Dim and Small Target Detection Based on Improved Spatio-Temporal Filtering

Li Juliu, Fan Xiangsuo, Chen Huajin, Li Bing, Min Lei, and Xu Zhiyong

Abstract—**Small target detection in high strength clutter background is in great in remote imaging system, a new improved spatio-temporal filtering was proposed in this paper. Firstly, traditional anisotropy filtering has poor suppression effect in strength edge contour region, so a new diffusion filtering function proposed in paper. According to the analysis with difference of each component of the image, a new anisotropy diffusion function is constructed in this paper. When the difference of background and target is small, this algorithm will give in large diffusion coefficient to filter most background clutter and retain target signal well which achieves background prediction better. Secondly, because the traditional spatiotemporal filter algorithm cant follow the motion object in the fixed search pipe diameter what will make lose the target detection, a new weight constraint function of adaptive change of the search diameter in this paper is built which can change the search diameter with the moving of target, and improve the detection accuracy. Finally, experiments show that compared with traditional algorithms and detected in different scenes, this method can enhance small target detection effectively.**

Index Terms—**Small target detection, multidirectional gradient, spatial filtering, bound pipeline filtering, background prediction.**

I. Introduction

THE acquisition and detection of long-distance target is significant for the photoelectric system. In the process of system imaging, target is easy influenced by light intensity, atmospheric turbulence, moving clouds and so on[1], which make target detector receive target energy unevenness, and bring about numerous non-stationary edge contour areas in image, and target often overwhelmed by these strong noise clutter, which leads to the target information being excessively weakened and the energy is low weak that it is difficult to target detect. And the traditional algorithm will mistake the strong noise point and the strong edge area for the target in the interference of strong background clutter, leading to lost target detection in the sequence image. Therefore, its particularly important to enhance algorithm detection capability under high background clutter interference sense.

Weak signal detection is an important field in image processing. Traditional algorithms obtain the difference image by threshold segmenting of sequence images in the form of a single frame processing, which is inefficient and dose not detect the target in the image where the background fluctuates violently and the interference information is much larger than the target signal. To improve accuracy in small target detection, domestic and abroad scholar had projected the sequence target detection algorithms and had achieved good performance [1]. For example, the adaptive butterworth filtering [2], bilateral filtering [3]–[5], PM model [6], top-hat filtering [7]–[9], least mean square filtering [10]–[12], anisotropy filtering [13]–[16]. The traditional filtering method mainly uses difference in image to finish the background modeling [17], and gets the difference image by the subtracting between the original image and the background image, so as to achieve the purpose of segmentation and extraction of small and weak target. Besides, these algorithms are relatively simple, less time consuming and have outstanding performance in the process of sequence image of small target detection [18], that provide some better research ideas for the algorithm in this paper. But these algorithms with poor detection effect on sequence image which with a strong background and lack of target texture information.Following the technology developed of detection of weak targets in the space-time domain is matured, the algorithm such as Low-rank sparse detection [19], [20], IPI model [21], STIPT model [22] and RPCA [23], [24] model etc, which gain the Low-rank and sparse parts by finding the rank decomposition of image. In addition, deep learning [25]–[30], which has been developed in recent years was utilized in small target detection also, it improved the accuracy of weak signal target detection and contributed to the small target detect in remote imaging. But different algorithm with their own advantage in different scenarios, its necessary to propose new algorithm thinking in the various scenes. To conquer the defect of traditional algorithms in airspace weak signal detection, a new diffusion function constructed to restrain the background, and to deal with the loss target detect phenomenon caused by the fixed pipe diameter, the adaptive modification model of center

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weighting for pipe diameter size was built in this paper, and ensure the target be extracted the average area index proposed in paper, which combine with target appearances and moves to highlighting the difference characteristics of target in the local neighborhood to achieve target extraction finally. The corresponding algorithm principles are described in detail in the related work.

II. Related Works

As mentioned above, the algorithm of weak signal detect of long distance can be divided into three parts is traditional filtering in space- time domain, low rank sparse decomposition model and deep learning. In the traditional algorithm, predecessors have proposed more feasible methods and gained good performance, for example, Lu *et al.* whom put forward the algorithm combining top-hat filtering and PM model background predicting [6], which firstly improves the contrast of the image and strengthens the difference between the target point and background. Then, combining with PM model to reject each noise point in the image, which can better suppress the stable background region interference with target, and create condition for small target extraction, but it also weakens the information energy of target at certain extent, which is not conducive to the detection of the target point in a long distance imaging which with strong background; Li *et al.* proposed the adaptive top-hat filter based on quantum genetic algorithm for infrared small target detection [8] which Utilizing the difference of pixel to modify the filtering model to obtain the difference image had received the better processing results. But this algorithm influenced by the filtering model easily, and greater impact in the sense with strong clutter, dark and bright etc. Lin *et al.* proposed Anisotropy Filtering [13], which realize target detection by utilizing gradient difference of target point and background to structure differential filtering, but this way is difficult to suppress the strong edge contour area and leads to more false target points in residual image. The method of infrared small target detection based on anisotropy [14] proposed by Zhou *et al.* utilizing the local characteristic of target and the background image difference to carry on real target detection and extraction, retained targets signal value, improve the efficiency of target detection, but the traditional anisotropy preserves the target and more edge contours at the same time. The improved anisotropy based on spatiotemporal motion Characteristics proposed in literature [15], which using the local neighborhood better than others, and combine eight direction gradient difference with diffusion function to constrain the background. It provide a better research idea for proposed algorithm of this paper. However, due to anisotropy algorithm relate the diffusion function closely that could cause incomplete background suppression in litter difference in image and make lot of edge noise retain which is unfavorable to target detection and extraction in next step.

Another, compared with traditional algorithms, the low rank spares matrix has a great process, but this way requires a dictionary containing all kinds of weak target information features and various samples need to be trained and extracted, which makes the sparse matrix extremely complex and improves the operation in target detection. For example, Gao *et al.* whom projected the IPI low rank spares detection algorithm [21], which uses the correlation of backgrounds to carry on corresponding background prediction, it can solve the problem of target detection when the position, size and other information of the target are unknown. But when IPI algorithm confront with non-stationary edge contour region in image, the number of non-zero singular values in the block is large, which it is difficult to satisfy the low rank hypothesis theory, and the image detail (like cloud changing, waves of waves and others) will be lost in the process of restoring the background, that will cause the restored background is blurred, and the higher false alarm rate in the obtained difference diagram. And the algorithm infrared dim small target detection technology based on RPCA [23] proposed by Fan *et al.*, the principle is using robust component analysis to calculate and finish background suppression which obtain the difference image and background image. But this way using four frame image to achieve background modeling which cause target loss in final four frames, and other than that, the algorithm focuses on single image frame processing and take a long time in calculate which is not suitable for the sequence image.

