Data Acquisition and Reduction Algorithm for Solar Differential Image Motion Monitor

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Abstract – The Solar Differential Image Motion Monitor (SDIMM) is an important instrument for day time seeing measurement. Development of one such instrument was done as a part of the site survey program of National Large Solar Telescope (NLST) for Indian Institute of Astrophysics. This paper gives details of the data reduction software for finding precise value of seeing parameter \( r_0 \). Reduction procedure is developed using National Instruments (NI) LabVIEW. A model computation demonstrates the complete reduction procedure.

Keywords – Data Acquisition, SDIMM, CCD

I. INTRODUCTION

The Solar Differential Image Motion Monitor (SDIMM) is an instrument used to measure atmospheric distortion called day time seeing. SDIMM measures seeing integrated over entire atmosphere column in terms of Fried’s parameter \( r_0 \) [1]. The primary components of the SDIMM instrument include a telescope, beam splitting optics, CCD camera and a computer. The Fried parameter is estimated from the co-variance of the differential image motion in the image plane corresponding to two small apertures placed at the front entrance of the telescope [2]. It has the advantage that it subtracts out any motion of the telescope, it only accounts effect due to atmosphere. This paper presents the detail software development of SDIMM.

II. DESCRIPTION OF THE INSTRUMENT

A 12 inch Meade Cassegrain telescope has been used for the SDIMM instrument. Fig. 2 shows the optical setup of SDIMM and Table 1 gives instrumental parameters of SDIMM. Two apertures of 50mm diameter with separation of 250mm are used to create two separate beams namely beam1 and beam2. The two beams after their passage through standard 3.8 neutral density filters, primary and secondary mirrors combination forms the focused image of the Sun on slit (12-15 microns wide). Neutral density filter has been used to appropriately adjust the intensity level entering the telescope. An achromatic collimating lens used at focal length from the slit produces two beams 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. 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 two images of the first slit on to the detector corresponding to two apertures kept in the entrance beam of the telescope. For measurement of the seeing one of the limbs of the sun is imaged onto the central region of the first slit.

Initially we define the region of interest (ROI) with given four positions (Left, Right, Top, and Bottom). The developed software finds properly the illuminated slits in the region of interest and it establishes the limb position in each slit. For each recorded frame at a précised rate relative limb differences are computed. For accurate measurement it is expected that the slits remain in the region of interest. Fig 1 shows the limbs of the sun as imaged on the CCD detector.
III. DATA ACQUISITION USING LABVIEW

LabVIEW is a highly productive graphical programming language for building data acquisition and instrumentation systems. It includes libraries for data acquisition, GPIB and serial instrument control, data analysis, data presentation and data storage. A GUI is developed using NI-LabVIEW for the application of the data acquisition, reduction algorithms and displaying the results.

The Genie M640 640 x 480 CCD has been used for acquiring image data. The Genie M640 takes advantage of gigabit Ethernet technology for transmitting data and direct link from the camera to a PC. The detail specifications are mentioned in the SDIMM technical report [4]. NI Vision acquisition software 8.2.1 with NI-IMAQdx driver has been used for data acquisition.

A. Steps to perform Data Acquisition

1. Call IMAQdx Open Camera to initialize the board and create an NI-IMAQdx Session.
2. Call IMAQdx Configure Acquisition to allocate resources for the acquisition.
3. Call IMAQdx Start Acquisition to start transferring data from the camera.
4. Call IMAQdx Get Image to obtain a copy of the requested image data.
5. After an acquisition, call IMAQdx Stop Acquisition to stop transferring data from the camera.
6. Call IMAQdx Unconfigure Acquisition to release the resources associated with the acquisition.
7. Call IMAQdx Close Camera to close the camera session.

For a given 2 ms exposure time the data is continuously acquired for about 10 sec which provides about 150 to 200 frames of data of the two limb records. Considering the image scale (0.527 arc sec/pixel) in the CCD plane and \( r_0 \) variance in the worst atmospheric seeing the limb difference in two slits may go to a maximum of about 16 pixels. For each frame the algorithm finds the relative shift of the limbs and the shift value is used to derive the \( r_0 \) value using eqn 1.

\[
\frac{r}{r_0} = \left[2\lambda \frac{2}{\Gamma} - \frac{\sigma}{l}\right]^{3/5}
\]

Eqn 1

Where \( \lambda = \) wavelength in cm = 0.00005
And \( \Gamma = 0.179 \times \frac{\text{Aperture Diameter}^2}{\text{Aperture Separation}^3} - 0.968 \times \frac{\text{Aperture Diameter}}{\text{Aperture Separation}} \)

Aperture Diameter = 5 cm
Aperture Separation = 25 cm

IV. ALGORITHM DESCRIPTION

Flow chart shows the Data Acquisition and Reduction Software procedures. The fundamental approach followed in the reduction of the data is similar to NSO SDIMM [3].

