LabVIEW Visualization For Inductive Sensors Used In Shaping Control of A Segmented Reflector Test Bed

ALOK DESAI, JESSICA ALVARENGA, HARSHIT TARSARIA, KHOSROW RAD,
HELEN R. BOUSSALIS
Department of Electrical Engineering
California State University, Los Angeles
5151 State University Drive, Los Angeles, California -90032
United States of America
alokdes1986@gmail.com, jalvare5@calstatela.edu, htarsaria@gmail.com, krad@calstatela.edu,
hboussa@calstatela.edu
http://www.calstatela.edu/

Abstract:- A large, segmented space telescope requires high precision and accuracy in its mirror shape to obtain clear images. In order for control of such complex structures to be achieved to high precision and accuracy, it is important for sensing equipment involved in shape control to be constantly checked for deviations from their required calibration. The Segmented Space Telescope Testbed at the Structures, Propulsion, and Control Engineering (SPACE) Laboratory at California State University, Los Angeles, utilizes segmented mirror panels and a network of 42 sensors to mimic a monolithic paraboloid mirror shape to high accuracy and precision. For such a high precision system, regular checking of sensor calibration is crucial to performance.

This paper describes a LabVIEW based visualization subsystem that has been implemented and used for sensor calibration of the SPACE Testbed. The subsystem allows for linearity check for each sensor. In addition, the visualization subsystem provides a real-time means of system monitoring. The visualization also reduces the time to check all 42 sensors while at the same time improve the precision and accuracy of the measurements. By reducing the time required, it is easier to verify sensor linearity at regular interval.

*Key-words:-*Sensor Calibration; Segmented telescope; Lab VIEW; Inductive Sensor

1 Introduction

With the increasing need to see further into space than can be achieved by current technology, such as the Hubble Telescope, it becomes necessary to increase the size of the primary mirror of a space telescope. However, there are several problems when increasing the size of the primary mirror. As mirror size increases, manufacturing a precise paraboloid mirror becomes more difficult. The size of a single monolithic primary mirror is restricted by the size and weight limitations of the current space launch vehicles. As the successor to the Hubble Space Telescope (HST), The National Aeronautics and Space Administration's (NASA) Next Generation Space Telescope (NGST), the James Webb Space Telescope (JWST), will employ a segmented primary mirror to overcome these difficulties. In such an application, it is critical that the mirror's paraboloid shape be maintained to high accuracy and precision.

In order to study the control of such large segmented systems, NASA in 1994 provided funding to establish the Structures Pointing and Control Engineering (SPACE) Laboratory at California State University, Los Angeles (CSULA). The goal of this project is to design and fabricate a testbed that resembles the complex dynamic behavior of a segmented space telescope.

The NASA URC Space Center team has developed a telescope testbed which emulates a Cassegrain telescope of 2.4 meter focal length with performance comparable to actual space-borne systems. It consists of a primary mirror made from seven hexagonal panels (6 peripheral and one center stationary), a secondary mirror and lightweight flexible truss structure. Each peripheral panel is controlled by three linear electromagnetic actuators. Four edge position sensors are used per panel are used to provide relative displacement and angle. The secondary mirror, a six-sided pyramidal mirror, is used to reflect the light from the primary mirror to the focal plane.

Because of the precision and accuracy required of the mirror shape, it is important that sensor calibration be verified regularly. The calibration of a sensor firmly establishes the accuracy of the measuring device. Any deviation from the desired gain and any nonlinearity in the calibration would result in deviation from the desired mirror shape.

LabVIEW can be used for real time system monitoring. In order to achieve greater precision in checking the linearity of the sensor calibration, as well as expedite the process of checking the 42 sensors on the SPACE Testbed, LabVIEW was used to develop an aid in the process.

