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Simultaneous Coronal Hole Segmentation from Solar EUV Images using the Image Co-segmentation Technique

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Abstract

Accurate detection of coronal holes (CHs) is an important issue in the domain of solar physics, since, CHs plays an vital role in controlling the overall space weather and generation of solar wind. In this paper a novel application of image co-segmentation (Co-seg) has been proposed for accurate detection of coronal hole simultaneously in two solar disk images of different band. For the task of Co-seg circular Hough transform inspired active contour method (ACM) have been proposed. Here the circular Hough transform has been introduced to setup the initial contours for the ACM based Co-seg. In later stage, the initiated contours has been evolved based on the energy function by incorporating the color features. At the final stage, when the contours do not deform any more is considered as the final contours position and the regions inside the contours is extracted as the CHs regions from both the images under consideration. The experiment has been conducted on few benchmark datasets and the corresponding results have been compared with the results of other existing techniques. The compared outcomes validate the performance of the applied technique in detection of coronal holes in solar disk.

1 Introduction

The coronal holes (CHs) are the low density and low temperature zones present within the solar corona. CHs occurs due to the opening of the solar magnetic field to the interplanetary space. This CHs regions of the Sun is responsible for several space weather phenomenon and occurrence of geomagnetic storms. Opening of the magnetic fields in CHs allows particles to escape and this in turn causes high speed solar wind streams. In turn, when these particles of the streams interact with the Earth, it leads to the geomagnetic storms. These high speed solar wind and geomagnetic storm has various impact on the Earth surface and its artificial satellites such as; it affect the GPS navigation Systems, causes problems in HF radio communication and satellite communication, results in satellite drag, causes interruption in electric power transmission. As such it become necessary to study and locate the CHs properly and accurately in order to handle the odd situation arise due to the existence of the CHs regions in the solar surface.

CHs regions are well visible in the extreme ultra-violet (EUV) and X-ray band images of the Sun. The CHs region appear as a darker regions in these images, due to their low density and low temperature characteristic compared to the surrounding plasma in the solar surface. Thus from the image processing point of view the task of CHs detection can be resembles with the localization of the darker region in the solar disk images. Earlier researcher has to depend on the hand drawn images for detection of the CHs. However, with the advancement of the technology, now a days some image processing based technologies mainly image segmentation techniques have been used for detection and extraction of CHs in solar disk images. Some of these techniques are, perimeter tracing [1], intensity thresholding [2], fuzzy clustering [3], edge-based segmentation [4] etc. Despite of having several advantages, there are some major concern associated with the automated CHs detection techniques. The issues are; proper selection of threshold value, high mathematical complexity, degradation of original resolution of image under consideration, etc. Region-growing based strategy had too been used for CHs segmentation [5]. But its output accuracy depends on the correct selection of the seed points in images. Boucheron *et al.*, [6] had applied ACM based segmentation technique for CHs extration. However, the method require meta data information for the exclusion of the off-disk region. Ciecholewski [7] had used watershed transformation for CHs segmentation in solar disk images. But, the main issue associated with this method is that, in some cases it results in over-segment of the images. The method is also having numerical complexity due to the utilize of three separate algorithms. Convolution neural network (CNN) based method has also been utilized for the segmentation of solar image[8]. This requires a expansive database of solar images for preparing and testing of the network. Moreover, all the existing method is capable of extracting CHs from a single image at a time.

In this work a novel application of image Co-seg has been introduced [9, 10, 11]. Here, the task of detection and extraction of the CHs simultaneously in two solar disk images has been carried out using the Co-seg technique. The term Co-seg basically refer to simultaneous segmentation of the common object from the given images [9, 10]. For this novel work of coronal hole detection using image Co-seg two solar images of different frequency band taken from the Atmospheric Imaging Assembly (AIA) located on Solar Dynamics Observatory (SDO) has been considered. The task of Co-seg has been carried out using the ACM based technique. In the work circular, Hough transform algorithm has been induced for the contours initialization, which is the first step of active contour algorithm. Here, first the contours have been initialized on both the solar images under consideration. In later stage these contours are made to evolve by incorporating the color features associated with the images. And based on the final position of the contours the holes are detected. Thus the main contribution in this work is;

- Novel application of ACM based image Co-seg algorithm for detection of CHs.
- Initialization of the contours for Co-seg task using circular Hough transform technique.
- Simultaneous detection of CHs in two solar images of different band frequencies.

