Development of Solar Differential Image Motion Monitor at IIA, for the NLST site characterization program

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ABSTRACT

The Indian Institute of Astrophysics is planning to setup a 2 m National Large Solar Telescope (NLST) in India. In view of this, a site survey program was initiated. A Solar Differential Image Motion Monitor (SDIMM) unit was received on loan from the National Solar Observatory, Tucson for starting the site survey program. In order to have parallel site survey work at three sites namely Hanle & Merak (at Pangong Lake) in Ladakh, and Devasthal in Uttarakhand, the in-house development of SDIMM, with suitably modified design, was taken up. One unit was built with a 14'' Celestron telescope and two more units were built using 12'' Meade telescopes. Following initial tests at Bangalore, the units were calibrated & tested using the NSO instrument and installed at different sites.

1. INTRODUCTION

The Solar Differential Image Motion Monitor (SDIMM) is an instrument used to measure atmospheric distortion and seeing in terms of the Fried Parameter [1-3]. It is based on the differential image motion of the solar limb generated by two apertures placed before the telescope objective.

Earth's atmosphere causes random motion of the diffraction limited image formed by a telescope. Random fluctuations in the index of refraction throughout the Earth's atmosphere result in image degradation. This effect is generally called as "seeing" and limits the telescope's angular resolution. Fried parameter $r0$ describes seeing effects and it can be measured from the image motion in a small telescope [4].

Direct measurements of image motion in the focal plane of a telescope are marred due to the motion induced by telescope vibrations, tracking errors and wind shakes. In contrast, differential image motion measurements do not suffer from the telescope vibrations. In SDIMM, the light that passes through two separated small apertures is separated by means of an optical wedge in one or both the apertures before falling on a detector. This produces two well separated images of the same object on the detector. Variations in the image separations can be used to obtain a quantitative estimate of the Fried parameter. It has the advantage that it subtracts out any motion of the telescope itself.

As part of the NLST site survey program, the In-House SDIMM instrument was developed at Bangalore and installed at Merak on May 2008.Two more instruments were developed and all three instruments were calibrated and tested using National Solar Observatory (NSO) SDIMM and they found to match very well. All three instruments were installed at Hanle, Merak and Devasthal respectively.

The detail of newly developed SDIMM is reported here.

2. Description of the Instrument

The optical setup of SDIMM and instrumental parameters are given below.

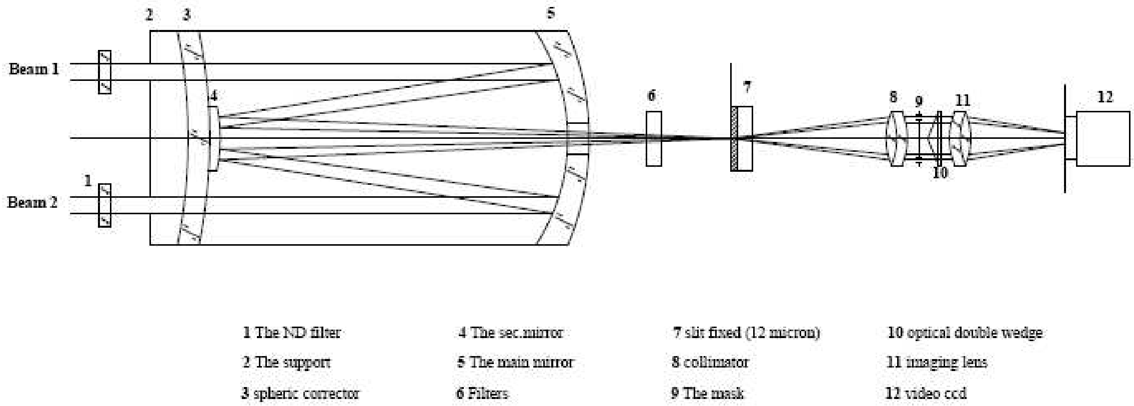

Fig.1) Optical setup of SDIMM

Telescope Aperture	300 mm
Aperture diameter	50 mm
Aperture separation	250 mm
Direction of separation	N – S
Telescope focal length	3912 mm (providing 52 arc sec per mm image scale)
Sun filter	~ 10^{-5}
Slit width	15µ-20µ
Slit length	3 mm
Exposure time	1 to 2 ms

