Fast Satellite Streak Detection for High-resolution Image

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***Abstract*— For the observation of satellites in earth orbits, the satellites must be detected within a certain time limit and the coordinates of the satellites must be delivered to the tracking system. For the satellite detection, a high-resolution image is required because using a low-resolution image may cause ambiguity of the positions of the detected satellites in an image, which leads to a large position error of the satellites in the celestial coordinate system. The problem is that processing a high-resolution image for the satellite detection requires a lot of computation time and may fail to deliver the satellite coordinates to the tracking system within a given time limit. In our work, we propose a fast satellite streak detection method by restricting the streak search area using the line fitting. The streak detection accuracy and speed of the proposed method is measured by conducting experiments, and we acquired accurate detection result within the shorter time than the existing method.**

Keywords— Satellite detection, Image processing, Line fitting

I. INTRODUCTION

In a modern era, satellites are one of major observation methods to survey the space and objects in the space, so many scientific institutes are trying to detect and track the satellites and to determine the accurate positions of them, so they can draw meaningful information from their observations. One of the systems to detect and track the satellites is using an optical system. In optical systems, the satellite movement is represented by multiple streaks [1] because of a long exposure time of imaging sensors, so accurate detection of theses streaks is essential to determine the satellite positions accurately. Many researches were conducted to detect the satellite streaks, but most of these researches used low-resolution images or did not reported about the processing time. Low-resolution images can be processed in a real-time, but the lack of resolution may cause a large error of the real coordinate of the detected satellite in the celestial coordinate projection process. For accurate satellite detection, high-resolution images must be used, and the detection must be performed within a certain time for the tracking. In this work, we propose a satellite detection method using a high-resolution image with fast processing speed. Fast processing is achieved by restricting the areas that contain streak source candidates by fitting the line in a reduced image and utilize these areas to detect streak sources in an original image. False sources and star sources that remain after candidate selection are removed by further image processing and referring the Guide Star Catalog [2], the coordinate list of stars.

II. METHODOLOGY

In our method, two types of images are used: the original image and the reduced image with the max-pooling. The max-pooled image is used to restrict the streak-existing areas to reduce the computation time. With the restricted areas, we extract the satellite streaks and their positions in the original image.

A. Image Max-pooling

The first step of our method is image reducing. There are many methods to reduce the size of image such as subsampling or using mean values, but we chose the max-pooling because losing high pixel values may lower the performance of streak candidate selection. Figure 1 shows the example of the max-pooling.

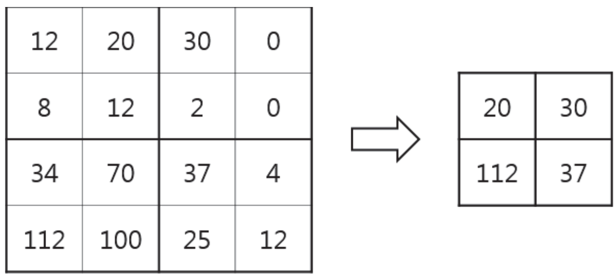

Fig. 1. The max-pooling for 2x2 area.

B. Background Modeling for the Pooled Image

Satellite streaks are normally brighter than void space, so we may be able to distinct the streaks and void space by comparing the pixel value, in other words, creating the background model. Depending on the optical system used for image acquisition, modeling the background for an entire image may require a complex model, but this model requires too much computation time, so this method is not proper for fast streak detection. Thresholding is a simpler modelling method than background modeling that considers the properties of the optical system, but applying global thresholding may generate many false foreground pixels when the noise model which caused by the optical system is complex. Thus, inspired by the existing method [3], we use partial thresholding by dividing the entire image into multiple subregions to minimize the noise effect to the background model. For each subregion, the mean, m, and the standard deviation, σ, are calculated. We set the property of each pixel in the subregion with m and σ, explained in (1).