The proposed work has been tested on few SDO/AIA datasets. For the porposed work SDO/AIA images of 193 Å and 211 Å wavelength have been taken into account.

The paper has been organised as follows. In Section 2 the CHs detection using Co-seg has been explained. Discussion on outcome has been carried out in Section 3. Ultimately, in Section 4 conclusions on the proposed work has been drawn.

2 CHs Detection using Co-segmentation

For the case of detecting CHs simultaneously using Co-seg algorithm, two SDO/AIA solar image of 193 Å and 211 Å have been taken from Solar Dynamics Observatory: SDO [1]. Two solar image of different band has been taken with a motivation to fulfill the basic requirement Co-seg algorithim. The Co-seg algorithm require two or more images sharing the same foreground object in front of a changeable background. Now the two SDO/AIA images of 193 Å and 211 Å are basically a false color image, where, non-CHs pixels in 193 Å are typically colorized in brown while 211 Å wavelength image is colorized in purple. As such there will be a variation in background without effecting the region of interest (CHs) in the images. As a consequence the implemented algorithm can easily extract out CHs from the images as a part of common region present in the images.

In the first stage of the used method contours are simultaneously initialize on both the images based on circular Hough transformation [12]. This will setup initial contours on the boundary of the solar disk. Later, the contours are made to evolve toward the boundaries of CHs region by minimizing a considered energy or cost function. The cost function for C-VACM based Co-seg for k numbers of images is given by [10, 11];

$$\begin{aligned} E(C_k)^*_{coseg} =& \mu Length(C_k) + \nu Area(C_k^i) \\ & - \lambda_k^i \int_{C_k^i} f[I_k(x,y), r(C_{1-k}^i)]dxdy \\ & - \lambda_k^o \int_{C_k^o} f[I_k(x,y), r(C_k^o)]dxdy. \end{aligned} \tag{1}$$

Where, $k \in \{0,1\}$. Here, regions r outside the curve C in image I_k is denoted by the notion $r(C_k^o)$, and the term $r(C_{1-k}^i)$ represents to the locale interior the bend of the confined image. For instance, when $k=0$, i.e., while working with *Image 0* at that point, the pixel interior the image will be indicated by $I_0(x,y)$, the area exterior the bend within the closely resembling image will be signified by $r(C_0^o)$, and the locale interior the bend of the isolated image will be convinced by $r(C_{1-0}^i) = r(C_1^i)$. Similarly it held genuine for the case of *Image 1*. In the work the contour position having the least esteem of cost function is considered as the boundary of the common region. The term $f[I_k(x,y), r(C_{1-k}^i)]$ signifies the estimation of similitude between the foreground pixels of the image I_k and the locales interior the bend of the other image, $r(C_{1-k}^i)$. For extricating out the common locale from the image which keeps up the foreground coordination among the images $f[I_k(x,y), r(C_{1-k}^i)]$ have been applied. The exterior term $f[I_k(x,y), r(C_k^0)]$ measures the closeness between the foreground image pixels and the region exterior the bend of the same image. It fundamentally extricates out the background locale of the comparing image. This by ideals keep up the background coordination. The term μ is a weight parameter for length of the curve, which depends on the number and the estimate of the object(s) to be recognized. ν is the weight for the area interior to the curve. This permit to thrust the contour towards the object(s). The weight values λ_k^i utilized to preserve the consistency within the foreground and λ_k^o keep up the consistency within the background of the image.

