Inspection of bulk material with *allPIXA wave* and *prism camera*

Whitepaper

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Executive Summary:

The aim of this work is to compare the trilinear line-scan camera allPIXA wave with a prism based camera with respect to bulk material inspection. Traditionally, prism-based cameras are often selected over trilinear cameras when it comes to bulk material scanning, as the inherent line-shift of a trilinear camera can only be corrected for when the object scan velocity is known. We demonstrate that this traditional approach is not always necessary if the right trilinear sensor is selected and operated in binning mode to average multiple pixels.

1. Introduction

There exist various applications in the producing industry for which bulk material is to be inspected in an automated fashion in high speed. Industrial cameras can be used for that, and because of the typical high velocity at which the bulk material moves, line-scan camera technology is very well suited. In the simplest case, such a camera consists of a single linear line of sensor cells. A two-dimensional image (similar to an image from an area sensor) is created by moving the scan scene perpendicular to the sensor while acquiring successive lines of the image.

The single-line sensor can produce a single-channel image, typically in grayscale. However, many bulk material inspection applications require color images. There exist two types of technologies to acquire full-color images:

- A single trilinear line-sensor
- Prism-based camera with three single line-sensors

The working principles are illustrated in Figure 1. For the case of the trilinear sensor, the three image lines of a single object point are acquired at different moments in time. The resulting channel-shift in transport direction is typically corrected camera-internally. For a perfect correction the scan object velocity needs to be constant and precisely predetermined. For the case of a prism-based camera, the three image channels are acquired at the same moment in time and therefore no extra correction is needed.

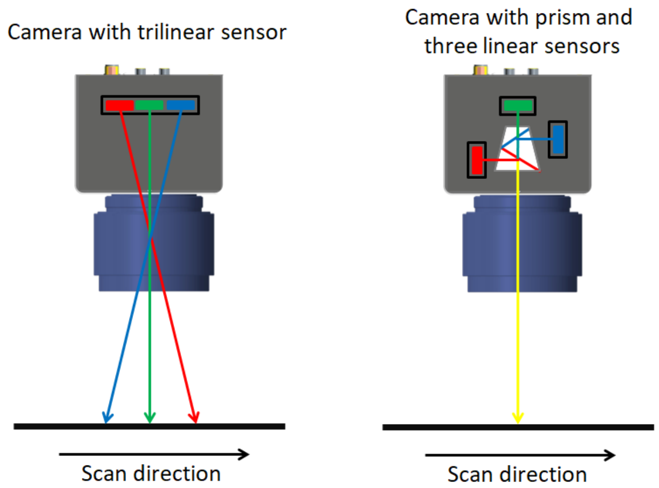


Figure 1: Trilinear (left) versus prism-based (right) line-scan technology.

Whenever bulk material is transported on a conveyer belt the object velocity is typically well-known. However, there also exist applications for which this is not the case, such as:

- **Free falling bulk material**
    - The velocity distribution among individual material pieces is rather homogenous and only influenced slightly by air friction.
- **Bulk material on an inclined plane**
    - The velocity distribution among individual material pieces is influenced by the coefficient of friction of the material and the plane.

For the case of a trilinear line-sensor, unknown object velocity can result in the so-called *color fringe* or *halo* effect, for which object contours appear with false color in transport direction. An example as such is given in Figure 2.

Figure 2: Color fringe effect due to uncorrected pixel line-shift.

In this work, we demonstrate that a smart selection of a trilinear camera sensor type and its configuration is equivalent to a prism-based camera in terms of color image quality.

In the following chapters, we illustrate the laboratory setup and components used for testing and investigate a typical velocity distribution of a sample bulk material. In Chapter 5, we perform a one-to-one comparison of the trilinear sensor based camera **allPIXA wave** with a prism camera and show sample images of bulk material on an inclined plane in Chapter 6. At last, we summarize this article in Chapter 7.

2. Camera selection

As mentioned earlier, trilinear sensor based cameras can be used as an alternative to prism based cameras in many conditions. The color fringe effect with trilinear sensors stems from the fact that the color image channels have to be shifted relative to each other by an amount that depends on the physical distance between the sensor lines (typically R, G and B) Δ and the magnification β. In sensor datasheets, the distance Δ is referred to as *pixel-pitch between sensor lines*. The physical size of the color shift between two lines (in meter) is $\beta * \Delta$. Typically, the scan speed v_{scan} of the object is adjusted to a nominal velocity v_0 in such a way that transport resolution and optical resolution are the same (“square pixels”). The size of the color fringe (in pixel) is dependent on the ratio of these two velocities and can be calculated using the physical size of a pixel S instead of the magnification:

$$d_{Halo} = \frac{\Delta}{S} * \frac{v_{scan}}{v_0}.$$

Selecting from the Chromasens trilinear line-scan camera portfolio, we consider a camera from the new **allPIXA wave** [1] family instead a conventional **allPIXA** [2] or **allPIXA pro** [3], as the pixel pitch for this camera is 10.2 µm instead of 40 µm and the pixel size is 5.6 µm instead of 10 µm. So the size of the color fringe effect is already reduced by a factor of 2.

