Measurement of Diode to Diode Spacing

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Abstract

Laser printers with multiple laser diodes in a single diode package may have diode to diode spacing requirements critical to print quality. Standard off-the-shelf equipment is seldom designed to measure to the nanometer resolutions and linearity desired, especially if the measurements are time constrained. Therefore characterizing the linearity of the measurement system is important to the understanding of the measurement system limitations.

Diode to diode spacing is a comparison of the centroids of multiple adjacent laser spots in one or more axes. It is physically possible to measure the centroid location of the spots using various methods including scanning aperture, CCD/CMOS cameras or position sensing devices. The accuracies and precisions desired for good measurements as well as for good manufacturing process capabilities are often smaller than what are easily available with these products, often by an order of magnitude.

A procedure has been developed to estimate the measurement system error over a wide range of scales. It can be applied to several of the common laser spot centroid measurement devices enabling estimation of measurement resolution of the relative centroid. This method is based on an innovative technique involving controllable movement on a much larger scale.

Introduction

In development and manufacturing of laser printheads it is useful to be able to measure laser spot centroids both very accurately to insure correct placement, and very precisely to insure minimal time spent in the measurement. The term centroid will be used here to describe the intensity weighted center of a laser spot. One such situation is the measurement of diode to diode spacing, a relative measurement of the distance between the centroids of two laser spots.

The centroid equation below is the same form as the center of gravity equation for one axis.

$$\bar{x} = \frac{\iint_R x\delta(x,y)dA}{\iint_R \delta(x,y)dA} = \frac{1}{\text{intensity of R}} \iint_R x\delta(x,y)dA \qquad (1)$$

In this case the data is quantized by pixel so the equation is based on a summation. The delta function of the general form is replaced by "I" indicating the intensity at each location.

$$\bar{x} = \frac{\sum_i \left[I_i \left(x_i - x_{center} \right) \right]}{\sum_i I_i} \qquad (2)$$

As a relative measurement, several types of errors tend to cancel themselves out. Errors associated with bow, skew and other optics problems tend to have similar values for spots spatially close because the optics are similar locally, and similar for temporally close spots because thermal and timing issues are similar. Relative errors associated with spot shape and spot power issues also tend to cancel themselves out. Less fortunately, higher accuracies and precisions, not normally required in other measurements, may be desired and or required in diode spacing measurements due to the eye's sensitivity to print defects like banding. In addition, requirements for ease-of-use of the test equipment and test time constraints in manufacturing can compound the problem.

Traditionally measuring the accuracy of a measurement system requires a more accurate reference. The accuracy of the daughter system can be known to no more than that of the parent system minus the additional uncertainty from the measurement. Problems abound when trying to confirm the capability of a high accuracy and precision measurement system when no appropriately accurate and precise reference is available. When confronted with the task of confirming measurement ability to much higher than normal requirements, one measurement system may not be able to measure everything desired. It can also be beneficial to characterize the ability using multiple method types. Characterization using different types of methods provides a greater assurance of the system's capabilities. Different methods cancel or enhance different error sources, allowing for analysis of non-linear sources. In this way multiple measurement methods not only confirm the result, but provide insight when the result is not optimum.

Measuring Centroids

It can be useful to measure the centroid for each of two laser spots which may be 10's or 100's of microns apart along an arbitrarily chosen axis, and at the same time measure each single centroid location to 100's of nanometers or microns, two orders of magnitude tighter. Confirming the accuracy would then traditionally require the use of a gauge with accuracy in 10s or hundreds of nanometers over a several hundred micron range. Reliable measurements at this scale are expensive, difficult at best and often less trustworthy, making a second type of confirmation valuable.

There are several types of measurement techniques available to measure laser spot centroids based on projecting the laser spot onto a single or array of optical sensors. Rotating slit devices use an inferred slit location over a single sensor. Isotropic position sensitive devices use the proportion of electrons traveling to different edges of the device to estimate location. CCD and CMOS arrays are discrete position sensitive devices that identify the centroid from the number of photons at each discrete pixel location for an image. These methods have similar resolution problems. CCD or CMOS arrays are used in this example.