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$$p(x,y) = \begin{cases} BG & |v(x,y) - m| \leq k \cdot \sigma \\ FG & otherwise \end{cases} \quad (1)$$

In (1), $p(x,y)$ and $v(x,y)$ are the property and the value of the pixel at the image coordinate (x,y). If $p(x,y)$ is true, the pixel at (x,y) is background. After the property setting, we update m and σ with the current background pixels and redefine p with (1). This updating process is conducted iteratively until there is no change in the background model or the number of iterations reaches the predetermined value. Figure 2 shows the result of background modeling.

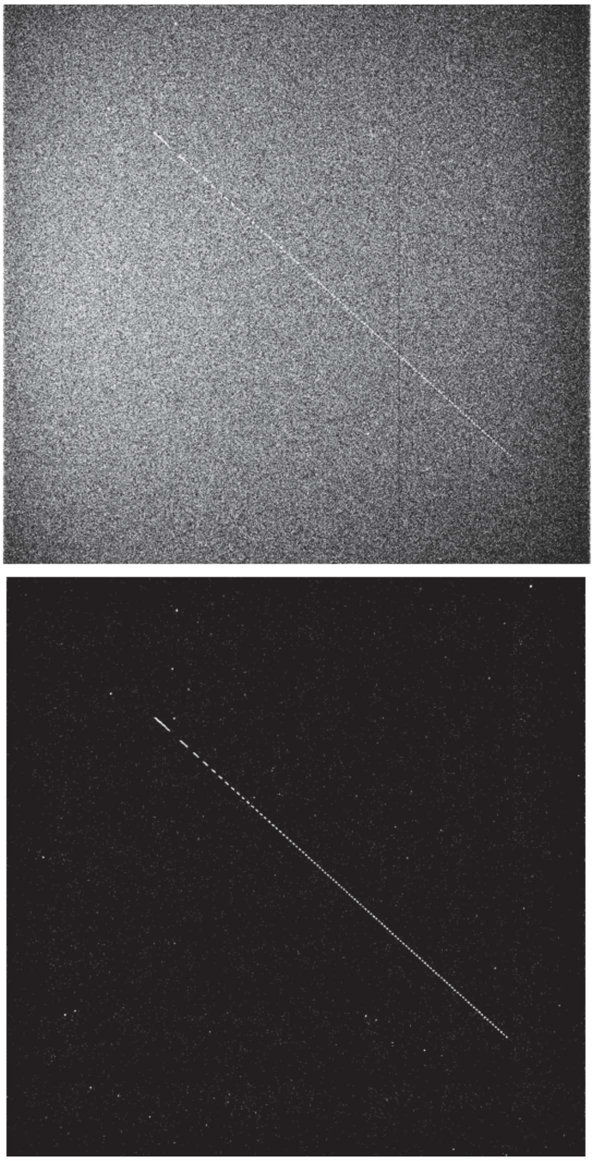

Fig. 2. The histogram-equalized original image (top) and the foreground image (bottom).

C. *Single-pixel Noise Removal for the Pooled Image*

In image acquisition process, many noise pixels may occur because of the low signal-to-noise ratio, and this results in many single foreground pixels. These pixels have very low probability to be a part of satellite streak, so it is reasonable to remove these pixels to reduce the computation time of further processes. If no adjacent foreground pixel exists, the pixel is set as background. Figure 3 shows the result of single-pixel noise removal.

