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Feature Extraction And Segmentation Of H-Alpha Solar Images Observed From Kodaikanal Solar Observatory

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H-Alpha images of astronomical objects often reveal elaborate filament structures, which may provide significant information about the fundamental mechanisms governing the objects' movement. These images are crucial for studying solar phenomena such as sunspots, solar flares, prominences, and filaments.The manual analysis of these images is subjective and time-consuming, therefore automated feature extraction approaches are necessary for accurate and efficient analysis. This paper presents a digital image processing pipeline for automatic detection and feature extraction of filaments in H-Alpha images. The acquired images are captured from the sun atthewavelengthof 6563Å and subjected to feature extraction. Our approach implements a combination of image enhancement, thresholding, and morphological operations to identify filament regions. We then employ techniques such as skeletonization, curvature analysis, and texture analysis to extract meaningful features from the detected filaments. The experimental results demonstrate the effectiveness of our method in detecting and characterizing filaments in H-Alpha images, enabling quantitative analysis of their properties and behavior. Using two hours of observation at a time resolution of two minutes each cadence, Hα images are used to produce the time series analysis. From these, the intensity at the center, 0.4Å and 0.8Å of the solar disk and time series graph are plotted. This work has implications for understanding the dynamics of astrophysical phenomena, such as star formation, solar flares which have impact on satellite communication, space weather and earth's climate.

Keywords: H-Alpha images, filament detection, feature extraction, digital image processing, astronomical image analysis.

Introduction

The Kodaikanal Observatory, located in India, has been monitoring the Sun's activity in H-Alpha wavelengths since 1904, providing a rich archive of images showcasing the dynamic solar chromospheres[1]. H-Alpha images capture the emission from hydrogen atoms at a wavelength of 6563 Å, revealing intricate structures like filaments, prominences, and plage regions. The filaments, in particular, are dark, elongated features that appear on the solar disk, tracing magnetic field lines and offering insights into the Sun's magnetic field topology and plasma dynamics. H-alpha solar images are taken using a narrow-band filter centered on the H-alpha spectral line (656.3 nm), which corresponds to the red part of the visible spectrum. It is used to obtain H-alpha solar imagery. Hydrogen atoms in the solar chromosphere radiate this particular wavelength, which is essential for studying a range of solar attributes. These filters eliminate all other wavelengths of light and only permit the specific wavelength related to the H-alpha spectral line to pass through. The sunspots, which are indications of strong magnetic activity, are shown in these images. The evolution of flares is made simpler by viewing H-alpha imagery, which is crucial for comprehending the mechanics generating the strong eruptions. H-alpha images reveal the features in great detail, helping in the study of their creation, structure, and evolution by researchers. The objective of feature extraction in H-Alpha images is to detect and describe filaments, deriving significant data regarding their shape, size, orientation, curvature, intensity and dynamics[2]. The automated feature extraction techniques can be applied to H-Alpha images to enhance image quality and remove noise, detect filament regions using threshold, edge detection, or machine learning algorithms and extract filament properties using shape analysis, skeletonization, and curvature estimation. The features enable the researchers to investigate the relationship between filaments and solar activity, understand the role of magnetic fields in shaping filament morphology and develop predictive models for space weather events. It also contributes to explore the connection between filaments and coronal mass ejections[3]. The rich data-set from the Kodaikanal Observatory, contribute to a deeper understanding of the Sun’s chromosphere and its impact on space weather.

Observation and Design methodology

The full disk image of the Sun at the 6563Å wavelength in the H-Alpha red line is perceived using theH-Alpha solar telescope. This enables us to examine the Sun's finer details to its great spatial resolution. The H-Alpha spectral line is isolated using a tunable filter known as a Lyot filter, which is adjustable to any spot on the strong H-Alpha line. The images at these points on the line profile will be acquired when the filter is adjusted in increments o f 0.4Å from one wing to core and then to the other wing. The telescope's detector system is made up of a CCD camera with 2048 × 2048 pixels. The size of each pixel is roughly 13.5µm. The CCD is back illuminated and has 16-bit digitization where the images are stored. The images are captured at the center line, 0.4Å and 0.8Å of strong H-Alpha line. The images of the Sun on the line profile will be captured and saved so that we get 60 frames of the Sun images per hour.The flat and the dark images are taken on hour basis which are used for calibration of images. Calibration of image is done by using ImageJ tool. The image processing techniques are used to process the images after calibration. Enhancement techniques are used for pre-processing of the calibrated images. A variety of methods, such as power law transformation, log transformation, and contrast stretching, are used to improve the image and make features more pronounced. Inorder to extract features from the improved images of the Sun' stopchromospheric layer, such as prominences and filaments, the edge detection methods are applied which are used to establish intensity levels.