The deep learning uses a neural network training to collect the texture features and the shape of target points in the image and the difference information of each sequence of background images, so as to gain the corresponding neural network model. But this kind of algorithm must support by enormous related data, and with target motion, the background of image varies greatly which increases the operation time of background prediction and training sample,that it is not applicable to real-time target detection. For instance, Zhou *et al.* whom put forward the algorithm based on deep learning [12] in small target detection, this algorithm reorganizes the infrared image pixels by constructing a three-dimensional imaging model of the infrared image and combining with gray information reconstruction to promote targets texture characteristics. Then, by constructing a deep learning model to realize small target detection, which takes a long time and the accuracy of detection depends on the quality of training samples. Bai *et al.* proposed the generalized detection method for the dim small targets by faster R-CNN integrated with GAN [26] had achieved better results, but the learning ability of R-CNN is limited and that is inconvenient in complicated and variable sense, further is it must approve by numerous training dataset and longer time consuming. Moreover, this method require higher cost requirements in hardware and others.

To sum up, intend to improve the detect rate in strong background, combined the thinking of literature [15], a new diffusion function was constructed to deal with background suppression. The new function is more suppression power than the literature [15], and it was sensitive in the gradient lower (shown in Fig. 1) which make less false target in different image. Secondly, considering that the target is moving in the

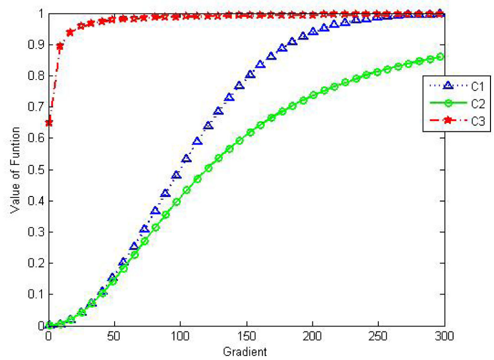

Fig. 1. The changes in gradients and function values of different algorithms.

observation process, while traditional spatial-temporal filtering only used fixed search diameter to detect the multi frame motion correlation [31], [32], when the target movement exceeds the fixed pipe diameter or there is strong noise in the target field, the detection loss is easy to occur. Thus, the center -of- mass weighting function was proposed to make the pipe diameter modify adaptively. Furthermore, according to the local range of pipe diameter, three indexes were built to identify target based on the number of target appearances, target moves and the average area. Different from the document [15] which take the target using the fixed pipe diameter, number of target occurrences, moves and total area to confirm the target final, the average area index construct in this paper was obtained from ratio of the area to the number of occurrences of the target, which can show the targets features in details in each image frame in current pipeline length. Comparing with total area which focus on the condition of target in whole pipe, the average area is more focus on targets moving characters and difference with noise in each frame image. The specific algorithm deduce show in next section.

III. Anisotropic Gradient Principle

According to the energy difference between image and background, the Anisotropy filtering can be used to estimate the energy difference of each pixel point in image [22], [23], that enhanced image contrast in multi-direction, so as to realize the separation end extraction of target and background. For example the Anisotropy filtering algorithm of document [24], a specific algorithm as below:

$$\begin{cases} \frac{\partial I}{\partial t} = \mathrm{div}[c(\|\nabla[\Phi(I)]\|) \bullet \nabla I] \\ I_{(t-0)} = I_0 \end{cases} \tag{1}$$

where $\nabla[\Phi(I)]$and $\Phi(I)$represent the nuclear gradient and spread gradient respectively, I is the original image. The diffusion principle of anisotropic filtering is adopted to construct the gradient function in four directions centered with any pixel, and the difference diagram is constructed through the ladder difference in four directions [25], [26]. The formulas are presented as follows:

$$\begin{cases} W = I_{i,j} - I_{i,j-x} \\ E = I_{i,j} - I_{i,j+x} \\ S = I_{i,j} - I_{i+x,j} \\ N = I_{i,j} - I_{i-x,j} \end{cases} \tag{2}$$

$$I'_{i,j} = I_{i,j} - \frac{1}{4} c(\|\nabla[\Phi(I)]\|)(W + E + S + N) \tag{3}$$

where W, E, S, N represent the gradient value of upper, below, left-side and right-side field with center pixel respectively,$I'_{i,j}$ represent the difference image, $I_{i,j}$ represent original image.

For sticking out target point more obviously in difference diagram and restrain the background map, two kinds of diffusion coefficients are modified in document [8], [9], the formulas as follows:

$$\begin{cases} C_1(\|\nabla I\|) = 1 - \frac{1}{1+(\|\nabla I\|/k)^2} \\ C_2(\|\nabla I\|) = 1 - \exp\left[-(\|\nabla I\|/k)^2\right] \end{cases} \tag{4}$$

where $C_1(\|\nabla\Phi(I)\|), C_2(\|\nabla\Phi(I)\|)$represent two diffusion coefficients respectively, $\|\Phi(I)\|$represent the distance between adjacent pixels, k represent diffusion constant. And studies show this formula is not effective in complicated image edge processing. For example, when target point is in a non-stationary background or the noise energy surpass than the target point, it will treat the target point as background for prediction, and resulting in target detection failure. So intend to heighten the accuracy of target detection, combing with image gradient information, a new diffusion function is proposed to suppress background in this paper. And through analysis found that the algorithm can adapt to the image which with high clutter jamming. For instance, when the target is in stable background area, a larger diffusion coefficient will be used to filter out this part background area since the difference gradient of target area and background area is not significant, for another is when the target is in an area which is non-stationary edge contour, the gradient difference between target and contour field is small, so it also takes the larger diffusion coefficient to remove the interference of this contour part area to target signal. Based on the above analysis, a new monotone increasing diffusion function was structured in this paper which united the multidirectional gradient to realize differential filtering in image in this paper, and it used a larger diffusion coefficient between small gradient differences. The background region and non-stationary contour region are effectively removed the difference in diagram, while the target signal is well preserved. The concrete formulas as follows:

$$C_3 = \frac{1}{1 + \frac{1}{1+\frac{M\Delta f}{K}}} \tag{5}$$

where C_3 represent diffusion function, Δf represent the gradient difference on each pixels directional function, where M is the constant used to constrain the direction of the diffusion function and improve the inhibitory effect, in the formulas the K is diffusion parameter set, usually the value is 100. After

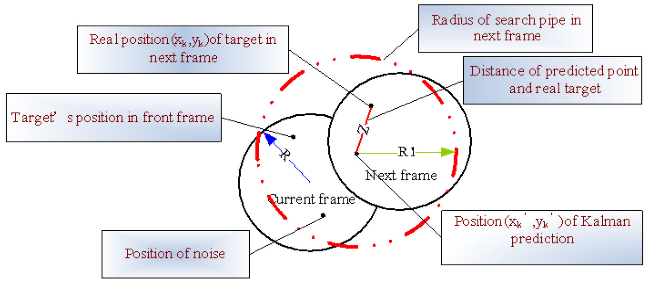

Fig. 2. Improved pipeline model.

comparing the traditional diffusion function C, found that the functionC_1, C_2, C_3 (shown in Fig. 1) is significant difference in function direction, based the Fig. 1 could found that the function C_3 of paper can adapt larger diffusion coefficient to filter the area where the value of gradient difference is not obvious between target area and background area, and this function can persist information of target effectively, so that ensure the target can be successfully detection in low gradient, and is convenient for subsequent target detection and extraction.

