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Effective pixel classification of Mars images based on ant colony optimization feature selection and extreme learning machine

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ABSTRACT

one of the most important tasks of Mars rover, a robot which explores the Mars surface, is the process of automatic segmentation of images taken by front-line Panoramic Camera (Pancam). This procedure is highly significant since the transformation cost of images from Mars to earth is extremely high. Also, image analysis may help Mars rover for its navigation and localization. In this paper, a new feature vector including wavelet and color features for Mars images is proposed. Then, this feature vector is presented for extreme learning machine (ELM) classifier which leads to a high accuracy pixel classifier. It is shown that this system statistically outperforms support vector machine (SVM) and k-nearest neighbours (KNNs) classifiers with respect to both accuracy and run time. After that, dimension reduction in feature space is done by two proposed feature section algorithms based on ant colony optimization (ACO) to decrease the time complexity which is very important in Mars on-board applications. In the first proposed feature selection algorithm, the same feature subset is selected among the feature vector for all pixel classes, while in the second proposed algorithm, the most significant features are selected for each pixel class, separately. Proposed pixel classifier with complete feature set outperforms prior methods by 6.44% and 5.84% with respect to average Fmeasure and accuracy, respectively. Finally, proposed feature selection methods decrease the feature vector size up to 76% and achieves Fmeasure and accuracy of 91.72% and 91.05%, respectively, which outperforms prior methods with 87.22% and 86.64%.

1. Introduction

Exploration and research in Mars has been increased significantly over the last decade. Geological and structural information of Mars conducted by robots are all the results of such explorations. Also, mineral classification of mars images presents valuable information of Mars environment [1]. Furthermore, the extraction of chemical and mineralogical properties of the Mars stones and soil could be helpful in the future researches and explorations [2].

Recently an automated robot, referred as Mars rover is equipped with a front-line Panoramic Camera (Pancam) instrument. A great deal of information can be extracted and organized from Mars images taken by Pancam. The transformation cost from Mars to earth is very high in the term of Mars rover supply power. Therefore, automated image analysis systems with a high degree of accuracy are required [3]. The main task in these systems is the classification of rocks and other objects in the images. This procedure is so important because it avoids sending the irrelevant and redundant images to the earth. It also helps Mars rover for its navigation and localization in the Mars surface. The rocks in Mars have diverse colors and textures, covered by dust soil with various intensities, rotation and scale. In addition, these images are blurred by instrument movement and are contaminated by environment noise. In [4], a theorem for efficient segmentation and detection of motion blur was presented which led to the classification of pixels as either blurred or unblurred. Furthermore, in [5], a new kernel-specific feature vector with a good discrimination property was proposed and then presented for the classifiers to detect different types of blur including motion and defocus blurs. All of the mentioned items address the main challenges in Mars images analysis [6].

Our goal in this research is to develop a new method for automatic pixel classification in Mars images. The first step in this method is features extraction from image pixels. There are many features proposed in the literature for pixel classification [7,8]. In one hand, increasing dimension of feature set leads to more computational time which is not acceptable in our interest, especially in on-board applications such as Mars rover, with its limited amount of power, memory and processing rate. On the other hand, there is an opinion that some extracted features are irrelevant which decrease the classification accuracy [9]. A good feature vector should be easily extractable from the images, discriminative, robust against noise and distortion. A key

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issue is that the feature vector should be short and efficient. Most of the classification methods presented for Mars rover involve high computational costs due to high dimensionality of feature vectors [3]. Some feature selection approaches are ant colony optimization (ACO) [10], particle swarm optimization (PSO) [11], genetic algorithm (GA) [12], feature selection with harmony search [13] and so on. Many feature selection approaches have been proposed for different applications such as face recognition [14], data mining and pattern recognition [15], speaker verification [16] and classifier ensemble reduction [17]. Feature selection has been applied in Mars image classification in the term of minimizing feature subset by fuzzy-rough feature selection [3] and information gain ranking technique [18].

The main contributions of this paper that lead to a high accuracy pixel classifier for the classification of different types of rocks and sands from their surrounding background in Mars images are summarized as follows:

1) The texture and structure of different types of rocks in Mars images are analyzed and then a new feature set for pixel description is proposed. The feature set includes texture and color features which discriminates all types of rocks and leads to better pixel classification. For texture features, statistical parameters of wavelet components are considered. This idea is very useful for classifying rocks with layered and waved structures since wavelet decomposition is sensitive to vertical and horizontal frequency components. Dominant color descriptor, local color histogram and color statistical features are all used as color features. These features are useful for describing structures such as small black stones and sand, dark large size rocks with shadow, and flat rocks. In the next step, Extreme Learning Machine (ELM) is used for pixel classification. In our previous work [19], a Mars image segmentation scheme was proposed based on SVM classifier and ACO. We will show that this work with ELM classifier with the proposed feature set not only leads to a high accuracy pixel classifier but also outperforms other classifiers such as SVM and KNNs with respect to both accuracy and run time.

