Coronal Loop Detection

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"*Coronal loops* are immense arches of hot gas on the surface of the Sun, thought to be jets of hot plasma flowing along in the alleys between the strong coronal magnetic fields. They are visible at X-ray, ultraviolet, and white-light wavelengths, consisting of an arch, extending upward from the photosphere for tens or hundreds of thousands of kilometres. Bright coronal loops, in the form of coronal condensations and bright spots, are common around the time of solar maximum while larger faint ones, that last days or weeks, are more typical of the quiet corona, when solar activity is low. The two ends of a loop, known as *footprints*, lie in regions of the photosphere of opposite magnetic polarity to each other." (text taken from paper [3])

The interest of the study on Coronal loops lays to the fact that they are involved in many complex phenomena occurring at the sun's surface, such as the coronal mass ejections, solar flares, etc. The data obtained through the coronal loops' study are essential in gaining better knowledge of the *coronal heating problem* which is of major interest. The detection of the coronal loops was used to be done by hand, though the process was very time consuming and tedious. An automated method is needed in order to detect the Coronal loops in the huge dataset of the images taken by SOHO, TRACE and the other telescopes observing the Sun.

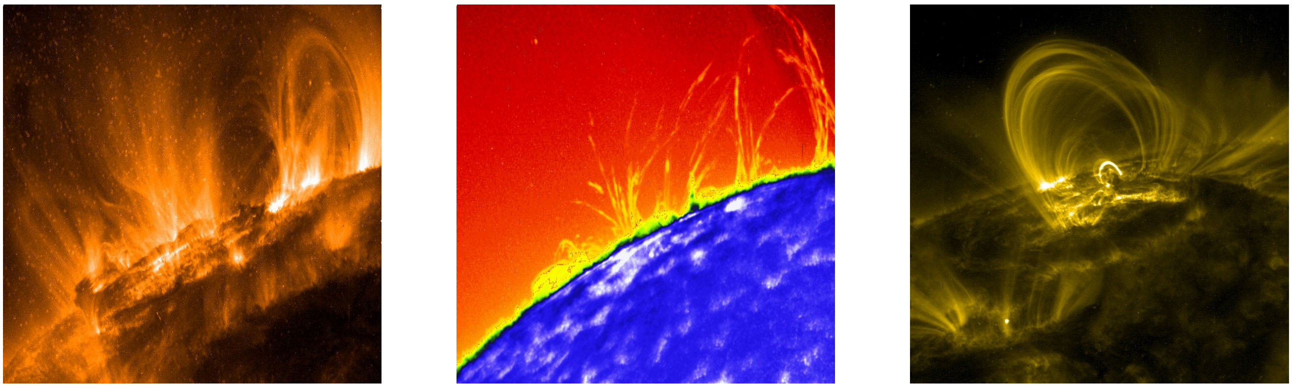


Fig. 1. Pictures of coronal loops taken from TRACE [6] (NASA Small Explorer).

Although, there had been lot of research [2-5], the overall outcome was insufficient. The images were picked with prior knowledge of containing coronal loops and also the proposed methods could not perform in noisy images or handle problems with curve discontinuities. The research of Durak et al. [1] is more consistent and closer to the needed method. Their proposed method is applicable in any image with noise or not, without any prior knowledge of the existence of coronal loop in it.

The *coronal loop detection* consists of three main parts: the preparation part of the image, the classification of the overall image as if a loop exists and the actual detection of the coronal loops in the image. Except from statistical and regular image features some other specialized features are extracted. The additional specialized features provide more information to the classifier in order to obtain more reliable results. The additional specialized features are: *curvature features*, *edge related features* and *spatial features* (more information on the features can be found at paper [1]).

Initially, in order to classify images as containing coronal loops, a training dataset is created by astrophysics experts that contained coronal loops. The same preparation process is also applied to these images and the same kind of features are extracted from them. This data was used to train the classifier and evaluate it. Even though several classifiers can used, according to [1] the *Adaboost classifier* proved to be more precise than others.

During the preprocessing, a median filter is applied to the images in order to reduce the noise and also background removal is applied to bring out the structure of the loops. Then, a global thresholding along with a Sobel edge filter is applied in order to obtain a binary image to be processed further. Next, the binary image is divided into several small blocks and each of these blocks are labelled as whether it contains a loop or not. In order for a block to be labelled, it is compared with the training data's coronal loops. If their similarity is greater than a certain percentage (about 70% is good), then it is labelled as *loop class.*

In every block that has been labelled as *loop class,* its features are being extracted. In order to extract the curvature features the algorithm being used is also detecting the actual coronal loop in the particular block. Below the features are presented.