12 inch Meade Cassegrain telescope has been used for the SDIMM instrument. Two apertures of 50mm diameter with separation of 250mm are used to create two separate beams beam1 and beam2. The two beams after their passage through standard 3.8 neutral density filters, primary and secondary forms the focused image on slit (12-15 microns). Neutral density filter has been used to appropriately adjust the intensity level entering the telescope. A achromatic collimated lens used at focal length from the slit produces two beams again with suitable separation. Mask is used to cut down the stray light. The pair of beams is then allowed to pass through a small angle (1.5 degree) biprism which produces the image separation of 1.3 mm (about 130 pixels) in the image plane. The angle of the prism is so small which does not introduce any significant dispersion. An achromatic focusing lens is used to image the slit on to the CCD Detector. The specification of CCD used is given in appendix 1. It is important that the solar image is well focused onto the first single slit and the combination of collimator lens 8 and imaging lens 11 produces the image of the first slit on to the detector. For measurement of the seeing one of the limbs of the sun is imaged onto the central region of the first slit. Fig 2 shows the first sdimm designed and developed and mounted on the back focal plane of the one of the Telescope.

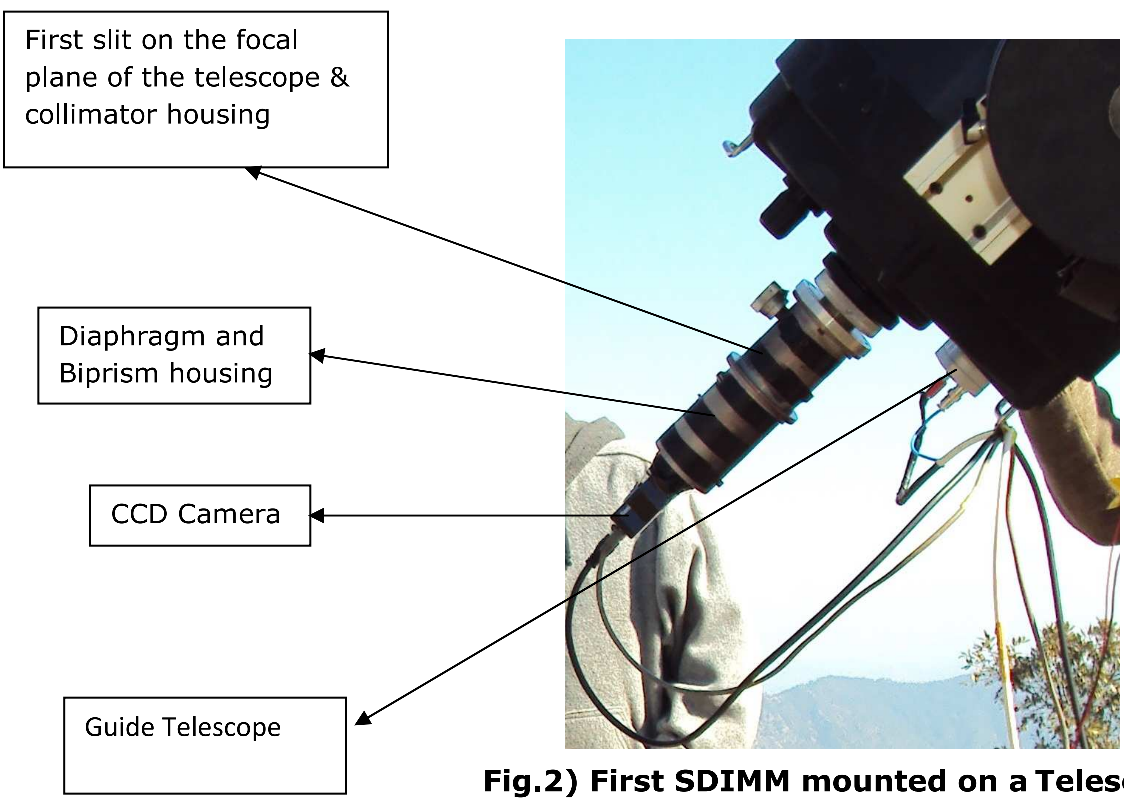

Fig.2) First SDIMM mounted on a Telescope

The limb motion is recorded on the CCD and 150 to 200 frames are grabbed in a 10 sec period. Exposure time for each frame given is around 1ms. The data of limb position on the two slit is used to derive the r0 value [5]. This is accomplished by computing the variance of the limb differences over the 10 seconds of data using the following expression for variance:

$$\sigma^2 = \left[n \sum x_i^2 - \left(\sum x_i \right)^2 \right] \div \left[n(n-1) \right] \qquad (1)$$

Where n (Varies from 20 to 30 and x (i) is the ith limb shift measurement)

