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EDITORIAL GUIDE

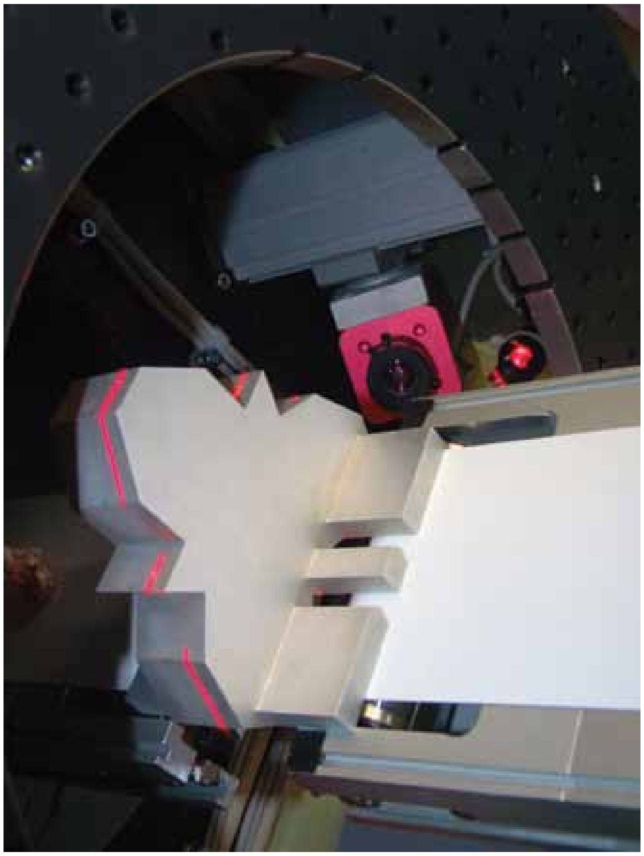
3-D Imaging for Machine Vision

By extracting 3-D information from an image, engineers can accomplish many important tasks, including robot grasping, navigation, and traffic analysis. To accomplish these goals, it's important to understand the human visual system, 3-D machine vision, and 3-D vision methods and applications, including single-camera methods, stereo-camera methods, 2.5-D methods, laser-based 3-D imaging, projected striped light imaging, and time of flight imaging.

This Editorial Guide helps engineers understand how 3-D systems have been developed for numerous applications, with articles on:

- Laser triangulation to measure food products
- 3-D displays for controlling unmanned vehicles
- 3-D systems that verify pallet packing
- Systems that help build 3-D models

Laser triangulation system measures food products



PRODUCERS OF PACKAGED meat products must ensure that the portions of meat that are packed are accurately portioned and cut. Deviating from specified weights by more than a half an ounce for a 16-oz steak, for example, can be expensive. Similarly, cutting the meat in smaller portions will result in unhappy customers, especially if the meat is to be offered to some of the world's most famous restaurants.

To accomplish economical product portioning, manufacturers of food slicing and packaging equipment are incorporating volumetric scanning systems into their products. By doing so, preprogrammed parameters, such as weight and thickness, can be used to determine various slicing configurations from the generated 3-D model of the meat and then provide the highest-yield cuts.

"In the design of these systems," says Ignazio Piacentini, CEO of ImagingLab (Lodi, Italy; www.imaginglab.it), "a three-dimensional model of the food must be generated before the slicing process can begin." Piacentini and his colleagues teamed up with Aqsense (Girona, Spain; www.aqsense.com) to build a prototype 3-D scanner that was shown at VISION 2009, held in Stuttgart, Germany in November (see Fig. 1).

To create a 3-D model, structured light is used to illuminate the product as it traverses the scanner's conveyor belt. By using three ZM-18 laser line emitters from Z-Laser Optoelektronik (Freiburg, Germany; www.z-laser.com) positioned at equal 120° angles around the gantry, the complete 360° surface of the meat is first illuminated. As the light is reflected from the surface of the meat, it is captured by three MV-D1024E-3D01-160-CL Camera Link cameras from Photonfocus (Lachen, Switzerland; www.photonfocus.com) that are also positioned at equal 120° angles around the gantry. Digital output from these three cameras is then transferred to a host PC using three NI-PCIe-1427 Camera Link frame grabbers from National Instruments (Austin, TX, USA; www.ni.com).

