The Economic Case and Market Drivers for Linescan Imaging

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Abstract

Linescan imaging will proliferate in industrial imaging applications as economics make linescan more attractive than area imaging—in particular, the newest linescan cameras can take advantage of cheap, reliable LED lighting. Speed and responsivity will continue to be the cornerstone of linescan, and with a more widespread adoption of linescan newer, better and faster algorithms will be created to exploit linescan's benefits. Economic pressures on the total imaging system will increase the importance of "secondary" camera features such as resolution, size, programmability, intelligence and usability.

Introduction

Two-dimensional images have always been the norm in consumer and industrial imaging, and traditional area cameras (e.g. RS170) deliver those rectangular pictures, one frame at a time. But frame-by-frame is not the only way to capture images. Two-dimensional images can also be created by line scanning, and industrial line scan imaging can offer significant performance and cost advantages.

The simplest example of linescan imaging is in a fax machine: instead of capturing a two dimensional area (ie. 512 x 512), a linescan imager captures successive long thin rectangles of area, effectively one-dimension (ie. 1 x 8192). The second dimension comes from moving the object (or the imager) and scanning successive lines. Linescan imaging is particularly well suited to inspection of fast-moving or long objects or continuous webs.

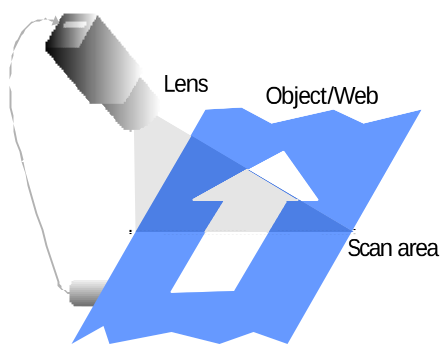

Figure 1. Typical linescan application.[1]

Whether they use area scanning or line scanning, most imaging applications are driven by three primary motivators: speed, responsivity and dynamic range. The first half of this paper examines linescan's economic benefits in these areas. The second half of the paper introduces new attributes, such as resolution and size, that are gaining value as linescan branches into new applications.

Speed

The need for speed is driven by the economic value it brings to your system. The faster the line rate, the greater the amount of area you can inspect in a given amount of time, leading to lower inspection costs per unit of inspected area. The drive to lower inspection costs is so great that many system integrators recognize the benefits of multiple tapped cameras. Multiple taps allow for parallel processing of data thereby doubling or even quadrupling effective throughput and saving 50 to 75% in production costs. Today the fastest linescan cameras can produce up to 10 bits of data at 40MHz per tap with up to 4 taps for an overall throughput of 160MHz, which exceeds the 100MHz sustained bandwidth of the current PCI bus. The expansion of the PCI bus from the 33MHz, 32 bit platform to the 66MHz, 64 bit platform theoretically

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provides a 4 times improvement over the current PCI bus' sustained bandwidth of 100MHz. This improvement will be a catalyst for further demand in speed and multiple tapped linescan cameras because of the room for growth.

Responsivity

Lower lighting costs drive the need for responsivity. Responsivity benefits the system integrator by requiring fewer or less powerful light sources, thereby reducing costs. Traditionally, applications required the use of powerful light sources (e.g. halogen bulbs) that degraded within a few thousand hours. The heat and blinding light emitted from these bulbs created an unpleasant working environment and could even damage the objects being imaged. To improve the environment and reduce system costs, system integrators have demanded camera responsivity to outpace speed in the capabilities of new cameras. The end result is a faster system that requires less light.

LED lighting has the potential for a large reduction in system downtime. LED lighting provides an order of magnitude increase in bulb lifetime over halogen bulbs. The net effect is a 10 times decrease in system downtime resulting in a huge cost savings. The drawback of LED lighting is the reduction in lighting power. This reduction has pushed the need for responsivity to the forefront in linescan imaging.

There are two methods to increase responsivity in a camera: increasing the camera gain and/or increasing the charge conversion efficiency (CCE) of the sensor. Improving CCE is the better method because it has less impact on the signal to noise ratio since only the sensor noise and not the camera electronics noise is gained with the signal. However, it is the most difficult to deliver because it requires technology advancements in the sensor. Advancements in CCE of the newest linescan cameras has resulted in an 80% improvement compared to cameras from 4 years ago. Today's cameras generally provide programmable camera gain of up to 10x greater than a few years ago, but increasing the camera gain using this method, increases the camera electronics' noise as well as the sensor noise. In comparison, improving the sensor CCE preserves the signal to noise ratio when increasing camera gain.

One way around this gain/noise tradeoff is time delay and integration (TDI) technology. TDI provides the leap in responsivity required to marry advanced linescan cameras with LED lighting without the increase in camera gain and noise. The responsivity gain is accomplished by shifting pixels synchronously with the relative speed of the object compared to the camera. Effectively this allows the camera to image the same area more than once, thereby extending the integration time by the number of stages in an advanced linescan camera. Advanced linescan cameras with TDI technology achieve 50X greater responsivity than comparable linescan cameras. This technology has been commercially available for over 10 years, but it is becoming more accepted with the advance in LED lighting.