The size of the fringes can further be reduced by increasing the image resolution (smaller β). To our knowledge, standard commercial prism based line-scan cameras for industrial applications have at most 4096 pixels. Cameras of the allPIXA wave family are available with up to 15360 pixels. Accordingly, given the same *Field of View but more pixels* the magnification can be decreased as shown in the following example:

- Field of view: 100mm
- Camera resolution:
  - with 2k (2048) pixel sensor 48,8µm/pixel
  - with 4k (4096) pixel sensor 24,4µm/pixel
  - with 15k (15360) pixel sensor 6,5µm/pixel
- Line-shift relative to the camera resolution:
  - with 4k (4096) pixel sensor factor of 2 smaller than for 2048 pixel sensor
  - with 15k (15360) pixel sensor factor of 7.5 smaller than for 2048 pixel sensor

Accordingly, using a 15k trilinear line-scan sensor of the **allPIXA wave** family instead of using a 2k trilinear sensor of the **allPIXA pro** family will have a factor of 15[1] less color fringe effect when considering the same field of view.

The remaining color fringe has the maximum visibility at an edge where the color changes from black to white in transport direction. For the **allPIXA wave,** the image of the edge in two neighboring color channels is shifted by two pixels relative to each other. An additional trick helps reducing the fringe further. If multiple pixels are averaged into one single pixel, a process called binning; the shifted edge of all color channels will fall into the same pixel. The remaining shift is now at sub-pixel level and results at most in a slight discoloration of the edge.

When setting up a trilinear line-scan camera the internal line-shift correction is set to the nominal velocity of the application. The binning approach then only has to correct for velocity variations. Typically, binning windows of 2 to 4 pixels are already useful in this case.

3. Laboratory setup and test material

We set up two configurations for testing. The first is the *inclined plane setup* (see Figure 3, left side). Compared to free-falling bulk material, the inclined plane setup is considered as worst-case, as the velocity distribution of bulk material particles is larger in this case. The second configuration is the *linear stage setup* (see Figure 3, right side), in which the bulk material is distributed on a plane that is then moved under the camera. This setup allows adjusting the movement velocity in a controlled fashion. By that, a 1-to-1 comparison of individual material particles with both camera types is possible for different velocities.

[1] Because of smaller pixel-pitch between sensor lines, we get a factor of 2. Because of using a 15k sensor instead of 2k sensor with additional binning, we get an additional factor of 7.5.

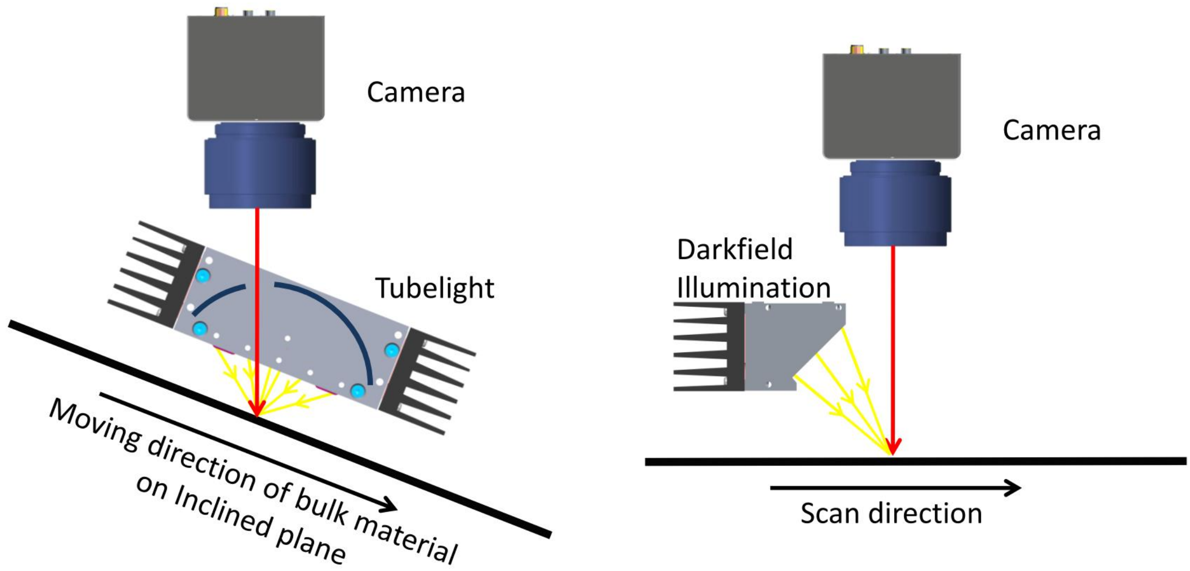


Figure 3: Inclined plane setup (left); linear stage setup (right)