To generate a 3-D image, ImagingLab adopted the SAL3D library from Aqsense, which provides a set of tools for laser peak detection, calibration, merging of multiple images, Z-mapping, and geometric computation. By running the Aqsense peak detection algorithm within the FPGA of each Photonfocus camera, the speed of estimating the maximum intensity point of the reflected Gaussian light is increased (see "Reading the Shapes," *Vision Systems Design*, March 2008).

FIGURE 1. To accurately determine the volume of food before it is sliced, a prototype system from ImagingLab uses three structured light sources, three CMOS cameras, and 3-D reconstruction software.

After this peak is computed in all three cameras, the data are transferred to the PC and a 3-D image is generated by merging multiple point cloud images. To build the user-interface for the system, Aqsense and ImagingLab integrated the SAL3D library within National Instrument's LabView software (see Fig. 2). "Because the SAL3D library can now be used within LabView," says Piacentini, "it can be used with NI's ImagingLab robotics library by other systems integrators, wishing, for example to build 3-D robotic vision systems."

Before the 3-D scanner can be used for food processing, however, the system must be calibrated. To achieve this, Aqsense developed a 3-D metal calibration object, accurate to 50 µm that is first imaged by the structured laser light and camera system.

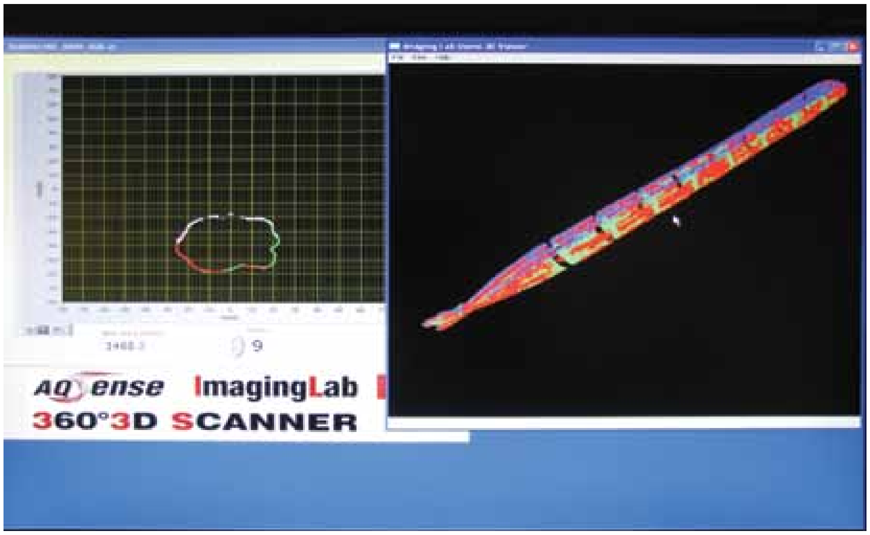


FIGURE 2. Running within LabView, the user interface shows a single slice profile of the structured light (left) and the 3-D reconstruction of the meat segmented in portions (right).

“Imaging and analyzing such a precisely formed object,” says Ramon Palli, general manager of Aqsense, “allows the tools within SAL3D to accurately calibrate the system.” After this calibration process, the system can then compute the volume of food products within 0.1% accuracy. These data are then used by the slicing system to cut portions of the food at a constant volume and, therefore, constant weight.

According to Piacentini, prospective customers in the food industry will benefit from this development because of the increased accuracy and speed it provides in determining constant volume and weight portioning. “Minimizing the waste in these automating portioning machines,” he says, “dramatically increases the yield.”

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3-D display uses dual LCD panels

ALTHOUGH 3-D MOTION pictures have only recently regained popularity, the principles behind the technology date back as far as the 1830s. Then, Sir Charles Wheatstone, an English scientist described how, by providing a different image to a viewer's left and right eyes, a person perceives a stereo depth image.

Many different methods exist to generate these disparate images. These include technologies that use passive red-cyan or polarized glasses, alternate frame sequencing methods that require active shuttered glasses, and auto-stereoscopic technologies such as lenticular displays.