The resulting variance is scaled from pixels to radians.

$$\sigma_l = \sigma^2 \rho^2 \qquad (2)$$

Where ρ = arc-seconds to vertical pixel conversion.
When applied to the following expression to yield r0.

$$r_0 = \left[2\lambda^2 \Gamma / \sigma_l \right]^{3/5} \qquad (3)$$

Where λ = wavelength in cm = 0.00005

And Γ = 0.179 * Aperture Diameter ^ (-1/3) – 0.0968 * Aperture Separation ^ (-1/3).

Aperture Diameter = 5 cm

Aperture Separation = 25 cm

3. Data Acquisition and Reduction

The software primarily creates a working image buffer from the region of interest (ROI) and extracts slit position values to find the limb position differences. The fig.3 shows the limb position in the Region of Interest. The pixel values are compressed and plotted i.e. intensity versus pixel number. A 3rd order polynomial is fitted to the compressed array to yield a slit position.

Using the column of pixels between the slits, a background (dark field) bias is computed. The background bias is subtracted from every pixel value in the working image buffer. Using an eight-pixel average at each y-coordinate (centered in the middle of the slit) a slit array is generated for each slit over the complete length of the ROI at the two slit coordinates. These slit arrays are filtered to remove any temporal effect caused by video sampling. The limb differences can be used to get r0 value from equation 3.

The fundamental idea surrounding the algorithm for determining an accurate limb difference is based on the notion of integrating the pixel differences while sliding one slit over the other. This yields an array of sums going from negative to positive (or positive to negative depending on slit orientation). The pixel position index where the sums go from negative to positive is the limb difference value.

The flowchart of SDIMM software for data acquisition and reduction is given in appendix 2.The software for the data acquisition and reduction of the data will be presented in a separate paper.

