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A Totally Transparent Alignment Sensor

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We describe the development of a totally transparent CCD based optical beam position sensing device that can measure transverse displacements with an accuracy of a few microns at a distance of many meters. The device includes on sensor DSP processing of the signal spectra with background subtraction and calibration to produce a compressed beam position, sensor address/status readout in token serial strings of sensors. The position monitoring system for the CMS Endcap Muon detector is presented as an intended application.

1. INTRODUCTION

In the CMS Detector for the Large Hadron Collider (LHC) , position monitoring of Endcap Muon detector elements will be done relative to laser beams which cross the CMS barrel for linking to the Central tracker/barrel muon systems. These lines couple to laser beam straight line monitors across Endcap Cathode Strip chamber layers.[1] We have been testing ATLAS (LHC) - Max Planck Institute aSi:H transparent silicon photodiode detectors on a glass substrate for use in these laser straight line monitors.[2] However, upstream detectors impact downstream detectors.

It is ideal to have detectors with minimum interactions and independent laser beam sampling with
 a large dynamic range using standard technology with well defined costs. The concept of a window frame CCD detector was proposed by J. C. Gayde (CERN Geodesy). [3] We developed a prototype window CCD sensor and electronics board (COPS) with serial digital readout of each of the pixels of linear CCD arrays in groups of 1, 2, or 4. We wanted to study ambient light background filtering, dark current vs exposure, laser beamshape and stability requirements, detector linearity, resolution, signal processing, and the effect of window boundaries. [4]

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2. FIRST COPS DETECTOR

The detector consists of four CCD arrays (52 mm pitch] around an open window. These are struck by 90 degree crossed line laser beams as the X axis and Y axis. Two X, two Y CCDs provide redundancy of X, Y position measurement or torsion. The linear CCDs are 2048 14µm x 14µm pixel devices in a 22 pin DIP package with a 28.67mm range (Sony ILX503A). A crosshair laser diode module (SNF-501H-6705-10-5 Lasiris; Quebec, Canada) was used as the source for testing. It has a uniform line intensity adequate for the initial 6m test range. The sensor does double correlated sampling with the CCDs multiplexed into a 16 bit ADC. The readout electronics provides calibration, timing signals, control, and a two byte readout-drive onto a PC I/O bus. With low dark current, the pixel dark voltage is a linear function of pixel sequence plus a thermal term; $V = kN_{pix} + T_{exp}$ and the background is small with respect to the laser beam peak. P C signal processing consisted of measuring/subtracting laser off background from laser on data, applying a 300 count threshold to remove tail effects, then doing a center of gravity (mean) of the difference signal peak. Background ambient light is suppressed by a vinyl tape filter over the CCD windows. The linearity of the COPS (tape) readout as the sensor was moved on a X-Y micrometer stage @ 4m from the crosshair laser module has been measured. In ten measurement averaging /position point, the simple mean fit has an RMS uncertainty =3 µm. The linearity fit to resulting data points has an RMS uncertainty = 5 µm across the range of the CCDs. The long term stability uncertainty over days was measured to be 5 µm.[5] COPS test results inidcate that an on sensor digital signal processor version with a simple means fit to output the beam center position will provide a good definition of optical beam position.

3. DCOPS1 DETECTOR

Our plan was to develop an easy to use, serial output, low power device, with flexible software run in strings by a system controller (again with flexible software) using only a phone cable connection. This connection consists of a bi-directional differential data line (RS485), one primary supply voltage, and ground. The DCOPS1 sensor includes an Analog Devices digital signal processor (ADSP2103 (10Mhz)), a 32Kx8 flash EPROM, a 32Kx16 SRAM, a 12bit (10us) ADC, and a 12bit DAC, two RS485 transceivers (1.2Mbaud). It does DC-DC conversion from a +12V input into on board +9v CCD, +5v analog, and +3.3 V digital supplies. There is an on board temperature sensor. Power requirements are +12v @ 300 mW. The major power goes to the CCDs. Future ON/OFF gating of the CCDs can reduce power considerably. The on board DC-DC converters are inductive regulators. For operation in high B fields, these regulators can be replaced by charge pumps The detector size is 75mm x 225mm.

The analysis code in ADSP-2100 Assembler language is loaded in detector assembly and booted on power up. In initialization, a string of detectors are queried which results in the self assignment of unique addresses.