To realize the target detection, according to the traditional algorithm proposed in a traditional algorithm for each pixel in image anisotropic filtering [26] to achieve the real target extraction algorithm, the anisotropic filtering function constructed in this paper as follows:

$$\begin{cases} CL = 1/(1 + 1/(M \times |(f(i,j) - f(i,j-t))|/K)) \\ CR = 1/(1 + 1/(M \times |(f(i,j) - f(i,j+t))|/K)) \\ CP = 1/(1 + 1/(M \times |(f(i,j) - f(i-t,j))|/K)) \\ CD = 1/(1 + 1/(M \times |(f(i,j) - f(i+t,j))|/K)) \end{cases} \tag{6}$$

where the t is represents the distance of a center pixel to its surrounding four directions, it also namely the steps size of a process and generally the value is fixed. The concrete experiment is carried out by fixing a step size distances, the calculation of direction gradient around each pixel can pave the way for further processing. Besides, the $f(i,j-t), f(i,j+t), f(i-t,j), f(i+t,j)$ represent the step distance corresponding to the position to center pixel $f(i,j)$ respectively, utilizing the center pixel and its surrounding pixels to build a small adjacent neighborhood information that can detect the target well and prevent the missed detection of target. Where CL, CR, CP, CD represent the step distance of four directions gradient diffusion function from the center pixel respectively. The gradient spread function of each pixels neighborhood in four directions is calculated to ensure that the target point can be truly detected and improve the overall processing efficiency of the algorithm.

After the processing of the anisotropic filtering, the reconstruction of the background estimation has been completed. The tradition algorithm uses the original image and the reconstruction background to make a difference to obtain the difference diagram, in this paper the difference diagram is obtained while conducting the anisotropic filtering on each pixel, and the formulas to gain difference diagram as follows:

$$\begin{aligned} \mathrm{cusm}(i,j) = [\ & \mathrm{CL} \times |f(i,j) - f(i,j-t)| \\ & + \mathrm{CR} \times |f(i,j) - f(i,j+t)| \\ & + \mathrm{CP} \times |f(i,j) - f(i-t,j)| \\ & + \mathrm{CD} \times |f(i,j) - f(i+t,j)|] \times 1/4 \end{aligned} \tag{7}$$

where $cusm(i,j)$ represent the sum of gradients in four directions, CL, CR, CP, CD represent the gradient spread function in four directions respectively, and $f(i,j-t), f(i,j+t), f(i-t,j), f(i+t,j)$ represent the step distance corresponding to the position to center pixel $f(i,j)$ respectively, t represent the step size from a central pixel to the prediction in four directions.

A. *Improve Spatiotemporal Domain Filtering Algorithm*

Pipeline filtering playing an importance role in small target detecting and tracking, it realize the detection by utilizing the target movement characteristics in a continuous frame, and according to the change of speed and position of targets motion in front and back frame to estimates the speed of the target to determine the center place of a small target, to find the real location of weak targets smoothly [27]. And because of weak small targets is sensitive with noise [2], the traditional pipeline filter processing are easily affected by edge noise that make target detection failures, and if there is a frame image which contains edge noise by pipeline mistakenly identified, it will cause erroneous judgment of real targets position of back frame image that deviates from the trajectory of real targets motion, which leads to target detection failure.

In order to effectively solve the above problems encountered by pipeline filtering in the detection process, the centroid weighting method had leaded into in this paper in literature [2] to solve the problem of one target is interfered by noise in pipe filtering. However, the algorithm uses a fixed pipe diameter, when the targets speed exceeds the radius of pipe filtering at a certain moment, it will lose the target detection. Thus, improved this defect by constructing new constraint function to predict targets position at next moment in this paper. Next according to the distance Z between the real targets position and the forecasted targets position to structure a new centroid constraint function to modify the radius of pipe filtering adaptively, so as to achieve target detection in sequence image. The improvement ideas are shown in the figure as follows:

As shown in Fig. 2, intend to adaptively modify the pipe radius according to the target velocity in the detection process, this paper introduces the idea of Kalman filter to construct a new constraint mechanism to adaptively modify the pipe diameter. Firstly, the Kalman filtering is used to project targets location (x'_k, y'_k) in next frame, next according to candidate target to determine the real targets position (x_k, y_k)in the next moment and calculate the distance Z of a real targets position and forecast targets position to structure a new weighting coefficient K to modify the size of pipe diameter R adaptively. The formulas as follows:

$$\begin{cases} Z = \sqrt{(x_k' - x_k)^2 + (y_k' - y_k)^2} \\ K = \frac{Z}{Z - R_1} \\ R = R_1, \quad if\,(Z < R_1) \\ R = R_1 + K_1 Z, \quad \text{if } (Z \geq R_1) \end{cases} \tag{8}$$

in the formula the Z represents the offset distance of a predicted targets position (x_k'-x_k) and real targets position (x_k'-x_k) which K_1 represents the restrain coefficient to control the search radius, R represents search radius of pipe diameter, and generates adaptive pipe radius to search with the change of the pipe diameter; R_1 represents the initial fixed pipe search radius.