Now, to optimize the cost function of the work Gradient-descent strategy have been connected on the Partial Differential Equation (PDE) of the level set detailing in condition (1). In this way the by and large equation changed to,

$$\begin{aligned} \Phi_k^{n+1}(x,y) = \Phi_k^n(x,y) + \delta(\Phi)\{\mu.\text{div}(\frac{\nabla(\Phi)}{|\nabla(\Phi)|}) - \nu \\ + \lambda_{\Phi k}^i.f[I_k(x,y), r_\Phi(C_{1-k}^i)] - \lambda_{\Phi k}^o.f[I_k(x,y), r_\Phi(C_k^o)] \end{aligned} \tag{2}$$

where, the notion $H(\Phi)$ is the Heaviside function of the curve Φ, while the term $\delta(\Phi)$ representing the Dirac measure. In the equation (2), the term Φ represents the level set energy function of the curve. On the other hand, the term $\Phi_k^n(x,y)$ legitimize the level set vitality work of curve for pixel area (x,y) at $n-th$ iteration.

Now, based on the energy function represented by equation (2) the initialized contour start shrinking toward the object(s) boundary. After certain number of iteration the contour get stuck at a boundary of region where the value of the energy

[1] https://sdo.gsfc.nasa.gov/data/aiahmi/

function is minimum. And thus the algorithm uncover the CHs regions by locating the regions inside the position of the final contour evolved by the stated energy function.

3 Results and Discussions

3.1 Parameters Settings

The contour has been evolved based on μ, ν, λ_k^i and λ_k^o parameters. The parameter μ has been kept kept at 0.001, with a motive to detect small regions as well as big CHs regions. The term ν also has been assigned with 0.001 so that minimum region area can be given maximum weightage, since CHs exist in the particular regions of the image. The parameters λ_k^o and λ_k^i have been weighted with 0.1, so, that same weightage can be given for maintaining the consistency within the background and for preserving the consistency within the foreground of the image respectively. The algorithm has been run for 2000 iteration in order to generate proper output with desired CHs region.

3.2 Visual Analysis

The work has been carried out using four-sets of SDO/AIA 193$\mathring{A}$ images taken at four different dates, on; **(a)** 2017-01-30 (Image-1), **(b)** 2017-03-14 (Image-2), **(c)** 2017-09-14 (Image-3), and **(d)** 2018-01-30 (Image-4), for particular time period. The proposed method of Hough inspired C-VACM based Co-seg has been applied on the four mentioned datasets. Corresponding output using the applied method is shown in Figs. 1-2.

In the Fig. 1-2, the first row contain the original SDO/AIA solar image, while the final contour position obtained after evolving the boundary equation given by equation (2) shown in the fifth row. The evolution of contours at different iteration of the proposed algorithm has also been shown in the Figs. 1 and 2. In the figures, column *(a)* indicates the 193 Å solar disk image while the images in column *(b)* of Figs. 1 and 2 indicate the 211 Å solar disk images used in the work. The third row in the figures highlight the first step after the initialization of the contours, where the off-disk region in the images have been eliminated. That is, the pixels intensity in this off-disk region have been replaced with intensity values 255-255-255 for RGB colored images. This has been done with motive to reduce the complexity of the algorithm, by keeping three points in view. First, the CHS regions does not exists within the off-disk. Second, there is a high probablity for any image segmentation technique to involve all the pixels (pixels in region of interest (RoI) and pixel outside RoI) in their corresponding calculation, this in turn increase the chance of misclassification. Third, both background and CHs regions in SDO/AIA solar image share the same color intensity so there is a obvious probablity that both region may be detected as RoI or CHs. The contour position in the intermediate steps of evolution of the C-VACM algorithm, final contour position obtained after the termination of the proposed algorithm and the final outputs

