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Integrating Machine Vision Directly in the PLC Runtime Boosts Performance

Optimize image processing and response times with scalable PC-based automation, robust network solutions and open standards for camera communication and hardware

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Machine vision continues to grow in applications across industries. Advanced image processing capabilities made possible by GigE cameras and specialized algorithms are now indispensable for quality inspection, track-and-trace and more. With decreasing cost and increasing capabilities, vision equipment is becoming an integral part of nearly every new machine built today. However, most systems miss their full potential due to system complexity, excess black boxes, communications latency, add-on software that operates outside the controls environment and wasted engineering effort.

Modern machine builders constantly look for more innovative controls solutions to reduce these issues and increase uptime while reducing OEM service and support efforts. PC-based automation that integrates machine vision and image processing directly in the controls programming environment and runtime offers significant benefits. To get a complete perspective, it is necessary to reevaluate how engineers typically implement this functionality today.

The current view of machine vision

Today, motion control, safety technology, measurement technology and robotics, among other functions, can all run in a single control system on one computer. By consolidating these multiple black boxes into a single hardware controller, programmers and controls engineers have branched into numerous disciplines. However, image processing has typically remained in a separate black box, involving a standalone smart camera, a high-performance computer or a standalone vision controller. Each of these requires specific configuration tools and programming languages, which exacerbates system complexity, engineering effort and costs.

> "To prevent the typical issues, modern automation and controls providers have taken a different approach to image processing."

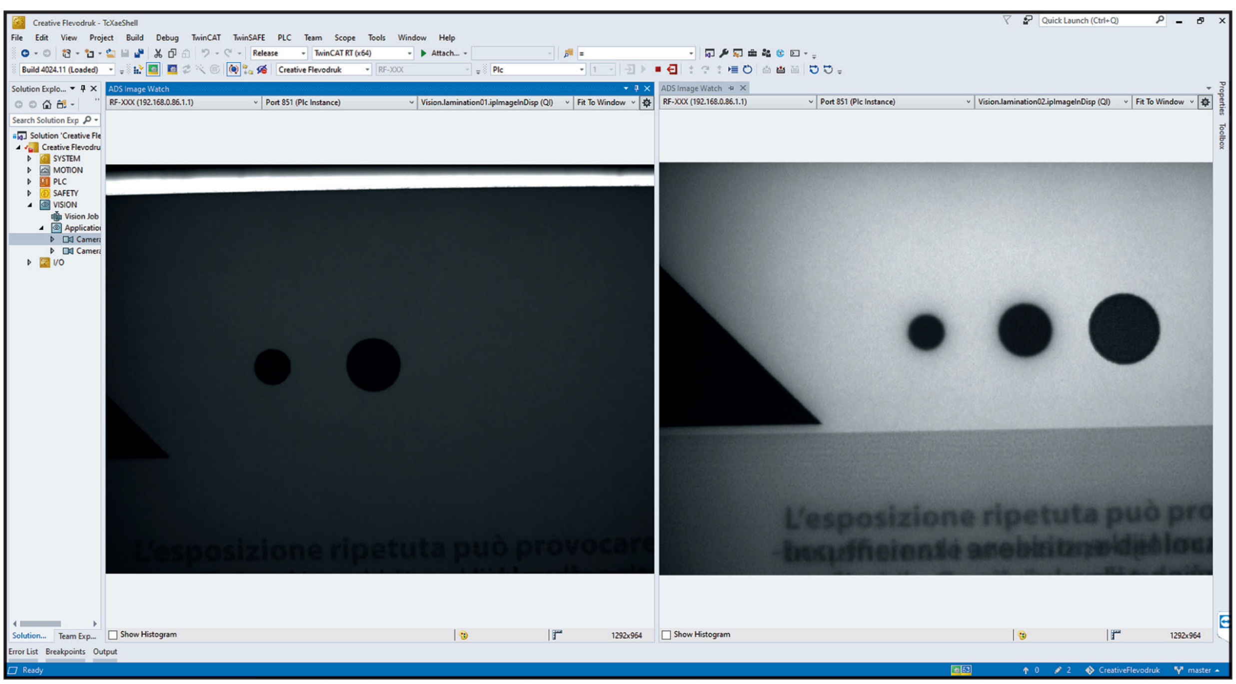
The main downside to using a separate computer or standalone smart camera, however, is that even the smallest changes require input from a vision specialist. Further avoidable costs result from dependence on someone with knowledge of that specific separate hardware component, rather than the main controls engineer. In cases where a third-party system integrator is involved, that expertise could remain external.

