

Test Target Design Considerations for Automated Image Quality Analysis of Samples Subject to Distortion

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Abstract

Measuring image quality automatically requires that feature locations be known and predictable. This predictability is necessary for successful application of both large field of view, low magnification image analysis (such as mottle) and small field of view, high magnification image analysis (such as line and dot quality) in a machine-vision based system. Variations in sample placement and in the registration of images on the samples produce systematic errors in absolute feature locations that require compensation.

Compensation for systematic image placement errors is straightforward. Macroscopic image or sample placement variations can be corrected automatically by using a large field of view camera and an image offset calculation. However, even after the macroscopic image placement correction has taken place, microscopic position variations can still exist. These variations can wreak havoc with high magnification measurements that rely on specific region of interest placement on specific features within the field of view. In some cases, dynamic location can be used for small adjustments within the field of view of the high magnification camera. This combination of macro and micro adjustment works well for most samples where absolute or relative feature positions are known.

Difficulties arise when positional variations of features are not systematic or rectilinear. Certain types of samples are susceptible to local or global deformation, which can change the relative position of features. For example, cockled paper, or ink jet samples with highly saturated areas are prone to local deformations, while textiles exhibit major topological variations as well as global deformations that result in non-rectilinear distortions caused by the fabric weave. Although topological variations in samples printed on paper and other paper-like substrates can be largely compensated for through the use of a strong vacuum to hold a sample flat, there are residual, non-systematic positional changes of features that can interfere with traditional automated measurement techniques.

This paper will present a series of specific test target design considerations and testing methods that can be used to enable automated image quality measurement of distorted image samples.

Introduction

The goal of automated image quality analysis is to repeatably and reliably measure image attributes with minimal need for operator intervention. In order to achieve this capability, there are many things that need to be taken into account. System set-up and target design can support or greatly inhibit the possibility for robust automated measurements. Successful image quality measurement requires a system level approach. This includes an honest assessment of measurement system limitations and capabilities, and the application of appropriate test target features and attributes. Robust measurement design will be quite dependent on what system level options are available to the user, and how much input the user has on target design.

Definitions

In discussing test target design and automated measurement methods, there are a few terms whose definitions are fundamental to understanding the overall approach.

Fiducial: A unique feature or set of features on a test target whose position is known relative to the features to be measured.

Dynamic Offset: Typically uses a large field of view camera to locate a fiducial and calculate its actual position relative to its expected position. This offset value is then applied to vision guided table motion to account for macroscopic positional changes in the image or sample. In some cases a higher magnification camera is used for a second offset calculation to further fine tune positioning accuracy.

Dynamic Location: Adjusts measurement locations within a single field of view according to the position of a fiducial (or set of fiducials). Measurement locations (regions of interest, or "ROIs") can be dynamically located via translation or via rectilinear offset and angular displacement.

Caveat

Sometimes the types and magnitudes of the distortions themselves are the desired quantifiable entity. More often, it is other image quality elements such as line quality or dot quality that are being quantified. The presence of distortions can change image content. When distortions are present, decisions need to be made about whether the resultant data of a given measurement will be legitimate and meaningful. It is simple to create data, but creating meaningful data is much more challenging and demands much more deliberate choice making during the test target and analytical method design and application process.

The examples included in this paper presuppose that any application of methods included in this text would be based on deliberate decisions regarding their appropri-ateness. For example, although there are certainly methods that can be applied that allow line width measurement on distorted image samples, the distortion itself may be adding a large source of error into the measurement result. This can have an undesired and perhaps unanticipated impact on analytical conclusions.

Global vs. Local Distortions

Global distortions affect the overall image placement. Registration and skew are two examples of "global" distortions. These sorts of distortions are relatively easy to overcome using simple, straightforward methods.

Making an image offset measurement of a fiducial can compensate for registration errors. The offset of the actual position of the element from the expected position can be calculated and applied to all subsequent measurement positions. Macroscopic corrections are possible using a wide field of view camera.

