Development and implementation of CCD based jitter sensor

S.K. Mishra\textsuperscript{a}, S. Mazumder\textsuperscript{b}, Vijayeta Gambhir\textsuperscript{b}, D.P. Ghai\textsuperscript{b} and M.N. Reddy\textsuperscript{c}

\textsuperscript{a}Instruments Research and Development Establishment, Dehradun-248008, INDIA
\textsuperscript{b}Laser Science and Technology Center, Metcalfe House, Delhi-110054, INDIA
\textsuperscript{c}G-FAST, DRDO HQ, Metcalfe House, Delhi-110054, INDIA

ABSTRACT

Quadrant detectors are widely used as position sensor for various applications like auto-tracking of missiles, high-speed moving targets, beam steering, alignment of industrial machinery, stabilization of beam jitter etc. A CCD based real-time position/jitter sensor was designed, developed and tested. Two different types of cameras were interfaced and tested for different applications. A visible camera of frame rate 25 Hz and another an IR camera of frame rate 30 Hz of video output PAL and RS-170 type respectively were interfaced. These cameras were interfaced and the jitter sensor was tested for the beam wander correction and jitter measurement of the GDL system installed on a vehicle respectively. The measured jitter was about 3 mrad and of 3-5 Hz bandwidth. The developed system was upgraded using monochrome 262 fps digital camera of format 532 × 516 and 8-bit digital resolution. The open loop bandwidth of this position sensor was tested as 60 Hz. A closed-loop Tip-tilt mirror system was also developed for the 80% jitter correction of 200 µrad up to 10 Hz bandwidth.

Keywords: Quadrant Detector (QD), Tip-tilt mirror (TTM), CCD camera, Frame-grabber card, Adaptive Optic System (AOS), Gas Dynamic Laser (GDL)

1. INTRODUCTION

The control of beam tilt, by itself, is important in any adaptive optic system. Babcock et al. showed in 1956 that tilt compensation alone could significantly improve an image. Modern AOSs have tilt control to stabilize the image or the transmitted beam and improve the signal for low order mode compensation. Resolved images on the quad cell can be used to determine wavefront tilt, if error due to object shape and signal to noise ratio (SNR) are neglected. The error in the angular measurement of the tilt for a circular object on a quad cell has been discussed by Tyler and Fried\textsuperscript{1}. The accuracy in the measurement of the angular jitter by QD is proportional to angular size of the image divided by the SNR associated with the detector. The exact value of the proportionality constant called position error constant is dependant on the normalized image size i.e. angular diameter of the image measured in units of angular resolution of telescope. This constant has different behavior in the two limits of very large and very small target size. When object is very small the constant is not a function of the image size. In case of very large object i.e. the object is clearly resolvable; the constant is proportional to the normalized image size.

With the advent of the CCD arrays, direct calculation of the centroid is possible. The error associated with these measurements and algorithms was studied by Grossman and Emmons\textsuperscript{2}. They derived an expression for the error that is a function of the detector geometry, the algorithm, the SNR, and array non-uniformity. Dow\textsuperscript{3} showed that the error is dependant on the noise and pixel-to-spot size ratio. For high resolution applications, in situations where the SNR is poor, a CCD camera in conjunction with auto-control Zoom lens can be used for imaging and jitter measurement. However, there is trade-off with the speed of measurement and the resolution. This problem has been solved to some extent by using high-speed camera and processing capabilities. Improvements in the bandwidth can also be made by using embedded processing board instead, PC based processing.

2. CCD BASED JITTER SENSOR

A CCD based real time jitter sensor was designed, developed and tested. It consists of a camera lens, a CCD camera and S/w for centroid processing. Image is focused on the center of the detector matrix. Depending on the image size region of interest (ROI) is selected to process the image in real-time. Image is processed for the centroid (X, Y), which is given by
Buffers Pool Created

ROI?

Grab Image, Put in Child Buffer & Buffer Count Incremented

Binaries Child Buffer & Calculate Centroid Based on Buffer Count

Get the Height, Width of the Child Buffer

Get no. of ROI & their Height & width of the Child Buffer

Create the Child Buffer Accordingly

Start

Create Buffer Pool

Buffers Pool Created

Get the Height, Width of the Child Buffer

ROI?