Black boxes and bottlenecks delay reaction times

With standalone dedicated equipment for vision, the image must be acquired and processed on that separate piece of hardware. Only when the image processing is finished does the hardware communicate results back to the main programmable logic controller (PLC). This typically occurs via a fieldbus or other communication protocol. The communication between image processing and the control system must be implemented per unique application requirements, which is often an error-prone process.

Once the PLC receives that data, it must process the results in the next PLC cycle to make decisions on what to do with the vision results. For applications such as vision combined with motion control or applications with products in motion, this delay can create a real challenge for efficient operation. Guaranteeing exact timing in image processing and reaction to the results is simply not possible under these circumstances. At the very least, the delays greatly slow motion capabilities and therefore throughput.

In traditional PC-based vision solutions, greater CPU and hardware availability for processing vision algorithms generally increase performance. However, external processes, such as the operating system (OS), can affect both processing time and transmission time. In addition, limited fieldbus bandwidth in these data-intensive operations can create bottlenecks that limit system performance. Although the approach is more powerful, the results still may not reach the controller in the required time period for the system to react successfully.



TwinCAT Vision combined with a GigE vision camera significantly reduces press proof waste when setting up and starting new jobs on machines built by Danish machine builder Refine Finishing.

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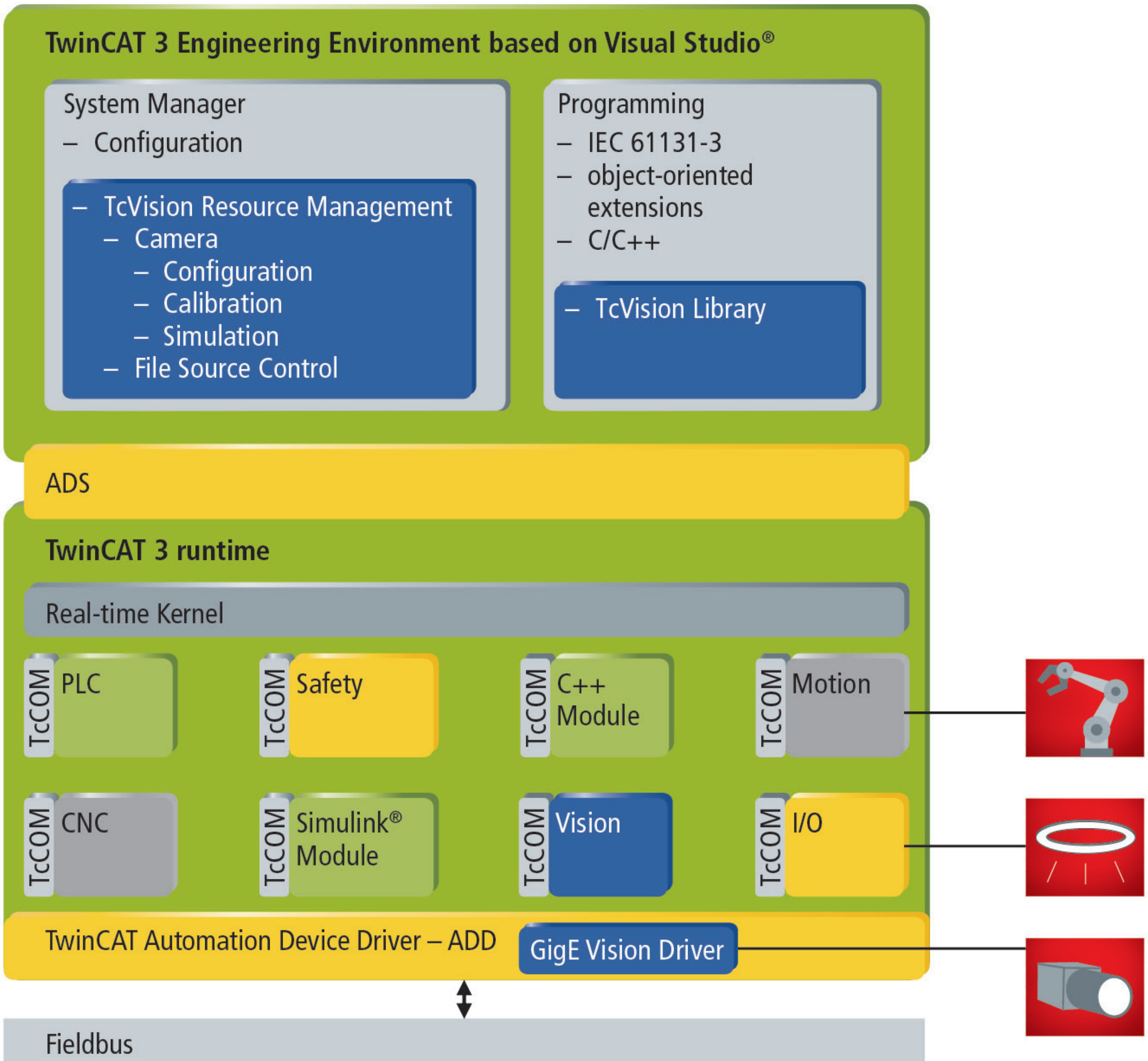


