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Reduction of sidelobe energy by shifts in training images for the Mach-Zehnder joint transform correlator

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Correlation reference function has been designed in our previous research for the non-zero order joint transform correlator. In order to yield the reference function, training images were put at the presumed center. However, it could not guarantee that the average cross correlation energy is smallest. To improve this, in this paper, training images are shifted for optical pattern recognition with a Mach-Zehnder interferometer. Numerical result shows that this technique can be implemented at the input plane of liquid crystal spatial light modulator. In particular, each liquid crystal spatial light modulator in reflective mode is modulated along the real-valued axis.

Keywords: Joint transform correlator; Mach-Zehnder interferometer

1 Introduction

LCD based joint transform correlator (JTC) [1] proposed by Yu and Lu is an attractive tool for pattern recognition. Since then, the JTC configuration has received increased attention because it can be easily implemented. Regardless, the JTC is found out a low correlation discrimination and strong zero-order peak. Later, non-zero order JTC (NOJTC) [2-5] was utilized to remove the zero order term. Chen *et al* [6-11] utilized the constraint optimization based on Lagrangian method to obtain the reference function and to produce sharp correlation peaks to detect targets with different geometric distortions. The primary idea is to maintain the value of correlation peak to be constant for each training image. More recently, Chen *et al* [12, 13] utilized Mach-Zehnder configuration on JTC (MZJTC) to remove the zero-order term in only one step directly and does not need recording the Fourier spectra of both the target and reference image ahead. The MZJTC construction can be more easily realized on real-time recognition due to the recent progress in the field of optoelectronics, such as compact laser device, liquid crystal spatial light modulator, and charge couple device (CCD). In fact, the sidelobe energy may be further reduced by properly selecting the spatial position of the original training image. In our previous research, generally, each training image is placed at the assumed center. However, it may not be the best position to yield minimum average cross correlation energy. To improve this, a concept of better training image database is proposed [14, 15]. In this paper, for joint transform correlator with a Mach-Zehnder interferometer, source training images are shifted from the left to the right and from the top to the bottom pixel by pixel. In order to obtain minimum average cross correlation energy, the reference function is yielded while shifting the training image each time. Finally, we determine an improved training image database, which can increase the recognition capacity.

2 Analysis

The structure shown in Fig 1 depicts the schematic diagram of the MZJTC including an electronic subtractor (ES). The ES is used to remove the zero term of JTPS. The NOJTC system with the Mach-Zehnder configuration contains a collimated coherent light as a source, and three reflective liquid crystal spatial light modulators (RLCSLM) and Four CCD cameras. Four separate CCD cameras (CCD1, CCD2, CCD3 and CCD4) are used to capture the following: aircraft image information, the joint transform power spectrum, and the distribution of correlation output. The RLCSLM consists of a polarizing beam splitter (PBS), a half wave plate, a quarter wave plate, and LC a modulator.

The MZJTC structure is used to yield a correlation between a reference image *h* and the target image *f*. The reference image and the test image are put into RLCSLM1 and RLCSLM2, respectively. Furthermore,

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we minimize the average cross correlation energy by using the Lagrange multipliers method to suppress sidelobes and maintain the correlation peak at a specified height.

