Light Beyond Vision: Illumination for Law Enforcement, Logistics, Safety and Security

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Imaging Technology

When we casually snap pictures with our smart phones and share our data around the globe, we employ the same basic components of an imaging system once the domain only of high-cost industrial and commercial systems: a light source (flash or ambient); a lens; an image sensor (camera) and an image processor. The societal impact of technological advances in electronics fabrication as they relate to the ubiquitous cell phone cannot be over stated. And just as the proliferation of smart phones has driven "big data" in the consumer markets, the comparatively low cost of the "Internet of Things" (IoT) is again expanding into commercial applications public and private. Data-driven solutions in areas such as intermodal traceability, vehicle security inspection and monitoring and biometric identification use low-cost, cameras, processors and band-width to generate and store images for analysis. Key to the success of these imaging applications is the optimization of the illumination source, facilitated by the parallel emergence of LED technology. Following are highlights of some of these applications. Clearly illumination applications have grown beyond human and even industrial machine vision.

LED Light Sources

Figure 1: Single LED

Image Courtesy Metaphase Technologies

"LED" is an acronym for "Light Emitting Diode". A diode is a two-conductor (positive and negative) electronic component that allows current to flow in only one direction when a voltage is applied. One conductor is positive ("anode") and the other is negative ("cathode"). The boundary between the anode and cathode, "the "p-n junction" contains material of differing types ("doping"). As the name implies, when a voltage is applied to the diode, light is emitted at the junction. The frequency ("color") of the emitted light is determined by the voltage and the doping material.

LEDs present the lighting designer with several advantages over their traditional incandescent, fluorescent, noble gas, etc. counterparts. Like other electronic components, LEDs can be quite small, 2mm is not uncommon. They may also be constructed in a variety of shapes: round, square, or triangular with flat or domed tops. Unlike filaments and tubes, LEDs emit light in only one direction. Mono-directionality implies that illumination need be produced only toward the task at hand, reducing the need for shades and reflectors. Small size and mono-directionality also save on energy. LEDs can be made to emit a variety of wavelengths, depending on the voltage applied and the doping materials. This provides a low-cost source for non-visible lighting solutions such as ultraviolet (UV) and infrared (IR). Another characteristic is the ability to “strobe”, or flash with a defined time delay. This has implications in stop-motion applications. Finally, LEDs last a long time. Their traditional counterparts are rated in hours of life; LEDs are rated in years. With all the aforementioned attributes, it's no surprise that lighting designers continue to introduce illumination for heretofore impossible applications.

LED vs. Laser

Some of the applications described below make use of a technique called “structured lighting”. Structured lighting involves projecting a pattern onto an object. The intent is for the camera to detect the pattern or its distortion so that changes from one image frame to the next may be detected. With the use of structured lighting, 3D information may be calculated from a 2D image. A simple example is illustrated at the right. If a single line is projected onto a cube it will appear as a series of line segments when viewed from above. Calibrating the camera with respect to the angle between the light and the camera will allow the measurement of the height of the object by measuring the distance between the segments. A similar technique is employed by video games, in which an invisible (infrared) pattern is projected into the room and software blends their apparent location with video in order to simulate movement, say, when exercising or dancing.

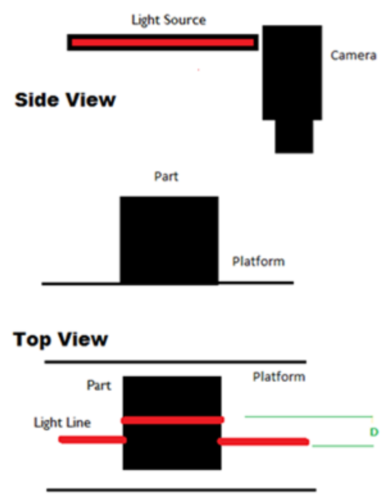


Figure 2: Structured Light Line

Prior to the advent of low-cost LEDs with the ability to generate sufficient brightness for structured lighting applications, projections were dominated by lasers and xenon sources. Safety and cost considerations, for lasers and xenon sources respectively, and continuing price/ performance improvements in LED technology had served to make LEDs the preferred option for structured light applications.

1D, 2D and 3D Illumination

One way to describe imaging applications is by the number of dimensions that the camera/ lighting combination is designed to acquire. 1D systems acquire length; 2D systems acquire length and width; 3D systems acquire length, width and depth. 1D systems use cameras with one line of picture elements ("pixels") and are typically paired with linear light generators. Single lines may be stitched together in software to generate a recognizable picture. 2D systems use the familiar array type cameras (pixel grid) to take a picture. They may use ambient light but more often use application-specific illumination. 3D systems also use array-type cameras, but use structured light techniques described above to generate depth information.

