Dot Placement Analysis Using a Line Scan Camera and Rigid Body Rotation

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Abstract

Printer manufacturers design print heads and halftone patterns to result in specific types of image characteristics. Many image quality artifacts are a result of differences in actual dot placement from intended dot placement. Quantifying dot placement variations can be a complex endeavor requiring image capture at high magnification for adequate sampling. Large dot fields are imaged in pieces, which requires re-stitching of images prior to assessment, and extensive post processing to calculate actual dot positions compared with intended positions.

This paper discusses a novel approach to dot placement analysis. This method includes a single, high magnification image, which is captured using a line-scan camera. Once the image is captured, the image is analyzed using principles of rigid body rotation to match a set of actual dot positions to a template of expected positions. Using this method, errors in dot placement can be assessed rapidly without errors that stem from image stitching.

Introduction

Controlling dot position is a key factor in controlling and effecting image quality in dot-based imaging systems. Often, halftone algorithms are developed to ensure minimal visibility. However, while the pattern is being rendered by the print engine, variations in imaging head speed or balance, jet-performance (in ink jet systems), paper handling, and other mechanical causes can disrupt the positions of the dots in the final pattern. In addition, interactions between marking and receiving media can further confound the rendering process by causing dot break-up or other effects.

Dot placement errors not only effect the quality halftoned regions, but they also effect other features such as line fidelity (particularly that of fine lines) and text.

Often the disparity between intended dot positions and actual dot positions is considerable. In some cases the positional errors can accumulate across a dot field. For example, in laser-based print engines, polygon mirror alignment issues can result in increasing errors in dot placement as one moves across the image in the cross process (or cross machine) direction.

Figure 1a shows an example of a small portion of an intended dot pattern, while figure 1b shows an example of a the same dot pattern with some positional errors.

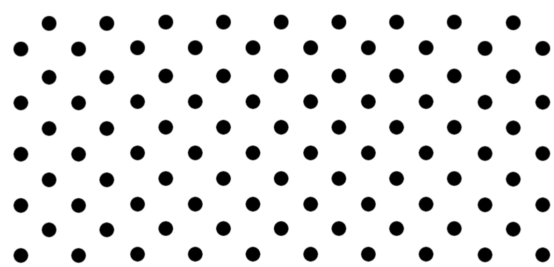

Figure 1a: Dot pattern with dots in their intended positions.

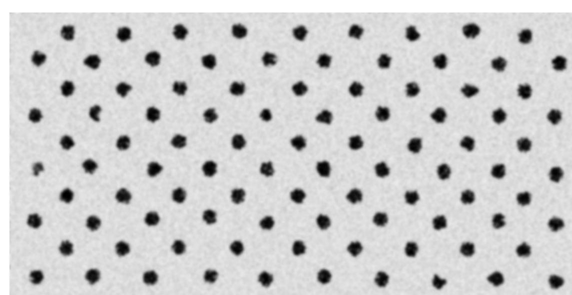

Figure 1b: Dot pattern with positional errors

Figure 2a shows a plot of the intended dot positions (as depicted by their centroid locations) and the actual dot positions from the dot patterns shown in figure 1a and 1b.

Figure 2b shows a plot of the positions of the actual dots versus the intended dots as a function of the vector distances of their centroid locations (sqrt(X^2+Y^2)).

If the dot positions were identical, Y would equal X and the R^2 value would be 1.