2) Dimension reduction with preserving classification accuracy is necessary due to the limitations of power, memory and processing rate in on-board applications such as Mars rover. This is addressed as another contribution of this research. For this goal, two feature selection methods based on ACO are proposed to select the most relevant and significant features from the complete feature set. For feature selection methods a new idea referred as Feature Grouping is proposed in this paper and its efficiency is shown. These feature selection methods decrease the computational time and preserve classification performance simultaneously. The first feature selection method selects the same feature subset for all pixel classes while the second one presents a feature subset for each pixel class separately. Both feature selection methods, with the same degree, considerably decrease the run time of classifiers in both train and test phases. The first method slightly decreases classification accuracy while the second one increases it.

Finally, the pixel classification accuracies of ELM, SVM and KNNs classifiers with different parameters and different feature subsets (complete feature set, feature subsets found by the first and second proposed methods and genetic algorithm) will be shown quantitatively followed by statistical interpretation of the results.

The rest of this paper is organized as follows: Section 2 describes the extraction of feature set from image pixels. Pixel classifiers are explained in more details in Sections 3 and 4. Our two proposed feature selection methods are described completely in Section 5. Experimental setup and results are described in Sections 6 and 7, respectively. Finally, the conclusion and future works are discussed in Section 8.

2. Feature extraction

Feature extraction is the procedure of extracting a feature vector from complex image data. Feature vectors represent a large set of data as well as simplifying the amount of memory and computation cost required for processing [20]. In all feature extraction experiments in this paper, a feature vector for each pixel is extracted from its surrounding window. Some types of layered rocks contain horizontal and vertical frequency components. A very good descriptor for these types of rocks is the texture features extracted from wavelet transform. Therefore, statistical parameters in wavelet domain are used as pixel representation. Other rock types such as rover tracks (which have a darker surface in comparison with other rocks), small black stone and sand flat rocks could be easily identified by color features. Finally, a feature set including wavelet coefficient features, dominant color descriptor (DCD) features, local color histogram features and color statistic features is proposed to be used in this experiment and is explained in the next sections.

2.1. Wavelet features

Each pixel of the input image is windowed and then one-level 2D wavelet decomposition is applied. Then, Euclidean norm is incorporated to the wavelet coefficients of rows and columns of LH and HL components, separately. Finally, the mean and variance of Euclidean norms of rows and columns are calculated which leads to 8 wavelet features.

2.2. Color features

Color features are considered as low-level features which are not sensitive to rotation, translation and scale changes. Therefore, these features may be used in pixel classification of Mars images which are noisy and degraded by rotation and camera transformations. In this work, we have used the DCD, local color histogram and color statistic features.

2.2.1. Dominant color descriptor

DCD is one of the approved color descriptors in the MPEG-7 Final Committee Draft among several number of histogram descriptors [21]. Both representative colors and the percentage of each color are included in DCD. In DCD, colors of an image are divided into a number of partitions named coarse partitions. All points in a partition are assumed to be similar. Partition centers are the average value of all pixel colors in each partition and are calculated by Eq. (1).

$$C_j = \frac{\sum_{p\in P_i} p}{\sum_{p\in P_i} 1} \tag{1}$$

In which P_i is the ith partition. In this research, the DCD features are extracted in RGB domain. Each pixel color is assigned to a partition and then its color is replaced by the center value of that partition. Therefore, the image colors are quantized. For each pixel, the DCD of a window around that pixel is calculated and presented as a feature vector. Fig. 1 shows an image and its corresponding DCD in RGB color space.

2.2.2. Local color histogram features

Histogram is the discrete statistical probability density of the image [22]. Mars images are in RGB domain with the range 0–255 in each channel. If all 256 bins are considered per R, G and B components in each histogram, it will be computationally expensive. Accordingly the color bins are quantized in 8 equal bins for each channel. To localize these features, a window is considered around each pixel and the local histogram is computed. Therefore, each pixel of the image is mapped to a 24D feature vector in term of local color histogram features.

2.2.3. Color statistic features

The first and second moments of a window around pixels represent mean and standard deviation, respectively. These features are also