Threat Object Detection using Covariance Matrix Modeling in X-ray Images

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1. Introduction

Improvements of technologies enable the inside inspection without any change in appearances and many applications are being developed in various fields. The X-ray imaging system for the aviation security is one of the applications. In airports, all passengers and properties should be inspected and accepted by security machines before boarding on aircrafts to avoid all treat factors. That treat factors might be directly connected on terrorist threats awfully hazardous to not only passengers but also people in highly populated area such as major cities or buildings.

Because the performance of the system is increasing along with the growth of IT technology, information that has various type and good quality can be provided for security check. However, human factors are mainly affected on the inspections. It means that human inspectors should be proficient corresponding to the growth of technology for efficient and effective inspection but there is clear limit of proficiency. Human being is not a computer.

Because of the limitation, the aviation security techniques have the tendencies to provide not only numerous and nice information but also effective assistance for security inspectors. Many image processing applications already have been developed to provide efficient assistance for the security systems. Naturally, the security check procedure should not be altered by automatic software because it's not guaranteed that the automatic system will never make any mistake. Therefore, the automatic applications should be utilized as a cross-check with human inspectors.

This paper addresses the threat object detection application for aviation security using an image processing algorithm. Considering the size and shape of an item could be different on the screened image with respect to the position and attitude of that, size and rotation invariant object detection algorithm is implemented. In order to verify the performance of the application diversely, other object detection algorithms are also implemented and compared in same conditions.

2. Covariance matrix modeling and detection

The covariance detection algorithm[1] is described in this section. The algorithm is a kind of sliding window technique, but utilizes covariance matrix modeling as an object and candidates data. First of all, feature vectors are extracted for a given image patch of an object. (Sec. 2.1) With the feature vectors, modeling procedure is conducted by calculating covariance matrix of feature vectors. (Sec. 2.2) In an input image, candidates are selected by sliding window method. For the candidates, the modeling procedure is also conducted and a best candidate that has the minimum covariance distance is estimated as the object. (Sec. 2.3)

2.1. Feature vector

In this section, feature vector extraction method is described. For an image, it can be obtained in various ways; represented by intensity only or three dimensional color spaces, or combination of intensity, color, edge, or other products. Let the F be the feature image and extracted from image I as

$$F(x, y) = \Phi(I, x, y) \quad (1)$$

where, (x, y) is a horizontal and vertical location of the image coordinate and the function Φ can any data mapped with image size such as intensity, color, gradient, edge product, etc. In a rectangular window R included by the feature image F, let $\{\boldsymbol{f}_k\}_{k=1..n}$ be the feature vectors. Feature vectors can be calculated in various ways depending on image data. The vectors can be calculated as

$$\boldsymbol{f}_k = [x \quad y \quad I(x,y) \quad I_x(x,y) \quad I_y(x,y) \quad ...] \quad (2)$$

$$\boldsymbol{f}^{\Gamma}{}_k = [\|(x',y')\| \quad I(x,y) \quad I_x(x,y) \quad I_y(x,y) \quad ...] \quad (3)$$

where, $\|(x',y')\| = \sqrt{(x'^2 + y'^2)}$, $(x',y') = (x - x_0, y - y_0)$, and $I(x, y)$ is the any image mapping value at the x and y location. Intensity, image gradient for x direction and image gradient for y direction are utilized as I, I_x and I_y respectively in this paper.

Two different representations of feature vectors have each distinct characteristic. $\boldsymbol{f}_k$ is precise information but sensitive to object rotation based on window origin, whereas $\boldsymbol{f}_k^{\Gamma}$ offers rotation invariant spatial information.

2.2. Covariance matrix

For a WxH rectangular window R, covariance matrix $\mathbf{C}_R$ is computed as

$$C_R = \frac{1}{W\ H}\sum_{k=1}^{W\ H}(\boldsymbol{f}_k - \boldsymbol{\mu}_R)(\boldsymbol{f}_k - \boldsymbol{\mu}_R)^T \quad (4)$$

where, W and H are width and height of the window R and $\boldsymbol{\mu}_R$ is the vector of means of corresponding features within window R.

Covariance matrix is always squared, positive definite and the size of that is determined by the dimension of the feature vectors. Covariance matrix is calculated by locational and image values of the original image, it can be treated as an image patch.

The covariance matrix is a region feature descriptor. Therefore, the result would be same although the size of candidate image patch is different with that of the object patch. It means covariance matrix modeling brings scale invariant characteristic.

As mentioned above, the rotation invariant effect is also anticipated with respect to choice the feature vector construction method. There are two different vector construction methods in accordance with utilized spatial data type. One utilizes x-y coordinate values and the other utilizes 2-norm of the location. 2-norm is also known as the Euclidean distance. If we utilize x-y coordinate values when constructing feature vectors, it makes the different vectors depending on rotational angles. However, feature vectors are made with the Euclidean distances, always same vectors are created regardless of rotation angles.

2.3. Dissimilarity calculation

After covariance matrices of the object and candidate patches are achieved, we have to compute dissimilarity between the object and candidate matrices in order to find the best matched candidate for a given object.

