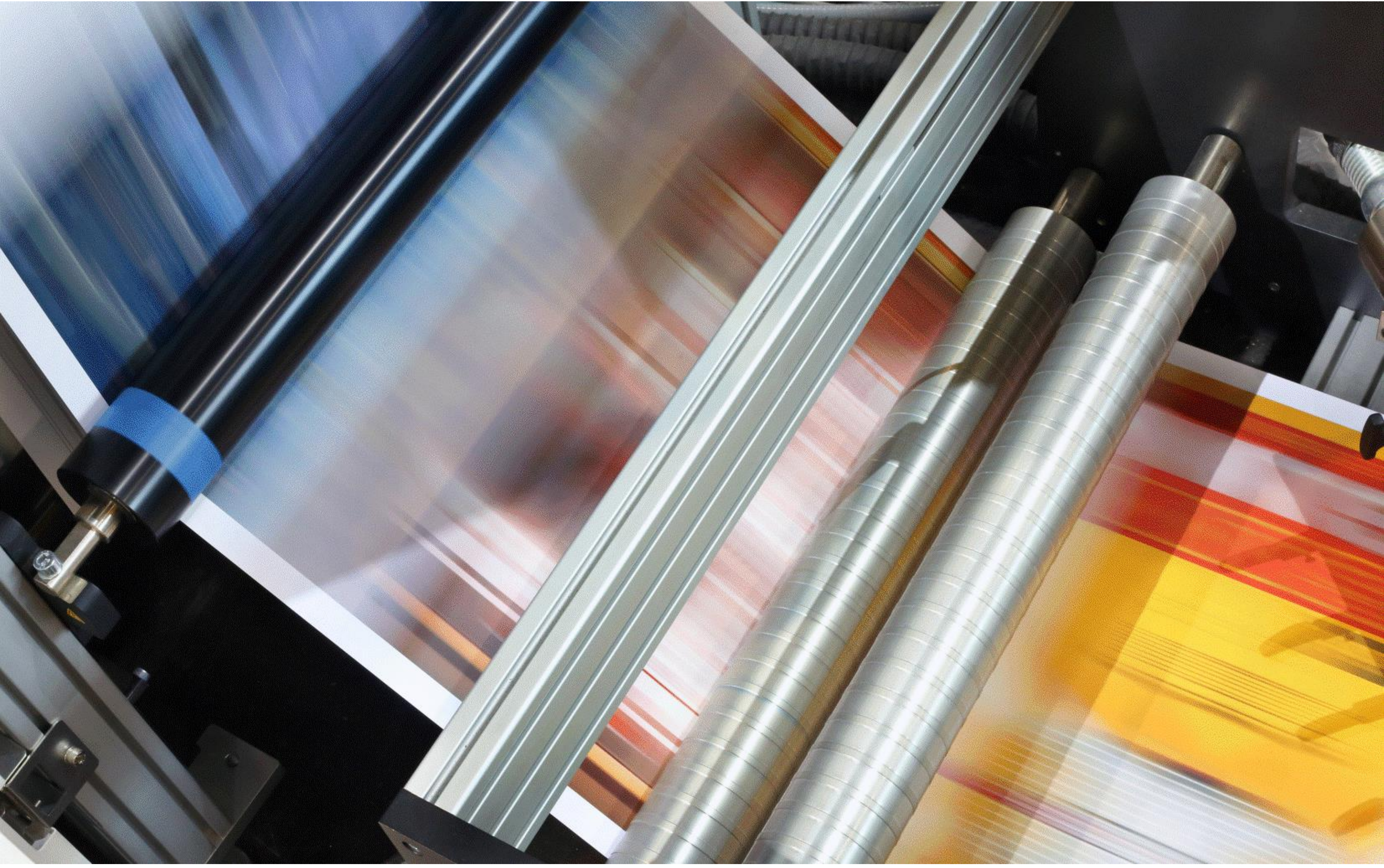

WHITE PAPER

Prism-based line scan cameras vs. single-sensor multi-line cameras for color and multi-spectral imaging

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Abstract

The selection of camera technology is determined largely by the requirements of a machine vision application. Line scan cameras have traditionally been chosen for applications requiring high speed, i.e., image capturing of fast moving objects. With more and more quality control processes in high speed industrial production requiring color or multi-spectral imaging, line scan technology must have the proper capability to meet this need.