Lighting for 1D Applications: Intermodal Track and Trace

Intermodal track and trace has seen tremendous growth in the last decade. There are approximately 2 million tractors [1]and nearly 6 million semi trailers[2] registered in the U.S. 2012, the latest year for which DOT data is available, lists over 1.3 million rail cars in use in North America[3]. In today's global economy and just-in-time manufacturing environment, America's needs move by truck and rail.

Keeping track of tractor trailers and rail cars is a daunting task. Expediting intermodal goods with safety and compliance requires real-time, automated intelligence. So important is this issue that the US Department of Transportation has funded a series of grants to facilitate the application of imaging technology[4]

Figure 3: Metabright (TM) Line Light by Metaphase

Lighting the variety of motor carrier numbers presents a significant technical challenge. The various number sets typically do not share the same fonts, size, background, color or other attributes. To accomplish this daunting task a variety of digital cameras, lenses

1 http://www.truckinfo.net/trucking/stats.htm

2 http://www.popularmechanics.com/cars/trucks/g116/10-things-you-didnt-know-about-semi-trucks/?slide=1

3 http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html

4 http://www.fmcsa.dot.gov/research-and-analysis/technology/automated-trailer-vehicle-id-number-and-sequencing-system

and lighting techniques are employed. These systems are typically "1D", employing linear light sources such as the Metabright™ Line Light by Metaphase Technologies.

Coupled with high-quality, high-repeatability LED illumination sources, high resolution line scan digital cameras with stitching and OCR software intermodal track and trace systems are able to acquire and process the high images required to read USDOT numbers, KYU, Motor Carrier and VIN numbers with high accuracy. The data is compared against multiple databases to screen large populations of commercial vehicles online in real time. This automated intelligence helps accelerate throughput and supports informed decision making to enforce compliance and maximize safety through weigh station inspection operations

Equally daunting is identifying and tracing rail cars and containers. Similar in function to truck traceability systems, these data collection and management systems automatically read and record container ISO code numbers as trains travel on the tracks. They use similar line scan cameras, linear light technologies and OCR engines. These systems are able to data log the exact location of each container on identified rail cars.

As truck and rail companies continue to update their "big data" infrastructure, and as intermodal track and trace systems continue to demonstrate reliability and repeatability, the applications for LED illumination in 1D can only be expected to continue to expand.

Lighting for 2D Applications

Automatically Reading Vehicle License Plates

On our nation's roads, to help move traffic along faster, many states have installed Automatic License Plate Reading (ALPR) systems on their toll roads. These systems allow drivers to proceed through toll booths without stopping or fishing for change. The driver receives a monthly bill for his or her road usage.

Figure 4: Long Range Strobe Light by Metaphase

These 2D, ALPR systems use an array-type, closed circuit television (CCTV) to acquire vehicle images from one or more lanes of traffic. These systems are able to read the text from vehicle license plates and in some cases take a picture of the driver of the vehicle. This data is used for billing purposes and may be stored for future use for road use and traffic law enforcement and for border enforcement.

Historically, high-powered xenon strobe lights were used for these types of applications. High initial costs, short bulb life and the potentially hazardous flash, however, limited the use of these types of light sources. The advent of Long Range Strobe LEDs like the one from Metaphase Technologies pictured in Figure 6, however, has contributed to the proliferation of ALPR systems. Long Range Strobe LEDs can project a beam of light that is invisible to humans, but visible to a digital camera, at distances over 150 feet. In multiple lanes of traffic, for example at highway toll booths, a single high-resolution camera can provide sufficient illumination for a high-resolution array camera to read up to eight different lanes of vehicles. Continuous image capture coupled with individual, directed LED strobes provides high quality images for OCR and, in certain instances, facial recognition.

The LEDs are typically housed in a NEMA rated polymer all weather vapor tight enclosure with o-ring and a powder coated side blocking projection hood so as to withstand the elements. The strobe pulse widths may be adjustable from seconds down to microseconds (the shorter the pulse width, the less light is captured by the camera, but short pulse widths produce crisper images). Most strobe controllers are remotely controlled and silent. A considerable advantage is the longevity of these lights, with maintenance periods over 100,000 hours (> 10 years).

Lighting for 3D Applications

Interestingly, 3D images can be generated from both line scan and array cameras, each with its corresponding high-quality LED light source. Two applications described illustrate an example of each.

