Application of Improved Frame Difference Method in Space Moving Target Detection (Postprint)

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Abstract

To address the susceptibility of space moving target detection to interference from illumination, clouds, and other factors, which leads to false detection of moving targets in their absence, an improved frame difference algorithm is proposed that integrates the frame difference method with background subtraction and periodically updates the current frame as the background frame. The proposed approach first applies binarization to the image under detection, effectively eliminating noise factors such as illumination and clouds while enhancing the space target imagery, followed by space target detection via the frame difference method. Experimental results demonstrate that this method effectively reduces the false detection rate of space moving targets. The improved algorithm eliminates the need to use every frame as a background frame, thereby enhancing computational efficiency, and obviates the requirement for statistical background modeling, thus simplifying the background establishment process. The algorithm is straightforward to implement, simple to operate, cost-effective, highly sensitive, and exhibits significant practical value.

Full Text

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Abstract

Space moving target detection is often susceptible to interference from illumination variations, clouds, and other environmental factors, leading to false detections when no actual targets are present. To address this issue, we propose an improved frame difference algorithm that combines frame differencing with background subtraction, periodically updating the current frame as the background frame. The method first applies binarization to images prior to detection, which effectively eliminates noise factors such as illumination changes and cloud movement while enhancing the space target signatures. Subsequent frame differencing then detects the space targets. Experimental results demonstrate that this approach effectively reduces the false detection rate for space moving targets. The improved algorithm does not require every frame to be set as background or statistical background modeling, thereby improving operational speed and simplifying background establishment. The algorithm is easy to implement, operationally simple, cost-effective, highly sensitive, and demonstrates significant practical value.

Keywords: frame difference method; space target; moving target detection; binarization; background subtraction method

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1. Introduction

Optical observation is a crucial means for space target monitoring, and automatic detection and tracking of space targets represent key technologies in this field. The accuracy of moving target detection directly affects automatic target recognition, positioning accuracy, cataloging precision, and telescope operational efficiency. Automatic detection can significantly improve space target detection efficiency and holds great significance for space target monitoring and space science research.

The frame difference method can be applied to space moving target detection as a simple and easily implementable algorithm. It operates by performing pixel-wise subtraction between consecutive video frames to determine whether moving objects have appeared. The process involves first smoothing and denoising the k-th and (k-1)-th frames, then subtracting the (k-1)-th frame from the k-th frame. If the resulting value exceeds a predefined threshold t, it indicates detection of a moving target; if the value is less than t, no moving target is present. However, the frame difference method is sensitive to illumination variations, which can cause pixel values in the frame sequence to change dramatically, potentially exceeding threshold t even without actual moving targets. This leads to false detection of space moving objects due to environmental changes such as lighting and clouds.

To mitigate the influence of illumination, clouds, and other noise factors, and to improve space target detection accuracy, this study designs an improved frame difference algorithm combining frame differencing with background subtraction. The method first binarizes both foreground and background frames before performing difference operations, reducing noise impact and enhancing algorithm reliability. The implementation utilizes OpenCV.

2. Moving Target Detection Methods

Moving target detection typically employs three main approaches: optical flow, background subtraction, and frame differencing, each with distinct advantages and disadvantages.

Optical Flow Method: The primary task is computing the optical flow field, which estimates motion fields under appropriate smoothness constraints. By analyzing moving object changes, it segments motion targets and scenes. Optical flow carries not only motion information but also rich three-dimensional structural information about the scene, enabling detection without prior scene knowledge. However, the computational method is extremely complex and computationally intensive, making it unsuitable for real-time applications.

Background Subtraction Method: After establishing the detection scene, a scene image is created as the background model. Current images are subtracted from this background. If subtraction results are near zero, the current image matches the background, indicating no moving target. Large subtraction results indicate significant differences, suggesting moving target entry. The method offers simplicity and precise target localization when background is known, but is vulnerable to environmental and weather changes affecting detection results.

Frame Differencing Method: This approach performs differential operations on adjacent frames with a threshold. Pixels exceeding the threshold are considered moving points. The method is simple and computationally efficient, commonly used in detection applications. However, it is sensitive to environmental noise, and threshold selection is critical: too high thresholds ignore useful changes, while too low thresholds fail to suppress image noise.

3. Image Binarization

Although frame differencing is easily implemented, it suffers from illumination and noise interference, causing false detections. Binarizing images before detection can effectively weaken noise interference and improve detection accuracy. Binarization converts color or grayscale images into binary images with only two pixel values (typically 0 and 1), simplifying subsequent processing and reducing data volume.

