AUTOMATIC DECTECTION OF CORONAL MASS EJECTION FOR SPACE WEATHER

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Abstrak

Coronal mass ejection (CME) is an important event that influences significantly the condition in interplanetary space as well as the Earth's magnetosphere. A traditional effort to detect CME event is by visual inspection of coronagraph images sequentially. In order to support space weather related services at LAPAN, computer software is developed to detect automatically the event based on running difference images of coronagraph data taken by LASCO (Large Angle and Spectrometric Coronagraph Experiment) instrument aboard SOHO (Solar and Heliospheric Observatory) spacecraft. The intensity profiles of selected area at several locations around the occulting disk are extracted from the running difference images. CME event will be identified when there is abruptly change in the intensity profile at particular position around the occulting disk. The time and location are recorded into a file for further verification. As an initial experiment, the procedures were applied to LASCO data taken in November 2003. This paper describes the methods, software development as well as the preliminary results of CME detection.

Key words: *coronal mass ejection, space weather, coronagraph, software development*

INTRODUCTION

Coronal Mass Ejection (CME) is a huge ejection of solar coronal plasma in a short time. The event is initiated by instability of an arcade of magnetic fields in solar corona [6]. It may be occurred within or outside an active region (sunspot group). Therefore, number of CME during maximum solar activity usually increases. Although, it does not mean that there is no CME event completely during a minimum solar activity. CME is the most powerful disturbance from the Sun. When it is directed to Earth it may cause severely damages to the advanced technologies in space and the Earth as well as may disturb human life [3,5]. Monitoring the occurrence of CME and predicting the arrival time of CME at the Earth's orbit are therefore very crucial [1,2,8].

Traveling time of CME from the Sun to the Earth depends on the initial speed CME leaving the Sun. The most powerful CME has speed greater than 2000 km/s and classified as a fast CME [3]. If the average distance of the Sun-Earth is about 150.000.000 km, a fast CME may reach the Earth as early as 20 hours after leaving the Sun. It is assumed that there is no acceleration or deceleration process during its propagation in the interplanetary space. In the other hand, CME may have speed as low as 300 km/s for slow CME. In this case, it will arrive at the Earth's orbit within 140 hours or six days.

These facts allow us to prepare how to minimize or avoid the damages caused by a CME. The most important is to know the start time and the speed of CME leaving the Sun as early as possible. Solar and Heliospheric Observatory (SOHO) located at L1 point between the Sun and Earth is able to observe the CME event using its Large Angle and Spectrometric Coronagraph Experiment (LASCO) instrument. The LASCO images come to spacecraft about 8 minutes after the launch of CME at the Sun. By detecting CME event automatically from the LASCO images, there will be an

enough time to alert the public concerning a possible threat caused by CME [4,7]. This work is devoted to develop a method to detect CME event automatically to support space weather program.

Section 2 describes the observation data used in this work, while the methods are presented in section 3. Software development for data reduction and analysis is given in section 4. The results are presented in section 5 and section 6 provides summary of the work.

OBSERVATIONS

Coronagraph onboard SOHO spacecraft provides images of the outer corona up to 30 solar radii. This makes possible to trace coronal mass ejection (CME) motion as well as its shape (Halo or partial). Combine with EUV images of SOHO, it is possible to find out the source region of CME at the Sun. Some examples of LASCO-C1 images are given in Figure 1, while the images of LASCO-C2 are shown in Figure 2. SOHO takes LASCO images with relatively short time interval that enough to catch the appearance of CME and its evolution during outward motion leaving the occulting disk. Identification of CME is usually performed by visual inspection of sequential LASCO images. In order to provide quick information of the occurrence of CME for space weather, it is therefore important to detect automatically the appearance of CME and derive its properties as early as possible. This work deals with the problem of detecting CME event by using image processing techniques as will be described in the following section.
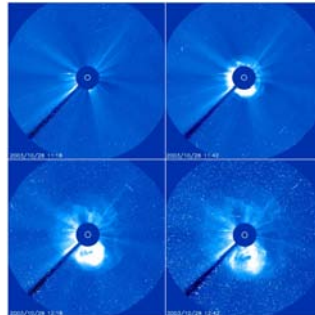

Figure 1. A sequence of "Halo" type CME occurred on 28-10-2003 starting at about 11:18 UT. It is obvious that a circular wave-front rapidly moving away from the Sun.

METHODS

In order to detect CME event automatically, the following steps have been performed:

Pre-detection
1. Read a directory containing LASCO-C2 or C3 images and sort the filenames based on the time sequence.
2. Compute the interval time between two consecutive images from the filenames. If there is a data gap of duration 3 hours or more, it is difficult to decide the existence or nonexistence of CMEs.
3. Create a variable to hold the data cube (time series of images).
4. Align the LASCO images so that the North direction is up and West direction to the right. The images provided by SOHO Team at their web site have actually been corrected from this alignment.
5. Create a running difference images: an image is subtracted from the previous image and this is applied to all images in sequence. The latter time is used for time labeling of the difference images.