Components used for testing:

- **Camera setup**

Technology	Trilinear	Prism-based
Model	allPIXA wave CP000498-15k	jAi – SWEEP+ SW2000Q-CL
Native sensor resolution	15360px	2048px
Maximum line rate	18.4 kHz	19.0kHz
Lens	76mm f/5.6 Conventional lens	56mm f/2.8 Optimized for prism camera
Field of view	690 mm	365 mm
Optical resolution	140 dpi[2]	140 dpi

- **Light source:**

Inclined plane setup	Corona II tubelight CP000200-C0007-340T-10_R2
Linear stage setup	Corona II darkfield illumination CP000200-510C-04-XXXX

Bulk material used for testing:

- White rice – White objects can be considered as worst case scenario, as the color-fringe effect becomes most visible
- Almond kernels
- Gravel

[2] The native optical resolution without the binning factor of 4 used in the experiment is 560dpi.

Table 1: Bulk material used for testing: white rice (left), almond kernels (middle), gravel (right)

4. Analyzing velocity distribution of bulk material on inclined plane

In conventional line-scan applications with trilinear sensor cameras, the line shift is corrected in the camera for a given global velocity. With free-moving bulk material (eg. inclined plane or free-falling), the adjustment is done for the average velocity, which has to be determined once when setting up the system.

For this article, we have analyzed the individual particle speed of bulk material on the inclined plane setup for the case of white rice samples. This was done by blob analysis of the line-shift of each rice corn of a scanned image. The resulting velocity distribution is illustrated in Figure 4.

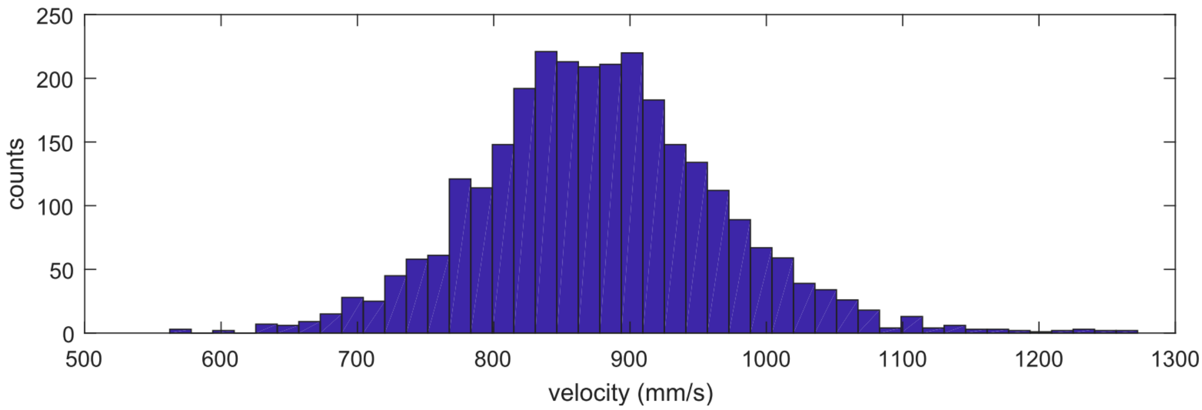


Figure 4: Velocity distribution of individual rice corns on inclined plane

We identified a velocity standard deviation of 10%. Assuming our distribution is adequately approximated through a Gaussian distribution we can conclude that 68% of all particles are within the velocity range of +/-10%, and 95% in the range of +/-20 % from the average velocity.

5. One-to-one comparison of allPIXA wave and prism camera

Assuming the parameters of the velocity distribution of white rice, we can acquire image data with the linear stage setup at different speeds. For this article, we considered the +/-20% velocity from average speed that is valid for 95% of all particles, given the aforementioned assumption. We repeated the experiment for the trilinear- and the prism-based camera using an identical scan scene.

In the following table, the direct comparison of image data is shown.