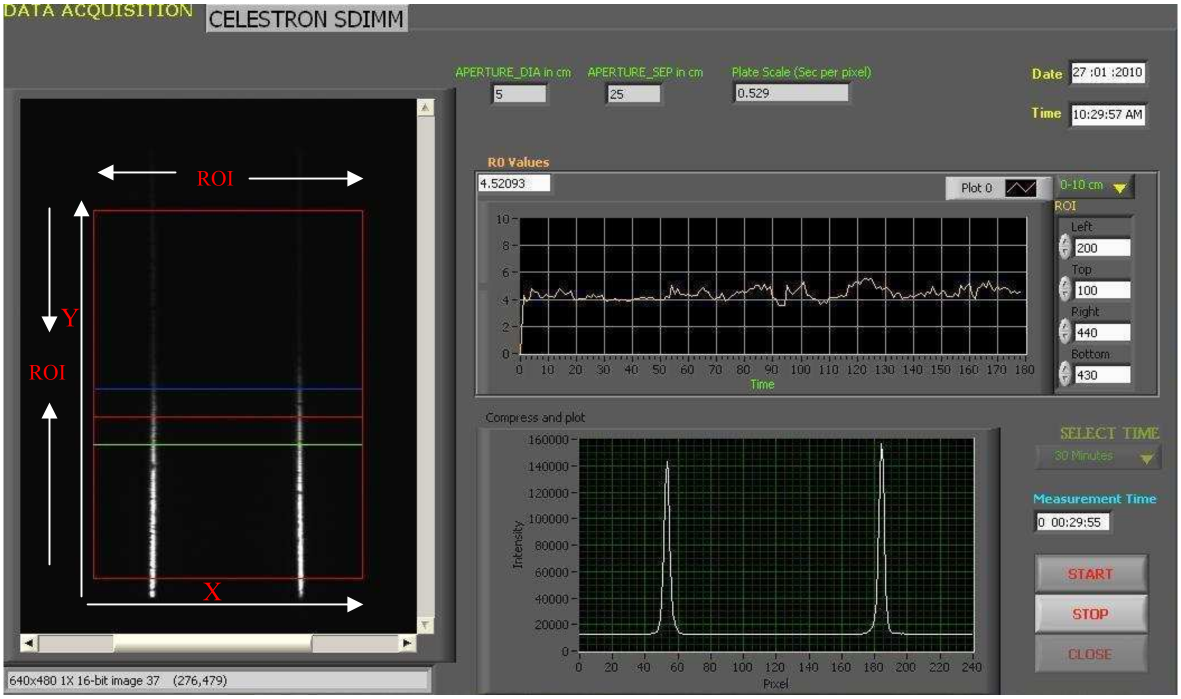

Fig 3.) Front panel for Data Acquisition (LabVIEW Platform)

Three in-house developed SDIMM were calibrated and tested using National Solar Observatory (NSO) SDIMM and their pictures and comparison results are shown.

