPU+FPGA and CPU+GPU+FPGA assemblies. Machine vision processing architectures can therefore be tailored to the application at hand, and scalable performance can be achieved. The roles are as follows: CPUs execute algorithms; GPUs encode, decode and display information; and FPGAs perform data pre-processing, especially in the spatial/frequency domain.

A refinement of this strategy is to combine a CPU and FPGA on one chip, which is known as System on Chip (SoC). SoC integrated circuits are common for mobile devices due to their small footprint and low power consumption. A CPU+FPGA SoC configuration such as the Zynq-7000 series from Xilinx provides tight integration between the programmable logic and the vision processing system.

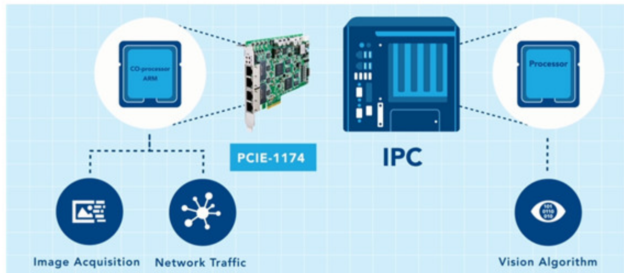
This in turn enables designers to develop C and other software programs which use the programmable logic resident in GPUs and FPGAs to accelerate selected parts of the algorithm, while high-level synthesis tools become increasingly effective to implement vision and other algorithms. As *ElectronicsWeekly.com* (Reference 3) puts it, “Machine vision is a good example of how scalable processing is making a difference in embedded applications.”

Figure 2 depicts an architecture performance comparison showing the kinds of operations each processor type is best suited for. For 3D machine vision applications, the CPU+GPU arrangement offers the best performance. On the other hand, for high bandwidth real-time inline inspection circumstances, the CPU+FPGA design gets the nod.

Architecture and Operation

Performance

Architectures versus their general suitability for the different kinds of operators:



Operation	CPU	GPU	FPGA
Pixel	+	++	++
Histogram / LUT	++	-	++
Neighbour / Kemel	-	++	++
Random Access	++	-	-
Geometrical Transform	+	++	-
Architecture	SSID, SIMD	SIMD	MISD

Figure 2

Building the Machine Vision Platform

The CPU is important, but it is still just a piece of the larger hardware puzzle. Another hardware consideration is whether the entire functionality should be embedded in the end device (the camera), or partially distributed to an associated PC. The decision is based on the application needs.

Basic applications with function-specific detection such as symbol reading, character recognition or present/absent detection of parts are best implemented with an embedded single-camera device. This device is connected to the central controller, such as a PC or a PLC, but only for communication of results.

More advanced applications requiring versatility and complex capabilities such as surface inspection, print inspection, or multiple camera integration are more readily achieved using PC-based systems closely integrated with cameras. In these types of applications, one or more cameras sent data to a PC over a high-speed digital data link, and the PC processes the data to yield the desired information.

Understanding the critical role of software is just as important as selecting the hardware. Camera interfaces are fundamental within a machine vision platform, and there have been several contenders as the field has developed over the years. However, the two interface standards that have risen to prominence for industrial applications are Gigabit Ethernet for Machine Vision (GigE Vision) and Generic Interface for Cameras (GeniCam).

GigE Vision is an open framework based on standard Gigabit Ethernet (GigE). Vision applications demand lots of bandwidth, but it turns out that “normal” GigE is more than sufficient for image transfer needs. GigE Vision is a strong choice due to its superior performance, interoperability, significant vendor support and widespread familiarity among end users.

GeniCam, on the other hand, is a generic software programming interface intended to provide “plug and play” capabilities for imaging applications regardless of the underlying hardware. A graphical user interface is available, and capabilities such as configuring cameras, grabbing images, and transmitting extra data and events are supported. As with GigE, many suppliers have contributed to the establishment and continued support of this standard.

Additionally, it is often important to select a “trigger” for camera operation, as opposed to processing a continual free-running stream of data. This can be handled with an external control system or PLC, but many vision platforms now support Trigger over Ethernet (ToE). ToE enables the operation of one or more cameras to be triggered (with sufficient speed and synchronous behavior) over the very same Ethernet link which networks the camera to the control system. This obviously makes installation easier as one Ethernet link can be employed for triggering and data acquisition.

Taken together, the camera, hardware processing platform, and interfaces provide all the tools needed to implement a machine vision system. These components are more powerful and easier to use than ever before. Of course, users still must harness these tools through software development to implement a solution for their applications.

Application Example

A few application examples can demonstrate the power and flexibility offered by the latest machine vision trends.

Consider a semiconductor manufacturing facility (Figure 3). Backend processing includes dicing the wafers into individual chips which must be tested, assembled and packaged. The manufacturer’s goal was to maintain high throughput with 100% inspection to ensure quality, even though chip dimensions have become ever tighter and more difficult to resolve. The solution in this case was to select a chassis-based industrial PC, with a PCI four-channel GigE Vision frame grabber which also included an FPGA.