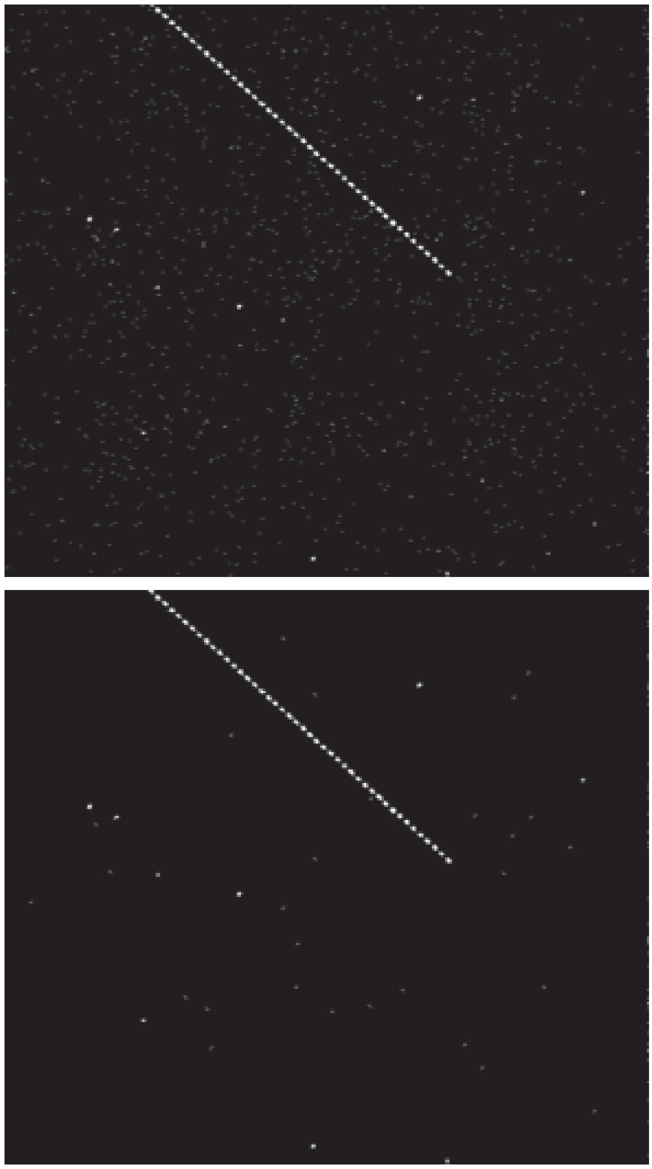

Fig. 3. The pooled foreground image (top) and the result of single-pixel removal (bottom). Both images are enlarged image.

D. *Two-pass Labeling for the Pooled Image*

Two-pass labeling [4] is one of the most successful labeling algorithm. The labeling algorithm make two passes over the labeling area. The first pass assigns temporary labels to pixels and makes equivalent sets for the labels, and the second one replaces the labels based on the equivalent sets. In our method, we used 8-connectivity a two-pass labeling algorithm to label the foreground pixels of the pooled image. After the labeling, the pixels with the same label number belong to the same light source.

E. *Small Source Removal*

There are many light sources represented as foreground other than satellite streaks, such as stars, and these sources should be eliminated to achieve accurate satellite streak detection. We assume that the light sources except the satellite streaks have the smaller size than that of the streak sources, so the sources those have the smaller size than a predetermined value are rejected.

