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Robust face recognition under partial occlusion based on support vector machine with local Gaussian summation kernel

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ABSTRACT

This paper presents the use of Support Vector Machine (SVM) with local Gaussian summation kernel for robust face recognition under partial occlusion. In recent years, the effectiveness of SVM and local features has been reported. However, because conventional methods apply one kernel to global features and global features are influenced easily by noise or occlusion, the conventional methods are not robust to occlusion. The recognition method based on local features, however, is robust to occlusion because partial occlusion affects only specific local features. In order to utilize this property of local features in SVM, local kernels are applied to local features. The use of local kernels in SVM requires local kernel integration. The summation of local kernels is used as the integration method in this study. The effectiveness and robustness of the proposed method are shown by comparison with global kernel based SVM. The recognition rate of the proposed method is high under large occlusion, whereas the recognition rate of the SVM with the global Gaussian kernel decreases drastically. Furthermore, we investigate the robustness to practical occlusion in the real world using the AR face database. Although only face images with non-occlusion are used for training, faces wearing sunglasses or a scarf are classified with high accuracy.

1. Introduction

Face recognition has many potential applications, for example, to security systems, man–machine interfaces, and searches of video databases or the WWW. Therefore, many researchers are actively working in this field and many face recognition methods have been proposed [1,2]. At present, human faces can be recognized with high accuracy in a restricted environment [1–4]. However, face recognition in practical environments is still problematic, with obstacles such as occlusion, illumination changes and pose changes to be overcome. A robust recognition method for use in practical environments is therefore desired. Pose changes of faces induce large variation in feature space [5–7], making pose-independent recognition difficult. However, some studies have realized pose-independent face recognition by combining certain pose-dependent classifiers [7–10]. It is important to make pose dependent classifier robust, especially to occlusion, because human faces are sometimes occluded by the wearing of sunglasses, scarves and other items in practical environments. Shadows on faces due to changes in illumination are also considered as a kind of occlusion. Therefore, robustness to occlusion would further improve face recognition accuracy in practical environments.

In recent years, the effectiveness of Support Vector Machines (SVMs) [11,12] has been reported [3,13,14]. However, because conventional methods apply one kernel to global features extracted from one image [3,4,14] and global features are influenced easily by noise or occlusion, conventional methods are not robust to occlusion. Effectiveness of recognition methods based on local features has also been reported in recent years [9,10,15–17]. Since partial occlusion affects only specific local features. Local features based methods are expected to be robust to partial occlusion if local features are integrated well. For example, Martinez realized robust recognition under partial occlusion by integrating the local similarities [18]. Thus, in order to give SVM robustness under partial occlusion, it is necessary to treat local features in SVM. In this paper, SVM with local kernels is proposed [19]. In this approach, local kernels are arranged at all local regions of a recognition target and are used in SVM to realize robust face recognition under partial occlusion.

Fig. 1(a–c) show a face image, the conventional global kernel and local kernels, respectively. The circle represents one kernel. SVM requires one kernel value when two images are given. However, many outputs of local kernels are obtained in the case of Fig. 1(c) and the outputs of local kernels must therefore be integrated. Both the product and summation of local kernels are considered integration methods that satisfy Mercer's theorem [20,12]. We will refer to these methods as the local product kernel and local summation kernel, respectively. It is considered that the local summation kernel is better than the local product kernel. The

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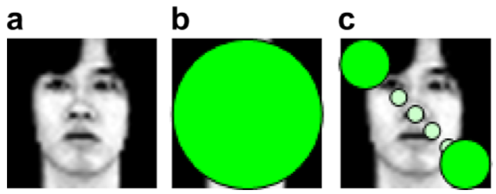

Fig. 1. Face image with global kernel (b) and local kernels (c).

reason is as follows. In the product case, if only one local kernel gives a value of nearly zero, then the product kernel value becomes nearly zero. This means that the product kernel is influenced easily by noise or occlusion. On the other hand, the summation kernel value is not influenced when some local kernels give a value of nearly zero, meaning that the summation of local kernels is robust to occlusion. Research on classifier combination strategies has found that integration by summation gives the best result [21]. Thus, summation is used for integrating local kernels in the proposed method.

