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Target detection algorithm of laser echo

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Abstract: The threshold algorithm of the target detection is often used to detect target echo signals. Its performance is based on signals-noise ratio. When signals-noise ratio is great than 6. 7, the target can be detected. In order to increase the signals-noise ratio, matching filter is often used. If the system is narrow band system, the noise is color noise and matching filter cannot be used. Therefore, the signals-noise ratio cannot be increased. However, the geometrical characteristic of the laser echo signal is different with the noise. This paper advises the algorithm that detects the target by the geometrical characteristic. When signals-noise ratio is great than 2, this algorithm can detect target. This algorithm has been used in practice.

Key words: fractal dimension; fractal scale; narrow system; signals-noise ratio

激光回波的目标检测算法

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摘要: 目标检测的阈值法经常用于检测目标的回波信号。它的性能取决于信噪比, 当信噪比大于 6. 7 时, 能够检测出目标。为了提高信噪比, 经常采用匹配滤波器。如果系统是窄带系统, 噪声为色噪声, 无法使用匹配滤波器, 不能提高信噪比。激光回波信号的几何特征不同于噪声。提出了一种利用这种几何特征检测目标的算法。当信噪比大于 2 时, 该算法能够检测出目标。该算法已经实际应用。

关键词: 分形维; 分形尺度; 窄带系统; 信噪比
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Introduction

The laser system is narrow band system, because the laser pulse is wide band signals and response speed of the laser receiver is slow. When we process the laser echo signal, the noise is not white noise. Therefore, we cannot match the laser echo signal and the signals-noise ratio cannot be increased. So the range of the laser ranger can only be increased by increasing power of the laser and the weight and volume of the system should be increased. However, the geometrical characteristic of the target echo signal is different with the noise. When the signals-noise ratio is very small, we make use of the difference between the target echo signal and the noise to detect target. Fractal dimensions describe geometrical characteristic of signals. By calcu-lating fractal dimension of target echo signal, target can be detected[1, 2].

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1　Fractal dimensions

Minkowoski dimension is one type of a lot of fractal dimensions. Because it has explicit geometrical means, it is widely used in many fields[3, 4].

Definition 1: if $E \subset R^n$, E is not empty set and E is finite set. $s \geqslant 0$. $N_s(E)$ is maximal number of the ball covering E which radius is less than or equal s, then upper and lower Minkowoski measure are respectively:

$$B^{*s}(E) = \lim_{s \to 0} \sup \frac{N_s(E)}{(2s)^{d-s}} \tag{1}$$

$$B_*^{s}(E) = \lim_{s \to 0} \inf \frac{N_s(E)}{(2s)^{d-s}} \tag{2}$$

If upper and lower Minkowoski measure exists and $B^{*s}(E) = B_*^{s}(E)$, then Minkowoski measure exists and is expressed $B^s(E)$.

Definition 2: if $E \subset R^n$, E is not empty set and E is finite set, then upper and lower Minkowoski dimension are respectively:

$$\overline{\dim} E = \sup\{s: B^{*s}(E) = \infty\} = \inf\{s: B^{*s}(E) = 0\} \qquad (3)$$

$$\underline{\dim} E = \sup\{s: B^s_*(E) = \infty\} = \inf\{s: B^s_*(E) = 0\} \qquad (4)$$

This definition is difficultly used. We often use equivalent definition.

Definition 3: if $E \subset R^n$, E is not empty set and E is finite set, then upper and lower Minkowoski dimension are respectively:

$$\overline{\dim} E = \lim_{s \to 0} \sup \frac{\log N_s(E)}{-\log s} \qquad (5)$$

$$\underline{\dim} E = \lim_{s \to 0} \inf \frac{\log N_s(E)}{-\log s} \qquad (6)$$