F. Line fitting for Streak Source Candidate Selection

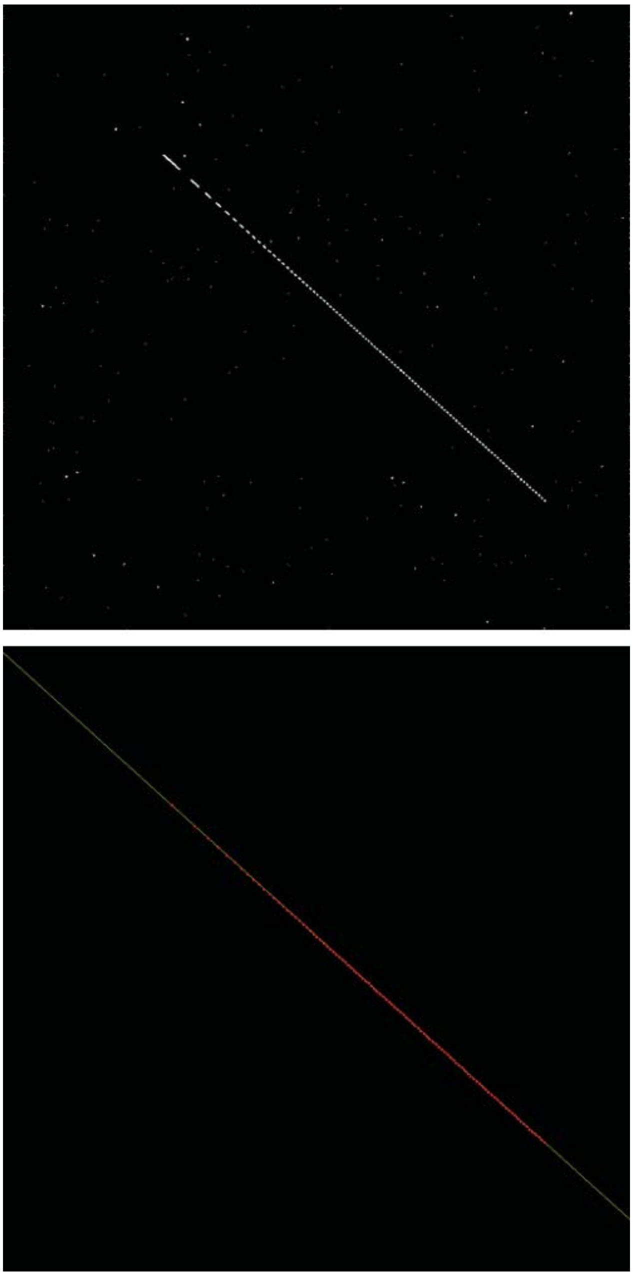

Fig. 4. The single-pixel removed image (top) and the line fitting result (bottom). Yellow line is the fitted line, and red dots are source locations that used for line fitting.

In an image that observed the movement of the satellite, the positions of the satellite streaks are located on the virtual line because the satellite moves toward a certain direction without changing its direction. Thus, we can assume that the positions of the satellite streak source candidates can be approximated by line fitting with the remaining sources from small source removal. In the proposed method, the random sampling consensus (RANSAC) is used for line fitting. The process of the line fitting with the RANSAC is shown as below.

(a) Set the sampling ratio, the minimum inlier ratio for the fitting, and the distance tolerance from the line for inlier determination, and initialize the error of the best fitted line as a very high value.

(b) Sample the sources randomly with a predetermined sampling ratio.

(c) Perform line fitting with the position of the sampled sources by using the least square method. The error of the fitted line is defined as the sum of the squares of the distance between the sources and the fitted line.

(d) Calculate the ratio of the inliers with the distance tolerance.

(e-1) If the inlier ratio is equal to or higher than a predetermined minimum inlier ratio, the current fitted line is set as the best fitted line and the line fitting process is terminated.

(e-2) If the inlier ratio condition in (e-1) is not satisfied, compare the error of the current fitted line and that of the best fitted line. If the error of the current fitted line is smaller than that of the best fitted line, update the best fitted line as the current fitted line.

(f) Repeat the process from (b). If the number of repetitions reaches a certain number, terminate the line fitting process.

After the line fitting process, only the sources within a certain range from the best fitted line are selected as streak source candidates. Figure 4 shows the result of line fitting.

G. Image Processing for the Original Image

Based on the fitted line from the max-pooled image, we can determine which areas have streak sources. Thus, image processing for the original image should be only applied to these area, not an entire image. For the original image, two-pass labeling and single-pixel noise removal are only performed for the areas include streak source candidates, while background modeling is performed for the entire image because the processes after background modeling are affected if only the areas with streak source candidates are processed. After the two-pass labeling is conducted, only the sources with a sufficiently large size and are located at near the fitted line remain.

H. Small Streak Source Candidate Removal

After the previous processes are performed, three types of sources remain: false sources generated by adjacent noise pixels, star sources, and satellite streak sources. In most cases, the size of false sources is smaller than that of other types because noise pixels are generated randomly so they are adjacent to each other by chance and not eliminated in single pixel removal process. Normally, the size of star sources is larger than that of false sources, but smaller than that of satellite streak sources except very bright and close stars. Thus, we assumed that we can eliminate the sources other than streak sources based on the size of the remaining sources. By setting the threshold for the size of the sources, the most of false sources and star sources are eliminated.