One approach is to use a single sensor with multiple lines. Typical configurations include dual-line interpolated color, RGB trilinear, and RGB + NIR quad-linear for multi-spectral applications. Some of these cameras even employ multiple lines for each information channel to enable binning or integration functionality that increases sensitivity under less-than-optimal lighting conditions. The other line scan approach is to use multiple sensors and separate the incoming light into required wavelength bands by using a dichroic prism. Three-channel (R-G-B), and four-channel (R-G-B-NIR) configurations are typical. These models may also use sensors with multiple lines to provide better sensitivity via binning. While both approaches can image at high speeds (including the latest generation of CMOS prism-based cameras), the image quality can vary greatly.

For example, there are many machine vision applications where the speed varies or is unknown. Single-sensor, multi-line cameras struggle to maintain image quality in these situations due to their architecture, while prism-based image quality is not affected. Furthermore, prism-based cameras are also ideal for cases where the camera needs to have a tilted view on the object surface and cannot be placed perpendicular to the object plane. Likewise, for object vibrations and undulations common in web inspection applications involving metal, plastic and paper, tests show that using prism-based line scan technology produces the best possible image quality. This white paper shows a comparison of single sensor multi-line cameras to multi-sensor prism-based line scan cameras.

1 Background and Motivation

Automation of industrial processes has led to commissioning of inspection systems which allow 100% quality control of goods. Automated inspection avoids human errors and helps to achieve quality control with high efficiency. In recent years, the quality consciousness of end-users has significantly increased and at the same time, the machine builders are constantly looking for technology additions which could add value to their end product. Many industrial products and their packaging, utilize paper or plastic and metal foils which have traditionally been based on a “web” – an endless supply of material in roll form that needs to be inspected either in the manufacturing step or during value added processes such as printing, converting, embossing or laminating.

Because of the nature of high speed manufacturing, such products can only be inspected using line scan cameras, which focus on scanning the object line by line. This style of inspection allows inspecting long objects or endless objects such as webs. In the last decade, the scope of line scan technology has expanded from web and document scanning to traffic and tolling; vegetable, mineral and granular sorting; outdoor applications such as railway carriage and track inspection; road and runway inspection; and wood and glass inspection. Fig. 1 shows the line scan market based on the most popular applications, most of which are color or multi-spectral in nature. The vertical axis highlights the typical sensor resolution requirements for the application while the horizontal axis from left to right denotes the typical speeds.

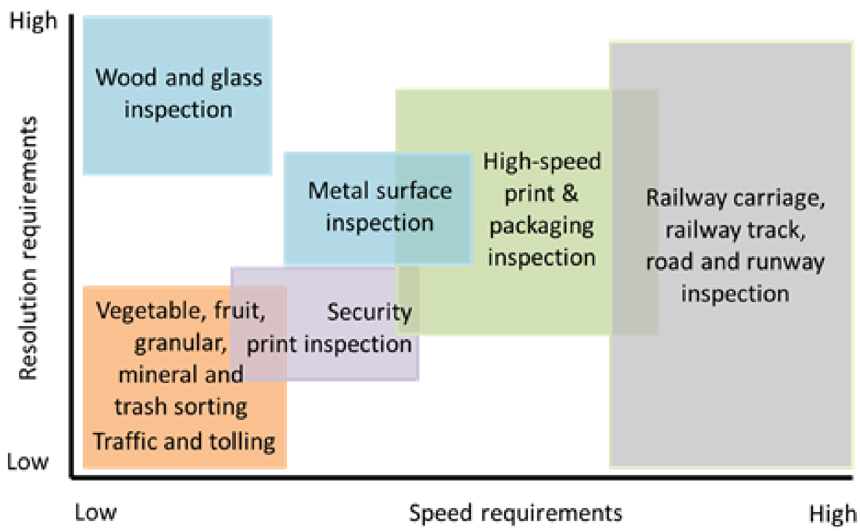

Fig. 1 - line scan market overview

It must be noted that even though Fig. 1 gives a general overview of the line scan market, it does not represent each and every use case. There could be exceptions to the speed and resolution requirement for specific cases.