Definition 4: if upper and lower Minkowoski dimension exist and $\overline{\dim} E = \underline{\dim} E$, then Minkowoski dimension is:

$$\overline{\dim} E = \lim_{s \to 0} \frac{\log N_s(E)}{-\log s} \qquad (7)$$

If $s > 1$, then Minkowoski dimension of signals is[5]:

$$\overline{\dim} E = \lim_{s \to 0} \frac{\log N_s(E)}{|\log s|} \qquad (8)$$

In fact, definition 4 cannot be used for the calculation of the Minkowoski dimension, because "s" cannot be infinite. Therefore, Minkowoski dimension can only be estimated. When $s = \delta$, $N_s(E)$ is the number of the box overcovering $X = f(t)$ and $\overline{\dim} E = \frac{\log N_s(E)}{|\log s|}$.

2 Algorithm

Fractal geometry describes geometrical charac-teristic of self-similarity signals. The self-similarity relates to the scale of signals. The signal acquired had finite details. It was not real fractal curse. Minkowoski dimension of the signal can not be calculated with Minkowoski dimension definition. Fractal dimension of signals can only be estimated. If the scale selected is not appropriate, the estimation of fractal dimension is not precise[6]. Fig. 1 shows the relation between $\log N_s(E)$ and $-\log s$. The relation between $\log N_s(E)$ and $-\log s$ is not always linear. Fig. 2 shows the Minkowoski dimension estimation is stable when scale is less than 0.12. Only if the scale selected is within the stable section, the Minkowoski dimension estimation of signal is precise.

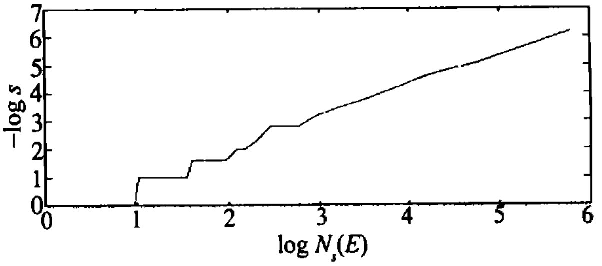

Fig. 1　The relation between $\log N_s(E)$ and $-\log s$

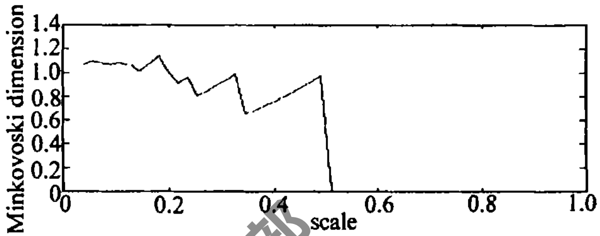

Fig. 2　Minkowoski dimension and the scale

Because there is the noise in the signal, the Minkowoski dimension estimation of signals is random variable. Averaging the estimation of Minkowoski dimension after calculating dimension of signals can improve the estimation performance of Minkowoski dimension. Fig. 3 shows the Minkowoski dimension estimation of the noise has gaussian characteristic.

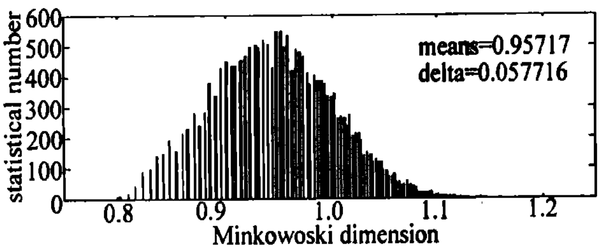

Fig. 3　The statistical characteristic of the noise's Minkowoski dimension

The Minkowoski dimension of the laser echo signal is stable when the scale is changed. However, the dimension of the noise is sensitive to the change of scale. The dimension and the scale can be look as the characteristic vector of the signal. If scale is changed, the change of the characteristic vector of the laser echo signal is less than the noise. Therefore, the distance between the characteristic vectors of the different scale can be used to distinguish the target and the noise. The distance of the characteristic vector is Gaussian. Calculating the variance and the mean of the distance of the characteristic vector can decide detecting threshold. Fig. 4 shows the distance of the characteristic vector. The distance of the target is about 16.6km.