TwinCAT Vision combines the worlds of machine vision and industrial controls into one integrated system. The configuration, especially of the cameras, is carried out in the same tool as the configuration of fieldbuses and motion axes. For programming, the familiar IEC 61131-3 programming languages can be used.

With this approach, substantial engineering cost savings can be achieved, since there is no need to learn special programming languages, and no special configuration tool is required. The challenges of communication between image processing and control are not only eliminated, but image processing and control components can directly communicate with each other, opening up entirely new application possibilities.

An integrated approach to machine vision

To prevent the typical issues, modern automation and controls providers have taken a different approach to image processing. This method involves completely integrating vision into the machine controller. Machine operations benefit by eliminating the need to communicate the results to the real-time control. Equally as beneficial is integration of vision algorithms and camera configuration into the same tool used to configure fieldbuses, motion axes, robotics, safety, HMI and so on. This also allows the vision code (along with all other machine control code) to be tracked with version control software such as Git.

With TwinCAT Vision, for example, engineering is much easier for many reasons. Integration of vision in the real-time environment – that is, all algorithms being executed in real time – makes vision, PLC and motion control consistently synchronous. The user always works in the same deterministic, multi-functional and multi-core CPU real time. The algorithms are executed in real time, i.e., they start deterministically.

With this type of vision solution, engineers can program in familiar PLC languages, which creates substantial savings in effort and cost. There is no need to learn special vision programming languages, and no special configuration tool is required. Programming of vision applications takes place with known function blocks and standard PLC libraries. For example, changing the state of the camera or triggering the camera for a new image is done via a PLC function block.

Often, image processing systems are programmed using proprietary graphical languages or C++/C#. Fully integrated vision systems, which come from the controls engineering world, use familiar programming languages, such as Structured Text (ST). For graphical programing, engineers can also program vision applications in Sequential Function Chart (SFC) or Ladder Logic (LD). Thus, vision programming is possible in any IEC 61131-3 language, along with Continuous Function Chart (CFC). With the number of available options, PLC programmers of all disciplines find this very easy to implement.

Image processing and camera setup benefits

By storing images in PLC memory, it is very easy to access and display the current image on the HMI without having to store the image to a temporary file. This could be the raw incoming image or any image at a current intermediary vision algorithm processing step. The HMI should display images and other important information, such as the configuration of vision or camera parameters. This allows the end users of the system to access the vision application parameters to adapt them to the respective conditions.

"By integrating machine vision into the real-time environment, the timing of image processing functions can be monitored via watchdogs."

Camera parameters can also be modified online using PLC code. This means process conditions could automatically change parameters, perhaps to retry an inspection based on different parameters, without having to change the configuration using engineering tools. In this way, a fully integrated approach eliminates the communication challenges between image processing and control. More importantly, image processing and control components can directly communicate with each other via PLC memory, opening entirely new application possibilities. Everything resides in one engineering tool and one runtime environment.