I. Guide Star Catalog Matching

As previously mentioned, the sources generated by satellites and bright stars may remain after small sources are removed, so these remaining star sources must be removed to detect satellite streak sources. This can be done by referring the Guide Star Catalog (GSC) [2], which contains the location of stars those are filmed by Hubble Space Telescope. If a source is generated by a star, this source is located closely to one of star in the GSC; therefore, star source removal can be done by matching each source to the GSC. The coordinates of the stars stored in the GSC is recorded as the equatorial coordinates (right ascension and declination), so those of the streak source candidates, which are Cartesian coordinates, should be transformed into equatorial coordinates.

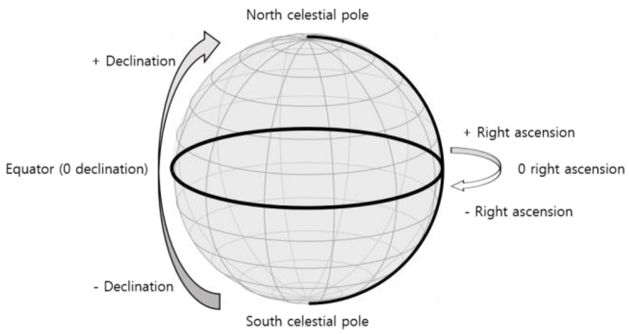

Fig. 5. The equatorial coordinate system.

Figure 5 shows the equatorial coordinate system. In the coordinate transformation process, the positions of streak source candidates are projected into a virtual sphere. The origin of the coordinate system is located at the center of the sphere. For the matching with the GSC, the vectors for the positions of the streak source candidates and stars from the GSC are generated. If the angle between the vector for a star and the vector for a streak source candidate is smaller than a predetermined value, we consider that the streak source candidate is matched to the GSC star and the candidate is eliminated. After the matching and the star source elimination, only streak sources remain.

III. EXPERIMENTS

We compared the proposed method and the existing method with 3 4096x4096 images. The existing method utilizes two libraries: SExtractor for streak source candidate extraction and Image Reduction and Analysis Facility (IRAF) for GSC matching. The computation time to detect streak sources is measured for both method.

In the proposed method, max-pooling is performed for 4x4 pixels; in other words, 4096x4096 images are reduced to 1024x1024 images. For background modeling, we divided an entire image into 8x8 subregions and set $k = 3$ for the original image and the max-pooled image. For small source removal, the sources with the size less than 12 pixels are removed for the max-pooled image and the sources with the size less than 50 pixels are removed for the max-pooled image. For line fitting, the sampling ratio is set to 70%, the minimum inlier ratio is set to 80%, and the distance tolerance is set to 102 pixels. For GSC matching, the threshold for the angle between the vector for a star the vector for a streak source candidate is set to 0.001 degrees. In our method, the position of each source is defined as the center of the smallest bounding box contains the source. Table 1 shows the result of streak detection and how much false detection occurs, and Table 2 shows the computation time for streak detection of the existing method and the proposed method. The proposed method detected the same satellite streak sources as the existing method did, but required less computation time than the existing method.

Table 1. The number of streak sources in the test images and the number of streak sources detected by the existing method and the proposed method.

	Image 1	Image 2	Image 3
Total streaks	101	95	90
Detected (Existing)	101	95	90
Detected (Proposed)	101	95	90
False detection (Existing)	0	0	0
False detection (Proposed)	0	0	0

Table 2. The computation time to detect the satellite streak sources for the existing method and the proposed method.

	Existing method	Proposed method
Image 1	6.9 s	1.61746 s
Image 2	6.1 s	1.64439 s
Image 3	7.3 s	1.62822 s

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