Experimental Method

A series of laser spots are placed in a straight line during a single scan across a camera. If the image generation and image capture systems have perfect linearity then the centroid to centroid offset, in the scan and cross scan axes, should be equal between each pair of adjacent spots whether the spots are parallel to the pixel array or not. If the image generation does not produce equally spaced spots, then the offset between various spots will not be equal, however the non-equal distance should be repeatable. This method does not require the image generation to produce equally spaced spots; it does depend on the mean relative spacing being constant for each pair of adjacent spots.

Repeating this process after moving the printhead microns or millimeters will produce another set of spot positions. In this case the image generation system has not realized any parameter changes and should be producing the same pattern, just in a different location on the image sensor. If the image capture system has perfect linearity then the offsets for each adjacent pair of spots should be the same. This can be repeated multiple times to estimate the changes in local linearity in various parts of the sensor, producing a linearity map of the measurement device. If the function is well behaved, it can then be used to compensate for future actual measurements.

A coarse movement to another location on the pixel array has an additional benefit. It allows data to be gathered at a fraction of a pixel offset because the movement is not expected to be accurate to a few nanometers. If this is repeated several times at several locations then errors due to sub-pixel non-linearity should be captured as part of the error in this measurement routine. Referring to figure 1, a movement from position A to position B may not capture any sub-pixel non-linearity error. Large movements, because they are not highly accurate will include a number of locations with respect to the pixel streets such as positions A, C and D causing sub-pixel non-linearity errors to be included in the measurements.

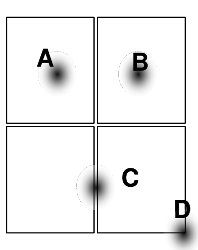

***Figure 1** Spot location with respect to the pixel array*

More Accurate Reference

A different type of method, and a more traditional one, is to use a more accurate reference. In this example a stage is driven by a piezoelectric stack using a strain gauge for closed loop location feedback. The laser is focused on the camera pixel array which is located on the stage. The stage is moved a distance, after a suitable time delay for stability, multiple spots are measured. The stage is then moved to the next location. Again small distances are being measured which make it difficult to get noise free data. A low pass filter such as a Butterworth filter is used on the raw data. The remaining data is then averaged for each requested stage location.

Results

The graph below shows the offsets obtained from each pair of adjacent spots as the printhead was moved from location to location on the image array. Data point 1 on the X axis of this graph is the difference in position between the first and second spots in the series. This data shows linearity error of +/- 2.7 um with a 99% confidence interval across a measurement span of 100s of microns.

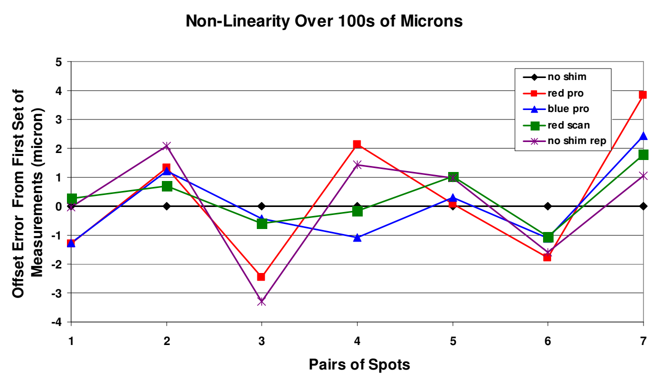

***Figure 2** Relative changes in cross scan axis location for multiple locations on pixel array*

Quantum efficiency, the efficiency of converting photons to electrons is not identical from one area of a pixel array to another. [1] This variation is due to the silicon array itself as well as the micro lens arrays used on most arrays with less than a 9 micron pixel pitch.

Figure 3 shows the non-linearity measurements obtained with a piezoelectric stack stage and strain gauge feedback. This is a higher accuracy reference, but this particular set of equipment is limited by only being able to traverse several camera pixels instead of several millimeters. In this case measurements were taken at a one tenth of a pixel interval in order to capture within pixel non-linearities. It provides an estimate of the non-linearity over this several pixel scale. Simply graphing the filtered and averaged data produces this graph.

