Correlation recognition for range image of laser radar

Jianfeng Sun (孙剑峰), Qi Li (李 琦), Wei Lu (陆 威), and Qi Wang (王 骐)

National Key Laboratory of Tunable Laser Technology,
Institute of Optoelectronic of Harbin Institute of Technology, Harbin 150001

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The target recognition of laser radar becomes hot research in recent years, because laser radar can produce high space resolution and collect rich target information, such as range image, intensity image and Doppler image. In the vertical detection of laser radar, the problem of in-plane target rotation invariance is firstly solved. In the paper, a new support vector machine (SVM) correlation filter is presented, which simultaneously has the attractive attributes of SVM and common correlation filter. Exploiting the idea of margin of separation maximization, the design criterion is produced. The filter is synthetic by the multiple training images which are generated by rotating one image. The real range images of laser radar are used to finish the correlation experiments. The results show that the filter is not sensitive to the noise, the correlation peak is changed slightly for the different testing images, and the precision of location is high. This design way can be used in other recognition fields.

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Support vector machine (SVM) is a small-sample recognition algorithm based on statistical learning theory (SLT), and it can obtain the high recognition accuracy with one or a few reference images[1,2]. So, it is suitable to solve the recognition problem of laser radar, because the real image set of laser radar is difficult to set up. In vertical detection, the often used recognition algorithm is the correlation filter, not SVM, because correlation filter has the shift invariance and rotation invariance[3,4], although its recognition accuracy is not as good as SVM. At present, the design of correlation filter is mainly based on the idea of synthetic discriminant function (SDF)[5,6].

In order to design a filter which has the attributes of recognition accuracy and shift-invariance, Thornton *et al.*[7] proposed a method bridge between SVM and correlation filter. They used one reference image to design the filter which offered some advantages over other filters about the face recognition problems. In this paper, a new SVM correlation filter is introduced to solve the in-plane rotation invariance of laser radar by exploiting their idea. Because the target shape in the vertical detection is not changed greatly when it is rotated in plane, one range image can be rotated to generate multiple reference images. Using the reference images, the SVM correlation filter for in-plane rotation invariance can be designed through combining SDF and the above idea.

Correlation in space domain means the template matches the sub-images whose sizes are equal to the sizes of template over the whole image. The correlation peak means that the sub-image whose location is at the correlation plane origin is completely matching the template, and the sidelobes surrounding the peak mean the corresponding locations are incomplete matching the template. Through maximizing the margin between the peak and the sidelobes, SVM correlation filter can be obtained, and the design method was given in Ref. [7].

The correlation output plane value y_{ki} can be written as a result of an inner product[7],

$$y_{ki} = \langle h, \tilde{I}_k \rangle, \tag{1}$$

where $\tilde{I}_k$ denotes a cyclically shifted version of the kth training image, h denotes the correlation filter in space domain. So, the margin exits between the values, and then the filter h can be found using the linear-kernel SVM optimization.

The unshifted templates which correspond to the peaks of correlation plane are used to denote the complete matching and they are the positive class, and the shifted templates which correspond to the sidelobes of correlation plane denote the incomplete matching, so they are the negative class. Using this way, the training sets of SVM can be obtained, and they follow the constraint

$$\begin{array}{ll} \langle h, \tilde{I}_k \rangle + b \geq 1 & \forall \text{ positive class } \tilde{I}_k \\ \langle h, \tilde{I}_k \rangle + b \leq -1 & \forall \text{ negative class } \tilde{I}_k \end{array}, \tag{2}$$

where scalar b is a free parameter. Through training the data set, the support vectors and corresponding coefficients can be computed. So, the SVM filter h can be derived as

$$h = \sum_{\mathrm{SV}} y_i \beta_i t_i, \tag{3}$$

where y_i is the label of the ith training image which is denoted by t_i, and y_i identifies a class, β_i is the coefficient of support vector for the ith training image.

For the vertical detection of laser radar, the range image is rotated around z-axis. Based on the idea of SDF, the SVM correlation filter for in-plane rotation invariance can be synthesized by the different rotation-angle training images which are generated by one image. The design flow chart is shown as Fig. 1.