It is evident from Fig. 1 that line scan technology has a wide scope of applications. The challenges of these applications can be addressed either by single sensor multi-line cameras or multi-sensor prism-based line scan cameras. Fig. 2 and 3 depict the line configurations that can be achieved by using either of these approaches.

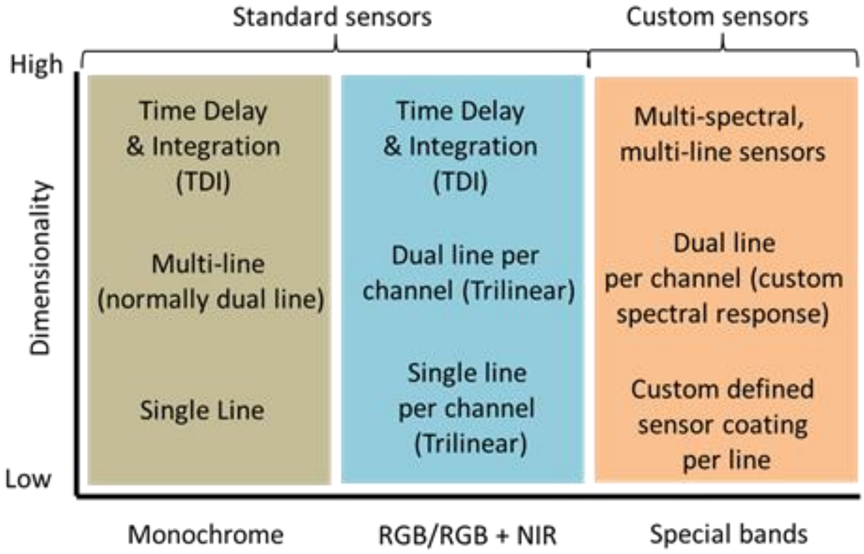

Fig. 2 - Configurations with single-sensor line scan cameras

As the name suggests, single-sensor multi-line consists of single-sensor architecture but can have different configurations to capture light falling on its surface (Fig. 2). On the other hand, multi-sensor prism-based line scan cameras consist of multiple sensor architectures in a single camera device (Fig. 3).

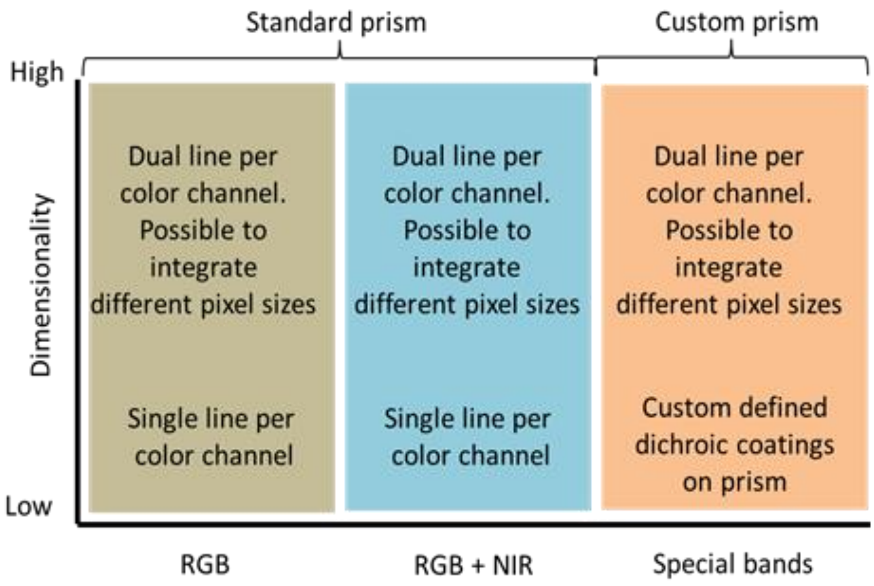

Fig. 3 - Configurations with multi-sensor prism-based line scan cameras

The use of a prism inside a camera facilitates separation of light into various spectral bands. Hence, a prism-based R-G-B camera is not needed in monochrome applications.