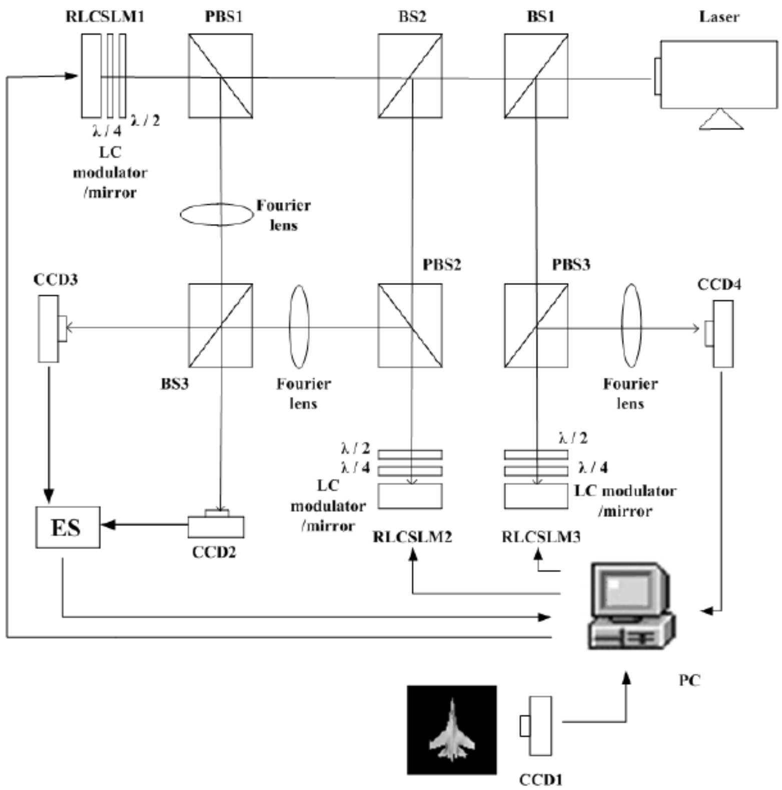

Fig 1. Schematic diagram of a MZJTC system

The way to obtain the synthesized solution of *h* and average cross-correlation energy E_{ave} is similar to the one we used earlier [9-11].The approaches involved in the selection of an improved training set are given as below:

1. Let original training set be S_0. Construct a set S_1 that contains only f_1 . Let $i = 2$.
2. Construct a set S_2 by including all elements in S_1 and f_i. Use all the images in S_2 to synthesize a reference function *h* and its inverse.
3. Calculate E_{ave}.
4. Shift the original image f_i by one pixel. Replace f_i itself in S_2. Calculate new E_{ave} and store it.
5. Shift f_i again. Replace f_i itself. Calculate new E_{ave} and store it.
6. Terminate if the shift process covers the whole training image plane; otherwise, go to step 5.
7. Discover minimum E_{ave}. The corresponding shifted image, which is not generally the original image f_i, is sum up into S_2.
8. Terminate if all training images in S_0 are utilized ($i = N$); otherwise, select another training image f_{i+1} from S_0, $i = i+1$, and go to step 2.
9. The final S_2 is the revised training image database to replace original database.

3 Result

To investigate the correlation performance, an airplane is chosen as the target (64*64 pixels with 256 gray levels) for numerical tests. A distortion range from 0° to 360° in orientation is considered. For simplicity, each image is selected at 5° apart.

We use the crossed solid lines on the image to make visual comparison easier. We can see that the classical training images are put at the presumed central positions. However, they may not be the best positions to achieve minimum average cross correlation energy. Using our proposed method, we can find out that the training images are shifted away from the presumed center. These shifted images are used to construct the revised training database. Some of these images are shown in Fig 2. The proposed technique has involved computationally intensive steps. Approximately 3 hours of CPU time has been taken to yield the shifted images by Matlab software.

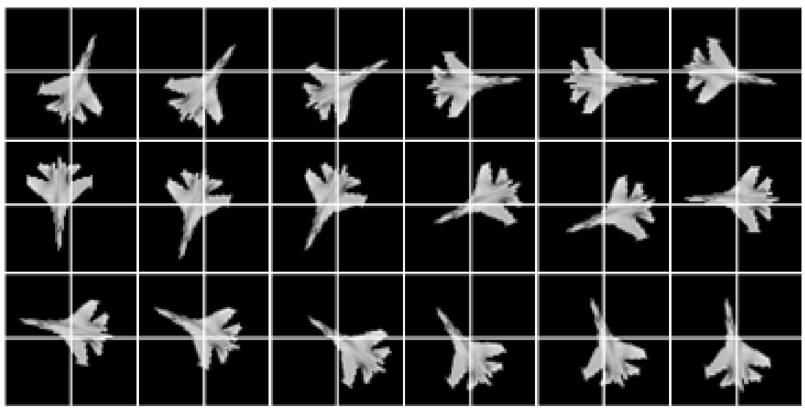

Fig 2. Revised training set

Next, we compare the correlation performances of the classical and shifted training database. The joint input test scene can be implemented by a binary-phase-only SLM together with an amplitude-modulating SLM [12,13] or merely by a real-valued SLM. The corresponding profile of the output correlation is shown in Fig 3, in which the zero-order term has been removed. We observe that one pair of correlation peaks between the reference image and the target of the in output scene are produced symmetrically with respect to the origin. Figure 4(a) shows reference function at one input, while the other input contains the training image with 0 degree rotation. The output correlation profile is shown in Fig 4(b). It is evident that the revised training set yields significantly better correlation result with lower sidelobe energy.