Image processing watchdogs keep production moving

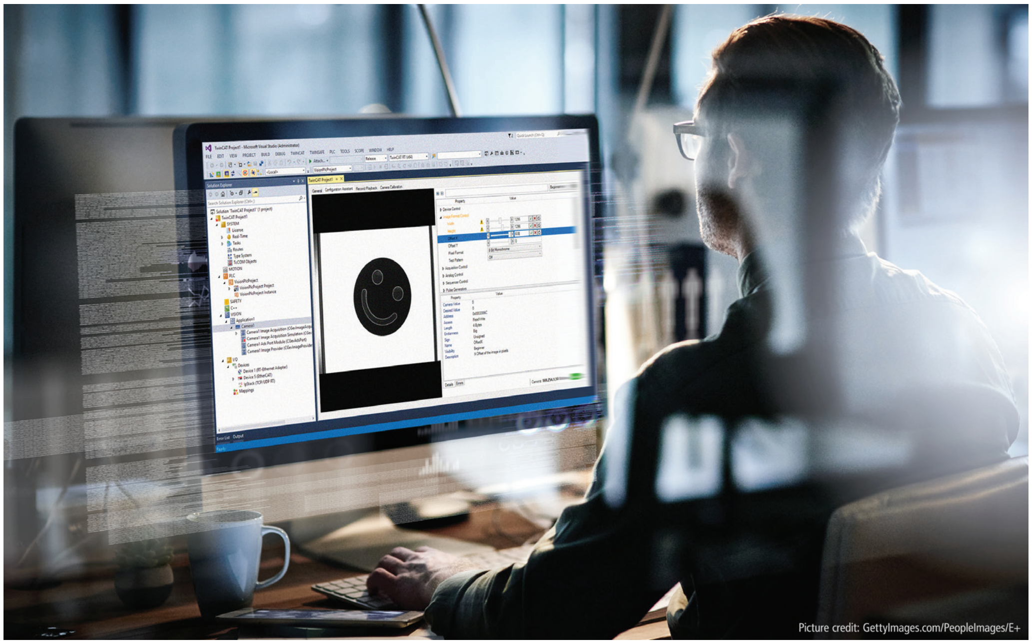
By integrating machine vision into the real-time environment, the timing of image processing functions can be monitored via watchdogs. These interrupt the functions after a defined period of time from the start of a processing cycle. Image processing algorithms, due to the different image information, need different lengths of time to calculate, so additional termination conditions (watchdogs) offer the option of termination after a specified time.

If processing is time-terminated, the user receives any partial results available at that time. For example, in a continuous flow process, the line should not – and typically cannot – slow down because there is more product grouped than usual. Even though this situation requires more time to review images in the vision system, attempting to stop product flow could be disastrous. The vision algorithms can stop processing based on a watchdog and return results of what was completed. In this way, the machine can continue to process the detected product and recirculate the remaining product throughout the system. This enables a continuous flow, not slowing or stopping the process, while still providing necessary vision inspection and insights.

Networking considerations for GigE vision systems

Integrated image processing on a powerful Industrial PC (IPC) first requires transmitting the image captured from the vision sensor to the controller. A standardized and efficient communication protocol, GigE Vision®, makes this possible. This very popular industrial camera standard is based on Gigabit Ethernet with scalable speeds. There are no requirements for extra connectivity hardware and camera cables can extend up

Fully integrated image processing systems, such as TwinCAT Vision, come from the controls world and enable machine vision programing in familiar PLC languages.



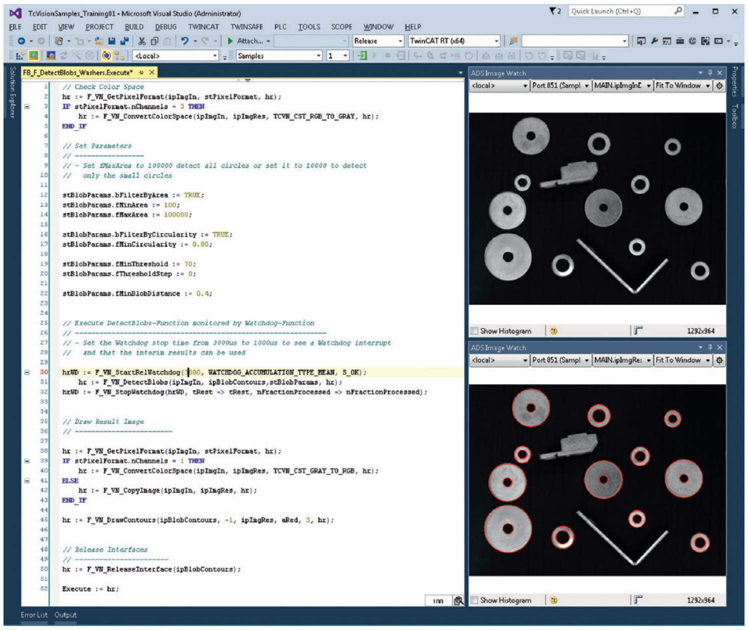
Picture credit: GettyImages.com/PeopleImages/E+