While these technologies have all found roles in both consumer, medical, and military displays, the systems to some degree compromise luminous intensity, frame rate, resolution, viewing angle, or a combination of these in their implementations. For example, while glasses-based systems remain the most popular form of 3-D display technology, current 3-D TV implementations are based on field-sequential shuttered glasses. When these glasses are used for stereo displays, field sequential images (at half frame resolution) are projected at 60 Hz, resulting in a need to produce LCDs with a 120-Hz refresh rate.

To overcome this high refresh rate while providing the user with lower-cost polarized glasses, Polaris Sensor Technologies (PST; Huntsville, AL, USA; www.polarissensor.com) recently demonstrated a novel stereo 3-D display that uses dual LCD panels in a 1920 × 1200-pixel monitor with a 60-Hz refresh rate (see Fig. 1).

Because two LCD panels are used, they must be accurately aligned and rear illumination with a high-brightness backlight is required. For this reason, PST contracted Rockwell Collins (Cedar Rapids, IA, USA; www.rockwellcollins.com) to develop a custom high-brightness backlight for the display and used Rockwell

Collins' Dry Film Optical bonding technology to maximize performance.

To produce a stereo image, light from the backlight first passes though a polarizer. Light polarized at 45° then passes though the first LCD and through a second polarizer where it is polarized again at -45°. Light then passes through the second LCD panel where the image is displayed to the viewer.

FIGURE 1. Polaris Sensor Technologies' stereo 3-D display uses dual LCD panels in a 1920 × 1200-pixel monitor with a 60-Hz refresh rate.

Both left and right images are first displayed simultaneously on the rear LCD panel. Pixels in the display's front panel are then modulated so that the output image is a left image at one linear polarization state and a right image at another. This occurs when each front panel's pixel polarization state is rotated the appropriate amount to deliver the correct percentage of light to each eye.

To direct the appropriate image to each eye of the viewer, passive linearly polarized glasses must be worn. This allows 1920 × 1200-pixel color images to be delivered to each eye of the viewer simultaneously on the display's 17-in. monitor.

PST developed and integrated a custom input/output board into the display that accepts two DVI inputs to display stereo images at video rates. Computer applications that are programmed to produce stereo 3-D using OpenGL then provide the necessary synchronized video when displayed using Nvidia FX graphics cards. Both views are updated at 60 frames/s.

"One of the most important applications for this technology," says Larry Pezzaniti, chief technical officer with PST, "is in teleoperated robotic systems that are used to handle improvised explosive devices." In such systems, he says, the lack of depth perception, sense of scale, and limited field of view of 2-D cameras makes robotic manipulation

FIGURE 2. Telerobotic systems incorporating stereo cameras are being evaluated by soldiers at Ft. Leonard Wood as a means to provide Explosive Ordnance Disposal technicians a more effective way to deal with improvised explosive devices.

very time-consuming and risky, especially when the robot is outside of the user's field of view.

PST is working with QinetiQ Foster-Miller (McLean, VA, USA: www.foster-miller.com/lemming.htm), the manufacturer of the TALON Robot system, on a stereo vision upgrade kit. This kit includes a gripper arm stereo camera, a mast stereo camera with pan-tilt-zoom, and a stereo display mounted in the operator control unit. The stereo cameras and display are drop-in replacements for the standard cameras and display.