IV. Algorithm Testing

In this article, a new multi-anisotropy gradient diffusion function is constructed to get difference image of sequence. Then the difference image is segmented by the method of a window back which gain the binary image and remove most noise in difference map; Secondly, use the weighted pipe filter function to restrain the pipe radius, which can make a pipe adapt to target motion to modify the search radius adaptively and enhance the accuracy rate of target detection. The specific scheme as follows:

A: Reading the unprocessed frame from sequence image;

B: Construction of multidirectional gradient diffusion function;

C: Stretching the difference image of the multi frame to obtain stretched image corresponding and make the target points and noise points appear more clearly and convenient for subsequent extraction;

D: Utilizing the window back method to segment the difference graph of sequence obtain the sequence binary image;

E: Initialization the pipe $radius = 5$ and continuous M frame image $M = 5$, combining constraint function with formulas (8) to modify the radius of pipe at the next moment adaptively, when the target moves within pipe radius recorded the mobile number as T_M and recorded the number of appears in pipe radius as T_O, and when the average area of candidate target can satisfy a certain threshold, this point will be stored. The formulas as follows:

$$\begin{cases} T_M = \sum_{i=1}^{M} \text{Mov}\,(f'(x,y,n)) \\ T_O = \sum_{i=1}^{M} \text{Num}\,(f'(x,y,n)) \\ \overline{\text{Area}} = \frac{\sum_{i=1}^{M} \text{Area}(f'(x,y,n))}{T_O} \end{cases} \tag{9}$$

where (x, y) represent coordinate of pixel point; f' represent a binary image; n is order number of image; M is a constant; T_M vis the total number of target moves in pipe; T_O is the number of target in pipe diameter; $\overline{\text{Area}}$ represent the average gray value of candidate target in pipeline, which gained by ratio the sum of candidate targets area in continuous frames M and total the number of targets appears;

F: Updating the pipe image M and the pipe radius R_1, until out put all sequence image.

The specific algorithm flow is as follows:

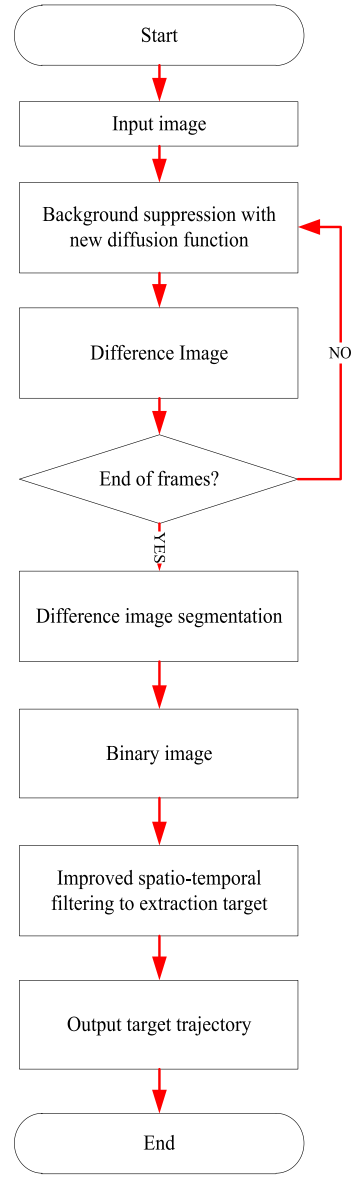

Fig. 3. The flow chart of papers detection method.

Where Fig. 3 represents the overall process of the experiment of algorithm mentioned of paper, it shown this algorithm inspect small target by background modeling, threshold segmenting, finally combing the formulas (9) obtain targets trajectory. The specific experimental steps as follow.

Above flow chart obtain with the pseudo code as follows:

V. Results and Analysis

Base on above research, intend to verify the feasibility in our method, the improved method was compared with traditional algorithms in difference diagram which obtained by background modeling in the sequence image to prove the feasibility of the algorithm with dataset C in literature [15] and the original dataset A, B. By quoting the improved Top-Hat filter, Butterworth filter, improved bilateral filter and the original anisotropic filter algorithm which proposed in literature, and the algorithm RPCA

Proposed Method: Pseudo Code of Detection Algorithm.

Initialization parameter of system: Setting stop parameter $k = 100$; Gradient step size $G = 4$; Constraint constant $M1 = 20$; Threshold of image stretching $Th = 20$; The size of window back $W_r = 15$; Original motion speed $M_S = 6$; Original search radius $R = 7$.

Step1. Input original image;
Setp2. Obtain difference image $I_(i, j)'$ by utilizing multidirectional gradient diffusion to background modeling, stretching the difference image which intend to enhance the difference of targets point and noise point in image;
Step3. Extracting target by combining formulas (8) and (9) in improved spatiotemporal filtering and output targets trajectory.

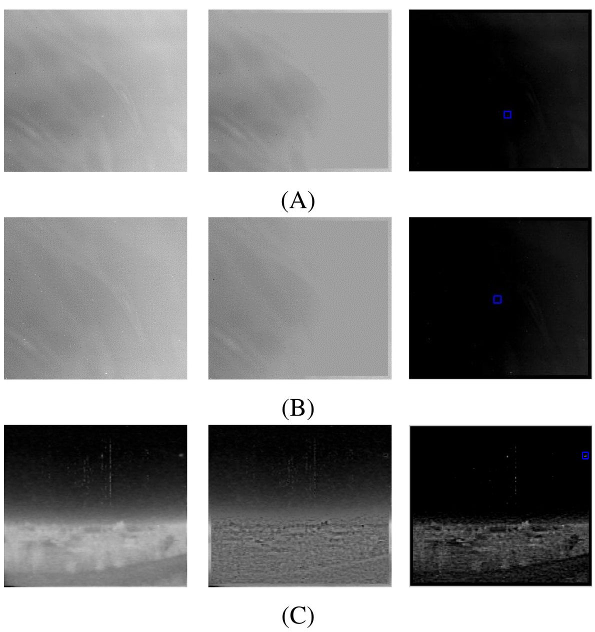

Fig. 4. The result of three sequences detection in Butterworth Filtering.

and IPI model. All above is common background modeling preprocessing methods in the traditional processing methods, and when carry out the background image with these methods in sequence image respectively can find that the effect of background image is worse than algorithm of this paper. Therefore, in this paper, the background modeling image and difference image of several different scenes in different algorithm detection are used to reflect the algorithms feasibility. Utilizing the processing of Fig. 3 and the step of table 1 to analysis the background modeling, evaluate different algorithm respectively and gain targets trajectory at last. Concrete result shown as Sections V-A, V-B, and V-C.

