Pattern Recognition 45 (2012) 3472–3489

Contents lists available at SciVerse ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/pr

An endmember-based distance for content based hyperspectral image retrieval

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ARTICLE INFO

Article history:
Received 9 April 2011
Received in revised form
17 March 2012
Accepted 21 March 2012
Available online 30 March 2012

Keywords:
Hyperspectral images
Content based image retrieval
Endmember induction algorithm
Image similarity

ABSTRACT

We propose a specific content-based image retrieval (CBIR) system for hyperspectral images exploiting its rich spectral information. The CBIR image features are the endmember signatures obtained from the image data by endmember induction algorithms (EIAs). Endmembers correspond to the elementary materials in the scene, so that the pixel spectra can be decomposed into a linear combination of endmember signatures. EIA search for points in the high dimensional space of pixel spectra defining a convex polytope, often a simplex, covering the image data. This paper introduces a dissimilarity measure between hyperspectral images computed over the image induced endmembers, proving that it complies with the axioms of a distance. We provide a comparative discussion of dissimilarity functions, and quantitative evaluation of their relative performances on a large collection of synthetic hyperspectral images, and on a dataset extracted from a real hyperspectral image. Alternative dissimilarity functions considered are the Hausdorff distance and robust variations of it. We assess the CBIR performance sensitivity to changes in the distance between endmembers, the EIA employed, and some other conditions. The proposed hyperspectral image distance improves over the alternative dissimilarities in all quantitative performance measures. The visual results of the CBIR on the real image data demonstrate its usefulness for practical applications.

1. Introduction

Mining the increasing amount of Earth Observation data has been recognized as a key problem even for panchromatic images or low spatial resolution multispectral images [8–10,13]. The increasing amount of hyperspectral images provided by new deployed hyperspectral sensors introduces new technical problems. Specifically, searching through these increasingly big databases using content based image retrieval (CBIR) techniques [12,43] has not been properly addressed for the case of hyperspectral images. Approaches to CBIR in remote sensing images proposed up to now have been focused on panchromatic or low dimension multispectral images [8–11,13,14,40,41], but not on hyperspectral images.

There are two main elements in the definition of a CBIR system [43]: (a) the image features and the corresponding feature extraction process and (b) the similarity measure defined on the feature space guiding the database search. Hyperspectral images contain rich spectral information, therefore it is natural to define spectral image features. As far as we know the only attempts to propose such a spectral image characterization to guide CBIR search in hyperspectral image databases are [33,49]. Assuming the image formation framework given by the linear mixing model [25], the image pixel spectra are a linear combination of elementary material signatures, called endmembers. Therefore, endmembers are appropriate spectral features providing a global characterization of the image. Endmember induction algorithms (EIAs) induce the endmember signatures from the image data, providing an autonomous processes for feature extraction which can be applied to each image independently. Thus, we are interested in this paper in assessing the descriptive power of endmembers for database search, and on the value of endmember induction algorithms (EIAs) as feature extraction processes.

The definition of an appropriate dissimilarity function must take into account that the endmembers are global image features, so that metrics or semimetrics defined for pattern matching in images can be less appropriate for this kind of data. Specifically the notion of outlier due to occlusions in shape detection [42], does not apply well to sets of endmembers. We need a dissimilarity measure which decreases when the hyperspectral images have more similar elementary materials, as characterized by their spectral signatures, regardless of their spatial distribution on the image. This paper introduces a formal distance between hyperspectral images based on spectral information. This hyperspectral image distance is a function of the distances between individual

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http://dx.doi.org/10.1016/j.patcog.2012.03.015

image endmembers. Therefore, the whole approach may be sensitive to the endmember distance and the applied EIA. We compare the proposed distance with the Hausdorff distance and a robust least trimmed squares (LTS) modification of the Hausdorff distance [42].

The issue of validation, or evaluation, of the CBIR approach is not trivial. CBIR systems are desired to handle large amounts of data, however, the available labeled information is scarce. Methodological frameworks for validation under conditions of little ground truth knowledge, such as the hybrid methodology in [48] are needed. However, it is preferable to use as much available information as possible. One useful approach is to provide an extensive collection of synthetic images whose meaning is well known, i.e. we have perfect knowledge of the ground truth allowing exact computation of the performance measures. Other approach is to perform bootstraping of image blocks of a large image containing well identified regions that can provide a convenient image block labeling. We have followed both approaches in the experimental validation of the CBIR system constituted by the endmember induction and the proposed distance.

