by Russ Hudyma

IMPROVEMENTS IN MACHINE VISION ACCURACY WITH ACTIVE LENS/SENSOR ALIGNMENT

MOTIVATION

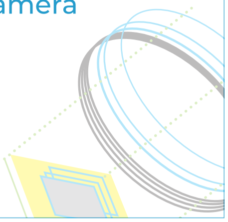
Machine Vision (MV) is a technology used to provide image-based automatic inspection, process control, security function, robotic guidance, or vehicle guidance in a variety of industries or applications. A machine vision system usually consists of an optical module and camera module designed to capture an image for subsequent processing in a computer vision algorithm. The information extracted from this algorithm can be a simple good-bad/bad-part signal, or a more complex feature set such as the identity, position, and orientation of each object within an image.

Navitar has become increasingly involved in the field of active lens/sensor alignment. This process is well documented, understood, and deployed in the automotive and mobile phone industries. In these fields, automated robotic work cells are used to optimally align CMOS global shutter sensors packages to mating optical assemblies in order to maximize MTF thru-focus at a particular spatial frequency. What is less understood, however, is the need to actively align camera assemblies to their mating optics in the field of machine vision for high-end inspection. One use case at Navitar is the support of HDI (high density interconnect) printed circuit board inspection. The HDI PCB is defined as a PCB with higher wiring density per unit area than a conventional PCB. They have finer lines and spaces, smaller vias and capture pads, and higher connection pad density than employed in conventional PCB technology. HDI PCB is used to reduce size and weight, as well as to enhance electrical performance of the device. The technology has found its way into personal computers, laptop computers, mobile phones, and game consoles.

BENEFITS OF ACTIVE SENSOR ALIGNMENT

There are three factors that drive the need for active lens/camera alignment in modern metrology systems, those being:

1. Basic lens field tilt
2. Field curvature
3. Errors in the placement of the camera sensor chip relative to the camera housing/camera mount.



There are three factors that drive the need for active lens/camera alignment in modern metrology systems, those being: (1) basic lens field tilt; (2) field curvature; and (3) errors in the placement of the camera sensor chip relative to the camera housing/camera mount. This aggregate tilt/place error can be as large as 0.25 degrees (±50 microns of sensor runout). Clearly the performance of the vision system will be severely degraded with this amount of runout and will result in a substandard data product. Errors of this magnitude are possible based on the placement of the sensor on the ball grid array, misalignment of a mechanical lens flange, and positioning of the sensor board in the camera housing, as well as the aforementioned field curvature of the lens.

These three factors combined degrade the ability of a metrology system to accurately measure and report

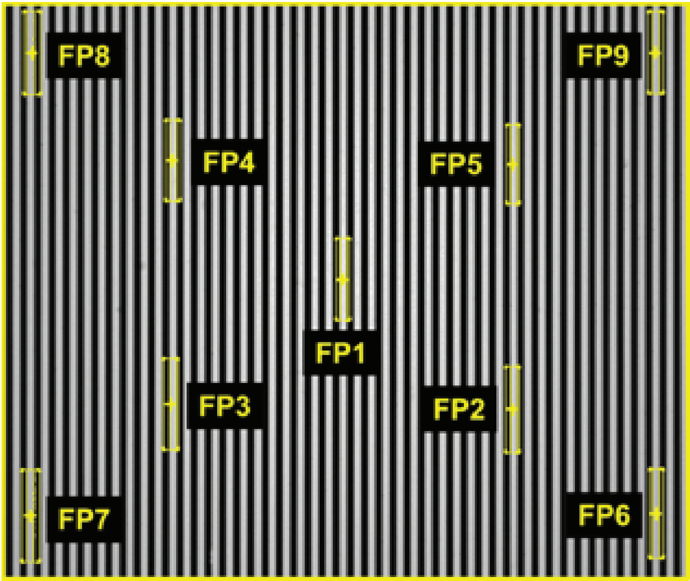


Figure 1. Standard alignment image 12X Zoom with 2/3” format camera.