2 Multi-sensor prism-based line scan cameras vs. single-sensor multi-line based cameras

Two differences between single and multi-sensor line scan cameras from an applications viewpoint are explained below. Although the comparisons shown are for prism-based cameras vs. trilinear, the logic for other single sensor multi-line cameras would remain the same. These differences would assist in selecting the right technology for a given application. Apart from high speed, the use of a prism inside a camera offers other advantages over single sensor line scan cameras.

2.1 Halo Effect

In line scan applications, the multi-sensor prism-based cameras have a technological advantage over trilinear cameras due to the nature of its optical design. Due to space limitations within machines, it is often the case that the only way to fit the camera is at an angle to the surface that is to be inspected. In the case of trilinear cameras, the sensor consists of three or more lines per color channel which are spatially distributed in the direction of scan. From the viewpoint of optics, these are three or more individual, optical paths.

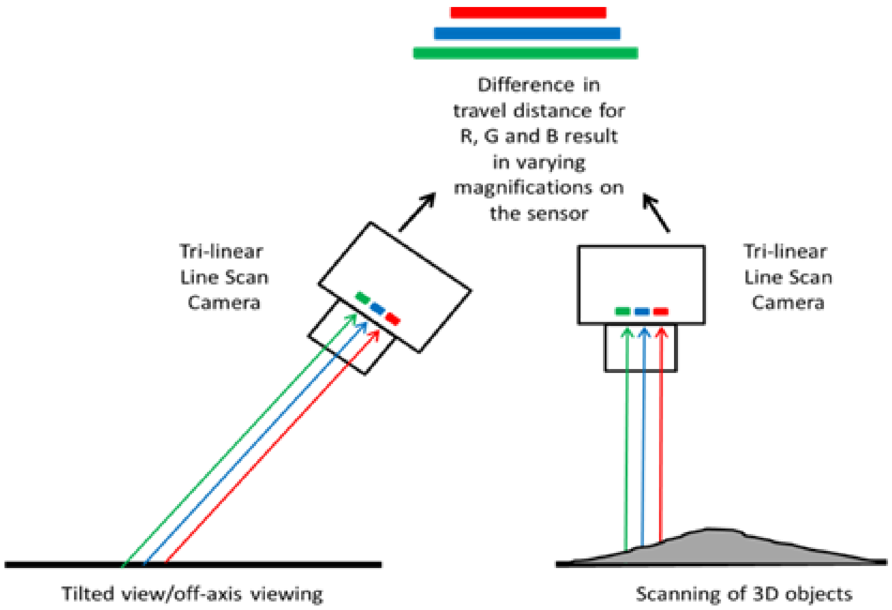

Fig. 4 - Off-axis viewing and inspecting 3D objects with trilinear line scan camera

A trilinear camera placed in an off-axis angle of viewing causes distortion of the image dimensions which makes a square or rectangle look like a trapezoid. This is also caused due to the fact that the optical path from object surface to the closest color channel on the sensor is shorter than the other two color channels. In Fig. 4, the optical path from object to the red channel is shorter than blue and green. As a result, the optical resolution for red is higher than blue and green causing color fringes typically referred to as the “halo effect” (Fig. 5). Nowadays, trilinear cameras implement on-camera correction algorithms to correct the keystone projection effect. This allows some flexibility with the tilted view. However, the tilted view correction is limited to a certain number of pixels (up to 4 pixels is most cases).

Fig. 5 - Depiction of image with and without halo

The same logic applies while inspecting 3D objects with a trilinear camera. The 3D structure can lead to the red, green and blue channel having varying optical distances to the sensor (as shown in Fig. 4) which can also produce color halos.

In the case of multi-sensor prism-based cameras, every individual light ray follows a single optical path before interacting with the main optical component, i.e., the prism. As the separation of light takes place inside the prism, the optical resolution for each color separation remains the same. Hence, the angle of tilt or the height of the 3D object is irrelevant with respect to the halo effect.