Create the Child Buffer Accordingly

Capture Thread

Analyze Thread

Display Thread

Grab Image, Put in Child Buffer & Buffer Count Incremented

Binaries Child Buffer & Calculate Centroid Based on Buffer Count

Get Processed Buffer Based on Buffer Count & Display

Stop

Get Height, Width of the Child Buffer

ROI?

Start

Create Buffer Pool

Buffers Pool Created

Get Height, Width of the Child Buffer

ROI?

Create the Child Buffer Accordingly

Capture Thread

Analyze Thread

Display Thread

Grab Image, Put in Child Buffer & Buffer Count Incremented

Binaries Child Buffer & Calculate Centroid Based on Buffer Count

Get Processed Buffer Based on Buffer Count & Display

Stop

2.1 Software (S/w) Development

The flow chart of the algorithm for the real-time processing is shown in Fig.(1). The whole buffer pool was divided into four parts so that at a time four frames could be stored. After that child buffers are created as per selected ROI. Out of that one buffer is accessed for the processing. Multithreading concept was implemented to enhance the processing speed. The process was divided into three threads capture, analyze and display the image as per child buffer. One integer variable was set for the buffer count so that all the child buffers should be processed and any frame should not get missed. A frame grabber card (COBRA/C6) was employed in one of the full length PCI local bus slot supporting master bus devices of an Industrial PC. The imaging board and its driver were installed in WinNT environment along with the real-time processing library for the development of the operation S/w. For the best performance and real-time acquisition the PCI bus clock was chosen as 132 MHz and in burst mode support. For processing Sapera library was used which takes a binary image for the centroid estimation therefore, first the captured child buffer was converted into binary image and then it was analyzed. S/w for jitter sensor was developed in VC++ and its front end GUI appears as shown in Fig.(4). Processing time for 200 × 200 pixel format was about 0.78 msec.

\[ \bar{r}_{cen} = X \hat{x} + Y \hat{y} = \frac{1}{i} \sum \sum x_i f(x_i, y_j) + \frac{1}{j} \sum \sum y_j f(x_i, y_j) \]

where \(i\) and \(j\) are the indices in \(x\) and \(y\) directions respectively. Here \(f(x_i, y_j)\) is the irradiance distribution function.

2.2 Testing and Application

Two different types of cameras were interfaced and tested for different applications. A visible camera of frame rate 25 Hz and another an IR camera of frame rate 30 Hz of video output PAL and RS170 type respectively were interfaced. These cameras were interfaced and the jitter sensor was tested for the beam wander correction and jitter measurement of the GDL system installed on a vehicle respectively. The specifications of the IR camera system used for the jitter measurement of the GDL beam are given Specifications (1). The results of the jitter for the X and Y displacements are shown in Fig.(2).
2.3 Upgradation of Jitter sensor

The same system was upgraded using monochrome 262 fps digital camera of format 532 × 516 and 8bit digital resolution. A high speed PIXI-D frame grabber was interfaced with the CCD to achieve the high-speed performance. In this case the imaging board and its driver was installed in Win-98 environment along with the XCLIB-2 real time processing library for the development of the real time operation S/w. The specifications of the high speed camera system used for the up gradation of the jitter sensor are given as Specifications (2). This jitter sensor was tested in open-loop and also in closed loop in a tip-tilt mirror system setup for the jitter correction. Testing results of the sensor for 15 Hz and 60Hz bandwidth are shown in Fig.(3).

3. RESULTS AND CONCLUSION

Jitter in the laser beam of GDL system installed on the vehicle is measured for a range of 60m. Y-component of centroid jitter is approximately 2.8 times more than that of the X-component. The measured jitter was about 3 mrad and of 3-5 Hz bandwidth. The open loop bandwidth of the upgraded position sensor was tested up to 60 Hz. A closed-loop TTM system was also developed for the 80% jitter correction of 200 μrad up to 10 Hz bandwidth. Also, a closed loop TTM system is designed for real-time image stabilization. We plan to undertake upgradation of the jitter sensor using 955 fps camera so that image jitter correction bandwidth could be achieved up to 100 Hz.
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*Email: sanjay_irde@yahoo.co.in, Phone: 91-135-2787392