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Tensor-based Traffic Sign Representation and Multilinear Analysis for TSR System

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Abstract- TSR(Traffic Sign Recognition) System is to recognize traffic sign while the vehicle is moving. It is one of major part of ADAS (Advanced Driver Assistance System). Traffic signs have diverse shapes in spite of the standard of country. If it recognized without pre-classification for the shape the recognition accuracy may degrade severely. Even if shape classification is performed separately within the recognition phase, it is obstacle for the real-time processing because it increases processing time. Thus, to manage the characteristics for recognition and shape information simultaneoulsy, this paper propses multi-dimentional representation for the traffic sign by using tensor. Becuase the proposed representaion for the traffic sign has features of sign recognition and shape classification as integrated form, it can increase the recognition performance as well as categorizing shape more detail.

Keywords- Traffic sign recognition (TSR), ADAS, Multi-dimensional representation, Tensor analysis.

1. Introduction

Recently, ICT Technologies are widely introduced to intelligent vehicle market. In Europe, safety assessments for new car are graded and opened to the public under Euro ENCAP (New Car Assessment Program) [1]. Development for ADAS (Advanced Driver Assistance System), which includes guarantee of driver's safety, driving assistance, and safety reinforcement by preventing car accident through IT-related technologies for the vehicle, are very active research field in the world [2]. As results of these studies, recent vehicles are being delivered with adopting diverse IT technologies for the safety and assistance [7]. In cases of researches related to TSR in domestic environment, because navigation system support speed limit information regardless traffic sign and other types of traffic sign may be considered as less important information related to safety, thus, recognition research is insufficient. However, it works an obstacle to the US and European markets in the automotive industry. Therefore, for the international competitiveness as well as domestic application of ADAS technologies, Researches and developments related to the TSR may be very urgent.

Traffic sign recognition is to acquire images when the vehicle is moving and then extracting sign area included in the images and recognize the information indicated by the traffic sign. Traffic signs have diverse shapes in spite that are manufactured and installed in accordance with the standard of country. If it recognized without pre-classification for the shape the recognition accuracy may degrade severely. Even if shape classification is performed at the recognition phase, it is obstacle for the real-time processing because it increases processing time. Thus, the method to manage characteristics for shape information and recognizing features simultaneoulsy is required. The mathod may reduce processing time and increase performance for recogniztion due to integrated managing of shape information and recognizing features.

The rest of this paper is organized as follows. In the next section, tensor-based representation of traffic sign including shape characteristics and recognizing features is introduced. Section 3 describes multilinear analysis of tensor by using mathematical forms. In Section 4, the strategy for using the proposed representation applying shape classification and sign recognition. Finally, this paper is concluded in Section 5. Scope of this paper is representation and analysis for shape and recognizing feature. That is, this paper assumes that traffic sign is completely extracted from road images gathered by camera in front of vehicle

2. Tensor Representation for traffic sign

In this section, Tensor-based representation for traffic sign proposed in this paper. Tensor is high-order matrix that represents diverse characteristic information into integrated form [3-4]. Thus, by using tensor, the characteristics for recognizing signification as well as shape information of the traffic sign are managed simultaneously.

2.1. Shape and recognition feature

Shape information is used for categorizing traffic sign. This paper uses the Angular Radial Transformation (ART) as shape feature extraction. The ART is method to extracting shape descriptor, which is included in the MPEG 7 visual feature extraction standard and applied binary images [5].

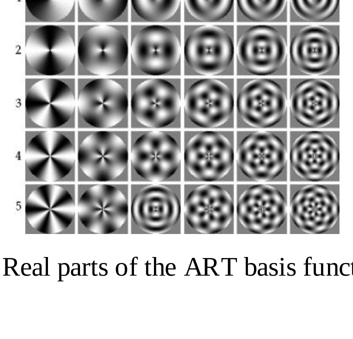

Fig.1. Real parts of the ART basis functions.

The ART is the orthogonal unitary transform defined on a unit circle as shown in figure 1. Basis functions are complete orthonormal sinusoidal functions defined in polar coordinates.

$$F_{nm} = \langle V_{nm}(\rho,\theta), f(\rho,\theta) \rangle = \int_0^{2\pi}\int_0^1 V^*_{nm}(\rho,\theta) f(\rho,\theta)\rho\, d\rho\, d\theta \quad (1)$$

where, F_{nm} is an ART coefficient of order n and m, $f(\rho,\theta)$ is an image function in polar coordinates, and $V_{nm}(\rho,\theta)$ is the ART basis function, i.e.,

$$V_{nm}(\rho,\theta) = A_m(\theta) R_n(\rho) \quad (2)$$

The angular basis function is defined as equation (3) by using exponential function and the radial basis function defined by a cosine function as equation (4).

$$A_m(\theta) = \frac{1}{2\pi}\exp(jm\theta) \quad (3)$$

$$R_n(\rho) = \begin{cases} 1 & n = 0 \\ 2\cos(\pi n\rho) & n \neq 0 \end{cases} \quad (4)$$

In the standard, shape descriptor is composed of 36-dimensional feature vector (n=3, m=12). In traffic sign classification, however, radial component is more significant than the angular component of the ART coefficient. Thus, this paper uses more radial coefficient than angular ones, i.e., n=9, m=4.

To recognize traffic sign, this paper uses the PCA-based approaches. Thus, the original image itself is used as feature.