The binarization method is defined as follows: Let x be the original pixel value and t be the given threshold. The binarized pixel value is: - Set to 1 when x t (representing the target object) - Set to 0 when x < t (representing background or exceptional regions)

Threshold selection is critical for accurate target segmentation. While adaptive thresholding is ideal for varying scenes, space observation images are predominantly black-background with white luminous targets, allowing fixed threshold usage. For space moving target detection, the binarization threshold can be set to 128, effectively enhancing image clarity.

4. Improved Frame Difference Algorithm

Frame differencing and background subtraction are essentially two variants of the same detection algorithm, both simple and practical. Our improvement combines these methods with modifications: rather than setting every frame as background, we update the background frame at intervals. This approach improves speed, quickly relegates stationary objects to background status, and eliminates statistical background modeling, greatly simplifying the process.

Background update period selection is crucial. If updates are too frequent, consecutive detection results may overlap, creating erroneous target contours. If updates are too slow, detection results show numerous voids. Experimental results indicate that setting the background update period to 0.3 seconds yields ideal detection results.

4.1 Implementation Principle Let q_i be the pixel value of the k-th pixel in the foreground frame, b_i be the pixel value of the k-th pixel in the background frame, width be image width, and height be image height. The algorithm computes:

$$width \times height \times sum = \sum_{k=1}^{width \times height} |q_k - b_k|$$

where sum represents the sum of absolute differences between corresponding pixels in foreground and background images. This sum is then compared with threshold t:

- When sum t: moving target detected
- When sum < t: no moving target detected

Threshold t selection depends on the observation scene. Different scenes produce different pixel value distributions, requiring appropriate thresholds. If t is too small, noise or background pixels may exceed it, causing false detection. If t is too large, actual targets may produce sum values still below t, causing missed detection. For space moving target detection where backgrounds are primarily sky and foregrounds are luminous objects, a fixed threshold works well. When few targets appear, t = 5000 is appropriate. With more targets, the sum necessarily exceeds t, enabling correct detection.

4.2 Algorithm Implementation Process

1. Acquire frame 1 from the camera as the background frame and binarize it
2. Acquire frame 2 from the camera as the foreground image and binarize it
3. Extract pixel values q_i from foreground and b_i from background at each position k
4. Compute absolute differences |q_i - b_i| and calculate their total sum
5. Compare sum with threshold t:
    - If sum $>$ t: significant difference indicates space moving target; trigger alarm
    - If sum $<$ t: no significant change indicates no moving object
6. When update period is reached, set current frame as new background frame
7. Acquire next frame as foreground and repeat from step 2

5. Experimental Results and Analysis

Experiments were conducted using video footage from a 500mm aperture wide-field telescope at the Yaoan Station of Purple Mountain Observatory, with image size 1024×2024 and field of view 2.1°×2.1°.

5.1 Illumination Variation Experiment **Without Binarization:** Using raw frame difference on consecutive frames with no targets but different illumination levels (weaker in first frame, stronger in second) produced false detection results despite identical backgrounds. Illumination changes caused pixel value variations that exceeded the threshold.

With Binarization: Applying the improved algorithm with binarization to the same frames correctly indicated no moving target detection, demonstrating accurate results despite strong illumination changes.

5.2 Cloud Variation Experiment **Without Binarization:** Consecutive frames with thick vs. thin clouds but no targets produced false detection due to cloud movement effects.

With Binarization: After binarization, the improved algorithm correctly detected no targets despite significant cloud changes.

5.3 Moving Target Detection Experiment Applying the improved algorithm to video sequences with actual space targets moving from lower-right to upper-left demonstrated effective detection. Binarization preprocessing reduced illumination and cloud noise interference, enabling accurate and reliable target detection when using appropriate thresholds.

6. Conclusion

This study demonstrates that combining binarization with an improved frame difference method effectively reduces interference from illumination and thin clouds in space moving target detection, thereby decreasing false positives. The method provides automatic alarm functionality upon target detection, offering a new approach for space moving target adaptive tracking. By integrating binarization with the improved frame difference algorithm, the method enhances telescope capability to handle illumination and cloud interference, providing an effective solution for automatic tracking and capture across different telescopes, particularly for fixed-point capture optical telescope arrays and fence telescope arrays where it demonstrates superior performance in space moving target detection.

References

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Note: Figure translations are in progress. See original paper for figures.