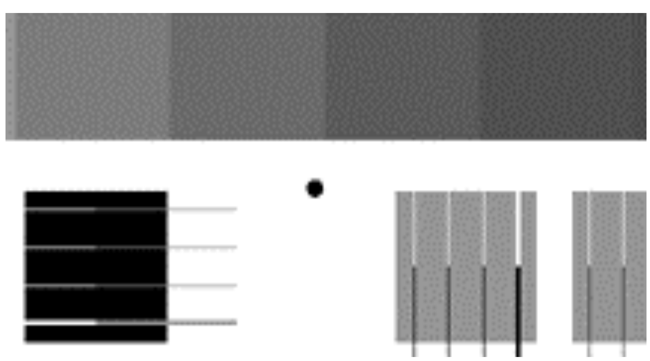

Figure 1. Fiducial in expected position in the center of the field of view

Figure 1 shows a dot in the center of a field of view. The dot is an appropriate choice as a fiducial since it is a unique feature, robust to changes in illumination, and a machine-vision based system will be able to identify it easily.

Figure 2 shows the same fiducial in an offset position. The measurement system will find the current location and calculate the difference between the actual location and the expected location. This offset will be applied to all positions thereby correcting for the mis-registration.

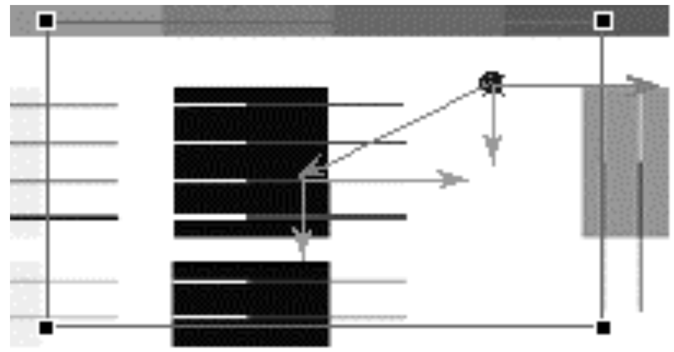

Figure 2. Fiducial in offset position

Since each pixel of a low magnification camera corresponds to a relatively large area, some positional error may still exist after the first iteration of the offset calculation. Finer tuning can be achieved by performing an additional offset calculation using a second, higher magnification camera to measure and correct for the residual position error of the same fiducial. This is shown in Fig. 3.

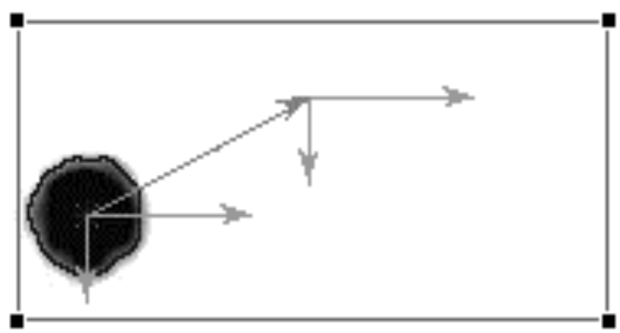

Figure 3.High magnification residual offset calculation

The goal of offset calculation and application is to guarantee that a specific field of view contains the image element or elements of interest for a specific analytical task. Often, even after macroscopic offset and even fine-tuning, elements are contained within a field of view but are not necessarily in the exact position expected by the software. This can result in errant measurement values, or failed measurements even when the element is present and perfectly measurable. In automated systems it is necessary to create methods for correcting these positional variations in order to insure against erroneous data and to minimize the need for operator intervention.

Global skew can be compensated for through the use of an angular rotation stage (also known as a Θ-stage). A line could be measured to determine the angular error, and this result could be fed to a motion controller coupled to the Θ-stage that would then physically correct for the angle prior to any further image analysis. If a mechanical rotation stage is not available, skew can also be corrected for mathematically although this is discouraged. Mathematical skew correction in the image buffer can lead to a variety of changes in the image itself that will affect the outcome of any measurements that rely on unadulterated edge data. So, as is the case for all image pre-processing, mathematical rotation should be applied judiciously. Minor amounts of skew may not require correction. In many systems skew can be accommodated for through choice of measurement methodologies, since some measurement techniques are more robust than others for samples exhibiting minor amounts of skew.

Local distortions may be very systematic (i.e.: residual offset errors may result in a small translation from the ideal location) or they may be much more complicated and difficult to compensate for. The next section addresses some types of local distortion measurement approaches.