The images in the training set and testing set are collected by the real laser radar equipment which is manufactured by our laboratory. Figure 2(a) gives the picture of QiuLin building which is far away from the sensor, Figs. 2(b) and (c) are intensity image and range image of the building, respectively, and the power signal-to-noise ratio (SNR) of the range image is −1.3 dB or so. The

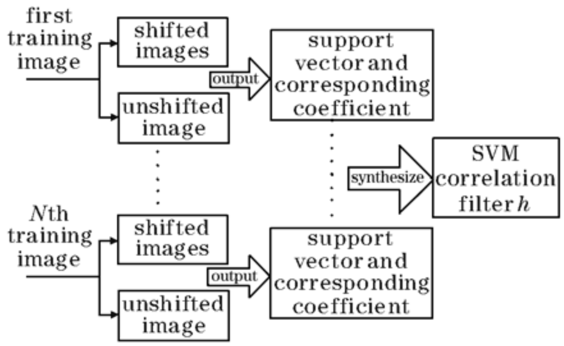

Fig. 1. Flow chart of the design.

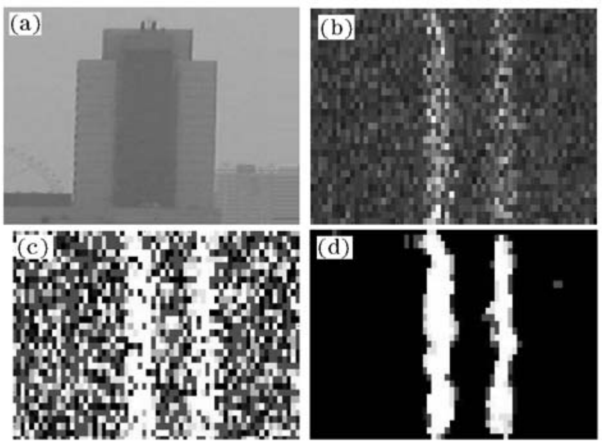

Fig. 2. Ladar images of remote building. (a) Picture of QiuLin building; (b) original intensity image; (c) original range image; (d) processed range image.

range image is processed with intensity information[8−10] because of the correlation between intensity and range images (peak detection can obtain intensity and range images simultaneously). The processed result is shown in Fig. 2(d), and its SNR is 7.4 dB or so.

At present, the real range image of different angles cannot be obtained because of the limiting to the experiment environment, such as the laser radar equipment cannot shift arbitrarily, and the proper target does not be found, and so on. So the training set does not include the rich samples. In order to solve the problem of in-plane rotation invariance, the range image in Fig. 2 is artificially rotated to different angles to generate multiple reference images. The reference images are taken at 5° intervals in aspect, so there are 72 samples. The odd-numbered images (i.e., image $1, 3, \cdots, 35$) are used as the training images. Other collecting range images and the reference range images generated by them are used as the testing images. The testing images are divided into two sets, one set is the original range images, and another set is the processed range images. All images should be adjusted to the center of image. The shifted images are shifted ten pixels from the center of image in the vertical and horizontal directions.

The training set is trained by polynomial kernel function, so the support vectors and corresponding coefficients are outputted, and based on Eq. (3) and Fig. 1, the SVM correlation filter h is computed. Peak to sidelobe ratio (PSR) values and peak error (PE) for

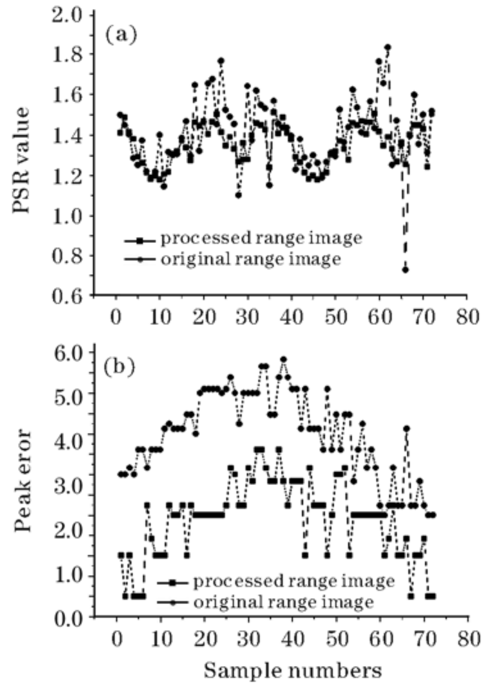

Fig. 3. Curve charts of (a) PSR and (b) peak error.

correlation output are computed[11], where PE is equal to computed Euclidean distance from the original to the actual correlation-peak position. Computing PSR and PE of all test samples, and the corresponding curves is shown in Fig. 3.