2 SYSTEM DESCRIPTION OF THE SPACE TESTBED

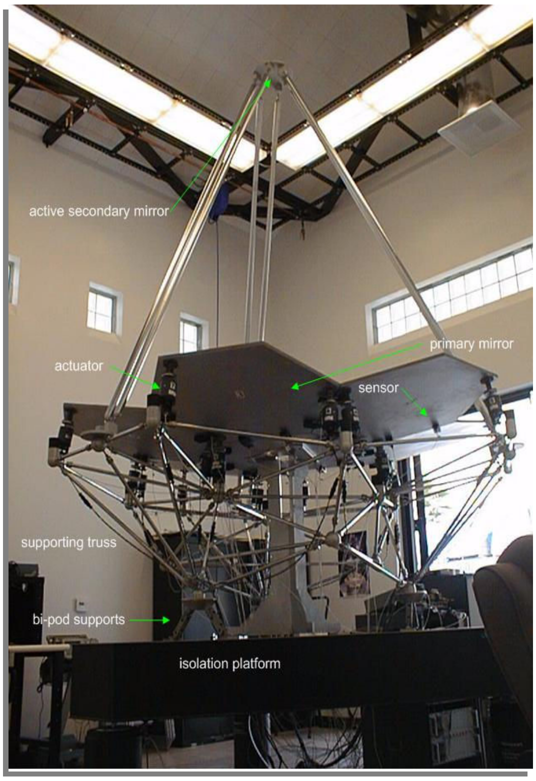


Fig. 1: SPACE Segmented Telescope Testbed

The SPACE testbed, shown in Fig. 1, emulates a Cassegrain telescope of 2.4-meter focal length with performance comparable to an actual space-borne system. The system's top-level requirements include maintenance of the primary mirror shape to within 1 micron RMS distortion with respect to a nominal shape of the primary mirror, and precision pointing with accuracy of 2 arc seconds. The SPACE testbed consists of a primary mirror, a secondary mirror, and a lightweight flexible truss structure. The primary mirror (mounted on the support truss) consists of seven hexagonal panels each 101 cm in diameter. The six peripheral panels are actively controlled in the three degrees-of-freedom by 18 linear electromagnetic actuators (3 actuators per active panel), and a seventh center panel is used as a reference. In addition, a set of 24 edge position sensors are used to provide measurements of relative displacement and angle of the panels. The secondary mirror is attached to the primary surface by a tripod.

3 Sensor Type and Details

The sensors being used are the inductive displacement sensors. Inductive type displacement sensors take advantage of Faraday's Law of Induction which states that a time changing magnetic field will induce an electromotive force in a closed circuit. These inductive eddy current displacement sensors are essentially inductive coils that form part of an AC bridge circuit. Fig. shows the interaction of magnetic fields between the sensor and target material. An AC current is provided through the sensor. As a result of this alternating electric field, an alternating magnetic field is produced and radiates out toward the target materials. When target material enters this field, Eddy currents are produced in the material. These Eddy currents are a result of the alternating magnetic field and circulate within the conductive material. Opposite to induction of current by an alternating magnetic field, an alternating current in a conductor will result in an alternating magnetic field. This newly induced magnetic field will oppose the magnetic field produced by the sensor coil.

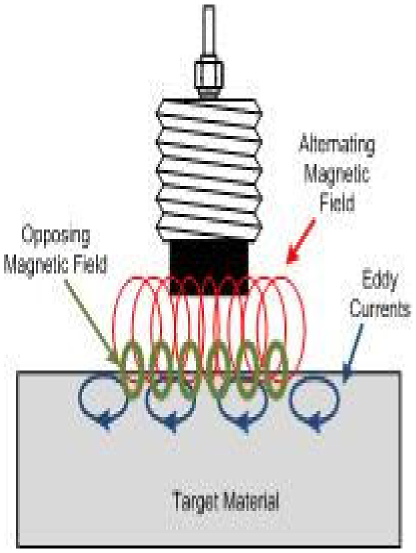


Fig. 2: Induced Eddy Currents

Fig. Fig. 3. As the distance between the target material and the sensor changes, the impedance change in the sensor coil is detected by the electronics in the sensor module and is converted into a voltage that is proportional to the displacement. The synchronous demodulator detects this change in impedance. The log amplifier circuit further linearizes the signal. Further calibration is done through the DC control stage which provides gain and offset amplification.