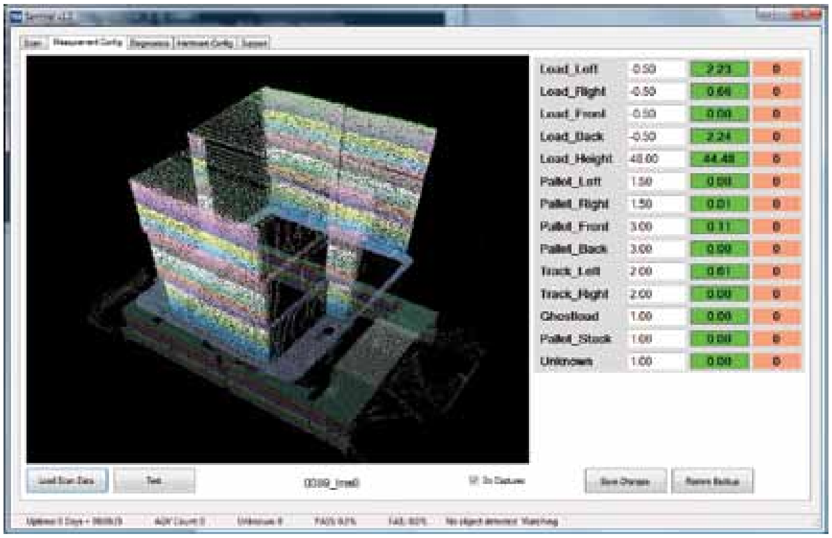
According to Pezzaniti, a prototype of the system has already been demonstrated to Explosive Ordnance Disposal (EOD) technicians at Indian Head, Ft. Leonard Wood, Picatinny, and Hill Air Force Base (see Fig. 2). ⊕

3-D measurement systems verify pallet packing

ONE OF THE problems faced by developers of fully or semi-automated packaging facilities is ensuring that packages are correctly stacked on pallets. Whether these be placed on autonomously guided vehicles (AGVs) or moved through a warehouse or packaging facility via conveyor, correct placement ensures that the goods will be transported without incident. Should these packages be incorrectly stacked, packages may clip the side of other pallets or objects in a storage area, or worse, they may topple from the pallet.

To ensure pallets are packed in a correct manner, two technologies are currently being used by developers of automated pallet packaging and transportation systems. Although both methods achieve the same result, they are based on two distinct technologies.

At the June 2009 International Robots, Vision & Motion Control Show (Rosemont, IL, USA), two companies showed how the technologies could be used to ensure correct transportation of packages placed on pallets. The first, dubbed the Sentinel AGV, from Nagle Research (Cedar Park, TX, USA; www.nagleresearch.com) uses two LMS 400 phase time-of-flight sensors from SICK (Waldkirch,



Load_Left	-0.50	2.23	0
Load_Right	-0.50	0.66	0
Load_Front	-0.50	0.00	0
Load_Back	-0.50	2.24	0
Load_Height	40.00	44.48	0
Pallet_Left	1.50	0.00	0
Pallet_Right	1.50	0.01	0
Pallet_Front	3.00	0.11	0
Pallet_Back	3.00	0.00	0
Track_Left	2.00	0.61	0
Track_Right	2.00	0.00	0
Ghostload	1.00	0.00	0
Pallet_Stack	1.00	0.00	0
Unknown	1.00	0.00	0

Two different types of image sensors are now being used to render 3-D models for pallet packaging inspection. The first (above), from Nagle Research, uses two SICK laser scanners to capture image data. The second (not shown), from ifm efector, uses a solid-state 3-D sensor. In both cases, captured data are rendered as point cloud images.

Germany; www.sick.com) to map a 3-D field as the pallet passes under a gantry.

“In the design of the system,” says John Nagle, president of Nagle Research, “the two sensors are positioned approximately 8 ft above a gantry. Because each sensor can scan an area of approximately 70°, positioning two sensors at opposite corners at the top of the gantry will ensure that the complete pallet is scanned as it moves under the gantry.” Measuring larger loads is also possible using different LMS models.

As laser light scans the pallet, the reflected light is detected and the distance from object to sensor is calculated from the reflectivity values of the returned light. Using software developed by Nagle Research, data from both sensors is then combined into a 3-D point cloud model (see figure).

“By examining this model,” says Nagle, “data about objects packed on each pallet can be analyzed to within 0.25 in.” Automated measurement of this data is then used to control a PLC that can reroute any AGV that is incorrectly stacked to a rework station for repacking. Currently deployed at two major retailer warehouses, the $55,000 Sentinel AGV is being offered as a fully integrated system. According to Nagle, the company is also interested in marketing the software as a standalone product.

At the same trade show, ifm efector (Exton, PA, USA; www.ifmefector.com) showed a system based on technology from PMD Technologies (Siegen, Germany; www.pmdtec.com). Rather than using structured laser light to illuminate the part to be inspected, the company’s 3-D image sensor comprises a rectangular array of red LEDs that are strobed at 20 MHz. As light is reflected from these LEDs, the light is captured by a 64 × 48 array of smart pixels.

