Linearity Studies of CMOS Image Sensors

Guadalupe Duran, James Bensinger, Kevan Hashemi

Martin A. Fisher School of Physics, Brandeis University, Waltham, Ma

Introduction

The Brandeis high energy physics group provides an alignment system for the endcaps of the muon detectors at ATLAS. An essential instrument we use in the alignment system is the Brandeis CCD Angle Monitor (BCAM), which is designed to monitor the geometry of large structures. This work focuses on studying two CMOS image sensors, the Omnivision OV5647 and the Sony IMX219, for potential use in BCAMs. This will require that the CMOS sensors take clear, uniform images. It also requires that the CMOS image sensor is spatially linear, and that the standard deviation of images taken across the field of view is less than 0.5µm.

Background and Motivation

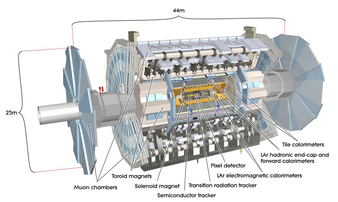

Figure 1: Diagram of the full Atlas detector(1)

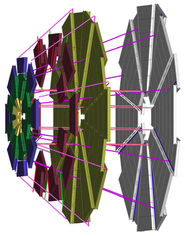

Figure 2: Detailed image of the muon chambers

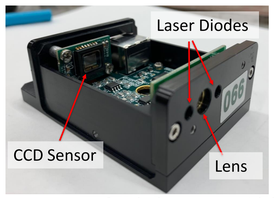

Figure 3: Image of a Black N-BCAM with lid removed

ATLAS is one of four experiments at the Large Hadron Collider (LHC) at CERN built to test the predictions of the Standard Model. Brandeis provides an alignment system for the muon detectors which uses BCAMs to monitor the geometry of the endcaps. BCAMs consist of at least one camera and two laser diodes which are used to monitor other BCAMs in its field of view. Thus, a BCAM can detect the movement of other BCAMs and can resolve the relative change in location of a point source to an accuracy of 5 microradians. They can also resolve the absolute location of a point source to an accuracy of 50 microradians (1). As the name states, BCAMs utilize a CCD image sensor, specifically the Sony ICX424. However, these CCDs are no longer being manufactured so our group is looking for another type of image sensor so that the alignment system may continue to work for years to come.

Methods

We measured the linearity of an image sensor by moving a laser across its field of view with a micrometer stage and plotting the image position vs stage position. The residuals from a straight line fit for the image position is the non-linearity of the camera with respect to translation of the source (1).

For this experiment we used a motorized stage that is precise to ±1µm and linear to better than 100ppm (1).

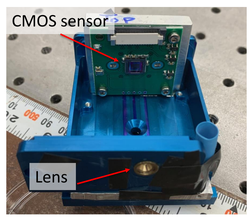

Figure 4: Test apparatus for a CMOS image sensor using a BCAM lens

Linearity Tests: Sony ICX424 CCD

The Sony ICX424 CCD is a solid-state image sensor with 7.4µm² pixels.

Full Field of View 0.5mm Tests

The first linearity tests we performed were on the image sensors currently used in BCAMs, the Sony ICX424 CCD. From about a meter away we moved two laser sources across the field of view in 0.5mm increments. The standard deviation was 0.31µm.

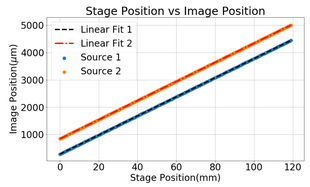

Figure 5: Graph of stage position vs Image position with a linear fit

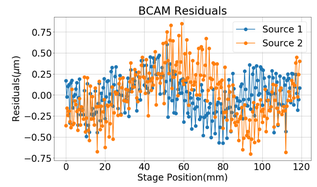

Figure 6: Graph of the residuals across the entire FOV for a BCAM

10um Tests and Cyclic Errors

We then performed a test where we moved the sources in 10µm steps. We saw two oscillations in the residuals. The first, with a higher frequency, we determined results from the light spot moving across one pixel. The second is due to the screw moving the stage.

Figure 7: Graph of the residuals for the 10µm test depicting 2 cyclic errors

Figure 8: Graph of the first 100 points of the 10 µm test, depicting errors occurring over every 1-pixel.

