



Automated Detection and Characterisation of CMEs



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1. Abstract

Coronal Mass Ejections (CMEs) are large-scale eruptions of plasma and magnetic field in the solar atmosphere. To date, these diffuse objects have been difficult to identify using traditional image processing techniques. Here, we investigate the applicability of *multiscale* image processing methods to *characterise* CME morphology (width, curvature, orientation) and *kinematics* (position, velocity, acceleration) in images from the SOlar and Heliospheric Observatory (SOHO) and the Solar TERrestrial Relations Observatory (STEREO). These methods are expected to be of practical benefit for *real-time* space weather monitoring and forecasting.

2. Background & Motivation

Several models have been proposed to describe CMEs. In the *flux-rope model*^{1,2}, foot-point motions trigger the eruption; the acceleration is then determined by the flux-rope geometry. The *breakout model*³ is based on magnetic reconnection between overlying field lines and neighbouring flux systems.

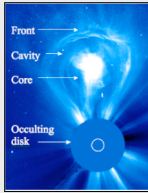


Fig. 1: A canonical CME.

The diffuse nature of CMEs means their detection with traditional imaging techniques is difficult. Thus, advanced image processing methods are necessary to 1) accurately measure the morphological and kinematical properties of observations, and 2) compare these results to theoretical models.

3. Difference-based CME Detection

Running difference techniques rely on subtracting consecutive images in order to highlight moving features⁴. Our algorithm operates as follows:

1. Creation of *running difference* images produces high contrast intensities of moving regions.
2. An *intensity threshold* is applied to identify the CME front.
3. An *ellipse fit* then enables us to parameterise the CME kinematics.

Figure 2, below, shows the height, velocity and acceleration of the apex of a CME (the farthest point from Sun centre). The velocity increases steadily with time, in a range of 200-800 km/sec, and acceleration was determined to be ~40 m/sec². Figure 3, at right, and Figure 4, below right, show an increase in CME orientation (ellipse angle), and also the expansion of the CME (ellipse width).

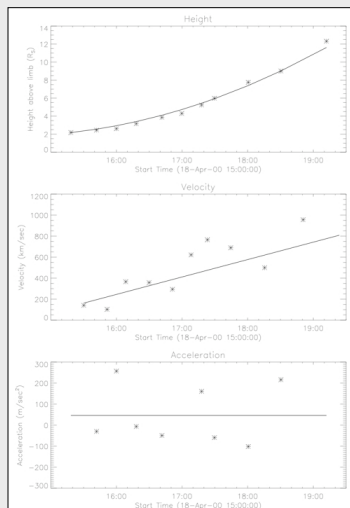


Fig. 2: The kinematics of a CME observed by LASCO on 18-Apr-2000.

4. Wavelet-based CME Detection

Running difference techniques are limited in their application and can be difficult to interpret. The subtraction of subsequent images creates a false data interval, leading to an erroneous measure of a CME's morphology and kinematics. Wavelet-based techniques overcome many of these issues^{5,6}.

The *à trous* algorithm is a fast method for decomposing an image into its characteristic scales^{7,8}. The wavelet coefficients of an image f are defined as

$$W_s^a f(x, y) = (f * \Psi_s^a)(x, y)$$

where Ψ_s^a , the mother wavelet, is given by

$$\Psi_s^a(x, y) = \nabla^2 \tilde{\theta}_s(x, y)$$

We have chosen the smoothing function, $\tilde{\theta}$, to be a B_3 spline approximation of a Gaussian. This method is described graphically (for 1-D) in Figure 5, below.

An *à trous* wavelet decomposition of the 18-Apr-2000 CME observed by LASCO is shown in Figure 6, above right.

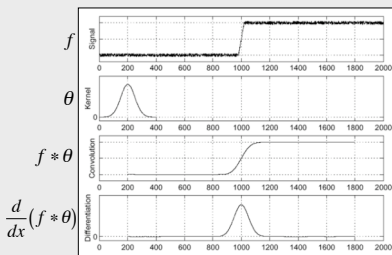


Fig. 5: The application of multiscale methods to edge detection in 1-D.

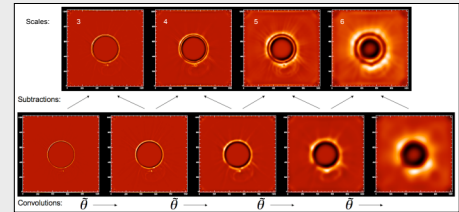


Fig. 6: Graphical illustration of the *à trous* algorithm for a CME observed by LASCO.

As can be seen from Figure 6, the CME front is most clearly visible at scale 4. The front can then be identified using the *Canny edge detector*, which is equivalent to:

$$\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

The direction of the gradient is then given by:

$$\alpha = \tan^{-1}\left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x}\right)$$

An example of the application of the Canny detector to scale 4 is shown below in Figure 7.

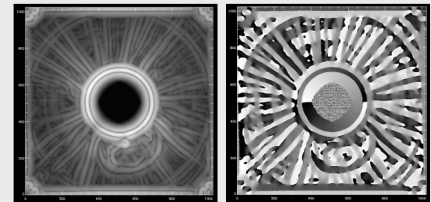


Fig. 7: The magnitude of the image gradient (left) and its direction (right).

5. Future Directions

The application of our methods to STEREO data (e.g., Figure 8) will provide a measure of the changing morphology and kinematics of *CMEs out to 1 AU*. The twin angles of observation will lend themselves to more accurate depictions of CME height and width.

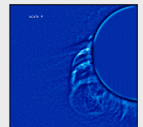


Fig. 8: CME seen by SECCHI on STEREO.

Multiscale analysis will be explored further; there is a wide variety of wavelets available and the *development of curvelets* may better suit CME structures.

Our methods have been designed with *automated CME detections* in mind⁹. They may therefore be applied to space weather forecasting, which is important for predictions of geomagnetic storms at Earth.

6. References

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