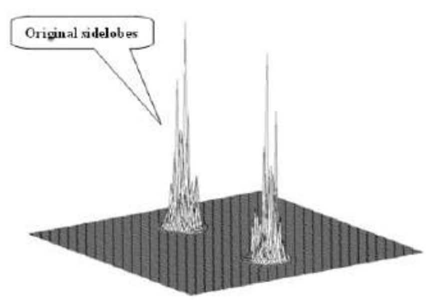

Fig 3. Original correlation profile.

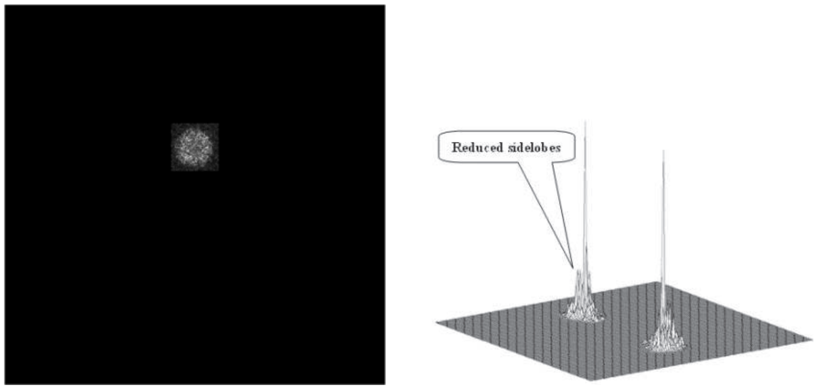

Fig 4. (a) One input that contains synthesized reference function, and (b) the corresponding correlation profile.

Figure 5 plots total sidelobe energy versus the number of training images for the classical and shifted training sets. One can see that the sidelobe energy can be effectively suppressed. It is clear that the method is much better.

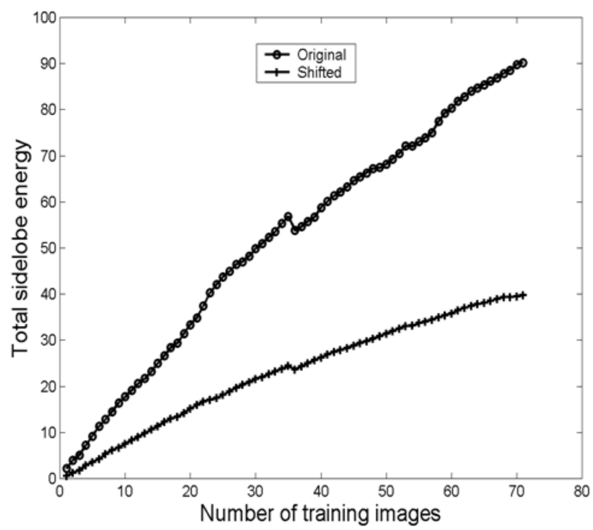

Fig 5. Total sidelobe energy from the classical and revised training set.

4 Conclusion

We have shown a novel method to select a proper set of training images for target recognition based on an MZJTC. In this proposed technique, training images are shifted pixel by pixel from the left to the right and from the top to the bottom in such a way that allows us to find a better set for the training images. We can see that the performance of the classical training image database is much poor. The appealing advantages using optimal training image database are less correlation energy and sharper correlation peak, which can actually increase the recognition performance. Moreover, we expect that more number of training images can be utilized to construct the reference function for the optimization in the optical pattern recognition. Numerical results confirm the effectiveness of the proposed technique.

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