Computing similarities between two dataset, subtraction is generally utilized. However, it's difficult to calculate the dissimilarity by arithmetic subtraction between the two covariance matrices, because the matrices are not in the Euclidean space. Förstner[2] proposed a distance measure between two covariance matrices as

$$\rho(\boldsymbol{C}_i, \boldsymbol{C}_j) = \sqrt{\textstyle\sum_{k=1}^{d} \ln^2 \lambda_k(\boldsymbol{C}_i, \boldsymbol{C}_j)} \quad (5)$$

where, $\lambda_k(\boldsymbol{C}_i, \boldsymbol{C}_j)$ id generalized eigenvalue function of $\boldsymbol{C}_i$ and $\boldsymbol{C}_j$, calculated as

$$\lambda_k \boldsymbol{C}_i \mathbf{x}_k - \boldsymbol{C}_j \mathbf{x}_k = 0 \;\; k = 1 \ldots d \quad (6)$$

where, $\mathbf{x}_k$ are the generalized eigenvectors.

For every candidate, dissimilarity calculation procedure is conducted and a candidate that has the smallest dissimilarity with the given object is determined as the estimated object in an input image. Figure 1 is the flowchart of covariance matrix modeling and detection procedure.

3. Experiments

3.1. Experiment method

To confirm the performance of the addressed detection algorithm, the algorithm is implemented in MATLAB environment. Scale Invariant Feature Transform (SIFT)[3] and Normalized Cross Correlation (NCC)[4,5] algorithm are also implemented in the same environment to compare performances of the algorithms. Input images are typical X-ray images that could be obtained by general airport security X-ray Imaging machines. Though there are some threat objects that are prohibited in cabin such as gun, knife, bomb and etc., pistol image patches are utilized as threat objects.

An object image patch is necessary to detect threat object within input images for implemented algorithms. We assume that the object database is already prepared sufficiently, and in practice object patches extracted from input images are utilized as the objects of the object detection simulations.

3.2. Experimental results

Input X-ray images are extracted from some websites searched by the google image, since it's impossible to screen X-ray images with real gun owing to the restrictions on the weapon possession.

Simulations are conducted For 10 images. To confirm the advantages of the covariance matrix modeling as mentioned above, performance confirmations with one-dimensional rotated and smaller resized object image patches are also conducted for each input image and algorithm. Table 1 is the detection results of detection simulations.

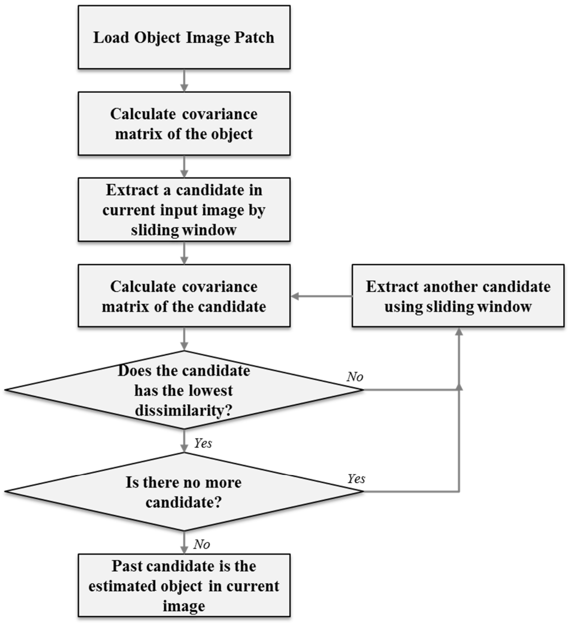

Fig. 1. Flowchart of the covariance matrix modeling and detection

Table 1: Detection Results

Contents	Original object	Rotated object	Resized object
SIFT	100 %	100 %	80 %
NCC	100 %	0 %	50 %
CMM	100 %	80 %	90 %

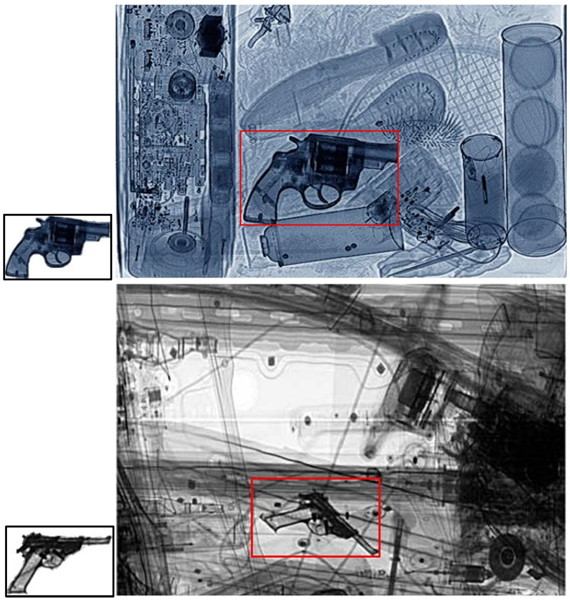

Fig. 2. Some threat detection results on X-ray images conducted using Covariance Matrix Modeling

For the table 1, the unit of detection results is described as the number of detected over total trails. As described above, result of the covariance matric modeling shows balanced detection performance for original, rotated and resized object. On the other hands, that of NCC shows the poorest performance on rotated object. That of Scale Invariant Feature Transform(SIFT) shows unexpected results. It shows scale variant result differently to its name. It might cause the size of the image patch. A SIFT vector is consist with 4-by-4 dimensional data. As the size of the image patch is decreased, the sufficient number of the SIFT vector is not created to performs object detection probably.

4. Conclusion

This paper addressed an application of threat object detection using the covariance matrix modeling. The algorithm is implemented in MATLAB environment and evaluated the performance by comparing with other detection algorithms.

Considering the shape of an object on an image is changed by the attitude of that to the imaging machine, the implemented detector has the robustness for rotation and scale of an object.

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