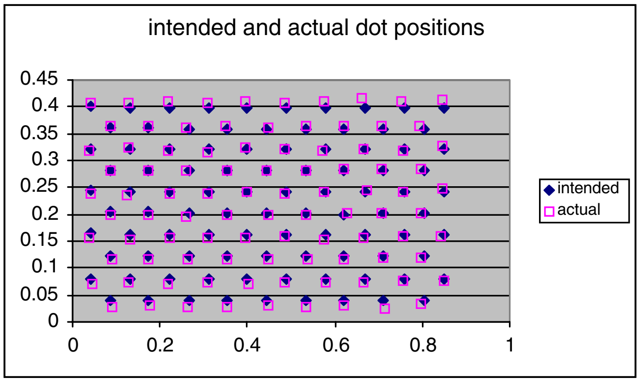

Figure 2a: Plot of dot positions

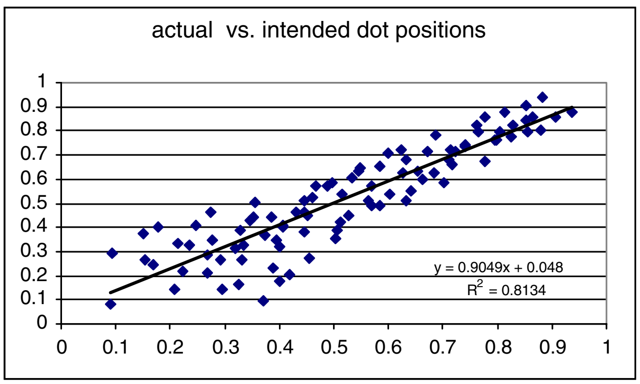

Figure 2b: Plot of dot positions

Introduction to Rigid Body Rotation

Rigid body rotation differs from some other definitions of rotation by restricting translation and rotation from one 2-D coordinate system relative to another. The guiding principle of rigid transformations assumes that no elasticity exists in the image ~~no~~ scaling and no distortion such as shear can be applied or accounted for.

Rotation and translation of a 2-D rigid body can be described in a simple 3 x 3 matrix as shown in figure 4.[1,2] The sine and cosine elements control pattern rotation while the X0 and Y0 elements control the magnitude and direction of translation.

$$\begin{bmatrix} \cos\Theta & -\sin\Theta & X_0 \\ \sin\Theta & \cos\Theta & Y_0 \\ 0.0 & 0.0 & 1.0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ 1.0 \end{bmatrix} = \begin{bmatrix} X_{new} \\ Y_{new} \\ 1.0 \end{bmatrix}$$

Figure 4: Rigid body rotation transformation matrix

By extension, the new positions (X_{new}, Y_{new}) can be calculated by the following equations:

$$X_{new} = X * \cos\Theta - Y * \sin\Theta + X_0 \qquad (eq.1)$$
$$Y_{new} = X * \sin\Theta + Y * \cos\Theta + Y_0 \qquad (eq.2)$$

Image Acquisition

The success of this analytical method relies on a robust image acquisition system. Images are captured using a line scan camera with resolution down to 1 micron per pixel. A line-scan camera was selected since it allows for the acquisition of a single, non-stitched, high-resolution image of a large area at high magnification.[3] Line scan cameras use a single row of sensors when capturing an image. A 2-D image is scanned in row by row as the sample is moved under the camera. Obviously, successful image capture requires careful synchronization between the motion of the sample and the image capture frequency of the camera. The system has a very capable motion control mechanism that is perfectly synchronized with the camera exposure frequency via a coupled encoder. If the system was not perfectly synchronized, the image capture process itself could result in the appearance of errant dot placement errors. Diagrams of the effects of some of the possible variations due to image capture motion control are shown in figure 5.

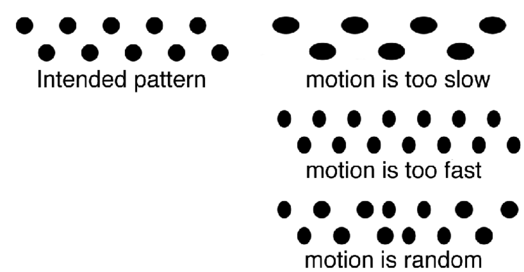

Figure 5: Dot Aspect Ratio and Spacing Deformation Due to Inadequate Motion Control

Using a well-synchronized line-scan camera for image capture results in undistorted, seamless images of large areas at high magnification.

The benefits of using a line scan camera over a 2-D CCD camera are myriad. Systems that rely on using a 2-D CCD array camera face a variety of challenges. The captured image size is fixed and limited by the size of the sensor array. For high magnification evaluation of large areas, only small portions of the entire area can be imaged at once using the 2-D camera. In order to image a larger area or swath, the camera needs to take a series of adjacent images across the sample surface. These individual images are then stitched together to create one aggregate image. This aggregate image is then used for assessment of the dot field.