2.2. Tensor representation

Through the process mentioned in Section 2.1, the proposed representation of traffic sign has three independent axes: pixels, signs, and shape coefficient. Pixel axis represents the normalized traffic sign image as a column vector. Shape coefficient axis is the ART coefficient to classify shape. The last is Sign axis which represents individual sign. As a result, tensor used in this paper is three-dimensional tensor $\mathcal{D}$.

Fig.2. Tensor representation concept for traffic sign.

3. Multilinear analysis

Tensor data $\mathcal{D}$ is defined as equation (5).

$$\mathcal{D} = \mathcal{Z} \times_1 \mathbf{U}_{pixels} \times_2 \mathbf{U}_{signs} \times_3 \mathbf{U}_{shape\_coeff.} \quad (5)$$

where, $\mathbf{U}_n$ means n mode matrix and x_n represents mode-n product. $\mathcal{Z}$ is known as core tensor which governs the interaction between the mode matrix $\mathbf{U}_1, \mathbf{U}_2, \ldots, \mathbf{U}_N$. The sign ensemble proposed in this paper is composed of factors corresponding to pixels, signs, and shape coefficient, respectively. $\mathbf{U}_n$ spans $\mathbf{D}_{(n)}$ matrix which is result by mode-n flattening of $\mathcal{D}$.

The core tensor is most important matrix in the tensor analysis and recognition problems. To compute core tensor $\mathcal{Z}$, this paper use N-mode SVD algorithm [6]. $\mathbf{D}_{(n)}$ is mode n flattening matrix. Due to large size of flatten matrix, the SVD algorithm cannot be applied directly to the matrix. Thus this paper adopt alternative approach by computing the SVD for $D^T_{(n)}D_{(n)}$ as equation (6), and then compute $\mathbf{U}_n$ using equation (7), where Σ^+ means the pseudo inverse of Σ [6].

$$D^T_{(n)}D_{(n)} = V_n \Sigma U^T_n U_n \Sigma V^T_n = V_n \Sigma^2 V^T_n \quad (6)$$

$$U_n = D_{(n)} V_n \Sigma^+ \quad (7)$$

$\mathbf{U}_n$ is obtained by computation of equation (7). Thus, $D_{(n)}D^T_{(n)}$ can be computed by equation (8).

$$D_{(n)}D^T_{(n)} = U_n \Sigma V^T_n V_n \Sigma U^T_n = U_n \Sigma^2 U^T_n \quad (8)$$

As a result core tensor $\mathcal{Z}$ is obtained by equation (9).

$$\mathcal{Z} = \mathcal{D} \times_1 U^T_1 \times_2 U^T_2 \times_3 U^T_3 \quad (9)$$

4. Strategy for shape classification and sign recognition

4.1. Shape classification

Observing the equation (5), mode matrix related to shape information is $\mathbf{U}_{shape\_coeff.}$, thus, $\mathcal{Z} \times_1 \mathbf{U}_{pixels} \times_2 \mathbf{U}_{signs}$ is construed as the basis. In other words, tensor data $\mathcal{D}$ is equal to mode-3 product between basis tensor $\mathcal{B}$ and $\mathbf{U}_{shape\_coeff}$ as shown in equation (10) and (11).

$$\mathcal{D} = \mathcal{B} \times_3 \mathbf{U}_{shape\_coeff.} \quad (10)$$

$$\mathcal{B} = \mathcal{Z} \times_1 \mathbf{U}_{pixels} \times_2 \mathbf{U}_{signs} \quad (11)$$

To classify unknown input sign images, the ART coefficient of unknown image is first computed and then, coefficient which is used for similarity computation to tensor data is calculated by using equation (12). In equation (12), $\mathcal{P}$ is the pseudo inverse tensor of $\mathcal{B}$ and $\mathbf{A}$ is the ART coefficient of unknown sign image. $\mathbf{P}_{(3)}$ is computed as equation (13) and then $\mathcal{P}$ is obtained through making tensor.

$$\mathbf{C} = \mathcal{P} \times_{shape\_coeff.} \mathbf{A} \quad (12)$$

$$\mathbf{P}_{(3)} = (B^+_{(3)})^T \quad (13)$$

Similarity which is used for shape classification is computed by equation (14).

$$\mathbf{s}_i = \mathrm{sim}(\mathbf{C}, \mathbf{U}_{shape\_coeff.}(i)) \quad (14)$$

where $\mathbf{U}_{shape\_coeff.}(i)$ is i-th row vector of $\mathbf{U}_{shape\_coeff.}$. If the similarity value is close to specific shape category, then it is classified such class.

4.2. Sign recognition

Sign recognition is also applied through similar method of shape classification. Difference between shape classification and sign recognition is merely constructing basis and computing coefficients. To elevate recognition performance, both similarity according to shape information and PCA-based sign feature are used. For example, if certain sign image is close to two kinds of registered sign without much difference, we can finally determine the one which has high similarity score according to the shape information.

5. Conclusions

In this paper, tensor-based representation and multilinear analysis for traffic sign. The proposed representation for traffic sign manages shape information and recognizing features with integrated form. In the case of shape classification, the proposed representation by using the tensor has capability to categorize shape with more detail because it has additional information for recognizing feature. In the case of traffic sign recognition, the proposed representation increase the recognition performance because it considers recognition feature and shape information simultaneously.

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