to 100 meters.

The Automated Imaging Association (AIA) maintains the GigE standard, and a diverse group of companies from every sector within the machine vision industry worked to develop it. The original purpose was to establish a standard that would allow camera and software companies to seamlessly integrate their solutions on Gigabit Ethernet fieldbuses. GigE is the first standard that allows images to be transferred at high speeds over long cable lengths.

While Gigabit Ethernet is a standard bus technology, not all cameras with Gigabit Ethernet ports are GigE Vision compliant. In order to be GigE Vision compliant, the camera must adhere to the protocols established by the GigE Vision standard and must be certified by the AIA. It is crucial to check this when specifying components for a vision application.

Manufacturers of cameras with the GigE Vision interface provide a configuration description in GenApi format. Integrated machine vision configuration tools read the parameters and make them available to the user in a clearly arranged manner. In this way, configuration changes, such as adjusting the exposure time and setting a region of interest, can happen quickly and easily. In terms of complexity, the parameterization of a camera for a vision application is comparable to the parameterization of a servo drive.



Advanced image processing using GigE cameras and specialized algorithms is now indispensable for quality inspection, track-and-trace and more.

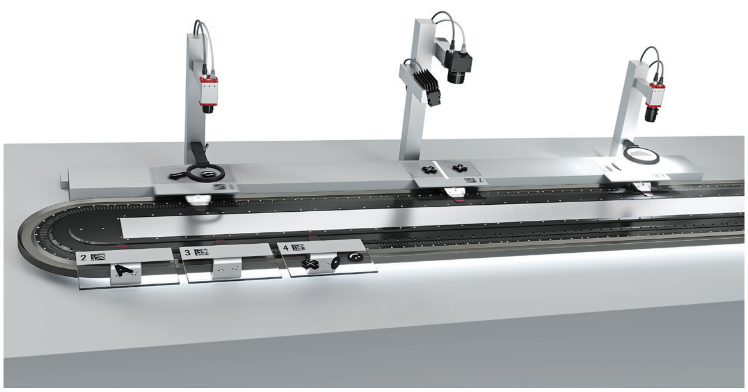
Scalable IPC selection for integrated vision

Using PC-based automation for machine vision opens up wide-ranging options for scalable connectivity and computing power. Connectivity options in modern IPCs enable, for example, easily adding 10-plus network interface cards to allow individual communication channels for each camera to efficiently transfer the image to the PC for processing. This eliminates expensive switches, which can induce unnecessary latency and complicate wiring.

The IPC performance spectrum begins with cost-effective platforms and scales all the way up to machine controllers with 40 processor cores. Having such a range is ideal for selecting the right computing power for individual image processing projects. Modern industrial control systems are architected from the ground up to harness the scalability of PC processors from single to many cores. Vision systems integrated into powerful PC-based control systems can also leverage the multi-core capabilities.

To make multi-core and core isolation implementation extremely easy for the programmer, configuration on some IPC platforms simply involves allocating “job tasks” to the cores. These tasks, which should be used for vision algorithms, are then grouped into a “job pool.” As vision is executed in the control system, the algorithms that can take advantage of parallel processing are automatically split between the multiple cores. They process in parallel, bring the results back together and present them to the PLC and the image algorithm’s results variable(s).

In this way, programmers need not worry about multiple cores, multiple threading or multiple tasks. They only need to implement the machine control logic and vision code, which then allows the system to handle the multi-core processing on its own.