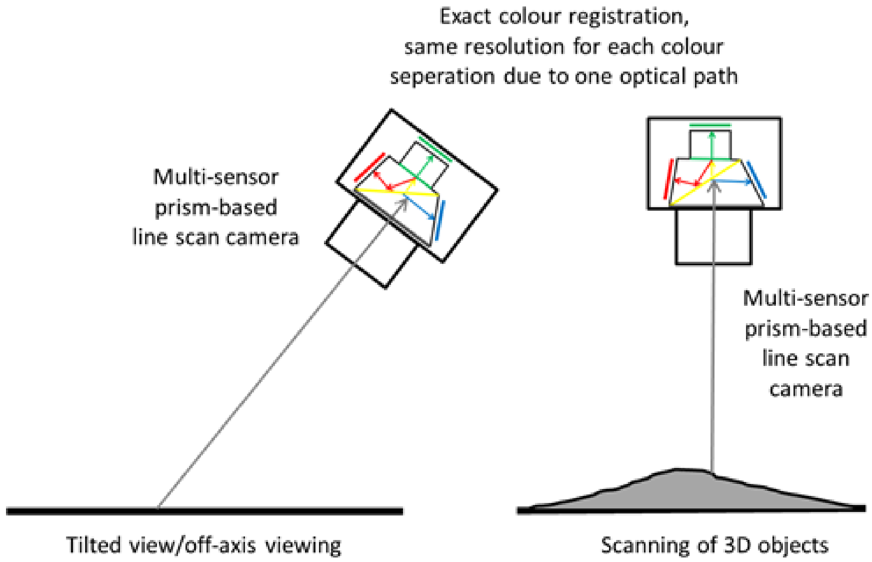

Fig. 6 - Prism-based line scan cameras in off-axis and 3D object inspection

In classical trilinear applications such as web inspection, normal vibration of the web can be a cause of concern. Even though, vibration of moving webs is well understood and there are several mechanisms in machines to minimize the vibration effect, there could still be vibration zones where optical inspection is carried out. As depicted in Fig. 7, a prism camera could assist in minimizing the effect of vibration in such applications. This is due to the single optical axis of the prism camera. The vibration of the web in the Z axis might change the optical resolution of the object but it will remain the same for all the three channels. In the case of dual line cameras, there would be a need to compensate a gap of 1 line. However, as the gap cannot be constant due to vibration, a bleeding effect at the edges would be visible.

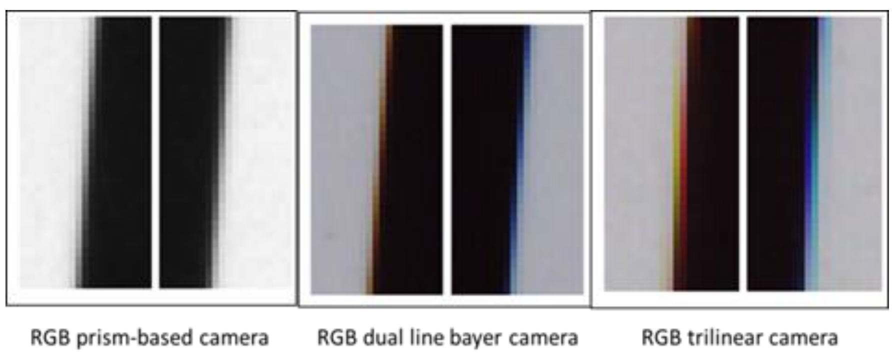

Fig. 7 - Image quality of a moving printed web using different camera technologies

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The image quality obtained with the trilinear camera is the lowest due to the need for compensating two line gaps.

2.2 Spatial compensation and line rate

In trilinear cameras having a single line per color channel, there is a gap between the individual lines. This gap can be of one pixel or more (as shown in Fig. 7). In some cases, it could also be less than one pixel. In order to reconstruct an RGB image, the RGB lines are combined and the space between these lines is compensated in the spatial correction algorithm on the camera head.