Serial commands are in two byte ASCII code plus one byte address.. The initialization command results in a [N] = (0-14) sequential echo from the near serial I/O driver of a detector plus a pass N+1 to the far I/O and next detector. The basic command is Send Processed Data; to an individual address or as a broadcast command to all detectors simultaneously, subaddress 15. Detectors respond in sequence with the command + its address word count(inc. raw data) status data, and data sets; where four beam position means are given in 8 bytes.

The algorithm of processing in the DST when it receives the command to read signal/find center of gravity is: COPS (front end) measures the signal spectra, the DSP performs calibration of the signal values (PC command), the DSP subtracts background as the background measured stored spectrum (MB command), the DSP does a simple mean calculation (one number/2 bytes each CCD chip), and then the DSP sends the word count (2 bytes), address/status (2 bytes), and 4 numbers (8 bytes); each detector in token sequence to the controller. End transmission is established by summed word count /(time-out). There are special commands and responses which include; MB: measure background spectrum, otherwise background = 0, PC: perform internal optical gain, SG: send gain values of the CCDs, SR: send Raw Data (external processing) + means, ER: error response.

Using a DSP software simulator, the program code has been tested on data buffers taken from the first test COPS board and demonstrated to yield the same fits as derived with the PC analysis. DCOPS1 was built and electronically tested.

4. DCOPS2 DETECTOR

We wanted to separate a fiducialized CCD sensor board from the electronics. This will allow for different CCD window configurations and minimize the space required for the sensor in our planned CMS application. Also we wanted a larger DSP (ADSP2185LKST) and serial software editing. Four DCOPS2 detectors are functional for tests and development. Calibration, linearity measurements, long term stability tests are being done at Northeastern University. Controller development will proceed at Fermilab.

5. CALIBRATION

Sensors can be calibrated using the CCD sensor board pin holes in a "standard" translation fixture. X, Y calibration of the CCD detectors (location, twist, pitch) themselves can be done with illuminated precision pinhole/slit masks. By using uniform illumination, we can measure the photo response/dark current levels to find "hot/dead pixels" and set pixel gain (size/shape) corrections; I. e., flat fielding of the CCDs.

6. CMS CONFIGURATION

Long straight line monitors with multiple DCOPS2 sensors have to avoid shadowing of downstream detectors by upstream detectors. This requires multiple window sizes and a minimum distance between detectors. This minimum distance can be greatly reduced by a rotation of the CCDs normal to the laser beam just at the edge of the window. A Lucite prism on the face of the CCDs under the mask allows illumination from both sides of the window. This scheme has been successfully tested on a prototype detector. [5]

A second issue is to produce a crossed laser line source adequate to work over 20-22m.Using lasers and cylindrical lenses, recent tests have demonstrated adequate intensity, stability, and line width (dynamic range) at a sensor 20m from the source. Figure 1 shows the raw signal spectra in the four CCDs. Figure 2 shows the stability of the difference of the fitted signal peak means for the horizontal (CCD1, CCD2) and vertical (CCD3, CCD4) over an extended test period and the signal amplitude (line) stability in the CCDs.
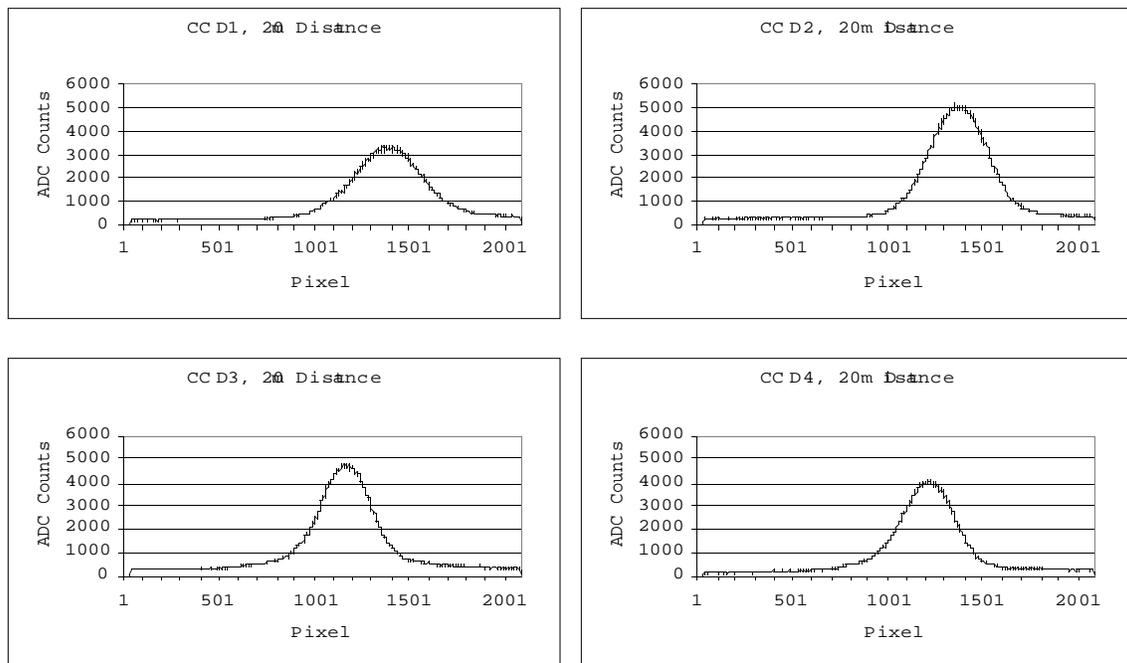