The determinism and synchronization of EtherCAT enable precise, microsecond-level trigger timing, even in applications with advanced coordinated motion.

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EtherCAT hardware and functional principle advantages for vision

PC-based automation delivers inherent benefits from core controls functionality such as real-time PLC and access to many fieldbuses, including the EtherCAT industrial Ethernet system. Due to the high determinism of EtherCAT networks and device synchronization via distributed clocks, very precise trigger timing and timestamp-based output terminals can send a hardware trigger signal with microsecond-level accuracy to the camera. Since everything takes place in real time in a highly accurate temporal context, image acquisition and axis positions, for example, can synchronize with high precision – a frequently occurring task for PLC programmers.

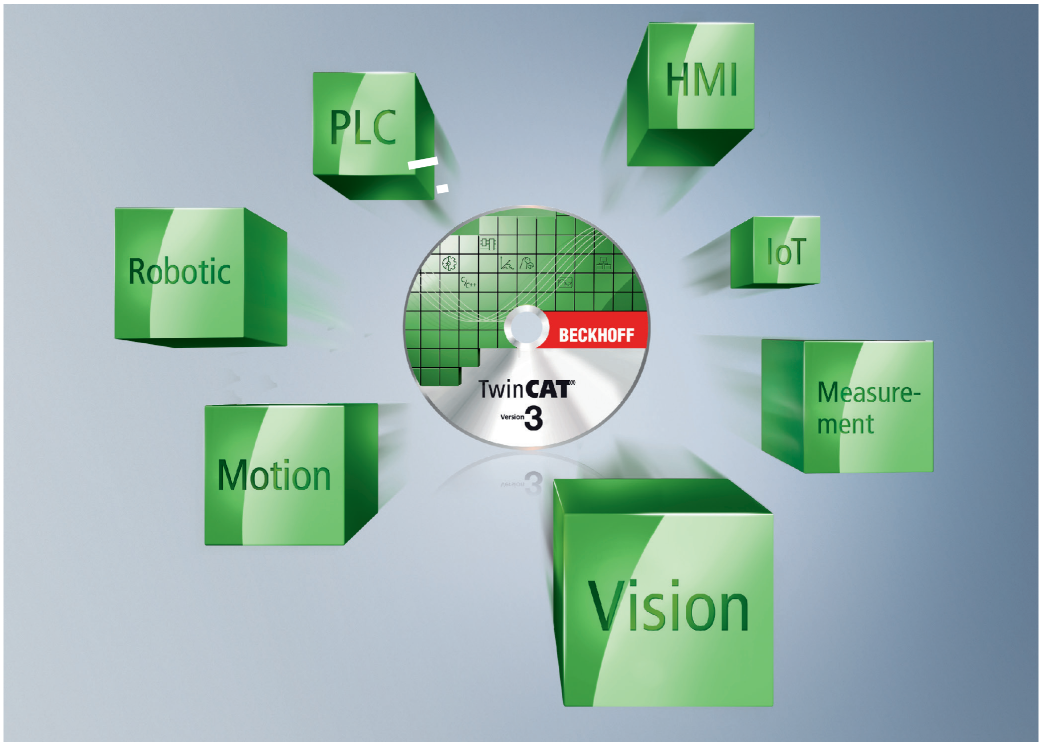
Many cameras can also send output signals at previously defined events, such as the start of image capture. These signals can be acquired with a digital input terminal on the EtherCAT network and then used in the PLC for precise synchronization of further processes.

Specially developed vision lighting controllers triggered via EtherCAT enable current-controlled lighting with a pulse length as short as 10 µs. Each individual pulse can be triggered with great precision by the controller via distributed clocks and timestamping. This ensures that products on a conveyor belt, for example, reach the exact position before each trigger event. Synchronization is ultimately a major factor driving the integration of vision technology inside the machine controller and fieldbus. This gives an EtherCAT lighting device high cycle synchronicity since it is triggered in the same cycle as the camera recording or the robot movement.

"Synchronization is ultimately a major factor driving the integration of vision technology inside the machine controller and fieldbus."