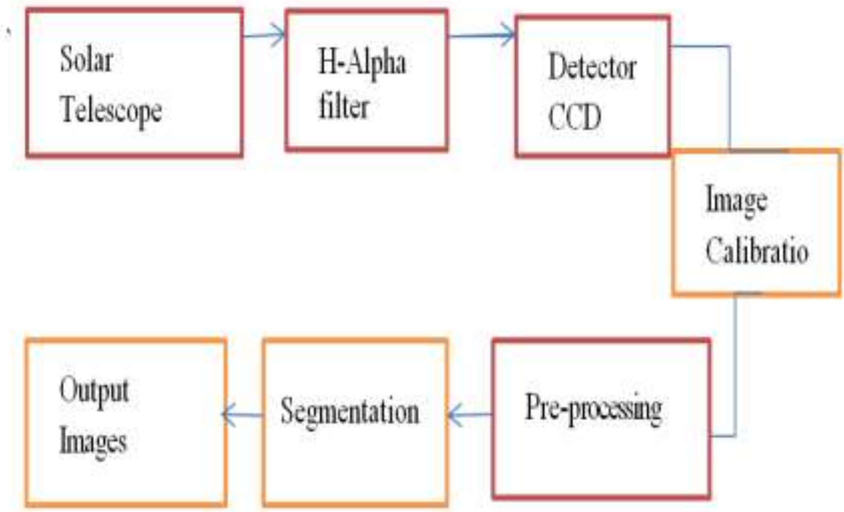


Fig.1: Observations of H-alpha Images and Extraction of Features

The overall arrangement is shown in Fig.1. Following that, registration techniques will be used to compare the images at various points along the H-Alpha line profile using the features that were extracted. Since we are unable to directly apply image processing techniques to the raw H-Alpha images collected from the H-Alpha telescope due to its noise, distortion, and watermarks, we must first calibrate the images before proceeding with any further processing. The image tool is used to accomplish this calibration. In this research work image tools are used for calibration of raw images for further processing and image processing techniques implemented.

1. Calibration of H-alpha Images

To obtain the master dark image, the first three dark images are taken, and their means are calculated. In a similar manner, to obtain the master flat image, take the three flat images and calculate their mean. A low-spatial frequency filter can be applied to an image by performing a polynomial surface fit, which can be computed using an image tool plug in and then normalized to obtain the polynomial surface fit. Next, in order to obtain the master flat surface fit picture, normalize the master flat image and divide it by the normalized polynomial surface fit image. Now take the raw image, then subtract the raw image with the master dark image and the result obtained is then divided by the master flat surface fit image to get the calibrated image.This process is done by using the equation1.

Calibrated image=raw image−master dark image / master flat surface fit ______________(1)

- **Raw Image–**It is the image observed directly from the H-Alpha telescope that is stored on CCD detector. The raw image contains water marks and noise shown in Fig 3.
- **Dark Image–** It is the image obtained as shown in Fig 4, by closing the aperture of them in a telescope.
- **Flat Image–**Itistheimageobtainedbyinsertingadiffuserplateintothelightpath wheneveritis necessary as shown in Fig 4.

Fig.2: Raw Image

Fig.3: Dark Image

Fig.4: Flat Image

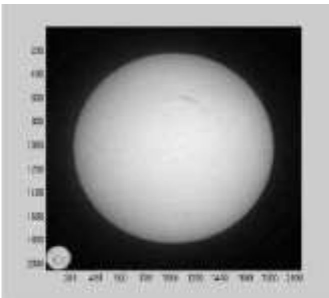
Fig.5: Calibrated Image

2. Image Processing Techniques

1. Pre-Processing

Pre-processing an image refers to "preparing" the sample or image for introduction to an algorithm for a particular purpose, such as feature extraction, tracking targets, recognition, etc. Pre-processing method is to improve the image data by reducing undesired distortions and enhancing certain crucial aspects of the image . One of the pre-processing techniques is image enhancement, which enhances the image's quality to enable reliable image analysis [4]. The different image enhancing techniques are as follows:

The enhancement technique is used to extract the features of the H-Alpha images, which are taken in the Sun's upper chromospheric layer, using the MATLAB tool. The chromatic networks and filaments appearing in the H-Alpha images are among the features to be detected and analyzed. When the Log transformation technique is applied on the original image the resultant image has not enhanced thefeatures which are as shown in the Fig 6.