Local Distortion

Local Skew

The most effective test target design is based on *a priori* knowledge of just how a given sample might be distorted. For example, if a sample is prone to local skew, test targets should include fiducials that allow dynamic locators to be created and placed to capture local rotation and accommodate for it. Fiducials need to be within the same field of view as the feature to be measured and they have to be designed (or chosen) such that they are not likely to change position relative to the feature that is to be measured. Figure 4a shows a target commonly used to measure bleed and wicking on ink jet prints. 1, 2, 4 and 8 pixel lines are partially superimposed on a solid color background. Line widths are measured for each of the lines both on and off the color block and the difference between the line widths is indicative of the magnitude of bleed between the colors. The line edge quality of the lines measured off of the color background (on paper) can indicate the magnitude of wicking or feathering. In order to characterize these attributes, eight measurement ROIs are defined, two for each line.

ROI placement is critical to the success and validity of the measurement results. Although in this case the ROIs have been sized such that some angular variations will be accounted for, there are many cases when distortion will result in features falling outside of the ROI. Two dynamic locators can be set up to measure feature translation and rotation and the measurement ROIs will be moved according to the relative positions of the locators. The two locators can be seen along the top edge and along the left edge of the feature. Figure 4a shows an un-rotated image, while Figures 4b and 4c show significantly rotated images. The dotted lines show the locations of the ROIs after dynamic location has taken place. As the figures show, the use of a single pair of dynamic locators works quite well in maintaining the desired relationship between the ROIs and the features to be measured.

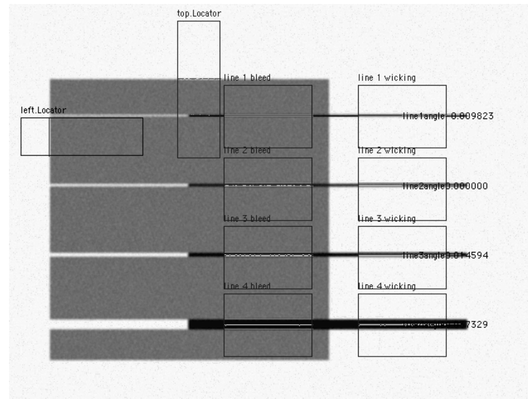

Figure 4a. Ideal, undistorted sample showing intended ROI positions

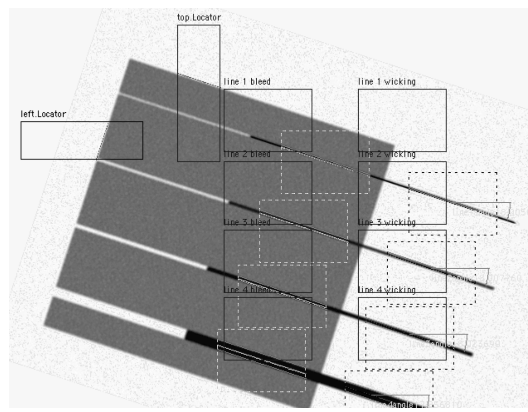

Figure 4b. image with 18 degree rotation

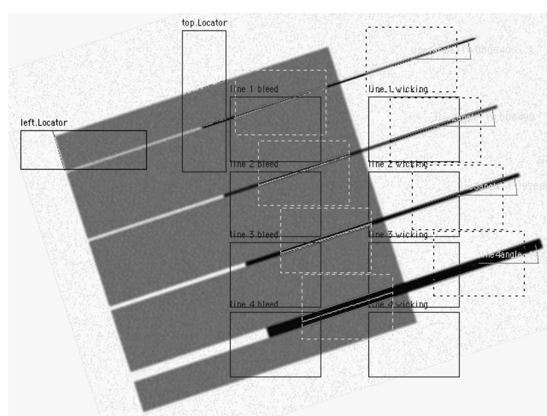

Figure 4c. -18 degree rotation

Simple local rotation correction using a single pair of dynamic locators can compensate for the distortion seen in Figures 4b and 4c, but it would be inadequate when trying to account for more complicated directional and angular deformations.