Detection of CME
1. Determine the center of the Sun and its radius from the first original image.
2. Specify that the occulting disk is located at 5 x solar radius (Ro).
3. Define boxes of a fixed size (for example 10 x 10 pixels) at the outside of the occulting disk at a certain radius (r = 5Ro).

4. For each difference images, takes the total of intensity inside each box defined in the previous step.
5. Do smoothing the intensity profile in step 4.
6. Do plot of the intensity profile along with its smoothed intensity for each box. This is used for visual inspection to study the properties of CME.
7. Calculate the time derivative of the smoothed intensity profile.
8. Find the maximum and minimum in the time derivative intensity profile. A pair of maximum (minimum) corresponds to the start (end) time of a CME.
9. Extract the date and time of start and end of CME from related filenames.

DATA REDUCTION AND ANALYSIS

We have performed data reduction and analysis using Interactive Data Language (IDL). The software provides enhanced capabilities in processing digital images such as array operations are handled efficiently. There are built-in functions and procedures based on standard numerical techniques available to users. Two procedures (difimg.pro and detect_cme.pro) have been constructed to perform various tasks mentioned in section 3.

Program difimg.pro is used to generate data cube of running difference images. The input parameters are directory path and a part of filename (such as file extension "jpg", "gif", etc.). If the directory is not given, it is assumed to looking for files in current directory based on a part of filename. The filename of CME has a format "YYYYMMDD_HHMM_c3_512.jpg", where YYYY – year, MM – month, DD – day, HH – hours, MM – minutes, c3 – type of coronagraph, 512 – image size and jpg – JPEG image format. Therefore, the date and time of observation can be extracted from the filename. The size of image is actually extracted from the image itself. Using the number of image files being processed, a three-dimensional variable that holds difference images was created. Creating difference images are simple as follows:

```
for i = 0
    dif (i) = img(i)
for i > 0 and i< n
    dif (i) = img (i) – img (i-1),
        with i=1, n-1; n is number of images
        img – orginal image
        dif – difference image
```

The image contains in variable dif(0) is the first original image (not a difference image). This is used for determination of position (x,y) of center and radius of the Sun in the image. The occulting disk for coronagraph c3 was designed to have radius of 5 x the Sun's radius (Ro). This information is important for defining position and size of a box for detecting a CME. Once the difference images are created, this data cube is used to input detect_cme.pro.

To develop a procedure in detecting the occurrence of CME, a box of size 10 x 10 pixels at the West part of occulting disk (r = 5Ro) was created and data processing described in section 3 was conducted. If there is a CME launched close to the West of occulting disk, there will be a variation of intensity as CME plasma flows passing the defined box area. The initial increase followed by the decrease of intensity would be indicating the start and end time of CME passing the selected box. The results and discussions are given in the following section.

RESULTS And Discussions

The number of SOHO/LASCO-C3 images processed in this work is 118, starting from 25 October 2003 0018 UT to 27 October 2003 2218 UT. Figure 2 is an example of the first image that shows coronal structure at East, East-South and North-West positions. A circle at the center represents solar limb (the Sun). Circular dark area around the Sun up to 5 Ro is the occulting disk. Inside the occulting disk no coronal features can be seen. Bright points that scattered in the image

are stars or other astronomical objects. They are a kind of noise that should be removed prior data processing for CME detection.

Figure 2. The first image of SOHO/LASCO-C3 used in the experiment of detecting a CME.

Figure 3 show an example of difference images that have been created to show the appearance of a CME. The figure should be read from left to right as indicated by sequence number at the lower-left corner of the image. In the first image, there is no indication of brightening feature that corresponds to mass flows. In the next image (upper-right), a brightening was appeared at the West part of occulting disk. This is a loop of CME as indicated by an arrow. As the time goes on, the size (width and height) of CME becomes larger in the lower panel.

To detect a CME event and study the behavior of the ejected plasma leaving the Sun, a box of size 10 x 10 pixels is defined at the West part of the occulting disk. This box is an area where the total intensity inside the box will be calculated for each difference image. In this experiment, there are two types of calculation on total intensity: (1) by using absolute function prior to summation of the pixel intensity, and (2) without absolute function for summation. This procedure is performed as, based on visual inspection, the difference images were not uniform in the intensity scale from one image to another (Figure 3). By evaluating two procedures, it is expected to find the most appropriate way to detect CME event. The results of the intensity profiles calculated using two methods are shown in Figure 4.
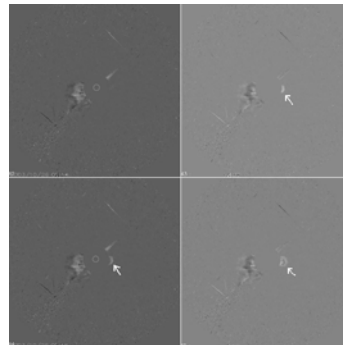

Figure 3. An example of difference image is initially showing no CME (upper-left). CME started to appear in the next image as shown by an arrow (upper-right) and continues to develop in size in lower panel.