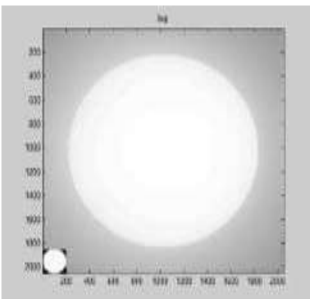
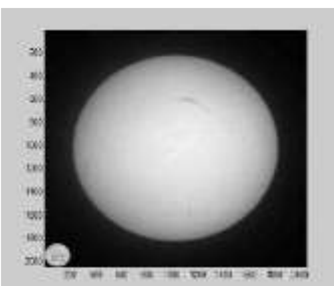


Fig.6: Log Transformation of original image



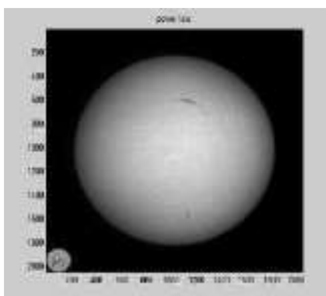


Fig.7: Power law transformation **of original image**

Power law transformation was best suitable for the images obtained where it could enhance the features which are as shown in the Fig 7.

2. Morphogical operations

A structuring element is a small binary image with a matrix of pixels with a value of zero or one. The structuring element is superimposed at all possible locations in the image and it is compared with the corresponding neighborhood of pixels. Morphological operations are the non-linear operations in digital image processing related to shape or the morphology of features in an image. These techniques probe an image with a small shape or template called a structuring element used for dilation and erosion. The power law transformation images undergoes the process of dilation and erosion whose results are shown is Fig 9 &11.SomeofthefundamentalMorphologicaloperationsindigitalimageprocessingte chniquesare dilation and erosion.

DIALATION

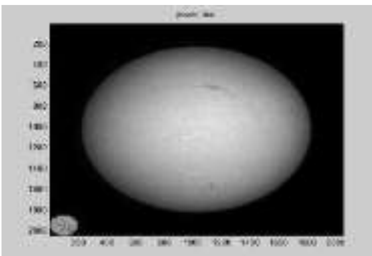


Fig.8: Power Law Image

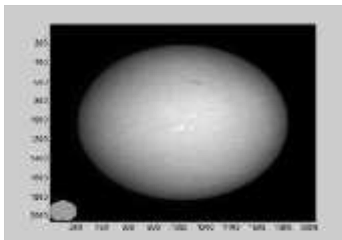


Fig.9: Dilated Image

EROSION

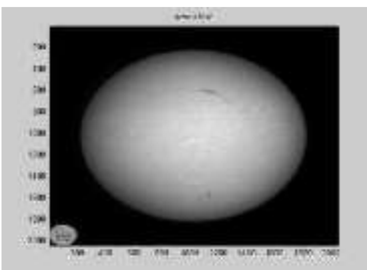


Fig.10: Power Law Image

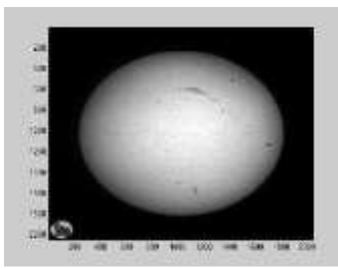


Fig.11: Eroded Image

3. Segmentation Techniques

Two fundamental characteristics of intensity values—discontinuity and similarity—form the basis of themajorityofsegmentationalgorithms.Usingthe"Discontinuity"technique, a picture I segmented according to an abrupt change in intensity, such as an edge. The second method divides photos according to certain predetermined parameters .Segmentation can be approached in three general ways: region-based, edge-based, and thresholding [5].

- **In Thresholding,** pixels are allocated to categories according to the range of values in which a pixel lies.
- **In Edge-based** segmentation, an edge filter is applied to the image, pixels are classified as edge or non-edge depending on the filter output, and pixels which are not separated by an edge are allocated to the same category.
- Finally, **Region-based** segmentation algorithms operate iteratively by grouping together pixels which are neighbors and have similar values and splitting groups of pixels which are dissimilar in value.

4. Watershed Transformation

The first step in Watershed transformation is to find gradient image using the sobel operator. Then, MATLAB function watershed ( ) is applied to the gradient image. The result obtained is the over segmentation which is as shown in the Fig 13, this can be seen easily as the transform was taken directly on the gradient image. Steps are used to avoid over segmentation areas shown below.

Step 1: find the location of regional minima of the gradient image. This is done using MATLAB function imregionalmin ().