An integrated platform multiplies vision system capabilities

As rapid image processing grows more important, PC-based automation with scalable controller hardware and a combined real-time and engineering environment help to futureproof vision-intensive applications. Complete control system synchronization, programming incorporated into the universal machine control platform, robust networking capabilities and open standards, such as GigE Vision, ensure that engineers can implement vision systems without extensive labor or learning new software. The benefits for manufacturers and machine builder OEMs compound by basing vision projects on proven, fully integrated platforms. After years of struggling with black box options, engineers can now see a path forward.



With Beckhoff's fully integrated approach, all tools needed for machine and automation controls can be found in a single software platform – TwinCAT – and all functions can be run inside one main controller. Compare this to the traditional approaches of multiple, costly hardware-based solutions.

Application example: Vision optimizes automated component assembly

Aixemtec GmbH in Herzogenrath, Germany, develops automated solutions for high-precision assembly of electro-optical systems. Founded in 2016 as a spin-off from the Fraunhofer Institute for Production Technology (IPT), the high-tech company offers customized solutions based on a modular system. These range from material feeding and handling to micromanipulation and measurement for ultra-precise assembly, rounded off with quality assurance.

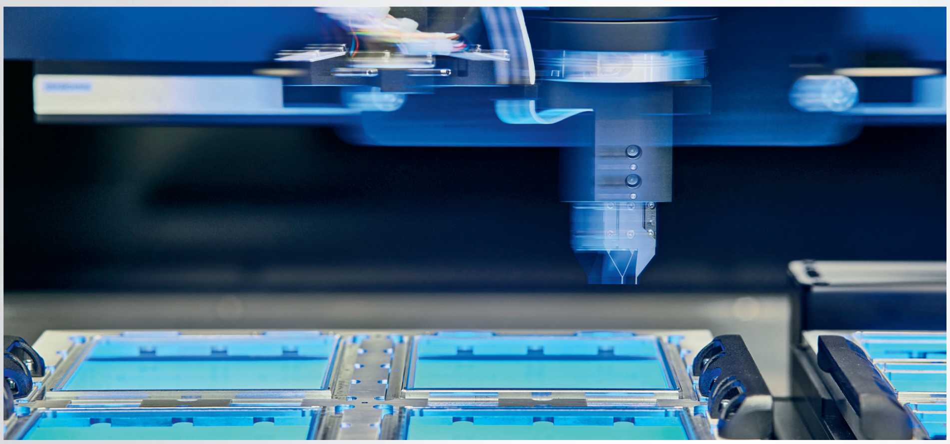
One application prepares randomly fed in micro-lenses for assembly. The fragile components must be arranged in a specific orientation on a tool carrier. It must position the fragile components quickly and precisely in a workpiece magazine. The components often have a cross-section no wider than a few hairs.

The micro-lenses are fed in bulk on a backlit surface. This surface is scanned with a camera via XYZ kinematics. The result is a 2D panorama of the area being examined. The precise time synchronization of TwinCAT NC axis control with TwinCAT Vision – as well as help from the distributed clocks functionality in EtherCAT – accurately aligns image capture with axial positioning.

Previously, a time-consuming PTP process was used. However, **TwinCAT Vision reduces the setup time of this process by a factor of eight or greater**. It is not necessary to stop for each individual image capture. The individual images created in this way during the "flyover" are inserted into an overall image with pixel accuracy in real-time. Using this overall image, the micro-lenses are identified by image processing and their current orientation is measured. This results in an efficient work plan for how the pick-and-place system should pick up the individual lenses, orient them in all spatial dimensions and place them. The linear axes controlled by AX8000 Servo Drives enable highly dynamic yet highly precise movement of the entire kinematics.