Compound Angular Distortion

Figure 5 shows a type of distortion that cannot be compensated for by the simple, single application of dynamic location for the entire local area.

In the more complicated distortion case shown in Figure 5a, line quality measurements are certainly still possible, but the measurement process would need to be parsed such that each pair of measurement ROIs would have dynamic locators that act independently. Figure 5b shows one step in this process. Dynamic locators are placed such that their orientation is related to the orientation of the elements to be measured. The lines found by the dynamic locators indicate both a local translation and angular displacement and the measurement ROIs are re-located accordingly. The dotted lines show the new locations of the measurement ROIs after dynamic location. The solid lines indicate where the measurement ROIs would have been located if dynamic location had not been applied.

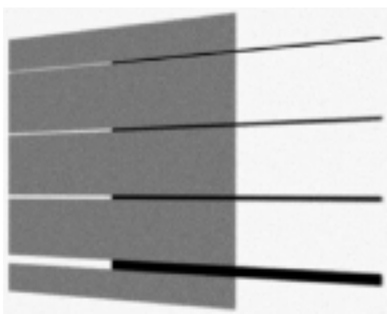

Figure 5a. compound angular distortion

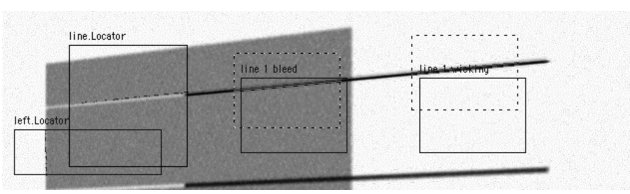

Figure5b. ROI and dynamic locator placement for top line of line array for bleed measurement

To fully characterize the line bleed and wicking for all four lines (as shown in Figure 4), similar steps would need to be repeated for each of the remaining pairs of measurement ROIs. Local dynamic locators would need to be positioned for each remaining line and locations of measurement ROIs would be adjusted automatically based on the translation and rotation information from the locators.

Additional Distortion Types

Since there are many types of image distortions that are more complicated and less well behaved than the ones shown in the previous examples, fiducials sometimes need to be added during test target design to assist in dynamic location. In addition, test target designs may need to be modified to facilitate the use of specific automated image analysis systems depending on their capabilities and limitations. For example, designing targets with lines that are farther apart may help the system to correctly identify and measure the desired attribute.

Choosing Appropriate Measurement Methodologies

Different measurement methods have different levels of sensitivity to the effects of distortions. For example, there are several methods of quantifying line width. One method assumes that the line is well aligned with the rows and columns of the CCD camera. Line widths are calculated along rows or across columns and are averaged together. If the line is rotated, this approach fails since it will result in falsely inflated line width values. Choosing a more robust line width measurement that operates orthogonally with respect to the orientation of the edges would be a better choice if line rotation were a possibility. Two methods are shown in Figure 6.

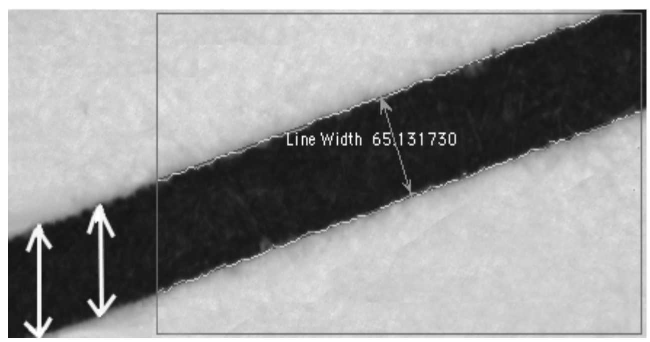

Figure 6. Measuring line width of a rotated line

Conclusion

Many types of distortions can be compensated for if they are anticipated with appropriate target design features and if the specific measurement system being used is sufficiently flexible.

Biography

Kate Johnson received her BS in Imaging Science and ME in Systems Engineering from RIT. She has worked in the field of image quality since 1992, spending over four years at Xerox Corporation as an image quality integration engineer. After leaving Xerox, Kate worked for Tally Printer Corporation in Kent, Washington supporting color product development. In early 1998, she joined KDY Inc. in Nashua, New Hampshire as an imaging scientist.