Step 2: obtain the internal markers. Internal markers are found on the original image using the MATLAB function extended min ( ). This assigns minima value as internal markers.

Step 3: obtain the external markers. External markers are obtained by finding watershed transform of distance transform of original image. Where ever output is zero, they are masked as external markers.

Step4:modify the gradient image. Gradient image is modified based on the location of internal and external markers. MATLAB function impose min ( ) modifies the image using morphological reconstruction so that regional minima are present only when there is a internal or external marker[6].

Step 5: Watershed transform of modified gradient image is taken and boundaries obtained by Watershed transform is made white. All major segments are found. Thus, over segmentation is avoided by using internal and external markers and restricting the minima to only few. The final segmented output is as shown in the Fig14, and extracted Filament1 & 2 are shown in Fig15 & 16.

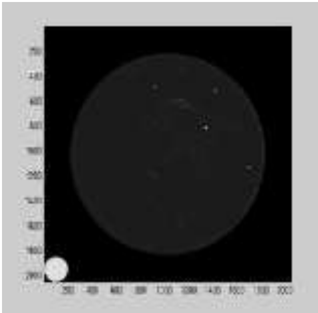


Fig .12: FilledImage

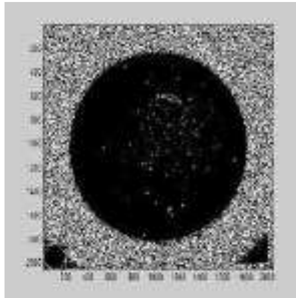


Fig.13: OverSegmentedImage

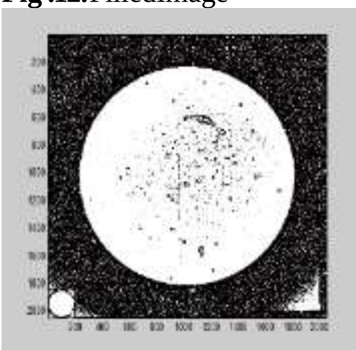


Fig .14: SegmentedImage

Fig.15: Filament1

Fig.16: Filament2

Analysis

TheH-Alphasolartelescopewasutilizedtoacquirethetimeseriesofcompletediskimagesintheh-Alphaline from January 22 to January 27, 2018, while on a visit to Kodaikanal Solar Observatory. During the visit to Kodaikanal Solar Observatory, no solar activity was seen; hence, the photos taken on January 8, 2018, are utilized to extract features. Two filaments, seen in Figs 17 and 18, are examined in this work. They were observed for two hours on January8,2018,at a time resolution of two minutes cadence. Quiet Sun at the center of the solar disk was observed for two hours with the time interval of two minutes per frame from January 22nd to 27th, 2018 at the wave length locations of 0.0Å,0.4Å and 0.8Å.In this study the intensity changes in the filaments and in the quiet Sun regions are studied and compared.