Automatic Under Vehicle Inspection Systems

One application that uses a 1D (line scan) camera and linear light source to generate 3D images is the Automatic Under Vehicle Inspection System, or “AUVIS”. As a vehicle (automobile, tractor, trailer or rail car) passes over the AUVIS, a structured line light is projected onto the undercarriage. The ability to manufacture LED fixtures in a rugged, compact, modular form factor allows these systems to be portable or even permanently embedded in a road or track. An AUVIS require a high degree of illumination repeatability and the lighting system must also be able to withstand extreme weather conditions. Line scan cameras coupled with Linear

Figure 5: AUVIS Linear Light Source by Metaphase

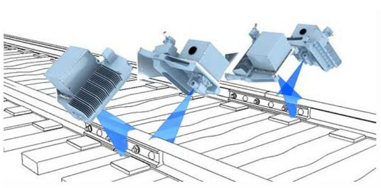
Light Sources such as those by Metaphase Technologies illustrated in Figure 5.

The AUVIS cameras acquire high-resolution images that are stitched together with software to generate virtual 3D images. These images may be logged into an image database and/ or displayed on a monitor. These systems can detect potential threats or contraband hidden under either roadway or train track vehicles. Locations where vehicle undercarriages may be inspected include train stations and switches, national border crossing stations, airports, government buildings, embassies and sporting event parking lots. Potential threats and discrepancies may be automatically “flagged” using machine vision algorithms or the system may be used simply as a display device.

Rail Safety Inspection

Figure 6: MBLL106 by Metaphase

Another rail application that uses a linear light source and a line scan camera to generate 3D images is rail inspection.[5] This inspection involves a linear light source like the MBLL106 by Metaphase Technologies depicted in Figure 5 and a line scan camera.



In these systems the light sources and cameras are often mounted to the bed of a truck equipped with rail wheels. As the truck drives along the rails, images are captured and stitched together and analyzed with sophisticated software. These systems automatically inspect of rail joints and rail sides for cracks, missing bolts, corrosion, welds and electrical connections. As with AUVIS, these systems must be very rugged and able to withstand temperature and moisture extremes.

Facial Recognition Systems

Perhaps the most challenging lighting/ imaging application in use today is that for facial recognition. Facial Recognition Systems may be divided into two applications: verification and identification. In the former, the identity of the facial image is given and a match is attempted between it and other pre-acquired images of that face in a data base. In the latter, the identity of the sample image is unknown and a match is attempted between it and other facial images in the

[5] http://www.mermecgroup.com/inspection-technology/fishplate-inspection/65/1/fishplate-inspection.php

data base. These systems may be further divided into the categories of 2D and 3D.

A typical 2D Facial Recognition System is used for *verification.* This involves acquiring an image with an array camera under controlled lighting conditions. These images are then compared to previously taught images and software algorithms detect geometric features, such as relationships among the eyes, nose and chin.

Figure 7: Area Front Light from Metaphase Technologies

These systems require repeatable, controlled lighting such as that found with the Area Front Light from Metaphase Technologies and they have become an increasingly viable method of biometric identification. Verification systems have been successfully deployed from private security to local law enforcement to the U.S. Department of State in applications such as building entry and access, border checkpoint monitoring and control and locking mobile computers.

Facial *Identification* makes use of a 3D system. An *identification* system makes use of image data taken from a number of angles (similar to vehicle undercarriage inspection discussed above). Often these systems project their own structured light onto the facial surface (Figure 7) and are thus less sensitive to lighting variation.

Facial *identification* is a 3D application that typically employs a pattern projected onto the face with an illumination source such as the Pattern Projector by Metaphase Technologies (see Figure 8). The pattern is captured by an array camera and processed with high-level image processing hardware and software. *Identification* is in its infancy and faces significant technical challenges from illumination to sampling to search. Thus, there are comparatively few robust applications deployed outside of government applications. However, the technology is advancing rapidly and indications are that these types of applications will be the preferred options in the future.

Figure 8: Metaphase Pattern Projector

What Lies Ahead

One may expect lighting and camera applications to proliferate even more as prices go down and components get smaller. Here is a sampling of what researchers are working on:

- Light sources that make you feel like shopping!
- Lighting that can be customized to suit your mood. Simply turn a dial and enhance or change your mood.
- Healing light- changing frequencies to help the body.
- Networks. Using sensors and “big data” for energy conservation, security and remote control and viewing.
- Increased surveillance and individual tracking.
- Low-energy, frequency-specific grow lights for indoor farming.
- “Smart screens” that incorporate display and capture in one unit.

And that’s just a sample of “Light Beyond Vision”.

Pete Kepf is a Senior Machine Vision Application Engineer with over 25 years of lighting experience.

Metaphase Technologies offers the world's largest selection of machine vision and specialty LED Illumination. Since 1993, their engineering expertise in designing for integration into vision systems has enhanced a vast array of products. Applications such as automation systems, line scan inspection, fast-capture imaging strobe and facial recognition give an edge to our customers in manufacturing, quality assurance, border patrol, law enforcement, and military markets. They offer free testing and encourage you to bring your most challenging applications for a custom solution.