“In a traditional time-of-flight image sensor system, returning light is mixed at the same frequency as that of the light detected by a pixel,” says Garrett Place, senior product manager with ifm efector. “But because the gate of each smart pixel within the 64 × 48 array is modulated at this frequency, this mixing process is performed on-chip, allowing each smart pixel to return phase and amplitude values.” The company showed the 3-D sensor in a system designed to measure the dimensions of a pallet as it sat under a 7-ft gantry.

“At this distance,” says Place, “the system can be used to measure an area of approximately 6 × 4 ft and resolve a minimum object of 1 × 1 in. across.” Like the system developed by Nagle Research, point cloud information from ifm efector’s image sensor is displayed as point cloud data and can be further processed to control a PLC-based factory automation system. Costing $1450, the 3-D sensor is shipped with software to render captured image data as point cloud information. ⊕

Off-the-shelf cameras and projectors team up for 3-D scanning

Using projected light stripe technology, the Mephisto 3-D scanner from 3D Dynamics can generate 3-D models of objects such as parts of a human cadaver at speeds up to 30 frames/s.

A **NUMBER OF** different methods exist to generate 3-D image data. These include structured laser light-based systems, time-of-flight (TOF)-based methods, and projected structured light systems. Structured light projection using laser-based systems is often used to create high-resolution 3-D images; however, scanning the object requires that the object or camera system move across the object's field of view. Alternate methods, such as TOF systems, can generate these 3-D models using a single camera with an embedded light source, although 3-D image resolution is far less than that of laser scanning-based systems.

In structured light projection systems, a visible light projector is used to project a series of intensity patterns with shifting periods across an object so that every subsequent pattern is offset by a fraction of its period with respect to the previous pattern. These phase-shifted images that are reflected from the object are captured by a camera and the relative phase map of the image is calculated. From this phase map, the coordinates of surface points in the image are also computed.

3-D image scanner

"In these systems, however," says Aivaras Grauzinis, CTO at 3D Dynamics ('s Gravenwezel, Belgium; www.3ddynamics.eu), "projected stripe patterns are not as small as a single pixel, resulting in ambiguous image data in regions of the image." To overcome this problem, image data within these regions can be resampled using a sinusoidal pattern projected at higher frequencies over the striped regions. Resulting reflections from these projected images are then used to enhance the resolution of the final 3-D computed image.

Using these techniques, 3D Dynamics has created a 3-D image scanner called Mephisto that uses off-the-shelf projectors and cameras to generate 3-D images at 30 frames/s. After each camera and projector system is calibrated, a digital light projector (DLP) from InFocus (Portland, OR, USA; www.infocus.com) is used to project structured light patterns onto the object to be scanned.

As relatively low-resolution phase-shifted images are projected across the field of view (FOV) of the object, they are captured using a 1920 × 1080-pixel, CCD-based Pike F210B progressive-scan FireWire camera from Allied Vision Technologies (Stadtroda, Germany; www.alliedvisiontec.com).

As these images are captured, a 12-Mpixel EOS DSLR consumer camera from Canon (Tokyo, Japan; www.canon.com) is then also used to transfer sub-pixel data from sinusoidal patters projected across the phase-shifted images. The data are then transferred to the host PC over an HDMI interface. After image reconstruction, 3-D images are displayed on the PC monitor at 30 frames/s.

Color image capture

"For the system to capture color images using this technique," says Grauzinis, "requires projecting RGB color planes and sinusoidal patterns across the image." This results in a color 3-D rendition of the captured image (see figure). For digitizing solid objects in 360° 3-D, 3D Dynamics offers an optional turntable that can be directly controlled from the system's user interface and synchronized with the cameras.

For larger or heavier objects such as the human body, up to nine Mephisto scanners can be networked to be controlled by a single PC. Already, the company's scanner has found medical applications such as digitizing biological samples that are either dried in wax or conserved in formaldehyde. In the future, the company expects to develop even higher-speed, higher-resolution scanners as faster DLPs and cameras become available. ⊕

Additional Resource:

➚ Webcast: Integration Insights: 3-D Imaging for Machine Vision