The "step and repeat" process of moving each sample a discrete distance that corresponds to the field of view of the sensor, taking an image, moving the sample, taking an image and repeating this process across a large area or swath can be quite time consuming. This process is also fraught with several potential sources of error such as focus (Figure 6a), illumination, (figure 6b) and motion control (image-to-image placement) (figure 6c), all of which can adversely effect the quality of the aggregate image.

Figure 6a: Focus

Figure 6b: Illumination

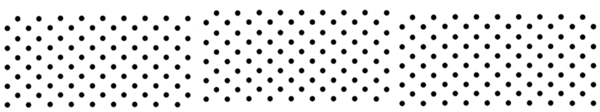

Figure 6c: Image-to-image alignment (stitching)

Using a line scan camera system allows for more control over illumination uniformity, better focus control, and avoids the need for image stitching and all of the potential errors that might result.

Image Analysis

Once the image has been captured, several steps are necessary to complete the analysis. First, the image needs to be registered to the intended pattern. Rigid body rotation is used for this alignment process. Next, the errors between the actual location of each dot compared with its intended position must be determined and reported.

To fully automate this analytical process, the image acquisition hardware is integrated with a powerful, commercially available image analysis package, ImageXpert™. Built-in functions exist for calculating the coefficients used in the transformation matrices between two data sets based on simple mathematical relationships. This allows for the dot pattern alignment that is necessary for error calculation.

To calculate the error in dot locations, actual dot centroids are compared with intended dot centroids. Error calculation can occur on a dot by dot basis or the accumulated error can be calculated for the entire pattern depending on the needs of the customer.

System Flexibility

One of the major benefits of this proposed method is its flexibility. This approach is appropriate for patterns that are nominally regularly spaced such as ink jet nozzle test patterns, and amplitude modulated halftone patterns. However, it is equally applicable to any pattern where a priori knowledge of the intended pattern exists. For example, the success of many frequency-modulated halftone pattern designs relies on careful dot placement for minimal visibility. The printed pattern can be assessed against the intended pattern for system diagnostics during the development process. In addition, dot placement accuracy in halfoning schemes that include multiple dot sizes in addition to spatial modulation can be assessed using this method.

Alternative Pattern Matching Methods

Other potential methods of pattern matching exist. Alternative methods include correlation, wavelet decomposition and neural network-based pattern searching. The image analysis software package that was used by the researchers included methods for both rigid body rotation and correlation. Correlation was dismissed immediately due to the computation and memory intensive nature of the method. Not only would full-size templates need to be created either on the fly or created before the analysis and then saved in memory for each angular search, the image buffer itself would need to be enlarged at least 2X to accommodate the required search parameters. Since the images that are most often used in this type of analysis are large (typically 10-30 Mbytes), the memory requirements for correlation analysis would be considerable. As a result, both the processing time and memory constraints make this method too prohibitive to be considered viable.

Conclusion

This method of measuring large fields of image features at high magnification is not without precedent. ImageXpert based line scam camera systems are currently in use for part inspection for inkjet manufacturers. Rigid body rotation transformation methods have long been applied to part inspection and robotics. Feasibility studies of applying this approach to a variety of real-life images and samples are currently underway.

References

1. *RAIL Library Reference*, v8.21, 1994
2. Richard P. Paul, *Robot Manipulators: Mathematics, programming and control*, MIT press, 1981
3. Yair Kipman and Scott Cole, *Test & Measurement World*, October, 1998 pp. 19-24

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Biography

Mr. Kipman is the founder and president of ImageXpert Inc. (formerly known as KDY Inc.), an industry leader in automated image quality inspection systems. Prior to founding ImageXpert in 1989, Mr. Kipman worked at Xerox for six years where he developed an optical scanner that was the basis for an automatic reading device for the visually impaired. Mr. Kipman holds a M.S. in mechanical engineering, with a major in electro-optics from the University of Connecticut and a B.S. from the Technion Institute of Technology.