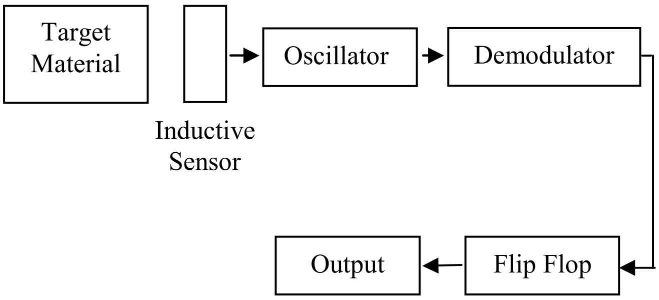


Fig. 3: Sensor and Sensor Module Circuitry

For the testbed, it is important that the calibration provides high accuracy and precision. Keeping within the specified linear range of the sensors (5mm) themselves along with the physical range of the testbed panels, it was determined that a linear gain of 4V/mm would be required. The type of calibration used is Bipolar Output Calibration. To determine not only the displacement of the panel from a reference position, but also the direction of the displacement. This is done by calibrating the sensor module such that the voltage output will range from some negative voltage for one half of the measuring range and some positive voltage for the further half of the measuring range.

4 LabVIEW Subsystem

The SPACE Telescope Testbed has a total of 42 inductive sensors; 24 are edge sensor and 18 are collocated sensor, Fig. 4. For the precision and accuracy required of the mirror shape, it is important that sensor calibration be verified regularly and check for deviation from the desired gain and linearity. In order to do so, sensor voltage output measurements must be taken for each sensor in the operational dynamic range (± 2mm). The linear correlation between voltage output and displacement for each sensor may then be calculated either by hand or by us of other software, such as spreadsheet software or math software. However, this requires the user or person performing the check to enter in the data manually. This may result in rounding errors and inaccuracies. In addition, manually entering data into spreadsheets or calculating linearity by hand is a tedious and time consuming task. To improve the efficiency, accuracy and precision of the sensor calibration check a LabVIEW GUI has been developed. Fig. 5 below shows the flow of the functions required of this GUI.

This LabVIEW GUI allows the user to select the sensor channel whose calibration is being checked. After the channel has been selected, the voltage level must be read by the DAQ. Because of the precision required of the reading, it is necessary to account for noise in the signal. To do so, n samples are averaged and the resulting voltage value is stored in an array such that this voltage level may be mapped with the corresponding sensor position.

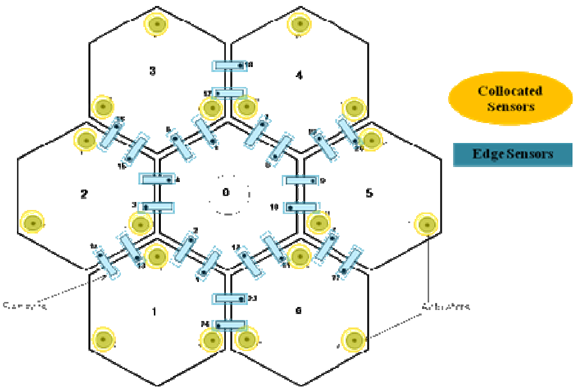


Fig. 4: Sensor Distribution

This process is then repeated for the remaining sensor displacements. Once the voltage values for all the displacements have been checked, the two arrays may then be used to check the linear correlation between the sensor displacement and the voltage output. By measuring and recording the voltages using the DAQ, a higher level of precision is achieved. In addition, the tedious task of entering data into spreadsheet software is eliminated.