A. Analysis in Background Modeling of Different Algorithms

Specific experiment comparison is shown as follows figures, where Fig. 4(A), (B), (C) to Fig. 10(A6), (B6), (C6) represent

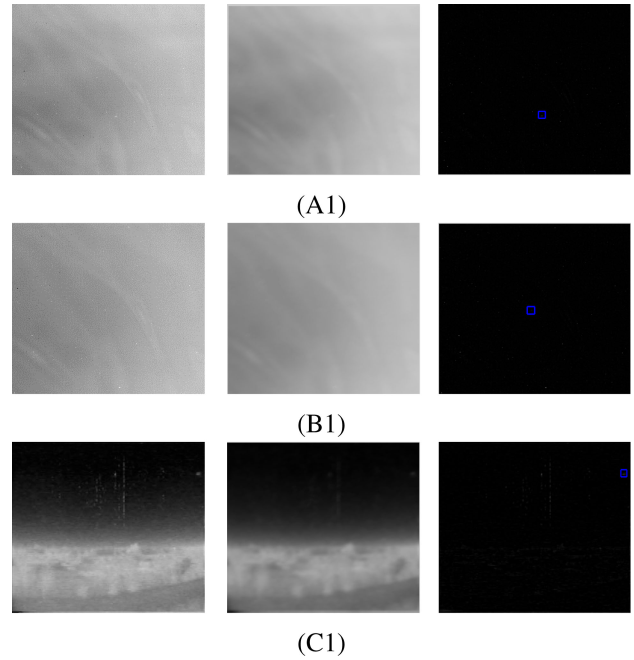

Fig. 5. The result of three sequences detection in improved Bilateral Filtering.

the original image, background modeling image and difference image in different filtering calculation of sequence A, B and C, the order of algorithm is the result of adaptive butterworth filtering [7], improved bilateral filtering [4], improved Top _ Hat filtering [2], traditional anisotropy filtering [16], RPCA model filtering [23], IPI model filtering [21], and paper's algorithm.

Accoing to the figures above, when take the background modeling in Butterworth found that it different obvious in modeling image and difference image in sequence A, B and C, as shown the (A), (B), (C) in the Fig. 4, because it filters the image by selecting the corresponding cutoff frequency with a complexity of background but when the complexity of background surpass the cutoff frequency it cant reach the effect and poor in background modeling. When in process of improved Bilateral Filtering can find that the background modeling image and difference image both unsatisfactory, cause this algorithm is flaw in high edge outline restrain of image which preserves little information of target and make numerous background outline in difference image and bad for target detection, just like shown in Fig. 5(A1), (B1) and (C1). In Fig. 6(A2), (B2) and (C2) represent the original image, background modeling image and difference image presented by different sequence under the improved Top-Hat filtering. Which processing image by combining with the internal and external structural elements to achieve background modeling. But the result of a modeling image was blurred and has poor adaptability. Only a faint target can be observed in the difference diagram of three sequences image. Where in the Fig. 7(A3),(B3) and (C3) represent the result of traditional Anisotropy algorithm, can find that the effect of background modeling is better than above algorithms and it highlighted the target point in difference image, but it also with a lot false alarms in a image that bring about difficulty in target detection which show the limitation of traditional Anisotropy at a certain condition. In the algorithm

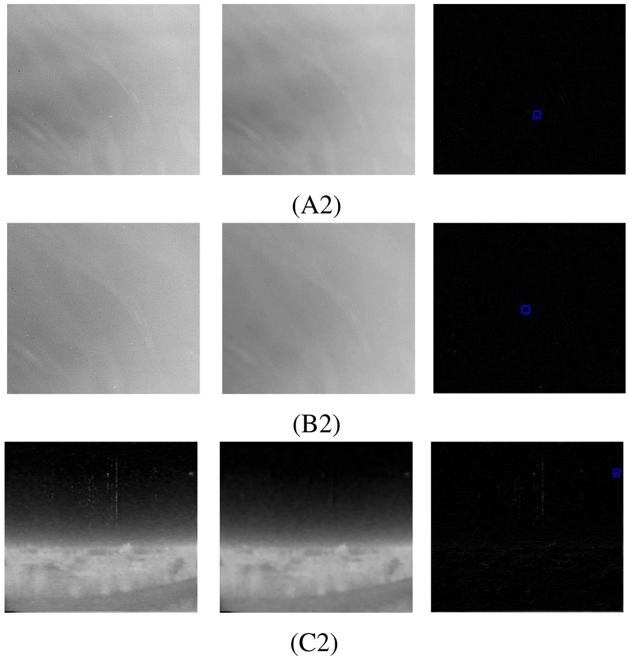

Fig. 6. The result of three sequences detection in improved Top _ Hat Filtering.

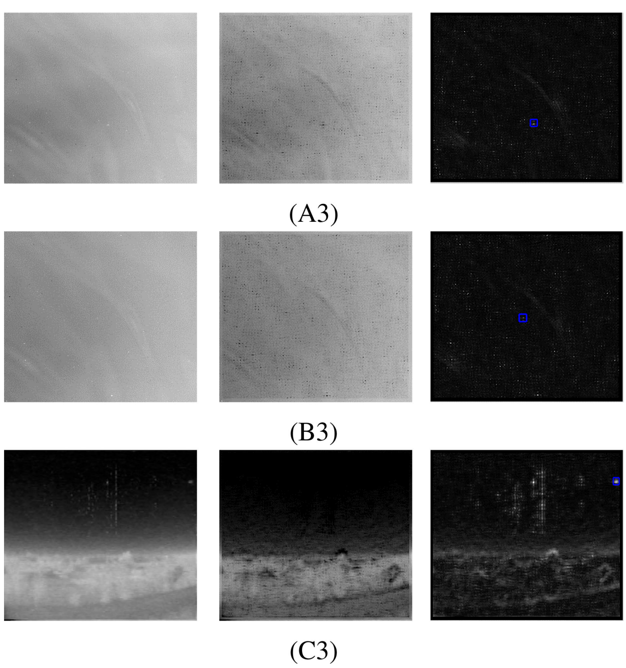

Fig. 7. The result of three sequences detection in traditional Anisotropy Filtering.

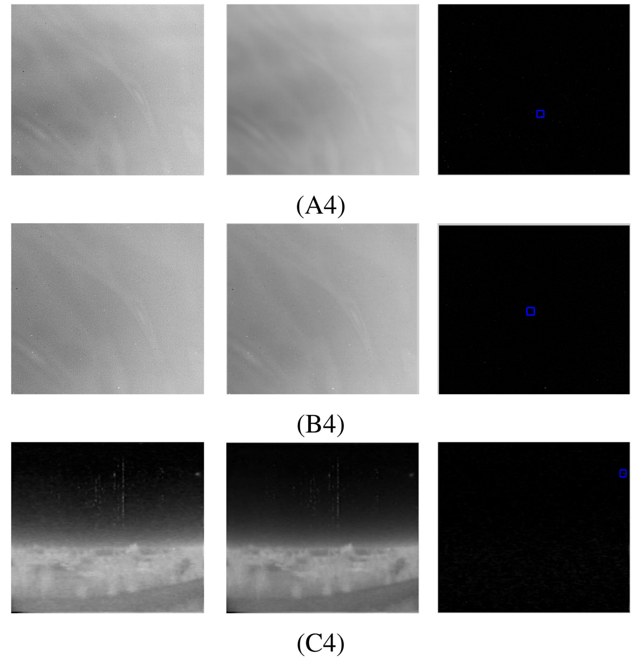

Fig. 8. The result of three sequences detection in RPCA matrix Filtering.