Figure 3

This vision hardware preprocesses the images, which offloads the PC to ensure there is no frame or packet loss during image acquisition. This application also includes a PCI servo controller and a PCI I/O card, enabling the platform to fully control the equipment. This combination provides the end user with a flexible and high-performance image acquisition and control platform, which is also easily maintainable.

Another heavy user of machine vision is the automobile assembly industry (Figure 4). Verifying a product has been made correctly is critical, but can be a repetitive and tedious job for personnel, and errors are common with manual inspection. This is why automated optical inspection is the preferred quality control method, replacing manual inspection by operators in many applications.

Figure 4

For this case, the situation was complicated by the fact that inspections had to be performed from many angles. The solution involved installing a total of 22 cameras on two 6-axis robots and in the associated work cells (Figure 5).

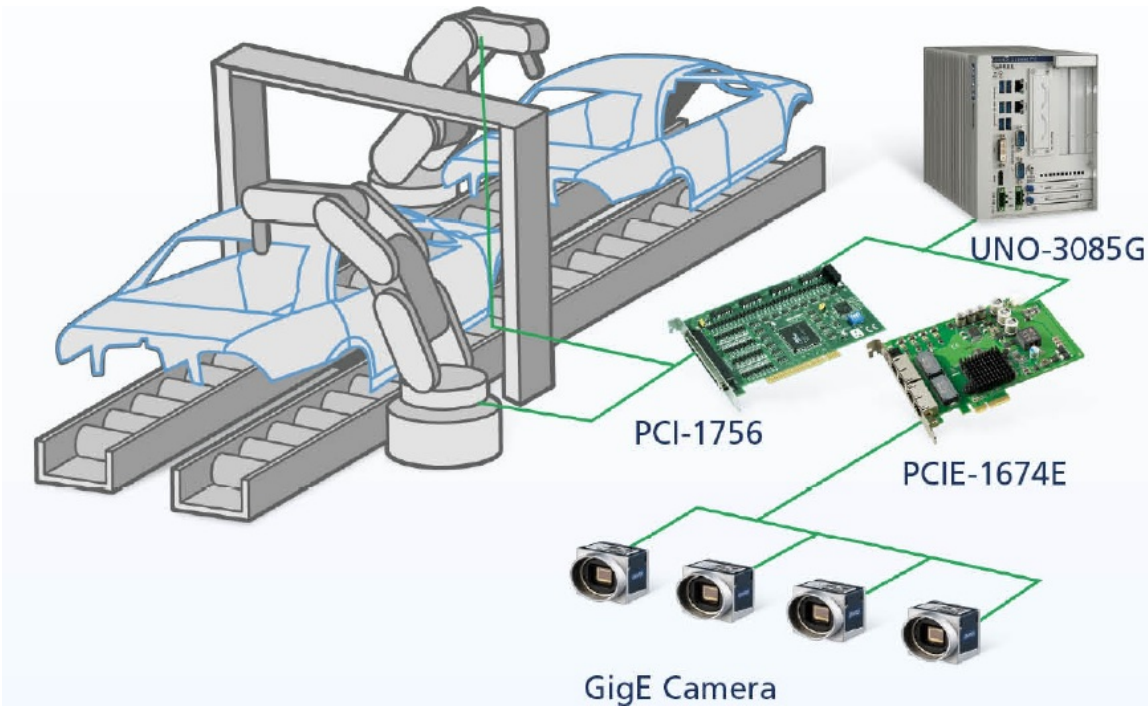


Figure 5

An industrial PC with PCI adapter cards allows the 5 mega-pixel Power over Ethernet (POE) cameras to quickly transmit images to the PC, which in turn manipulate the equipment as needed in real time. The package improved on the accuracy and speed of inspections for the customer, and also cut labor costs.

Conclusion and Outlook

Machine vision technology has advanced on many fronts, from the realm of science fiction to the territory of industrial fact. These vision systems make a very attractive choice for more applications than ever. Any time there is a tedious recognition task requiring high speed and accuracy, particularly in a challenging location, machine vision is a candidate for process improvement. Declining costs are making accelerating return on investment and reducing TCO, spurring further use.

The latest hardware platforms provide a much greater degree of user friendliness and convenient component interconnection as compared to previous generations. Hardware capabilities have advanced to provide multi-mega-pixel resolution, fast processing and fully digital data handling. Systems using combination CPU+FPGA SoC integrated circuits are particularly positioned to offer the right mix of performance and value.

Software and communications have kept pace with hardware developments, especially as industry has adopted standardized protocols, making it far easier for users to network, configure and operate machine vision systems. User-friendliness will continue to be a key factor to successful vision platforms, and the end result will be increased adoption of vision systems in manufacturing environments, providing improved operations and improved safety.

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