Photometric stereo for industrial applications uses 3D surface orientation and its effect on reflected light to produce a contrast image accentuating local 3D surface variations. The technique is gaining attention, thanks to new specialized algorithms, awareness of the importance of good lighting to machine vision success, and low-cost multi-light solutions.
Real-world objects have depth, width, and height. To operate successfully, automated systems such as robots need to “see” in these three dimensions. Machine vision systems comprising a camera, lighting, and a PC for image processing give robots the “sight” they require. But one of the biggest challenges confronting the machine vision industry has been reducing the amount of data that needs to be processed to correctly locate and analyze an object.

To shrink the data, machine vision designers would use lights, filters, and black-and-white cameras to address color machine vision applications. The resulting grayscale images contain less data for quicker processing. Similarly, engineers would develop mechanical fixtures and motion control systems to solve a traditional 3D application with a 2D machine vision solution.

Today’s microprocessors, graphic processor units (GPUs), and field programmable gate arrays (FPGAs) give designers more processing power — but processing power isn’t infinite. An emerging machine vision technique called photometric stereo can be the most cost-effective solution in 3D applications.

**3D VISION AT A GLANCE**

Affordable processing power has eased the need for data reduction for color and 3D applications. For example, cheap data processing, lasers, and optics have facilitated integrated laser triangulation systems for conveyor-based 3D systems that can generate tens of thousands of 2D profiles per second as a step toward creating a 3D object map. Alternatively, new time-of-flight cameras offer low-resolution 3D maps for many applications without the safety concerns of laser illumination.

For larger-area 3D projects, single camera photogrammetric systems mounted on the end of a robot take multiple pictures of the same object from different locations and calculate the 3D position of every pixel in the image based on a predetermined geometric relationship between camera and object. When it comes to large-area 3D inspections, two cameras are aligned next to each other like human eyes to capture 3D information.

But for high-speed inspection of objects where the field of view isn’t large, quantitative 3D data isn’t always required for measurement purposes, whereas qualitative 3D data can be very useful. That’s where the photometric stereo technique comes in.
PHOTOMETRIC STEREO ADVANTAGES

Photometric stereo isn’t primarily concerned with measuring the height of any given pixel. Rather, the technique uses 3D surface orientation and its effect on reflected light to produce a contrast image accentuating local 3D surface variations, which are potentially invisible with traditional 2D imaging.

Photometric stereo solutions do not need to know the exact 3D relationship between the camera and the object under test, nor do they require two cameras to capture 3D data. Instead, they use a single camera with multiple sources of illumination. The photometric stereo technique estimates the surface of an object by observing that object under different lighting conditions. This method is based on the fact that the amount of light reflected by a surface is dependent on the orientation of the surface in relation to the light source and the observer.

Photometric stereo for industrial applications is gaining attention, thanks to new specialized algorithms, a growing awareness of the importance of good lighting to machine vision success, and low-cost multi-light solutions like Smart Vision Lights’ LED Light Manager (LLM), which allows control of four lights through a simple browser-based interface at less than the cost of a frame grabber or smart camera break-out box.

Today, the unique benefits of photometric stereo applications are enabling many common industrial inspection applications that once were difficult, if not impossible, to solve.

APPLICATION: CLIPS AND TIRES

Reading raised letters on parts has always been problematic for machine vision systems. In this example, a plastic connector has several functional features on its surface, as well as the number 2 and a directional symbol. There is no difference between material that comprises the clip and the raised letter, and therefore no contrast. On larger objects, such as tires, manufacturers have used laser triangulation systems to create a 3D surface map. Laser scanning systems for 3D measurements have become much more integrated and effective, but the solution is often complex and costly.

In these photos (figures 1-4), the black plastic clip is illuminated from Smart Vision Lights’ linear miniature (LM) LED lights positioned at 90-, 180-, 270-, and 360-degrees around the tire’s perimeter and controlled by an LLM. As the Matrox camera triggers each exposure, the LLM triggers a light from a different direction. The camera feeds each image into a PC running an image library photometric stereo registration algorithm, which combines all corresponding pixels to establish local surface properties and produce one or more types of composite images from these, such as a contrast image of the local 3D geometries or an albedo image (figure 5). These composite images reveal more than any of the constituent images by them-
selves. The resulting composition clearly shows the edges that form the black-on-black lettering on the clips surface, as well as the edges of the various injection molded parts that comprise the whole.

**APPLICATION: SYNTHETIC LEATHER PERFORATIONS**

The next example shows four more pictures of a synthetic leather material (figures 6-9). Like the organic material that it mimics, leatherette has considerable surface texture. Visualizing 100% surface texture across the full image is nearly impossible for the human eye, much less a computer.

In each constituent image, the warp of the material as it lies on a supporting substrate creates strong shadows, while other parts of the image tend toward saturation due to strong light reflection. The final composition from the photometric stereo registration algorithm (figure 10) shows an evenly illuminated texture across the camera's full field of view with sharp contrast along each crevice and the highlighting of holes.

The photometric stereo technique can also be used on pores on metal machined surfaces, such as engine heads. Direct part marking systems such as dot peen, laser marking, and even cast parts represent another area that will clearly benefit from cost-effective photometric stereo solutions.

**PHOTOMETRIC STEREO OUTLOOK**

Our 3D world will continue to depend on 3D vision solutions. DBMR Research recently forecast that the global 3D machine vision market will grow at a CAGR of 9.5% between 2017 to 2024, increasing from $15.4 billion to nearly $32 billion annually. The primary challenges to 3D machine vision market growth include the high costs of installation and lack of technical knowledge. As shown by a packaged photometric stereo registration tool and one-click programming of the LLM LED light manager, the machine vision industry is poised for the next big step in 3D machine vision.