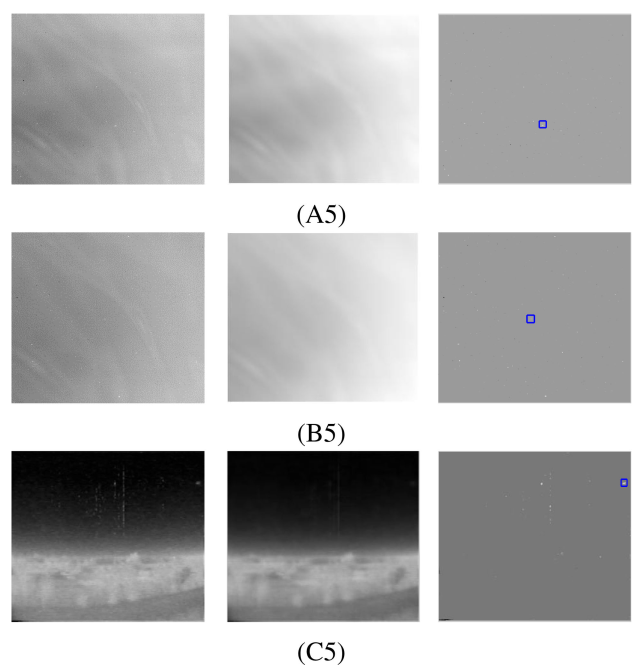

Fig. 9. The result of three sequences detection in IPI low rank matrix Filtering.

RPCA (Robust Principle Component Analysis) could found that it takes the background modeling by dimension reduction processing in a original image, but this way bad in saving the targets information, which makes in difference image of three sequences image cant even found the existence of target, and that will a loss target when taking the process of image binary, shown as Fig. 8(A4), (B4) and (C4). These Fig. 9(A5), (B5) and (C5) are outcome of IPI model of low rank sparse, found that the background non-local autocorrelation is used for the background modeling in this algorithm and the effect of modeling image is ideal(shown as Fig. 9). And the energy of the target could be retained the difference of the image, which convenient for image binary, but this way suit for single frame image processing only and take much time in sequence image processing, its unsuitable for the target detection in a real time. Finally, the Fig. 10(A6), (B6) and (C6) is the result of a algorithm this paper proposed, it can find that the effect of background modeling much ideal than above methods (shown as Fig. 10) and an improved significant

TABLE I
EVALUATION OF SEQUENCE A

Sequence (A)	Butterworth[7]	Top-Hat[2]	Bilateral Filte[4]	Anisotropy[16]	IPI[21]	RPCA[23]	**Our method**
SSIM	0.8481	0.9902	0.6003	0.9954	0.9462	0.9925	**0.9958**
SNR	1.2900	0.7700	1.1900	0.5200	1.0300	1.4900	**1.2100**
BSF	21.0970	87.8908	3.4269	105.3613	118.8917	77.8000	**109.5563**

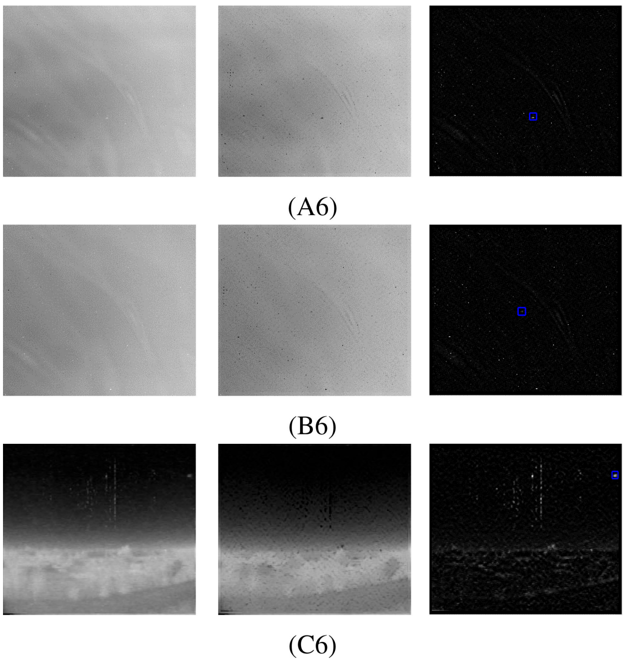

Fig. 10. The result of three sequences detection in this paper algorithm.

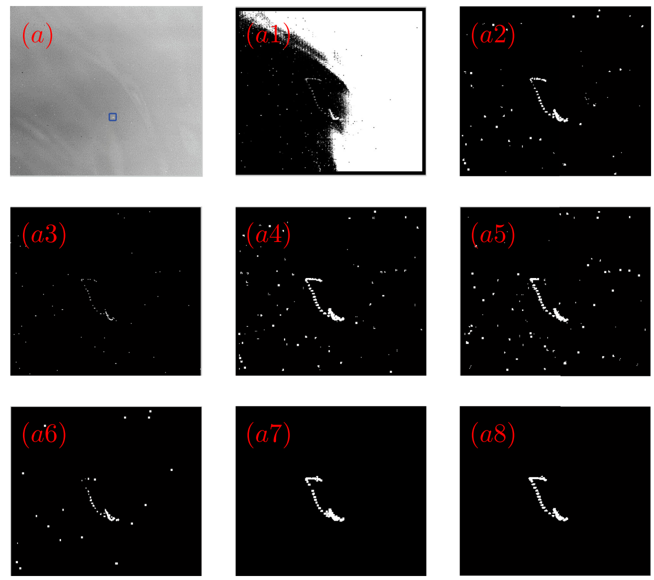

Fig. 11. The result of different algorithms in sequence A.

than tradition Anisotropy Filtering. According to the Figure, the performance of restraining background and retain targets energy better with the algorithm in this paper, which fewer false alarms and improver brighter target point in difference image which in favor of target detection in different sequence image.

B. Evaluation Algorithm

To reflect the feasibility of algorithm in this paper, the algorithm is compared with traditional algorithms above mentioned in structural similarity $(SSIM)$, signal-to-noise ratio(SNR) gain and Background inhibitory factor (BSF) to evaluate the different algorithms effect in background suppression. The calculation method of reference [28] is used to calculate the above indexes respectively and the specific formulas shown as follows:

$$\begin{cases} SSIM = \frac{(2\mu_R\mu_F+\varepsilon_1)(2\sigma_{RF}+\varepsilon_2)}{(\mu_R^2+\mu_F^2+\varepsilon_1)(\sigma_R^2+\sigma_F^2+\varepsilon_2)} \\ SNR = 10 \times \log_{10}^{(ET-EB)/\sigma_B} \\ BSF = \sigma_{\text{in}}/\sigma_{\text{out}} \end{cases} \quad (10)$$

where μ_R and σ_R represent the value of average and standard of input image separately. σ_{RF}represent covariance of an original image and background modeling image. ET and EB represent average area of targets and backgrounds respectively. SNR represent the local signal to noise ratio of image. BSF represent background inhibitor factor. σ_{in} and σ_{out} represent standard value of raw and differential images, respectively. The specific result of experiment shown the table as follows Tables I–III.