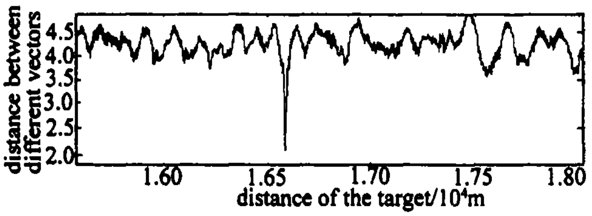

Fig. 4 The distance of signals characteristic vector

The width of the laser echo signals is about 20ns. The unit time is 20ns. The algorithm is the following: (a) to define the original scale and the step of the scale; (b) under this scale, to calculate the Minkowoski dimension of signals within the unit time; (c) if the variance of the Minkowoski dimension of different scale signals is greater than the threshold, then to modify the original scale and step of the scale and return step (b); (d) to average the Minkowoski dimension of signals; (e) to change the scale and repeat the step (a) to (d); (f) to calculate distance of the vector estimated; (g) to detect target.

3 The result of target detecting

Fig. 5 is the laser echo signal. The distance of the target is about 16km. The signals-noise ratio is 3.03.

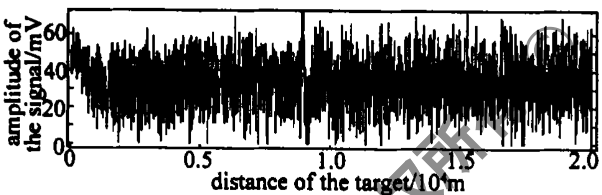

Fig. 5 Laser echo

The result of the threshold algorithm is shown in Fig. 6. If the amplitude of laser echo signal is greater than the threshold level, the target can be detected. Whereas targets

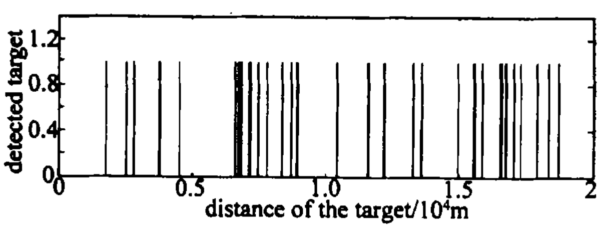

Fig. 6 The target detection of comparing the level

cannot be detected. Fig. 6 shows that there are many false targets. In order to decrease false alarm rate, the threshold level should be increased. However, the range capability of the laser range finder is going to be decreased, and to some extent, the target can not be detected. It means that the laser range finder cannot be used when signals-noise ratio is 3.03. Fig. 7 is the result of the fractal dimension target detection algorithm. Detected target is real target. This algorithm improves the performance of detecting target. When the signals-noise ratio is 3.03, the laser range finder can still measure the distance of the target. It means the fractal dimension target detection algorithm increases the range of the laser range finder.

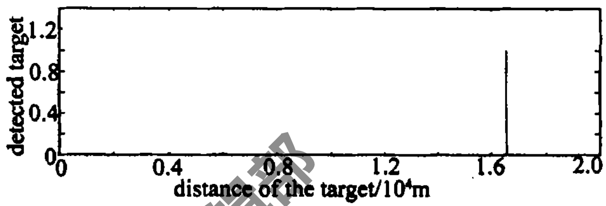

Fig. 7 Fractal dimension target detection

4 Conclusion

The fractal dimension target detection algorithm has been used in the laser system. The performance of the target detection is improved. When the signals-noise ratio is 2, the fractal dimension target detection algorithm can detect the target. However, the threshold algorithm can only detect target when the signals-noise ratio is about 6.7. When the visibility is 8km, fractal dimension target detection algorithm can measure 16km. However, the threshold algorithm can only measure 12km. It increases the range of the laser range finder about 33%. The practical measurement proves that the fractal dimension target detection is an effective method.

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