Figure 4 (upper panel) is the intensity profile of a selected box calculated using absolute function to avoid a negative pixel values. In this Figure, the horizontal axis represents sequence number of image that corresponds to observation date and time. It obvious that when a CME passing the box area, it is detected as a sudden increase in intensity. This corresponds to a starting time of CME event. Unfortunately, the end time of CME cannot be caught obviously by this method. Furthermore, other CME events that probably follow the first CME can not be recognized.
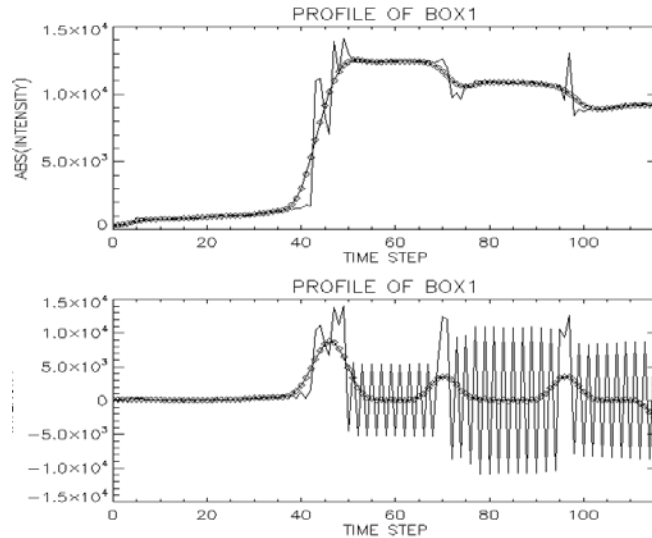
Figure 4. Comparison of the intensity of pixels inside a selected box at the West of occulting disk with 10 x 10 pixels. Absolute function is used to change negative values of the pixels (upper) and without using absolute function (lower). Smoothed values (◊) are plotted for each case.

Figure 4 (lower panel) shows the total intensity profile without using absolute function prior to summation of the pixel intensity. The indication of a CME passing the box is detected, while its ending time can be seen. There was a periodic fluctuation in the intensity after this event. This may be caused by the difference images that are, in fact, not uniform (Figure 3). There are two peaks after the first peak, which may resemble the occurrence of CME. Unfortunately, the noises are relatively large so that the peaks are not obvious. To remove the influence of noises, a smoothing method was applied and the results are shown as "diamond" legend in the same figure. The smoothed plot shows obviously three peaks that are expected to correspond to the appearance of three CME.
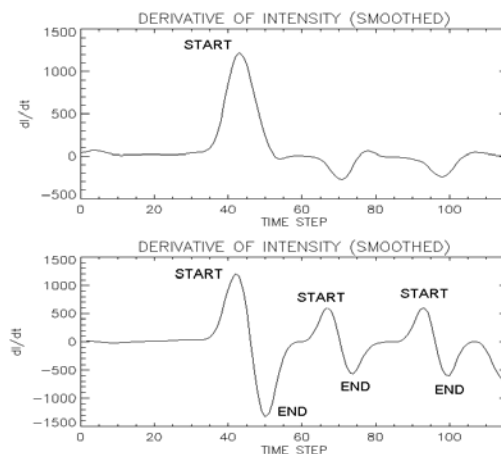

Figure 5. Derivation of the smoothed intensity profiles in Figure 4 in order to find the start and end time of CME. Maximum (minimum) peaks related to start (end) time of CME. Upper (lower) panel corresponds to the first (second) method as shown in Figure 4.

In order to determine automatically the start and end time of a CME, the smoothed intensity profiles of the two methods were derived to observation time and the result is shown in Figure 5. The first method (using absolute function) results in a good detection of the start time of a CME, while the end time was not obviously recognized. The second method (without absolute function) can detect nicely the start and end time of three CMEs that occurred during the observation.

CONCLUDING REMARKS

We have described the methods and data processing techniques to detect automatically CME events in SOHO/LASCO-C3 images. The method constructed running difference images to recognize a weak mass flow of CME. By defining a box at the West part of the occulting disk, the method can successfully detected three CMEs that occurred during the observation period, along with their start and end time. Extracting the properties of CME automatically from SOHO/LASCO images is an important task to support space weather program at LAPAN. This will be conducted in the future.

Acknowledgements

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