Indicators in Tables I–III indicate that the SSIM, SNR and BSF are obtained by calculating the algorithm of this paper and tradition algorithms, which found that the data of this paper proposed greater than others, the data of structural similarity has reached more than 99 in three sequences, and the mean of background inhibitor factor has reached 134.9373, and the average signal-to-noise has reached 2.2433. Especially in structural similarity and background inhibitor factor, which restrain the noise and edge contour in image that convenient for target detection, it is greater than others in background modeling which make a foundation for the target detection and extraction.

C. Analysis in Trajectory of Different Algorithm

In the light of an experiment above, this paper comparing the result of target detection in three sequences image with adaptive butterworth filtering [7], improved top-hat filtering [2],bilateral filtering [4], traditional anisotropy filtering [16], IPI model filtering [21], RPCA filtering [23] and improved anisotropy filtering [15] that to demonstrate the feasibility of algorithm of this paper. The figure (a), (b), (c) represent original image of sequence of A,B,C, and the figure (a1) to the figure (a8) represent the result of sequence A of algorithms above, and the order follow the above statement order. Similarly, the figure (b1) to the figure (b8) and the figure (c1) to the figure (c8) represent the result corresponding to sequence and algorithm, respectively. The specific result shown as follows Fig. 11–Fig. 13.

TABLE II
EVALUATION OF SEQUENCE B

Sequence (B)	Butterworth[7]	Top-Hat[2]	Bilateral Filter[4]	Anisotropy[16]	IPI[21]	RPCA[23]	**Our method**
SSIM	0.8314	0.9859	0.5027	0.9936	0.9327	0.9930	**0.9939**
SNR	1.6200	2.04000	−8.7000	1.3700	2.3600	−2.7100	**2.5100**
BSF	20.2292	72.3257	2.8700	88.7085	78.2678	82.4912	**91.1016**

TABLE III
EVALUATION OF SEQUENCE C

Sequence (C)	Butterworth[7]	Top-Hat[2]	Bilateral Filter[4]	Anisotropy[16]	IPI[21]	RPCA[23]	**Our method**
SSIM	0.7861	0.9955	0.8791	0.9960	0.9331	0.8926	**0.9982**
SNR	2.9500	2.3700	1.9800	2.8900	2.7100	2.0200	**3.0100**
BSF	20.2120	122.5284	6.9463	168.5564	173.8028	27.7517	**204.1541**

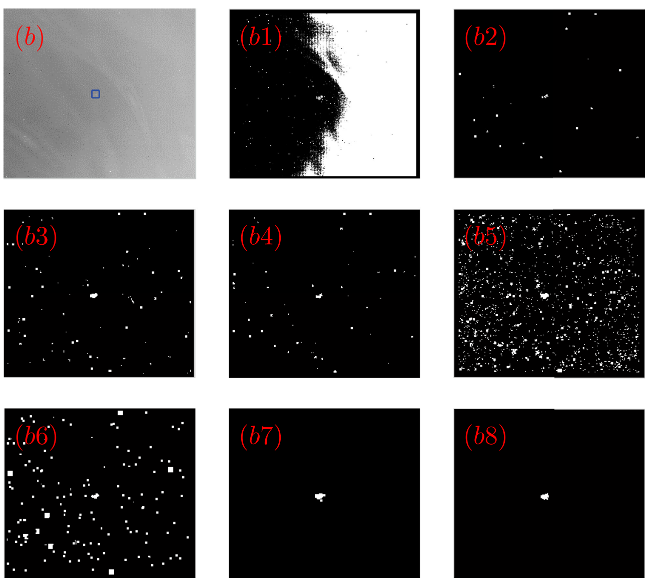

Fig. 12. The result of different algorithms in sequence B.

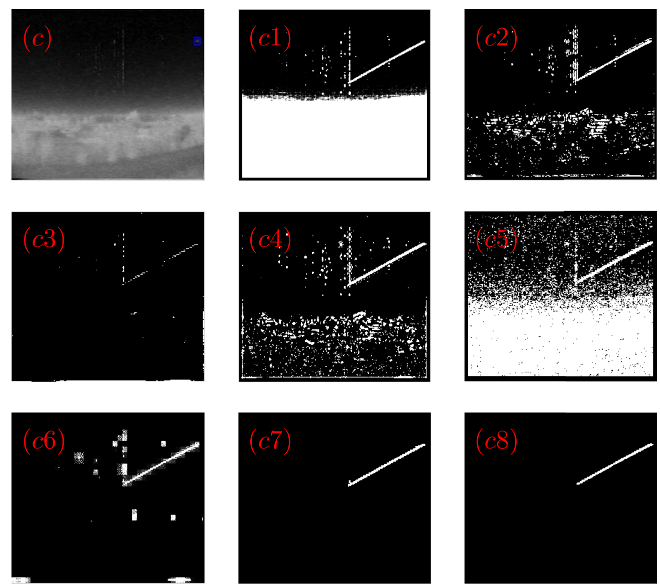

Fig. 13. The result of different algorithms in sequence C.