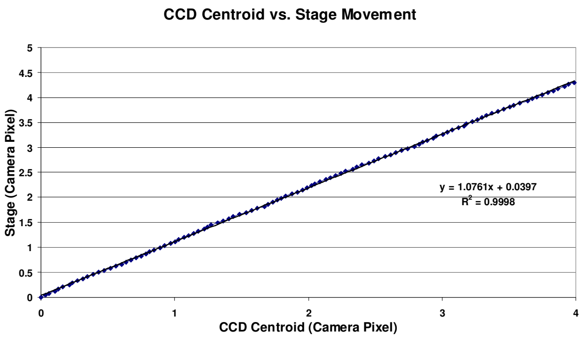

Figure 3 *Non-linearity over several pixels*

Normalizing this data over a several pixel span to a linear fit helps remove the variation due to larger scales and bring out the variation on a sub-pixel level. This particular data has a strong second order trend which has also been normalized for figure 4. This data exhibits a strong repeating pattern on the same scale as the pixel pitch suggesting that this component of the non-linearity is due to within pixel causes, in this case +/- 3% of the pixel pitch, a small component of the non-linearity seen in figure 2.

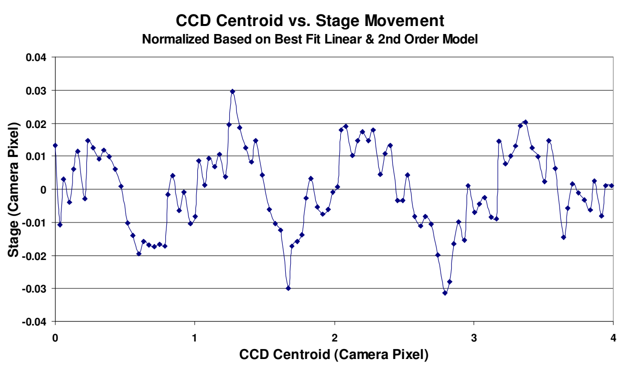

Figure 4 *Non-linearity due to within pixel sources*

Sources of Error

There are several possible sources of error in measuring diode to diode spacing. Larger scale errors from movement over 100s of microns or millimeters include quantum efficiency and optical contamination. Quantum efficiency of the charge generation areas varies spatially within a sensor array. A simple demonstration of this effect is made by moving a continuous wave laser spot across a single sensor PIN diode and noticing the changes in output with respect to location. Optical contamination is often dust, oils and other contaminants that settle on the optics from the air. This contamination is always a problem and concern.

Due to the excellent accuracy of photolithography, camera pixel pitch (center to center pixel spacing) is very uniform within a single array. This accuracy is dependant upon mask accuracy, mask magnification, the photoresist used, etc. Information from one manufacturer suggests that pixel pitch error is generally within 2 parts per million of the stated pitch. Common pixel pitches are in the single digit micron range with some to 25 microns or more. A 2 part per million pixel pitch error over 100 um is a 0.2 nm error, which is not normally a significant issue.

Smaller scale errors include sub-pixel errors which accumulate with the other errors mentioned previously. If measurements occurred in integer multiples of the camera pixel pitch, the issue would be much simpler. Because centroid measurements are not made in neat multiples of the pixel pitch, the localized linearity of the measurement system over sub-pixel distances should be estimated such as presented here.

Other Concerns

Although smaller pixel pitches provide greater resolution without lenses, smaller pixel sizes are naturally less efficient due to the areas required for non-light sensitive functions such as charge collection, charge transfer and charge measurement. [1] This quantum efficiency is improved with the addition of micro lens arrays, but these lens systems are very sensitive to the incidence angle.

Pixel mapping calibration linearizes each individual pixel in an array to a common reference. Although not convenient, this does offer improved measurement accuracy. One alternative is to produce an intensity calibration for each pixel in the array, thereby normalizing the non-uniform quantum efficiency and optical contamination effects, although this introduces its own difficulties.

Summary

Measuring a series of laser spot centroids with a CCD/CMOS camera by moving either the camera or the stage macroscopically between measurements provides insight into measurement equipment linearity. Sub-pixel non-linearities are clearly present and measureable. Non-linearities on a pixel basis can be mapped and therefore corrected for, even though accurate characterization of these is beyond the specification of the CCD/CMOS camera.

References

[1] James R. Janesick, Scientific Charge-Coupled Devices (SPIE Press 2001) pg 151, 167, 891

Author Biography

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