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Table 1. The instrumental parameters of SDIMM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope Aperture</td>
<td>300 mm</td>
</tr>
<tr>
<td>Aperture diameter</td>
<td>50 mm</td>
</tr>
<tr>
<td>Aperture separation</td>
<td>250 mm</td>
</tr>
<tr>
<td>Direction of separation</td>
<td>N – S</td>
</tr>
<tr>
<td>Telescope focal length</td>
<td>3912 mm (providing 52 arc sec per mm image scale)</td>
</tr>
<tr>
<td>Sun filter</td>
<td>~ 10-5</td>
</tr>
<tr>
<td>Slit width</td>
<td>15μ-20μ</td>
</tr>
<tr>
<td>Slit length</td>
<td>3 mm</td>
</tr>
<tr>
<td>Exposure time</td>
<td>1 to 2 ms</td>
</tr>
</tbody>
</table>

Fig. 2 Optical setup of SDIMM
A. Noise removal and Smoothening of the data

The algorithm has been developed in such a way that it assembles a working image buffer from the region of interest (ROI). A ROI (Top - 100, Bottom – 430, Left - 200, Right – 440 i.e [Row] [Column] = [330] [240] has been used in the present example). For computing background bias a column of pixel in the center part of the ROI is taken and its average is calculated. For checking image saturation, the background bias is subtracted from every pixel value in the ROI image buffer. While subtracting conditions are implied like if the pixel value is greater than background bias then it subtracts and if it is less than the background bias then it inserts zero in the ROI image buffer. To remove further noises, the pixel values are smoothening by multiplying even index by 4 and odd index by 2[(i-1) + (i+2)] in the ROI image buffer. The corresponding slit positions and intensity data is then extracted from this working image. The clean slit profiles are then used for finding the limb positions and subsequently limb shift values.

B. Defining the Slit Position

To find the slit position precisely in the ROI, the image is compressed by adding all column values (240) of the image and plotting the graph by intensity versus pixel fig.3. The Data Acquisition window helps to select a time range between 5 minutes to 8 hour for measurement. In this figure given below, the red box is the selected ROI. The data acquisition window displays the values of Aperture diameter, Aperture separation, Plate scale date, time, current measurement time, two limbs with corresponding compressed plots and plots of r0 value for every 10 seconds. Once the time limit is selected click Start button to start the observation. Once the selected time is over it automatically stores the data file in the name of DataFile + Current year + Current month + Current Date + the observation starting time. Always keep limb of the sun within the ROI if it exceeds the ROI then it will not give accurate results.

The intensity versus pixel plot is then divided into two halves and for each half (i.e. from 0 to 120 and 120 to 240) maximum intensity is determined. At these two respective

Flow chart for Data Acquisition and Reduction Software
maxima points and on each side of the maximum 5 pixel intensity data is taken. A 3rd order general polynomial is fitted for these 11 data points respectively. A maximum of these fits provides the accurate well defined reliable location of the slit to an accuracy of single pixel. Following the same approach and by suitable interpolation of the intensity between the pixel sub pixel accuracy can be achieved. These maxima point define the exact location of the slits. The intensity data along the slit is then generated by taking average value of the intensity across the width of the slit (slit1 and slit2) typical plot is shown in fig.4. Accurate shift of the edge of the limb is then determined from this intensity data along these two slits. Following procedure is adopted for locating the edge of the limb and evaluating the shift precisely.

![Fig.4 Typical plot of intensity along the slit1 & slit2](image)

C. Finding Limb Shift

To ensure that both slit have same intensity, one slit must be gain adjusted. Since the solar limb on the slit may not have sharp defined line and there is an effect of limb darkening in the solar image and to take in to account for integrating noise a mid value of the intensity variation across the slit is taken for estimation of the limb position. The fundamental idea surrounding the algorithm for determining an accurate limb difference centers 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 gives the shift of the limb. All the arrays taken in the calculation are corrected for background and gain each time.

D. Finding Variance

The limb shift values so obtained for all the frames in 10 sec data is used to derive the r0 value using the following expression for variance:

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

Where \(n = 20*N\) (approximately) and \(x_i\) is the \(i^{th}\) limb shift measurement. The resulting variance is scaled from pixels to radians.

\[
\sigma_l = \sigma^2 \rho^2
\]

V. SYSTEM DESCRIPTION

The developed software for SDIMM resides on the computer running under Windows XP. The SDIMM software contains different windows like Login, Data Entry, Main Menu, Initial Setup and Data Acquisition for different purpose. The software for SDIMM is developed in NI-“LabVIEW” and uses Vision Acquisition Software for acquiring images from CCD for software application. Hence many of the features provided in that application are available to accomplish tasks like image enhancement, region of interest frame definition, image grabbing and basic video control.

VI. CONCLUSION

In this paper, the SDIMM data reduction procedure is analysed. The instrument was calibrated and tested using National Solar Observatory (NSO) SDIMM and they found to match very well. Presently three SDIMMs are installed for regular observations.

III. REFERENCES