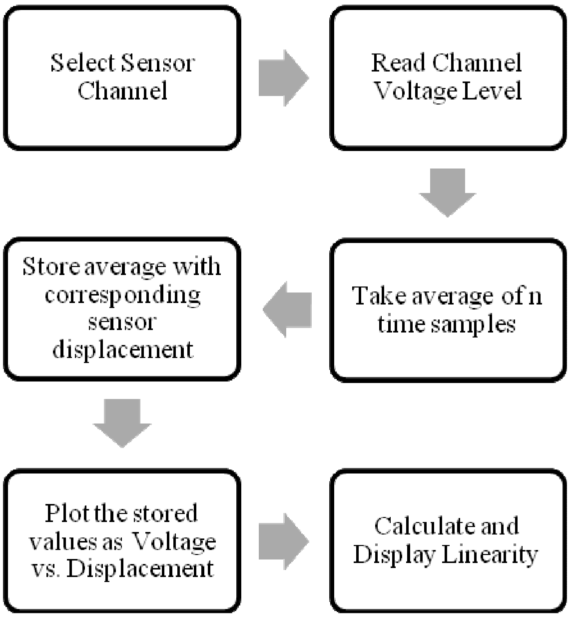


Fig. 5: Flow Diagram of Sensor Calibration GUI

5 Sensor GUI and results

Fig. 6 below shows the LabVIEW front panel. The user may easily select from the 42 sensors. Data may be logged into a file for record keeping. In addition, the user may see the real-time voltage signal in the bottom right graph, as well as voltage vs. displacement in the top right graph. As the user changes the voltage, the top-right graph will update accordingly.

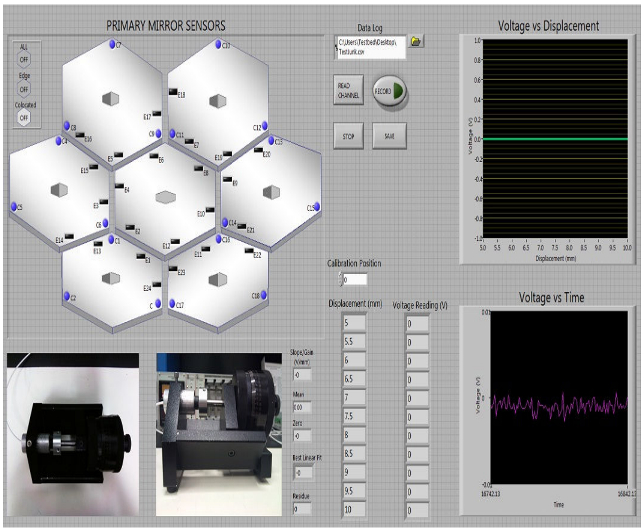
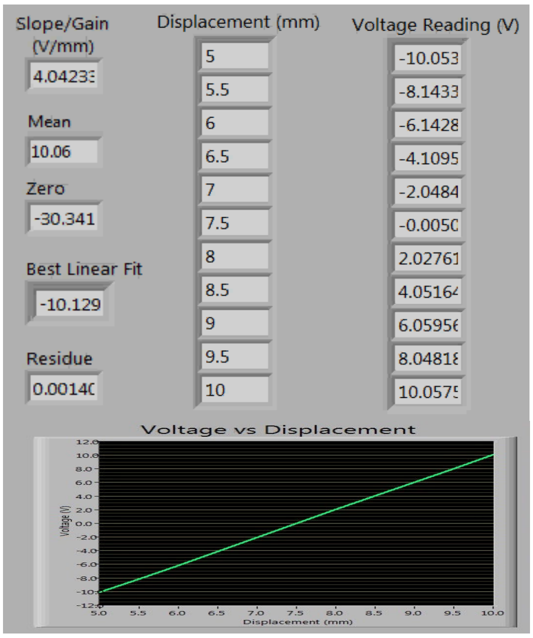


Fig. 6: LabVIEW Front Panel

For the SPACE Testbed, a linear gain of 4 volts/mm is required. The GUI was tested for a spare sensor on a test apparatus in the lab. Fig. 7 below shows the results of the calibration check. From this, it was possible to easily obtain the gain, and residual error of the best fit line.