The circle dot curve represents the correlation result for the original range images, and the square dot curve represents the correlation result for the processed range images. In Fig. 3(a), both PSR values are almost equal, and a few circle dots are higher than the square dots. Although the original image is low SNR and the processed image is high SNR, the filter has similar correlation results for them. In Fig. 3(b), the location precision of square dots are better than the circle dots, and the maximal PE value in circle dot curve is less than six pixels. The filter can accurately detect the target location.

From the above results, the SVM correlation filter not only has the in-plane rotation invariance, but has the noise-tolerance ability. When the detection is not vertical, the correlation performance of the filter will reduce. The more deflexion angles increase, the more correlation performance decreases. However, the deflexion angles are less than 10°, the correlation results can be accepted.

Through analyzing the mean and variance for both curves (see Table 1), the noise of range image cannot greatly affect the correlation output plane. The analysis means that the SVM correlation filter can directly correlated with the original image in practical application, and the pre-processing step can be omitted, if the whole recognition algorithm need save computation time to meet the real-time requirement.

Supposing a high resolution range image, whose size is 256×256 pixels, there are four test samples of different rotation angles in the scene, which is shown in Fig. 4(a). The correlation output plane is shown in Fig. 4(b). The correlation peak is sharp and high, and with the angles

Table 1. Statistical Analysis

	Original Range Image		Pre-Processed Range Image	
	PSR Value	PE	PSR Value	PE
Mean	1.35	1.89	1.41	3.99
Variance	0.1	0.95	0.18	1.05

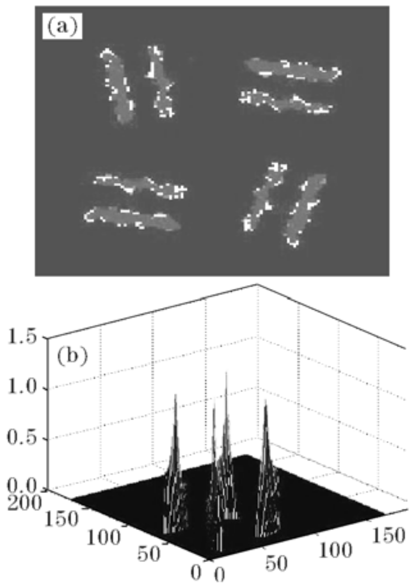

Fig. 4. Multi-target correlation experiment. (a) Ladar range image; (b) correlation output.

changing, the peak is almost not changed, that is to say, the filter has the in-plane rotation invariance.

A new SVM correlation filter for in-plane rotation-invariance is introduced, and the corresponding experiments using the real images of laser radar are completed. The results show that the filter has the noise-tolerance ability, that is to say, the correlation output for the noise image is stable. The correlation peak is changed slightly for the non-training images. The location decision is high, and its mean errors for original and pre-processed range images are two and four pixels, respectively. At last, correlation itself is a parallel operation, and it can be achieved in real time on high speed digital signal processor, so SVM correlation filter has the well actual application worth.

J. Sun's e-mail address is afeng_09@163.com or hit_sunjianfeng@yahoo.com.cn.

References

1. X. Zhang, Acta Automat. Sin. (in Chinese) **26,** 32 (2000).
2. V. N. Vapnik, IEEE Trans. Neural Networks **10,** 988 (1999).
3. J. Yao, S.-M. Tan, and Y.-B. Liew, Opt. Eng. **41,** 81 (2002).
4. B. V. K. V. Kumar, A. Mahalanobis, and A. Takessian, IEEE Trans. Image Processing **9,** 1025 (2000).
5. B. V. K. V. Kumar, Appl. Opt. **31,** 4773 (1992).
6. A. Mahalanobis, B. V. K. V. Kumar, S. Song, and S. R. F. Sims, Appl. Opt. **33,** 3751 (1994).
7. J. Thornton, M. Savvides, and B. V. K. V. Kumar, in *Proceedings of ISSNIP 2004* 183 (2004).
8. Q. Li, Y. Wang, Q. Wang, and Z. Li, Acta Opt. Sin. (in Chinese) **25,** 581 (2005).
9. Z. Li, Q. Wang, Q. Li, and J. Sun, Chin. J. Lasers (in Chinese) **32,** 356 (2005).
10. Z. Li, Qi Li, Z. Tian, Y. Wang, J. Sun, D. Wei, and Q. Wang, Chin. Opt. Lett. **2,** 210 (2004).
11. A. Mahanlanobis, Proc. SPIE **3073,** 25 (1997).