- The statistical features consists of the mean, standard deviation, smoothness, entropy uniformity and skewness.
- The edge related features are extracted using the *Hough transform* [7] that is a very good method to detect lines and curves in an image. More edge related features are extracted by the use of the *edge histogram definition* (EHD) method.
- In order to retrieve the spacial features, each block is divided into smaller parallel bands and the number of edge pixel in every band is counted.
- The curvature features that are obtained are the curve length and distance, the curvature strength (how curvy the traced curve is) and the peak angle (the angle between two segments when they intersect). The Hough based ellipse detection is not performing accurately in noisy environments, so in [1] they have developed a new algorithm to trace curves in images. Their algorithm performs well in noisy images and also with curves that present discontinuities. An example of the algorithm is presented at the Fig. 2 below.

After the extraction of the features, the data of the curves are fed to the classifiers. Then the classifiers label the extracted curve as *coronal loop* or not, having the prior knowledge of the training dataset.

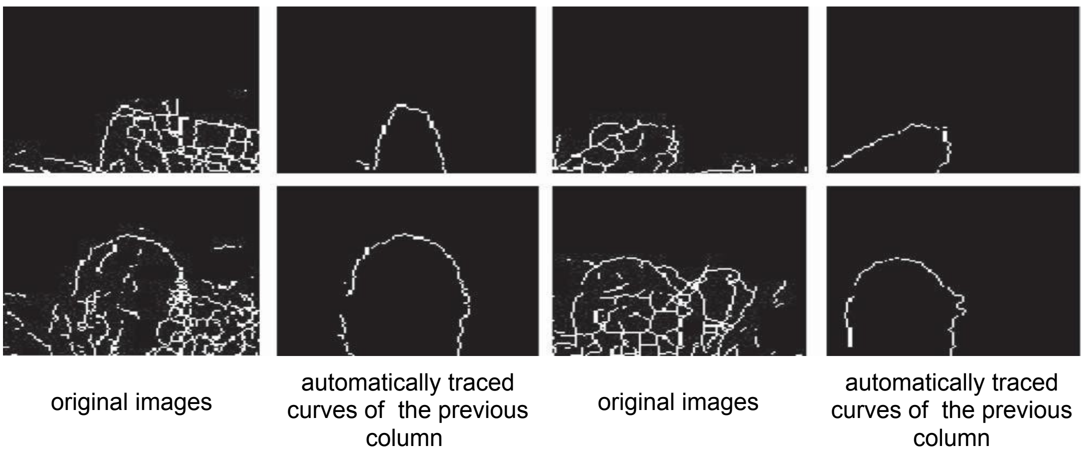
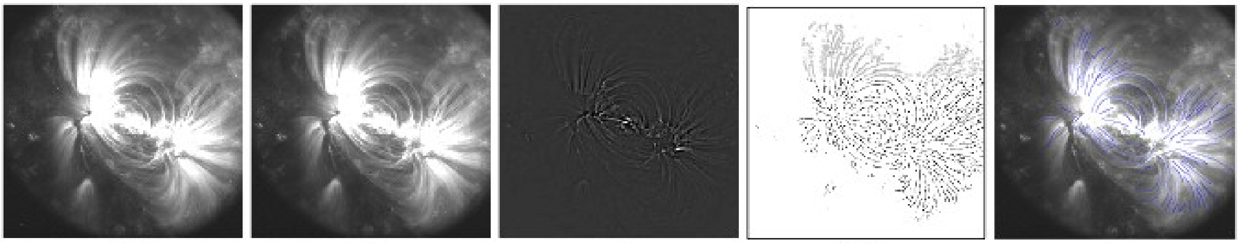


Fig. 2. Automatically traced curves.

The procedure of the overall classification of an image to the loop class is a combination of the preprocessing and the feature extraction. Based on the label of each block, a general decision is made whether the image contains a coronal loop. The whole image is classified into the *loop class i*f it contains at least one block that it is already labelled as *loop class.*

An example of the results of a coronal loop detection are shown in the Fig 3 below that were taken from the paper [2].



(a) (b) (c) (d) (e)

Fig. 3. (a) Coronal image, (b) Median filtered image, (c) (Contrast enhanced) Unsharp masked image, (d) Thresholded curve features, (e) Detected loops. (Image taken from [2]).

References and Relative links.

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[6] Transition Region and Coronal Explorer website. [http://trace.lmsal.com/]

[7] R. O. Duda, P. E. Hart, *"Use of the Hough Transformation to Detect Lines and Curves in Pictures",* Comm ACM 15, 1972. [http://www.ai.sri.com/pubs/files/tn036-duda71.pdf]