Linearity Tests: Omnivision OV5647

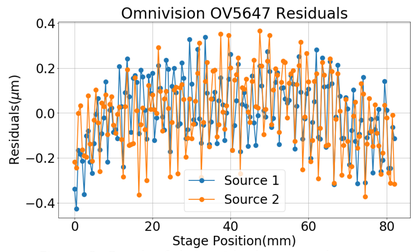

Figure 9: Graph of the residuals across the entire FOV for the Omnivision OV5647

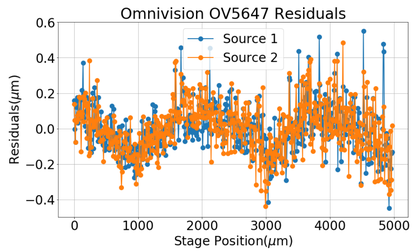

Figure 10: Graph of the residuals for the 10 µm test

The Omnivision OV5647 is a back lit CMOS image sensor with 1µm² pixels(5).

Full Field of View 0.5mm Tests

There is a slight parabolic shape to the residuals across the field of view, this is consistent with the sensor being mounted at some angle with respect to the plane perpendicular to the camera axis(1).

Standard Deviation: 0.17µm

10 µm Tests

We observed the cyclic error due to the micrometer stage, however we did not observe a 1-pixel oscillation with a 10µm step size at a distance of 1.3m.

Standard Deviation: 0.14µm

Linearity Tests: Sony IMX219 CMOS

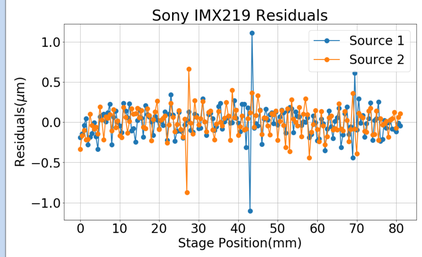

Figure 11: Residuals across the entire FOV for the Sony IMX219 CMOS

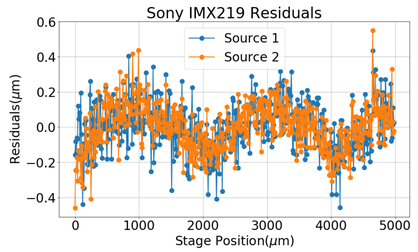

Figure 11: Graph of residuals for the 10 µm test

The Sony IMX219 is a back lit CMOS image sensor with 1.12µm² pixels(4).

Full Field of View 0.5mm Tests

For the Sony IMX219, we do not see any well-defined shape in the residuals.

Standard deviation: 0.20µm

10 µm Tests

In Figure 11 we observe 2.5 periods of the oscillating error that results from the micrometer stage. We do not observe a 1-pixel oscillation.

Standard deviation: 0.14 µm

Conclusions

Both the Omnivision OV5647 and the Sony IMX219 CMOS sensors have good linearity. The standard deviation of the residuals for the Omnivision OV5647 was 0.17µm and for the Sony IMX219 was 0.20µm. These are both below the limit of 0.5µm necessary. Both CMOS sensors also out perform the Sony ICX424 CCD in terms of linearity. For while we saw a 1-pixel variation with the CCD, we did not see this either CMOS sensor, due to their smaller pixel size. Thus far both the Omnivision OV5647 and Sony IMX219 CMOS sensors appear to be suitable for future use in BCAMs.

Future work to be done will focus on how binning the images to smaller resolutions will affect the linearity of the sensors. This is necessary because reading out the images at full resolution is time intensive.

References

[1] “Detector & Technology.” *ATLAS Experiment at CERN*, CERN, 2 Aug. 2017, atlas.cern/discover/detector.
[2] Hashemi, Kevan. “BCAM User Manuel.” *BCAM User Manual*, Brandeis University, 2019, alignment.hep.brandeis.edu/Devices/BCAM/User_Manual.html
[3] Hashemi, Kevan. “Stage Controller (A2060M) Manual.” *Brandeis University High Energy Physics Electronics Shop*, 2014, alignment.hep.brandeis.edu/Electronics/A2060/M2060M.html
[4] “IMX219PQH5-C.” *Sony*, publiclab.org/system/images/photos/000/023/294/original /RASPBERRY_PI_CAMERA_V2_DATASHEET_IMX219PQH5_7.0.0_Datasheet_XXX.PDF.
[5] “OV5647 Datasheet.” *Omnivision*, cdn.sparkfun.com/datasheets/Dev/RaspberryPi/ov5647_full.pdf

Acknowledgments

This material is based upon work supported by the US ATLAS Summer Undergraduate Program for Exceptional Researchers 2019 grant.

Contact information: glduran@brandeis.edu