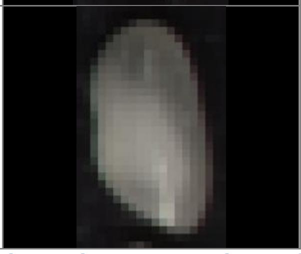
	Prism camera **140dpi** Native Resolution	Trilinear camera **140dpi** 4x4 px binning	Trilinear camera **280dpi** 2x2 px times binning	Trilinear camera **560dpi** Native resolution
-20% velocity				
Nominal velocity				
+20% velocity				

Table 2: Direct comparison of prism and trilinear camera of a single rice corn

Comparing the trilinear camera images with native resolution and nominal velocity (right column, 3rd row) with those acquired with +/-20% speed (right column, 2nd and 4th row), we can observe color fringes at the upper and lower end of the rice corn. A zoomed in image of the upper end of the rice corn illustrates the effect in more detail:

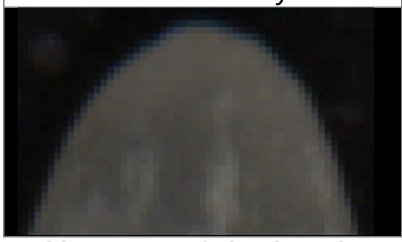
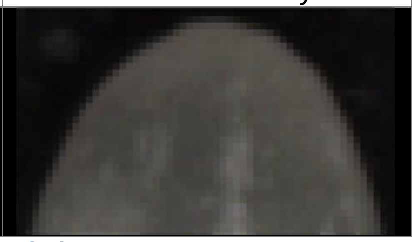
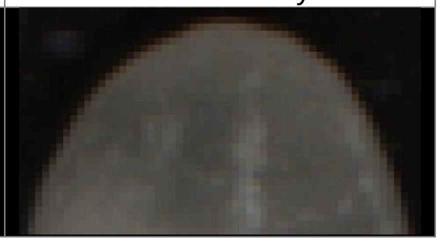
-20% velocity	Nominal velocity	+20% velocity
		

Table 3: Zoomed view in native resolution

Binning the native resolution images with 2x2 or 4x4 pixels removes the effect down to minimal discoloration residue. For the case of 4 x 4 pixel binning, we show zoomed in versions in Table 3.

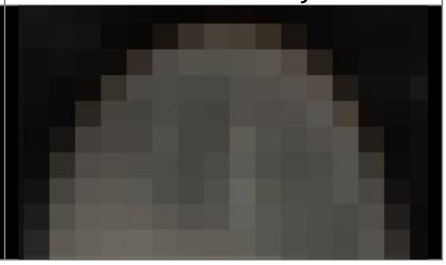
-20% velocity	Nominal velocity	+20% velocity
		

Table 4: Zoomed view with 4x4 binning

White objects on dark background are the worst-case scenario in terms of the color fringe effect for trilinear cameras. In the following figure, we illustrate sample images of the other scan objects considered:

	Prism camera **140dpi** Native Resolution	Trilinear camera **140dpi** 4x4 px binning	Prism camera **140dpi** Native Resolution	Trilinear camera **140dpi** 4x4 px binning
-20% velocity				
Nominal velocity				
+20% velocity				

The image quality of trilinear and prism-based camera seems rather similar. The color difference between the cameras stems from differences in the spectral responsivities of the two sensors.

6. Sample images of bulk material on inclined plane

In previous experiments, bulk material was scanned with the linear stage setup for 1-to-1 comparison. A more realistic scenario is acquiring images of bulk material on the inclined plane setup. The following tables list images accordingly.

Prism camera **140dpi** Native Resolution	Trilinear camera **140dpi** 4x4 px binning
	
	

Table 5: Almond core bulk material on inclined ramp.

Prism camera **140dpi** Native Resolution	Trilinear camera **140dpi** 4x4 px binning
	
	

Table 6: Rice corn bulk material on inclined ramp.

7. Summary

A comparison of trilinear and prism-based cameras for bulk-material inspection was performed in terms of visual assessment of the so-called color-fringe effect. This effect appears for instance when individual particles have distinct velocities. It was demonstrated by example of sample bulk materials that selecting a camera with small physical pixel-line distance in combination with using high-resolution sensors and pixel-binning can effectively remove visible color-fringes.

Objects for which the reflected light is spectrally flat (e.g. objects that appear white in images) exhibit the largest color fringe effect. For other objects, the color fringe effect is generally smaller and for many applications invisible. If in doubt whether or not color fringe effects are visible in images scanned by a trilinear sensor, it is advisable to test empirically. Chromasens offers such initial testing to their customers free of charge.

The proposed approach is useful for various reasons. First of all, there exist trilinear sensors for reasonable price with much higher resolution as compared to prism-based cameras. Further, using a trilinear sensor offers much more flexibility in the selection of stock lenses, as there is no special compensated lens required for the extended optical path of a prism-based camera.

References:

[1] Chromasens allPIXA wave:

https://www.chromasens.de/en/product/cmos-color-line-scan-camera-allpixa-wave-10k

[2] Chromasens allPIXA:

https://www.chromasens.de/en/product/line-scan-camera-allpixa-2k-nh

[3] Chromasens allPIXA pro:

https://www.chromasens.de/en/product/color-line-scan-camera-allpixa-pro-2k