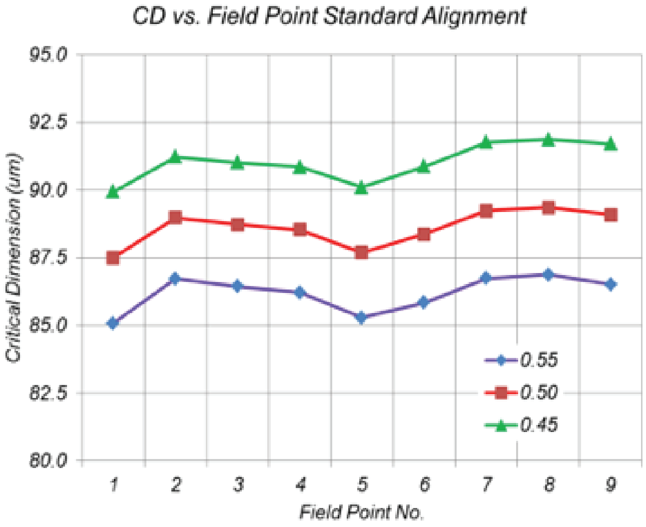


Figure 2. Variation of CD vs. field position standard alignment.

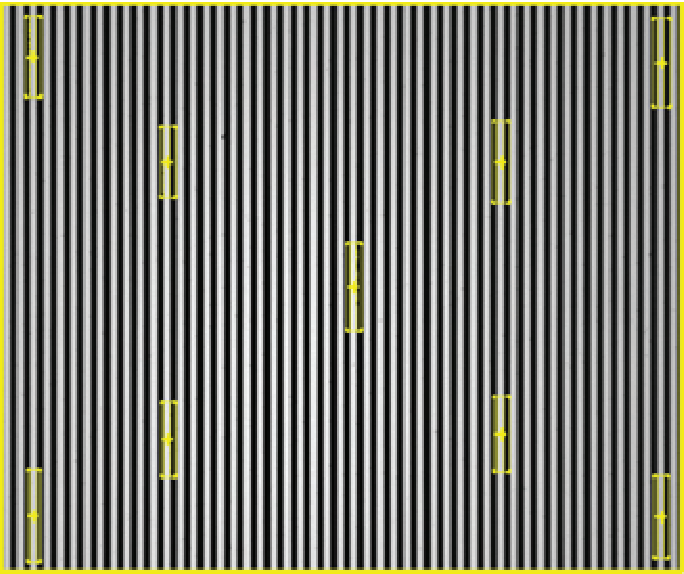


Figure 3. Precision alignment image 12X Zoom with 2/3” format camera.

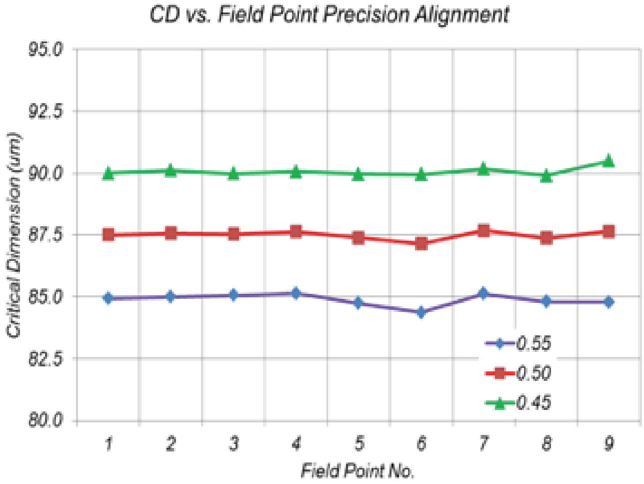


Figure 4. Variation of CD vs. field position precision alignment.

the critical dimension (CD) of an object field even after these errors have been “calibrated” out. Further, these errors force the camera/lens/computer vision system to report variations of the measured CD across the field of view which we label the “delta-CD” (ΔCD).