Slope/Gain (V/mm): 4.0423
Mean: 10.06
Zero: -30.341
Best Linear Fit: -10.129
Residue: 0.0014

Displacement (mm)	Voltage Reading (V)
5	-10.053
5.5	-8.1433
6	-6.1428
6.5	-4.1095
7	-2.0484
7.5	-0.005
8	2.02761
8.5	4.0516
9	6.0595
9.5	8.0481
10	10.057

Fig. 7: Linear Regression, Displacement and Voltage Data (Top), Voltage vs. Displacement (Bottom)

6 Conclusion

This paper describes the LabVIEW Sensor Calibration Visualization Subsystem develop for SPACE testbed in the Structures, Pointing and Control Engineering Laboratory at California State University, Los Angeles. LabVIEW gives best linear fit, slopes and residues for the sensors of testbed from where we can check sensor require gain and if does not meet our requirement then we change the sensor linearity using sensor calibration procedure.

Acknowledgements

This work was supported by NASA under Grant URC NCC NNX08BA44A. Special thanks go to the faculty and students associated with the SPACE Laboratory.

References:

[1] H. S. Stockman, “The Next Generation Space Telescope Visiting a Time When Galaxies Were Young”, June 1997.

[2] H. Boussalis, “Decentralization of Large Spaceborne Telescopes”, Proc. 1994 SPIE Symposium on Astronomical Telescopes, Hawaii, 1994.

[3] H. Boussalis, M. Mirmirani, A. Chassiakos, K. Rad, “The Use of Decentralized Control in Design of a Large Segmented Space Reflector”, Control and Structures Research Laboratory, California State University, Los Angeles, Final Report, 1996.

[4] H. Boussalis, “The use of Decentralized Control in the Design of a Large Segmented Space Reflector,” Structures, Pointing and Control Engineering Laboratory, California State University, Los

Angeles, Final Technical Report, 2002.

[5] T.L. Johnson and J.G. Lin, "An aggregation method for active control of large space structures," in Proc.18th IEEE Conf. Decision Contr., Fort Lauderdale, FL, 1979, pp. 1-3.

[6] G. Safonov, R. Y. Chiang, and H. Flashner. h1 robust control for a large space. J.Guidance Contr., 513-520, 1991.

[7] H. Boussalis, "Stability of Large Scale Systems", New Mexico, USA, November, 1979.

[8] Helen Boussalis, "The Use of Decentralized Control in Design Of A Large Segmented Space Reflector", Structure Pointing and Control Laboratory, California State University, Los Angeles, Final Technical Report, 2002.

[9] H. Boussalis, E.B. Kosmatopoulos, M. Mirmirani, and P.A. Ioannou, Adaptive Control of Multi-variable NonliSnear Systems with Application to a Large Segmented Reflector, ACC 1998.

[10] Mosier, Gary, Mike Femiano and Kong Ha, Goddard Space Flight Center, Redding, Dave, JPL, National Aeronautics and Space Administration, "An Integrated Modeling Environment for Systems-level Performance Analysis of the Next Generation Space Telescope", SPIE Conference, Kona, 1998.

[11] P. C. Hughes, "Spacecraft Attitude Dynamics" New York, NY: John Wiley & Sons, 1986.

[12] Wiley J. Larson and James R. Wertz, editors. "Space Mission Analysis and Design," Microcosm, Inc., Torrance, CA, second edition, 1995.

[13] H. Boussalis, H., Stability of Large Scale Systems. Ph.D. dissertation, New Mexico State University, 1979.

[14] D. D. Rowlands, J. J. McCarthy, M. H. Torrence, and R. G. Williamson, "Multi-Rate Numerical integration of Satellite Orbits for Increased Computational Efficiency," The Journal of the Astronautical Sciences, vol. 43, pp. 89–100, Jan-Mar 1995.

[15] A. Khoshafian, K. Rad, J. Dong, C. Liu, S. Fallorina A. Chassiakos, E. Kosmatopoulos, "Application Of Decentralized Neural Control On Space Reflector," WSEAS Multiconference 2003, Grecotel Rethymna Beach, Crete Island, Greece, October 2003