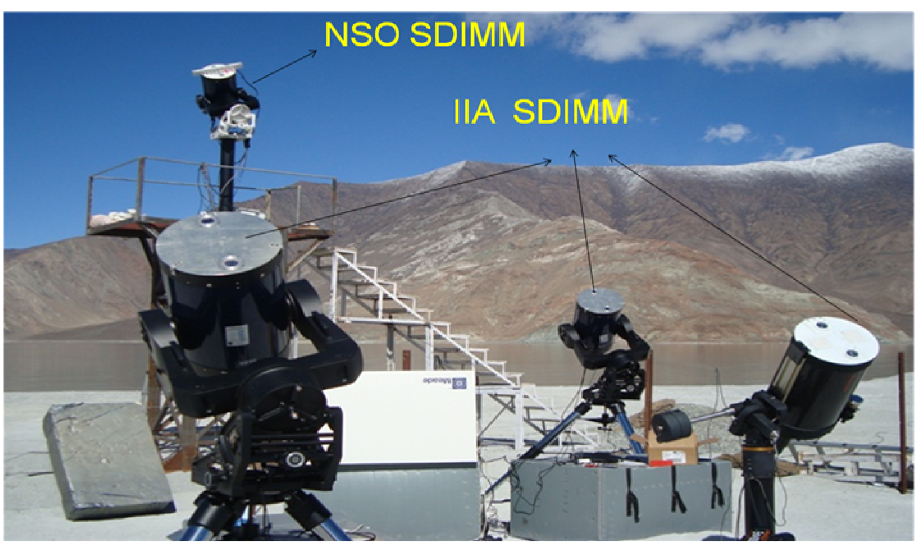

Fig 4.) NSO & IIA SDIMMs at Merak during calibration – October 2008

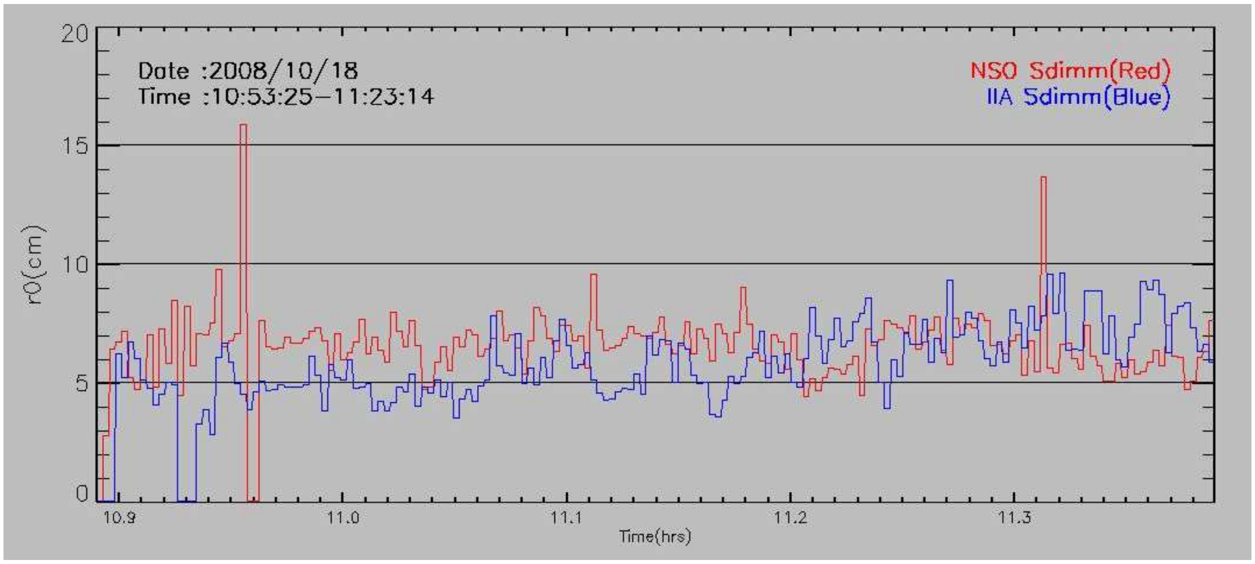

Fig 5.) Comparisons of NSO and IIA SDIMM Results

4. Observations in Hanle & Merak

Observations with Solar Differential Image Motion Monitor (SDIMM) procured from the National Solar Observatory (NSO) continued at Hanle till October 2008. A 4m tower was installed for the SDIMM unit at Hanle. Observations with the Celestron 14'' telescope based IIA SDIMM unit started at the Pangong lake incursion site in May 2008.Earlier, trial runs were carried out at the camp site starting March 2008.

The NSO SDIMM device was moved to Merak for calibration of two Meade 12'' telescope based IIA SDIMM units and one Celestron 14'' telescope based IIA SDIMM unit. Following the on-field calibration of three IIA units with the NSO unit in October 2008, one of the 12'' Meade IIA unit was moved and installed on a 4m tower at the summit near Himalayan Chandra Telescope (HCT), during the same month and NSO unit was installed on a 4m tower at Merak. Observations also continued with the Celestron telescope based instrument at Merak. The Second Meade 12'' based unit was readied for transport to Devasthal for installation.

5. Observations in Devasthal

Meade 12″ IIA based unit was dispatched to ARIES on October 2008. A tower with slide off roof was built at Nainital and installed at Devasthal for SDIMM observation. Initial problems of the 12″ Meade Telescope drive unit and power problems were sorted out on January 23rd 2010 and the SDIMM using 14″ Celestron Telescope from ARIES and IIA based SDIMM unit was successfully installed and observations started on 26th January 2010.

6. RESULTS

Observational results of NSO SDIMM (Fig. 5) and in-house built SDIMMs (Fig.6 and Fig.7) are shown below.