This CD error and corresponding ΔCD variation is being exacerbated by machine vision applications that adopt 4K CMOS sensor technology with a 1” sensor format (17.6mm sensor diagonal). High end machine vision systems are shifting to high quality, high dynamic range sensors that achieve fast frame rates and use global shutter to capture large frame images. Higher frame rates result in increased throughput without the distortion effects seen when using a more traditional tailing edge rolling shutter sensors. In addition, these new global shutter sensors use larger pixel sizes than consumer cameras (e.g., 3.45μm vs. 1.25 μm), meaning the sensor size increases as the resolution of the sensor is increased.

This greater sensor area allows for a much larger inspection region and drastically improves the throughput achievable with smaller sensors.

As an example, let's consider the creation and qualification of a machine vision system (lens module + camera + computer vision algorithms) designed to support the inspection of 75μm (3 mil) traces and spaces on an HDI PCB over an 8.8mm x 6.6mm image field. The system is constructed using a standard Navitar 12X Zoom machine vision optical module coupled to a 2/3" format camera with Sony's IMX250 sensor, Summit Lithography Analysis Software for back-end image processing and analysis, supported by internal MATLAB code to process images. The camera package includes a global shutter function that eliminates focal plane distortion as a result of rolling shutter artifacts, small 3.45μm pixels that realize higher sensitivity and low noise, high frame rates, external triggering, and ROI processing. To simulate the HDI interconnects, a back-light surrogate target consisting of a lithographically mastered 87.5μm lines and spaces (e.g., linewidth to space width or pitch of 1:1) are used.

Figure 1 illustrates the post-processed image of 87.5μm L/S pattern using our 12X Zoom coupled to a 2/3" format camera via the standard C-mount coupling kit. The critical dimension of the lines is analyzed in an "X" pattern at 9 field points across the 2/3" format of the camera. The variation of critical dimension is depicted in Figure 2, which shows the CD as a function of three different threshold values used to extract the image CD. A threshold value of 0.5 corresponds to an image width of 87.5 at field point 1 (FP1) which is located at the center of the metrology field. As we move thru the metrology field extracting the CD at that threshold value, we find a variation in linewidth of 1.85μm, or 2.1% of the known value. The assessment is that "out of the box" lens-to-camera alignment via the standard c-mount induces a metrology error of up to 2.1% in our knowledge of the CD across the metrology field. Figure 3 illustrates the post-processed image of 87.5μm L/S pattern using our 12X Zoom coupled to a 2/3" format camera using our precision alignment process. In this case, the camera assembly is actively adjusted in tip, tilt, and focus (dα, dβ, dz). These motions are compensators used to actively remove the relative two-dimensional field tilt between the optical axis of the lens module and the normal to the CMOS sensor surface. In addition, the dz-motion or focus compensation is applied across the entire metrology field in such a way as to minimize the variation in linewidth within a range of image threshold values. The resulting variation of critical dimension post alignment is depicted in Figure 4, which shows the CD as a function of three different threshold values used to extract the image CD. With the precision alignment, the ΔCD is reduced from 1.85μm to 0.54μm, or 0.6% of the known value. The technical assessment in this case is that the ΔCD across the metrology field, or equivalently, the system error, is reduced by a factor of 3x using precision lens-to-sensor alignment.

CONCLUSIONS

By actively aligning the camera assembly to better sample the aerial image formed by the optics module, we can achieve a 3x improvement in the accuracy in measured CD such that the residual metrology error is reduced to 0.6%. In linear terms, the variation in CD across the metrology field is reduced from 1.85μm to 0.54μm. We have performed a larger study across a range of features (rectangles, squares, circles) and measurement conditions (variations in threshold, variations in focus, etc.) and find that a similar analysis demonstrates that the measurement accuracy is typically improved by a factor of 2x to 4x without the use of complex calibration schemes. We acknowledge that for most inspection paradigms error levels of ~2% "out of the box" are acceptable; but point to the fact that for critical metrology applications, active alignment can be used to drive accuracy to even higher levels.