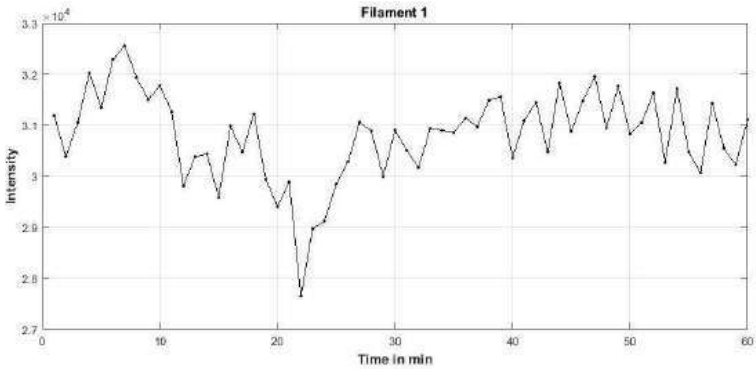


Fig.17: Intensity variations in filament1

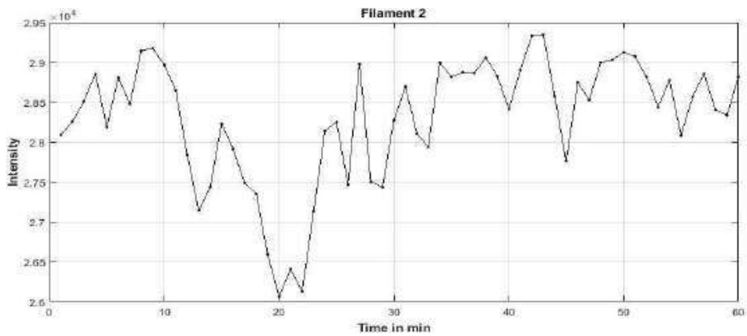


Fig.18: Intensity variations in filament2

1. Intensity variations in the Quiet Sun region at the center of the solar disk

The images on the strong H-alpha line profile at 0.0Å, 0.4Å, and 0.8Å that were observed for two hours have undergone time series analysis. The time resolution used was two minutes cadence, obtained on January 27, 2018, using the H-Alpha Solar telescope at Kodaikanal Solar Observatory. where the various layers of the solar atmosphere are represented by the values 0.0Å,0.4Å,and0.8Å.The Sun is calm and not very active as it is nearing the end of its solar cycle minimum. At the solar disk's centre,intensity fluctuations are calculated, and graphs with respect to time are shown in Fig 19. Intensities at different levels of line profile (0.0Å, 0.4Å and 0.8Å) are inter compared and is as shown in the Fig 20. From theFig17 & 18 itwasfoundthatfilamentsshowaverylargeintensityfluctuationscomparedtoquietSun regions observed in H-Alpha images. It is noticed that filaments are active regions which help to contribute and give rise to solar flare.

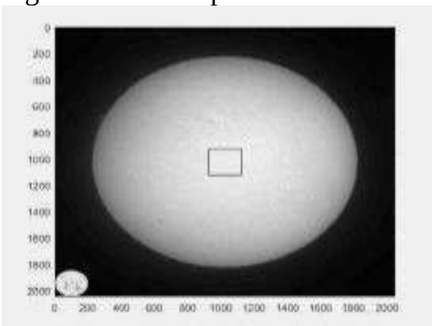


Fig.19: QuietSun region taken at the center of the disk

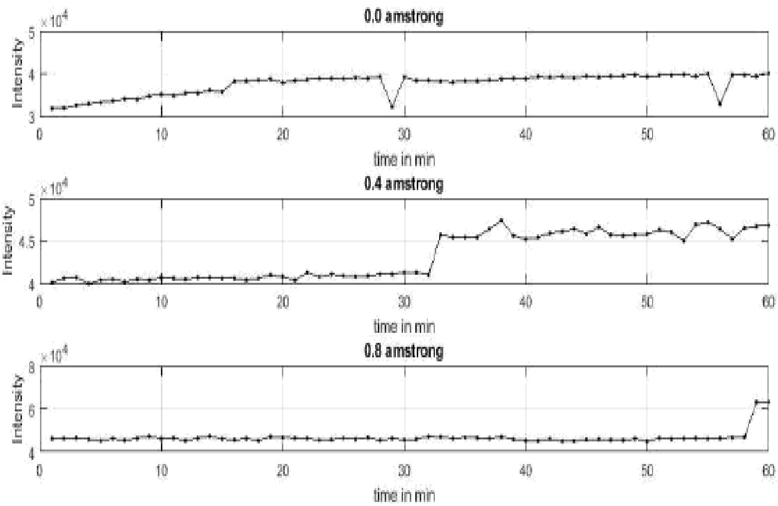


Fig.20: Intensity vs. Time plot at the center of the solar disk

Results, Discussion & Conclusions

The team conducted a detailed examination and operation of the Kodaikanal Solar Observatory's Hα telescope. The Hα line images of the Sun are obtained with a telescope. Accurate segmentation of filaments from H-alpha images is achieved using a combination of morphological operations, watershed transformation, dilation, and erosion techniques. Comprehensive feature extraction of filaments included geometric properties (shape, size and orientation), intensity profiles and orientation and directionality. A dynamic change in filament intensity over time and pattern of intensity variation are reveled in intensity vs. time plot analysis.

The intensity v/s time plot was obtained by performing a time series analysis on the Hα images obtained at various positions (0.0Å, 0.4Å, and 0.8Å) on the line profile that was observed for two hours on January27,2018,atatimeintervaloftwominutesperframe.In 2016,a solar flare was produced by the observation ofthe filament's progression over a four-month period (January-April). These solar flares release high-energy radiation particles that have an impact on space weather, earth's temperature, and satellite communication. The numerous aspects seen in satellite images, enabled us to extract and comprehend with the help of this research. Overall the employed techniques demonstrated robustness in segmenting and extracting meaningful features from filaments in H-alpha images. The extracted features and intensity vs. time plot analysis offer valuable insights into filament dynamics contributing to enhanced understanding of solar magnetic field evolution, improved predictive capabilities for solar activity and informing space weather forecasting.

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