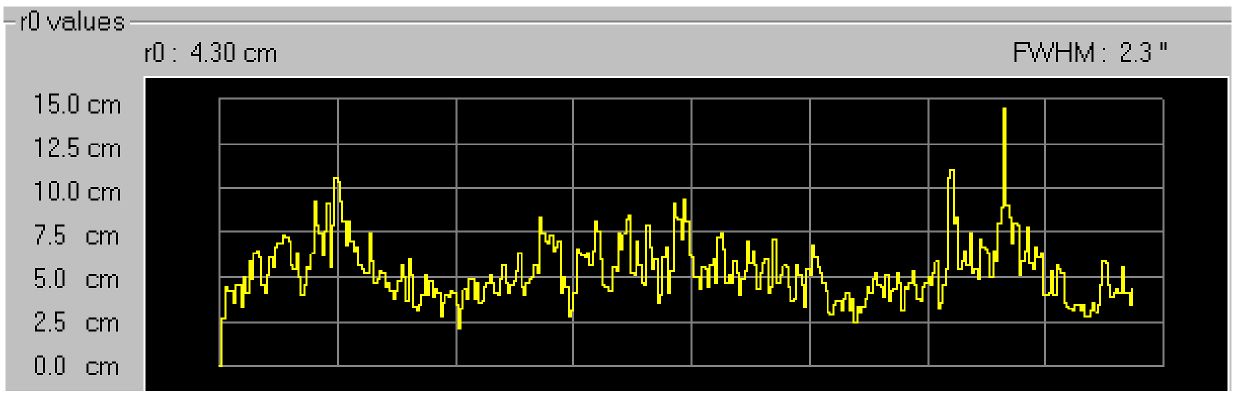

Fig 6.) Sample plot of r_0 on October 06, 2007 at Hanle

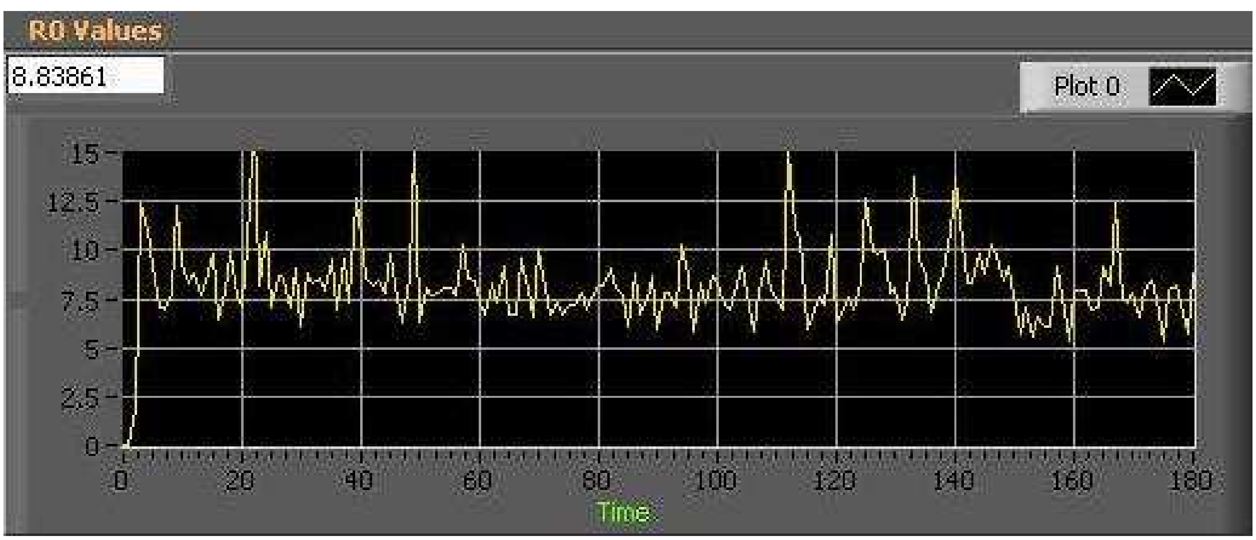

Fig 7.) Sample plot of r_0 on August 01, 2008 at Merak

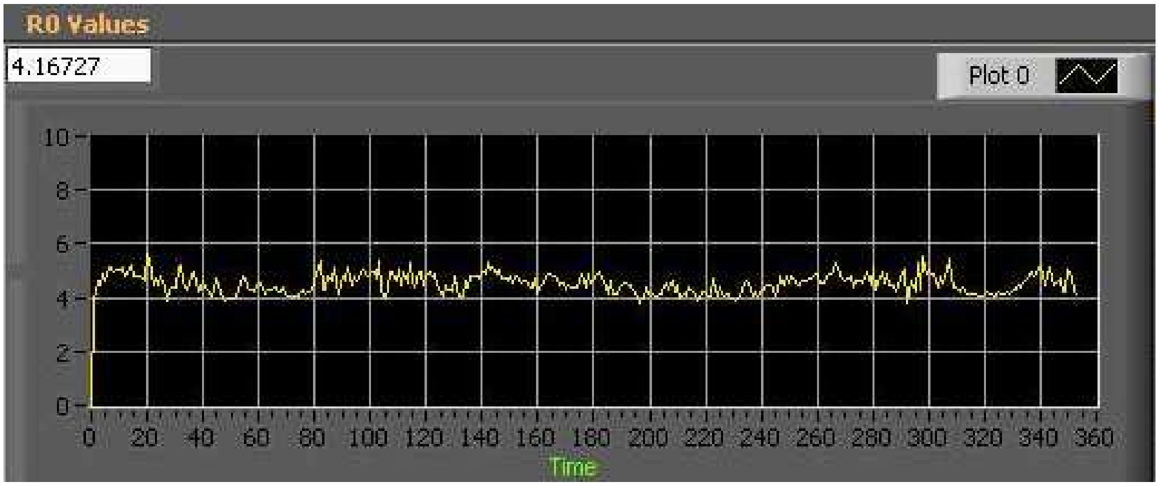

Fig 8.) Sample plot of r_0 on January 27, 2010 at Devasthal

7. REMARKS

In-house development of SDIMM has greatly facilitated the site survey program of NLST project. It will help in the final choice of the site. The above work has gone through many odds but has met the final schedule.

8. Acknowledgement:

Thanks to Dr.Ramsagar, Director, ARIES, Dr.Wahabuddeen & team for his kind help and cooperation for setting up SDIMM facility at Devasthal.

9. References

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2. Roddier, F: 1981, in E.Wolf (ed.), Prog.Optics, Vol.XIX.
3. Andreas Quirrenbach - Adaptive Optics for Vision Science and Astronomy ,ASP Conference Series , The Effects of Atmospheric Turbulence on Astronomical (preprint)
4. JACQUES M. BECKERS, 6 February 2002, A Seeing Monitor for Solar and other extended object Observations.
5. STEVE FLETCHER, December 2001, NSO SDIMM Software Design Document.

Appendix 1.

CCD Details:

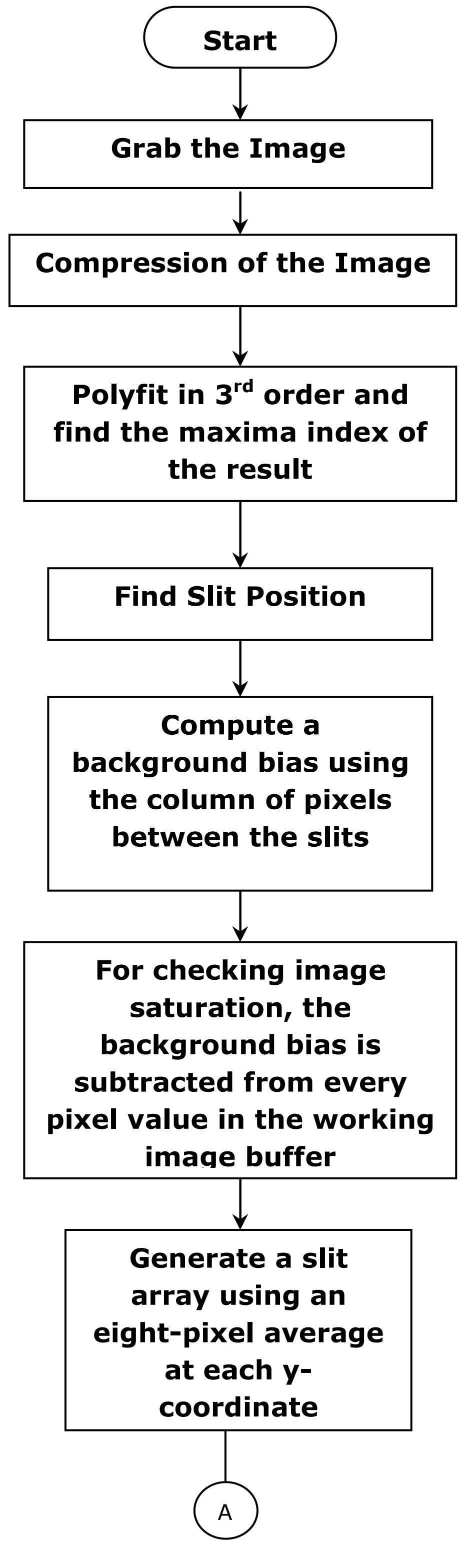
The Genie M640 with a resolution of 640 x 480 CCD has been used. Operating at 60 frames per second at full resolution, the Genie M640 takes advantage of gigabit Ethernet technology for transmitting data and direct link from the camera to a PC.All Genie cameras are supported by DALSA's Sapera™ LT software libraries featuring CamExpert for simplified camera set-up and configuration.

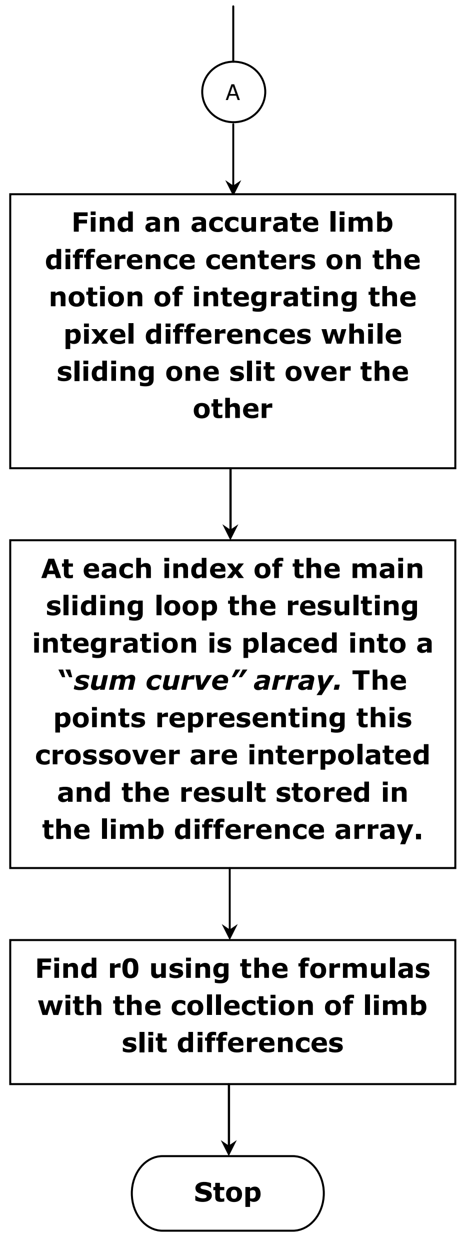
CCD Specifications

Sensor	1/2 inch Sony ICX414AL 640 x 480 pixels 9.9 µm x 9.9µm 60 Frames per second
Pixel Format	8-bit or 10-bit mono
Ethernet	10/100/1000 Mbps, image data and camera control over UDP (based on GigE Vision specifications) 100m reach over CAT-5e
Power	12V supply voltage, 6W max

Appendix 2.

Flow chart of SDIMM Software





Flow chart for Data Acquisition and Reduction Software