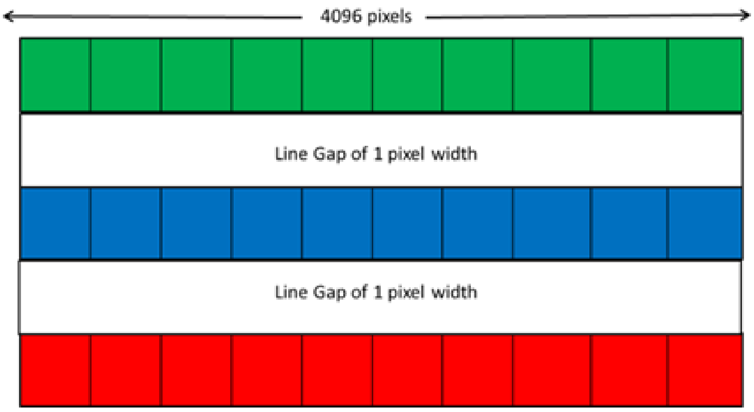

Fig. 8 - Spatial compensation in trilinear cameras (image from AIA training material)

The accuracy of spatial correction depends on the possibilities of fine tuning the correction at a sub-pixel level. In cases where the scanning speed is equal to the line rate of the camera, the spatial correction is equal to the physical gap between the lines. If the object speed is faster or slower than the camera speed, the camera automatically corrects the resulting spatial difference. However, this approach only works in applications where the speed of the object is known and fed back to the camera through a direct or an indirect encoder connection. Fig. 8 shows an example image of spatial compensation in trilinear cameras.

In applications where the object speed is unknown or unpredictable such as sorting of fruits, vegetables and granular objects, stones, gems and marbles, cotton and leaves, pharmaceutical pills or even in case of web applications such as print, metal, paper and foil where the web is fluttering, it is not possible to efficiently provide a feedback to the camera through any device regarding spatial compensation. In such cases the trilinear technology does not work efficiently.

Fig. 9 - Spatial compensation in trilinear cameras (image from AIA training material)

To overcome such challenges, multi-sensor prism-based cameras are used. The advantage of having a single optical axis, (as shown in Fig. 6) can be efficiently applied to scan objects with unknown speeds. Furthermore, there is no need for spatial compensation as the R, G and B separations are carried out on individual sensors which have no line gap.

3 Conclusions and Outlook

Even though a prism-based line scan camera has higher costs as compared to trilinear or other single sensor multi-line cameras (because the major cost of a camera is the sensor and prism-based cameras have more sensors), the advantages it offers are remarkable. Apart from superior image quality which is inherent from the interference-based dichroic coatings, plus unique advantages to optimize image quality (e.g., individual analog gain, digital gain and exposure time per sensor), prism-based line scan cameras, with their single optical plane, do not require spatial compensation. They can work optimally well in applications where object speeds are unknown, and they easily handle camera tilt or inspection of 3D objects without any image artifacts such as halo effects.

Prism-based cameras do require special lenses. This is because the optical path inside a prism camera is different than a single sensor camera. Fortunately, there is a wide range of lenses available on the market optimized for prism-based imaging.

This paper is a part of the JAI white paper series on prism technology. The advantages of a prism to achieve excellent and superior image quality over other camera technologies such as Bayer pattern and trilinear technology are discussed in the first white paper of this series, titled: “How does prism technology help to achieve superior color image quality?”

About the author

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Paritosh is a part of JAI product management team since April 2017. He studied print and media technology at Chemnitz University of Technology in Germany and specialized in multi-spectral camera systems for high speed applications. Having worked in previous positions within R&D for paper technology, camera development, application management for 3D & spectral cameras and sales he brings a broad perspective to the table.

About JAI

JAI provides innovative digital CCD/CMOS camera technology for applications in industrial machine vision, medical imaging and high-end surveillance systems, as well as complete solutions for traffic imaging/vehicle recognition in Intelligent Traffic Systems (ITS). The company has a global presence through companies in Denmark, Germany, Japan, China and USA, and via distribution partners in more than 35 countries.

JAI's vision systems help improve customer businesses in numerous ways, whether by improving quality and accuracy of products, lowering production line inspection costs, increasing production yields or creating higher efficiency in road traffic. Common to our customers around the globe is that they value the trademark characteristics of our products: proven technology, high reliability, consistent quality and superior image fidelity backed by JAI’s long-term viability.

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