According to the above image sequence detection experiment found that the butterworth filtering can detect the target in three sequences and output the targets trajectory, but this way has dark and bright scenes formed in three sequences, shown as the Fig. 11(a1), Fig. 12(b1) and Fig. 13(c1), and there is obvious target missing phenomenon in the detection of sequence B, which illustrates that this way has a big defect in target detection when the light distribution is uneven in a sequence image scene. Using the improved Bilateral Filtering for target detection can found that the effect is better in a stable of background changed, like the Fig. 11(a2), and badly in an unstable background changed, like the Fig. 13(c2) which have lot of false alarms, and the target loss in sequence B, like the Fig. 12(b2), which makes the output trajectory have obvious breakpoints. When using the improved Top- Hat Filtering for target detection and extraction can found that the background reconstruction effect of the internal and external structural elements and different scale structural elements applied in this filter algorithm is different, which make the difference in trajectory image of sequence A, B and C, shown as the Fig. 11(a3) and the Fig. 12(b3), the trajectory of target is relatively complete, but the targets trajectory is incomplete in Fig. 13(c3), and all there also many false target points it show this algorithm cant achieve the goal of target detection. When the traditional Anisotropy Filtering algorithm detects the weak and small target points can find that this way can output a relatively complete target trajectory in sequences image as shown in Fig. 11(a4) and the Fig. 12(b4), but when the images background is complicated and there are many edge contours in the image, the background cannot be distinguished from the target, which will make the algorithm extract the edge points and target points, like the Fig. 13(c4). When applying (RPCA) in small target detection in sequence image can be seen that the process of dimension reduction in different sequence image the information of high latitude data is retained different, which leads to different effects in target detection in three sequences image, like the Fig. 11(a5), 12(b5) and 13(c5). Which all can real the target detection, but there all with many false alarms that is not conducive to small target detection. The Figs. 11(a6), 12(b6) and 13(c6) show the target detection result of three sequence images A, B and C by IPI model algorithm. In three sequences image can be seen that the loss target obviously in sequence A (like the Fig. 11(a6)), and in the sequence B, it is hard to differentiate target and noise, because energy of noise is similar to target, (like the Fig. 12(b6)), In sequence C (like Fig. 13(C6)) the target detection effect is good and there are fewer false alarms. The result of Figs. 11(a7), 12(b7) and 13(c7) is the algorithm of literature [15], show as figure can found that this way is better than other traditional algorithm. This phenomenon show the anisotropy combined with multidirectional gradients possess excellent effect on background suppression. Finally is algorithm in this paper, building the multidirectional gradient to reject the strong edge contours and noise point in image, utilizing local characteristic difference between target and background to obtain the modeling image by background modeling with each pixel in image, and then gain the difference image by making a difference with original image. Secondly, building the constraint function of Kalman to protect the radius of search adaptively, ensure the real time detect in target, and the specific result of experiment shown as Figs. 11(a8), 12(b8) and 13(c8).

VI. Drawing and Analysis the ROC Indicator

For further reflect the feasibility of algorithm, drawing ROC index to compare the above algorithms. The specific results are shown in Fig. 14:

As Fig. 14 can be observed that the result of algorithm in this paper is better than other algorithms, like the sequence A of Fig. 14 shown, when the false alarm Pf = 0.0116, the detection rate of algorithm of this paper Pd = 92%, and next is algorithm of literature [15], which the false alarm Pf = 0.0131 and the detection rate Pd = 91%, and all other algorithms detection rate is less than this value. In sequence B the ranked first is papers algorithm, which detection rate Pd = 98% and the false alarm Pf = 0.0017, the improved Top-Hat Filtering is ranked second which Pd = 90% and false alarm Pf = 0.0377, shown as Fig. 14 sequence B. At last is sequence C, the detection rate Pd = 99% and the false alarm Pf = 0.0013 of method proposed in this paper and followed by RPCA and algorithm proposed in literature [15], both them detection rate Pd = 95% and the false alarm Pf = 0.0065, shown as Fig. 14 sequence C.

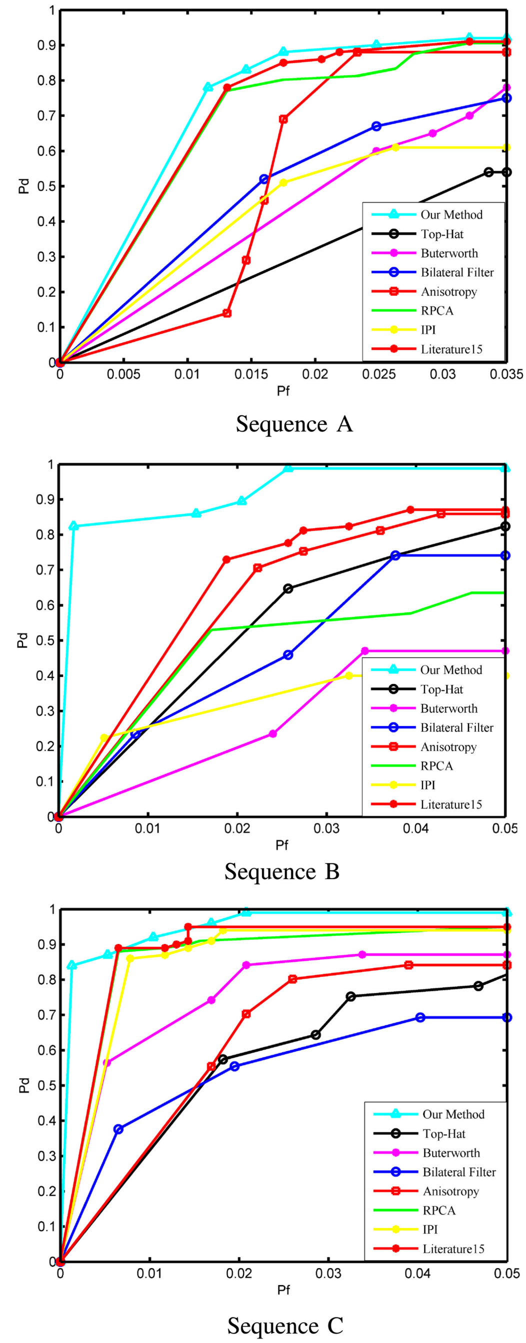

Fig. 14. ROC curves of three sequences.

VII. Conclusion

In article, new algorithm about weak signal target detection in space time domain is proposed, which using the gradient discrepancy in small target and background image features and selecting the mean value of gradient of the four direction to build a new multidirectional gradient diffusion function, which can filter out the noise and edges in processing the difference image and preserve the energy of target that convenient for small target extracting. Secondly, in purpose to extract the target points completely and achieve target tracking, building a new restrain function weighting to updates the radius of pipe filtering adaptively in this paper, and predict the position of small target in front and back frame to achieve small target detection and avoid to read the other false targets. Third, according to the constrain function and feature of targets occurrences and moves in image, the average gray value function was structured in paper to enhance distinction in target and noise, and extracting target finally. The conclusion is as follows:

(1) Analyzing the four directional gradients of image by constructing a new function in this paper, and achieves good result in the image processing and retains most energy of small target points in sequence image. Where the mean value of structural similarity (SSIM), background inhibitor factor (BSF) and the signal-to-noise ratio gain (SNR) reached 0.9959, 134.9373, 8.1366 respectively, and the background inhibitor factor is better than other algorithms.

(2) Obtaining the difference image by making difference with background modeling image and original image, and predicting targets position in front and back frame by new restrain function,

the efficiency of algorithm was increased and achieve targets real time detection and extraction.

(3) Through experiment can be observed that the performance of papers method is better than others in processing background modeling. The inherent difference between target point and image is used to calculate for the difference image, it retains larger energy value of target point in difference image. Then, combining structured restrain function to limit the radius of search pipe with average gray value model can real targets extraction and tracking.

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