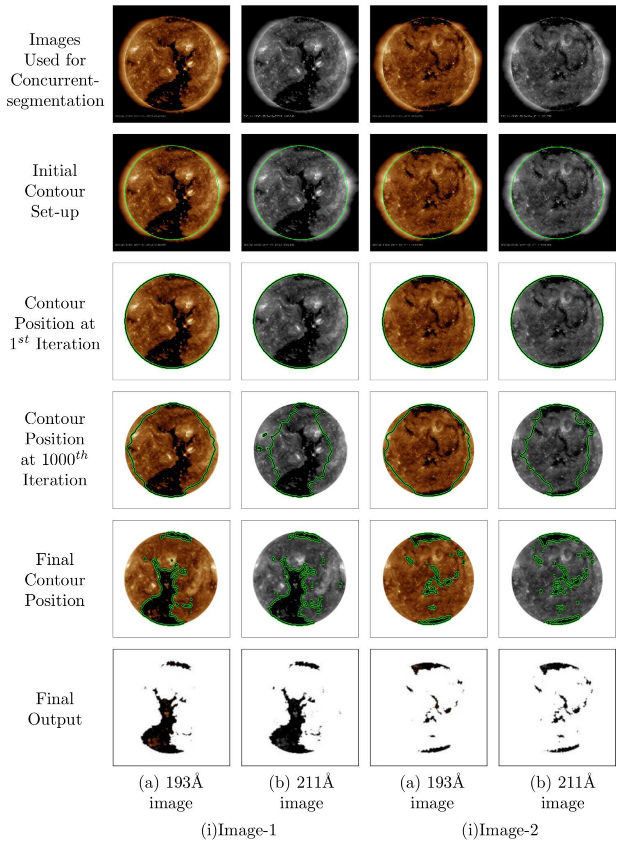

Figure 1. Contour initialization, contour evolution, final contour position and corresponding output obtained after applying the proposed method of Co-seg.

obtained after the execution of the proposed algorithm have shown in the subsequent rows of the Figs. 1 and 2. In the image the common regions (non-white regions) extracted as shown in the images given in column *(a)* and column *(b)* in the last row of the Figs. 1 and 2 indicates the regions or objects of interest, i.e., the CHs regions. From the outcome it can be stated that Co-seg algorithm has extracted out CHs (darker regions) from all the images accurately.

4 Conclusion

In this work circular Hough transformed inspired Chan-Vese active contour model of co-segmentation has been implemented for the detection CHs regions simultaneously in two different solar disk image. The circular Hough transformed has been used to setup initial contours for the purpose of Co-seg using modified C-VACM. The proposed algorithm has few major advantages. These are, firstly, due to the use of circular Hough transformation the contour setup issue as present in the work [10] has been eliminated, furthermore, it does not require meta data information for initialization purpose. Secondly, it does not need large database of solar image for accurate outcome, unlike CNN based method of CHs detection [8]. However, the number of iteration and corresponding iteration time making (near about 420-600 sec) the algorithm unfit for the real time use. Thus the in-

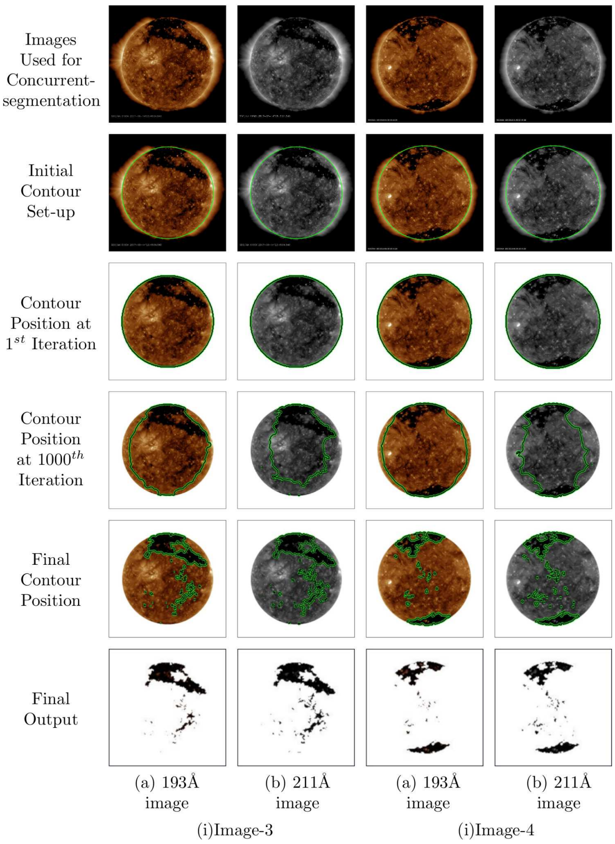

Figure 2. Contour initialization, contour evolution, final contour position and corresponding output obtained after applying the proposed method of Co-seg.

crease of the computational speed of the algorithm without sacrificing the other constrain of the method will be in focus for the upcoming work.

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