To investigate robustness to partial occlusion, we use face images to which a white or black square is added randomly. Effectiveness and robustness of the proposed method are shown by comparison with global kernel based SVM. The recognition rate of the proposed method is shown to be high under large occlusion, whereas the recognition rate of the SVM with the global Gaussian kernel decreases drastically. In addition, we investigate the robustness to practical occlusion in the real world by using the AR face database [22]. Although only face images with non-occlusion are used for training, faces wearing sunglasses or a scarf are classified with high accuracy. In the experiments, the proposed method is also compared with another robust recognition method, the weighted voting method using local eigenspaces, under partial occlusion [18]. Effectiveness of the proposed method is demonstrated by the comparison.

This paper is organized as follows. First, related works are described in Section 2. The contributions of the proposed method are clarified. In Section 3, a face recognition method based on SVM with local Gaussian summation kernel is explained. Section 4 presents the experimental results using artificially occluded face images and then demonstrates robustness to practical occlusion such as the wearing of sunglasses or a scarf. Conclusions and future work are described in Section 5.

2. Related works

A face recognition method based on multiple local SVMs was proposed in recent years [13]. Although the method pays attention to local features, SVM is applied to all features extracted from a local region, that is, the global kernel based SVM is applied to the local region. Thus it uses all features of local region, so is not robust to occlusion. The method proposed here is different in that it is based on local kernels.

Recognition methods based on SVM with local kernel have also been proposed [23,24]. Such methods are based on characteristic feature points detected by Harris operator. As the number of detected feature points differs between images, zero is added to normalize the vector length. These methods compute the similarity between characteristic feature points of two images. The characteristic feature point given a maximum similarity value is selected and used to compute the kernel output. However, taking the maximum of kernels does not satisfy Mercer's theorem [24]. Therefore, only the local minimum solution is obtained. The recognition performance was reported to be improved when position information was included in the local features [23]. This indicates that max operation cannot solve the correspondence problem well. In [24], the parameter of a non-Mercer kernel is selected such that the Gram matrix becomes positive definite. However, analytical proof is lacking and, moreover, robustness to partial occlusion becomes low if the important characteristic feature points are occluded. Recognition methods based on feature selection have the same weakness [25,26].

In contrast, the proposed method arranges local Gaussian kernels at all local regions of a recognition target because we cannot know which part is occluded. Since features on each local kernel are used for kernel computation, we can avoid the correspondence problem and utilize topological information well. In addition, the proposed kernel satisfies Mercer's theorem and we consistently obtain the global optimal solution without parameter selection. The proof is shown in the Appendix. These represent the fundamental differences from the aforementioned methods [23,24]. In addition, the proposed method is robust to practical occlusion and the experimental results are shown in Section 4. The proposed method is effective but simple; it can be used easily if the kernel function of SVM software [27,28] is changed. Furthermore, this paper clarifies the relation between the global Gaussian kernel and the product of local Gaussian kernels from the viewpoint of integration of local Gaussian kernels. We demonstrate why the global Gaussian kernel is not robust to partial occlusion in Section 3.

The contributions of the proposed method can be summarized as follows.

1. Robustness to partial occlusion is obtained by the summation of local Gaussian kernels. This is not realized by conventional global kernels. Section 4 shows the robustness under artificial and practical occlusions.
2. Summation of local Gaussian kernels satisfies Mercer's theorem while the other recent kernels [23,24] do not. Therefore, a global optimal solution is always obtained.
3. The proposed kernel is effective but simple; it can be used easily by changing the kernel function of SVM software [27,28].
4. Since local Gaussian kernels are arranged at all local regions of a recognition target, the correspondence problem is avoided and topological information is used naturally.
5. From the view point of integrating local Gaussian kernels, the reason why the global Gaussian kernel is much influenced by partial occlusion is clarified.

3. A robust recognition method under partial occlusion

This section explains the face recognition method based on SVM with a local Gaussian summation kernel. The proposed method is based on local kernels. In order to use local kernels effectively, we want to use local appearance features. For this purpose, we use Gabor features which give good performance in face recognition [29,30,26]. The flowchart of the proposed method is shown in Fig. 2. First, Gabor features are extracted from a recognition

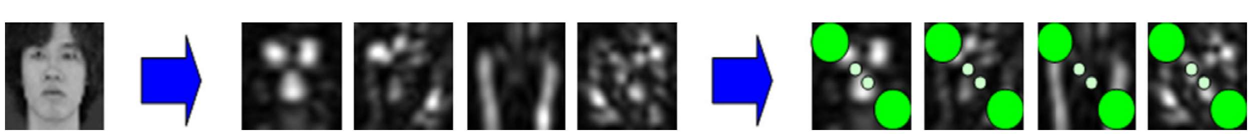

Fig. 2. Flowchart of the proposed method.