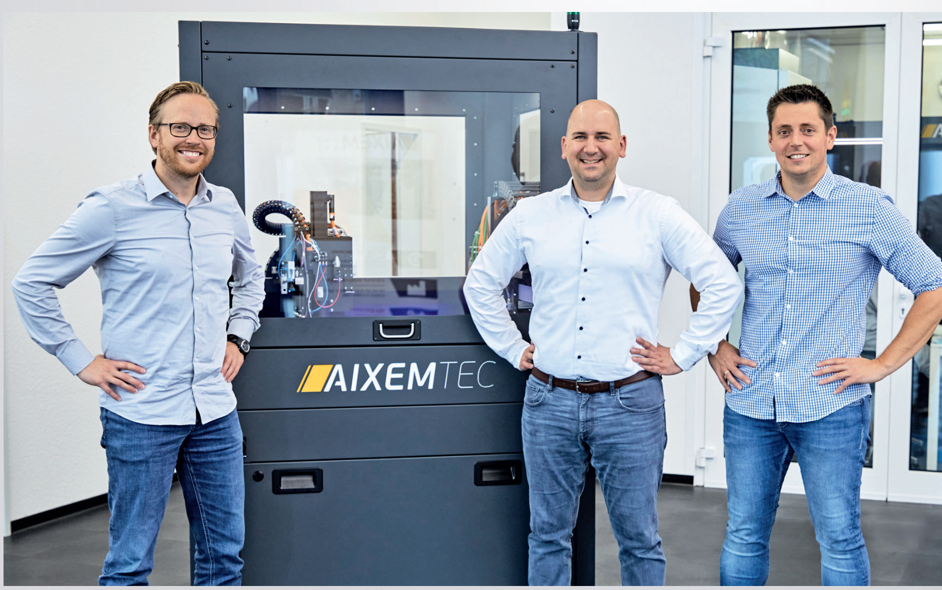
The micro-lenses that have been prepared for assembly are bonded with a light source in a subsequent step. For this purpose, an adhesive dispenser applies a fixed amount of adhesive to the micro-lens. Precise dosing is essential for correct assembly, which is why the drop flow is continuously monitored and adjusted by a camera system during the dispensing process. In the future, this task will also be taken over by TwinCAT Vision. **Triggering, image capture and exposure can be ideally synchronized with the EL2596 LED strobe control terminal and distributed clocks**. Before the adhesive cures, the optical function of the system to be assembled is optimized with the help of a 6D manipulator in a closed control loop.

► PC-Control.net/english



Above: Modular and highly precise assembly system from Aixemtec.

Below: Aixemtec Managing Director Sebastian Haag (left), Christian Kukla, Application and University Management at the Beckhoff Aachen Office (center), and Sebastian Sauer, Head of Machine Development at Aixemtec (right), stand by the component assembly system.



The high-performance C6032 ultra-compact Industrial PC controls all machine and process sequences with numerous TwinCAT software functions, such as TwinCAT Vision.

TwinCAT Vision: Current software packages available from Beckhoff

TF700x | TwinCAT 3 GigE Vision Connector

- integrate GigE Vision cameras directly into the TwinCAT architecture
- configuration is carried out completely in TwinCAT Engineering

► www.beckhoff.com/tf700x

TF7100 | TwinCAT 3 Vision Base

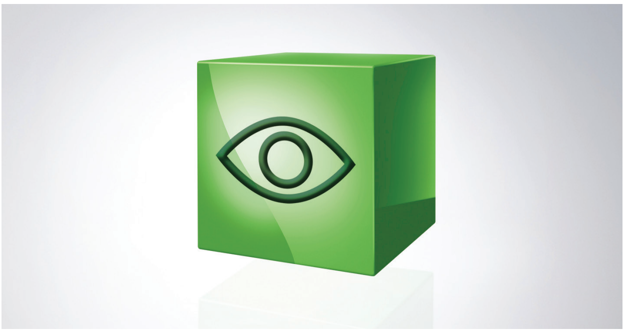
- extensive PLC library with a large number of functions and algorithms for image processing
- programming is carried out in the IEC 61131-3 languages

► www.beckhoff.com/tf7100

TF7200 | TwinCAT 3 Vision Matching 2D

- find and compare objects based on learned references, contours, feature points and more
- determine whether objects or features exist in an image for quality control, sorting, etc.

► www.beckhoff.com/tf7200



TF7250 | TwinCAT 3 Vision Code Reading

- functions for reading 1D and 2D codes to check code content in real time and to track products
- display results for image process monitoring purposes or save them for quality assurance

► www.beckhoff.com/tf7250

TF7300 | TwinCAT 3 Vision Metrology 2D

- detect edges, holes, etc., and measure lengths, angles and more with sub-pixel accuracy
- enable metric display, output of values and direct presetting of gripping points for robots

► www.beckhoff.com/tf7300

Learn more about integrated machine vision technologies from Beckhoff and how others have implemented them — visit us online!

► **www.beckhoff.com/vision**

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