Dynamic Range

Dynamic range is defined as the total camera output at saturation divided by the noise in dark—basically, how bright are the brights compared to the darkest darks. Applications, such as medical imaging, which require extremely high bit depth, value dynamic range. Most of these applications are not suitable for linescan because they do not involve object movement relative to the camera. So how important is dynamic range to linescan? It is important. It does provide better image quality, but compared to the value of responsivity it is a distant second because linescan imaging requires significant light. For example, a high speed RS170 area camera might deliver 60 frames per second, allowing each pixel to integrate light for one sixtieth of a second. A high speed linescan can obtain an image at speeds of 60000 "lines" per second, shortening the integration time by a factor of 1000 times compared to RS170 camera. The need for responsivity is paramount especially when coupled with the desire to move towards LED illumination. For linescan the economic value of responsivity and speed outweigh the benefits of dynamic range.

The demand for speed, responsivity and dynamic range have determined the path for linescan imaging for the past 15 years—camera customers have always asked "give us more speed and let us use less light." But as development cycle times shrink and speed of deployment becomes ever more critical, "secondary" camera characteristics such as resolution, size, low-light effects, intelligence, programmability and ease of use are emerging as critical requirements or concerns in applications.

Resolution

The electronics industry has undergone radical changes to reduce the size of components (0201 resistors, BGAs and fine pitch chips) populated on printed circuit boards. Circuit board inspection requires more pixels per camera or more cameras in order to inspect smaller components. Similarly, web inspection requires more pixels to improve end-product quality by finding find smaller defects. In both applications the solution is to obtain greater resolution in one camera or use more cameras.

Economics are motivating a shift from area based imaging to linescan imaging. System costs are less when one 8K resolution linescan camera is integrated instead of 8 1K x 1K area cameras. Moving to larger 2K x 2K area products is even more cost-prohibitive. Using a single linescan camera rather than 8 area cameras reduces system complexity by reducing the number of framegrabbers required and eliminating the need to synchronize each camera with one another. These economics not only drive typical area applications towards linescan, they also drive the need for larger and larger linescan resolutions. Currently, the largest resolution widely available in high speed linescan cameras is 8192 pixels.

Size

The need for linescan cameras to operate under conditions usually performed by tiny area cameras has driven a reduction of size. Many area applications are in gantry type systems that require the camera to be moved instead of the web. This has pushed cameras to be of smaller size and lighter weight. Camera body sizes and weight will continue to shrink as the electronics within reduce in size.

Low Light Effects (Image lag, dark current and FPN)

In the quest for responsivity and LED lighting, companies have constantly increased camera gains. This has emphasized image quality problems with low light effects, such as image lag, fixed pattern noise (FPN) and dark current. Pinned photodiode technology and real-time digital solutions help combat these issues.

Image lag occurs when a portion of the image is left behind in the sensor after a line is shifted into the readout register. An excellent example of image lag is when you turn off your TV and you can still see a partial image left on the screen. In the last three years most linescan sensors have been developed with pinned-photodiode technology to reduce image lag to undetectable levels even in applications using high camera gains.

Beyond image lag, increased camera gains and responsivity have brought fixed pattern noise (FPN) and dark current to the forefront as issues. FPN occurs because each pixel resets to a slightly different level when pixels are reset such that they are ready for a new image. At higher gains, FPN can ruin your image with gross distortions at low light. Dark current is the inherent generation of electrons due to temperature. Every 6-7°C dark current doubles. At high temperatures and high camera gain dark current can consume the entire image. Further, dark current adds to your FPN because it does not generate electrons evenly across an entire line array.

The newest generation of linescan cameras employ digital processing to compensate for dark current, FPN and pixel response non-uniformity (PRNU). The latest cameras have incorporated real-time algorithms that can perform 2-point correction to compensate for PRNU and 2-point correction to compensate for dark current and FPN. By having the end-user teach the cameras what is “white” and what is “dark”, the camera can automatically balance all pixels with the same responsivity. This normalizes the performance of each pixel regardless of uneven illumination across the web, the FPN or PRNU of the sensor, and any vignetting associated with marginal optics. This allows system integrators to match the camera to their environment with less expensive optics and lighting while maintaining good image quality.

Programmability and Ease of Use

To speed the acceptance of machine vision, cameras have become more versatile through programmability and ease of use. The first programmable cameras that appeared about 4 years ago were produced to make it easier for setup in applications. Previously, system integrators were required to tweak gain potentiometers for each camera in their setup. This was cumbersome. Programmability, now standard in linescan cameras, allows camera gain and offset setup to be performed remotely saving time and effort, and it allows the option of creating a closed loop system where gains and offsets are changed as required in real-time.

Interfacing with a camera has become easier through the evolution of standard interfaces and protocols. Camera Link™ is a new camera interface that can handle the bandwidth required of high speed state of the art linescan cameras. Even the newest and fastest linescan cameras running at 40MHz per tap have plenty of room to increase speed up to the maximum speed of 85MHz per tap supported by Camera Link™. With room for speed growth and the support of many key vendors, Camera Link™ is becoming a compelling standard.

Conclusion

Better quality inspection and lower production costs are driving the demand for speed, responsivity and larger resolutions in linescan imaging. Traditional area applications are shifting towards linescan to improve manufactured product costs. Body size, intelligence and ease of use allow linescan to bring economic benefits to new applications. The future of linescan imaging is growth in applications and improvement in characteristics critical to economic success.

References

1. DALSA Product Catalog, Waterloo, Ontario, Canada. p. 7, 2001