Figure 1. Raw Data Spectra in the four COPS CCDs with a crossed line laser source at 20m upstream.
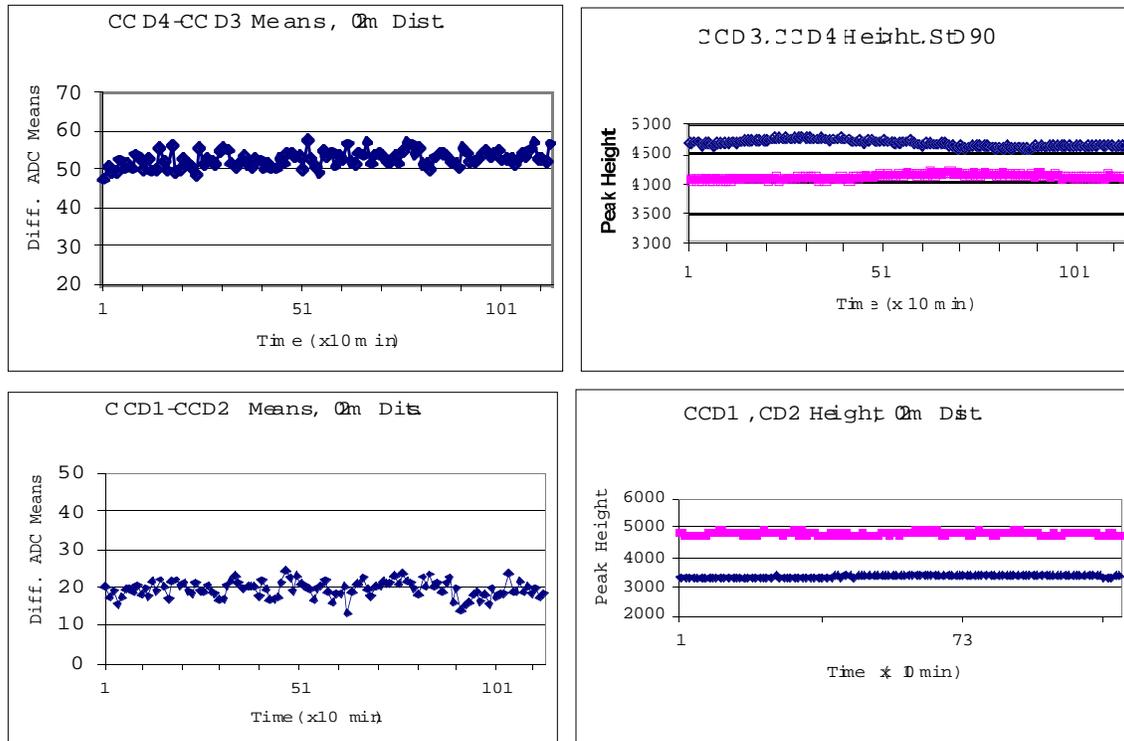
Figure 2. Stability of differences of fitted signal means and observed amplitudes in COPS CCDs at 20m.

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