1.1. Contributions and structure of the paper

The contributions of the paper are the following ones.

- The definition of image endmembers induced by a given EIA as the hyperspectral image features for CBIR.
- The definition of a dissimilarity function over the image endmembers, proving that this image dissimilarity is a distance, to guide the CBIR search.
- The test on CBIR performance of the effect of the distance between endmembers (Euclidean versus Angular), and of the EIA (N-FINDER [50] versus EIHA [20,21]).
- The realization of an extensive experimental validation on a collection of synthetic hyperspectral images, and on an image dataset extracted from a real hyperspectral image.

In summary, the results of the computational experiments show little sensitivity of the CBIR system to EIA and endmember distance. The proposed distance improves over the comparing distances.

The structure of the paper is as follows: Section 2 introduces the CBIR for hyperspectral images relating it to the general field of CBIR. This section introduces also the formal definition of endmembers, the EIAs, and a discussion of relevant validation issues. In Section 3 we prove that the proposed hyperspectral image dissimilarity is a distance. Section 4 introduces the dissimilarity functions used for comparison. In Section 5 we give comparative and sensitivity results computed on the synthetic hyperspectral image databases. In Section 6 we give results on dataset composed of image blocks extracted from a large real hyperspectral image. Finally, we give some conclusions in Section 7. Appendix A contains miscellaneous results on the comparing dissimilarity functions. Appendix B describes the EIAs used for the experiments: the N-FINDER and EIHA algorithms.

2. CBIR in hyperspectral image databases

The acknowledgment of the semantic gap in general CBIR approaches [12,29,43] has diverted significant efforts in the CBIR literature into two avenues. One is focused on specific domain systems, such as medical images [15,24,35,22], where there is a reduced semantic uncertainty, and similarity based search is always meaningful. The other is the development of relevance feedback approaches for broad domain image databases [7,51]. Relevance feedback approaches include feature weighting [26], probabilistic combination of image distances [2], genetic algorithms [3], kernel machines [4] among a multitude of other techniques. Relevance feedback has also been applied to remote sensing images [14,16]. In fact [14] applies a CBIR-like approach to image segmentation, instead of database search. This is an indication of the terminological confusion found in the literature. In [1] there is an attempt to define a relevance feedback CBIR approach using several features, among them the average of the image pixel spectra. The main handicaps when trying to design a retrieval feedback on hyperspectral image databases based on spectral information are the design of an appropriate user interface, and the difficulty to interpret the spectral information by untrained people. Hyperspectral image database CBIR is at an early stage of development, when appropriate dissimilarity measures need to be designed for the adequate exploitation of the rich spectral information contained in the images. An additional difficulty is the lack of available public databases for CBIR system validation and evaluation. Most reported validation experiments of CBIR systems over remote sensing images rely on one image or a relatively small collection of images [1,14,16,33]. For hyperspectral images this problem is even stronger, because there are few public images with a known ground truth which can provide supporting evidence for CBIR approaches.

In this paper, CBIR on hyperspectral images is treated as a specific domain CBIR problem where a key technical issue is to find a domain-dependent dissimilarity measure providing enhanced database search results. We follow a query-by-example approach, where the database interrogation is done through the presentation of a query image, and the most similar images in the database are returned as the answer [43]. The image features are the endmembers and the feature extraction processes are the EIA, both explained below. Previous works using endmembers to obtain image features [33] did not provide a formal distance between endmember-based image representations, but a heuristic search based on corresponding fractional abundances obtained from a greedy spectrum matching. The emphasis in [33] was the design of distributed computing systems to approach real-time response, not CBIR performance.

The structure of the proposed Spectral CBIR system is illustrated in Fig. 1. Users interrogate the system providing a sample query image. The EIA calculates the image endmembers which will be used as feature vectors. The same EIA is applied to both the query image and all and each of the hyperspectral images in the database, and will remain the same along the database exploitation. A dissimilarity measure between the query and the database images is computed on the endmember-based features. Finally, the k most similar images on the database are returned as the answer to the query.

2.1. Spectral features

We assume the linear mixing model [25] of hyperspectral image formation. Each pixel is the result of the linear combination

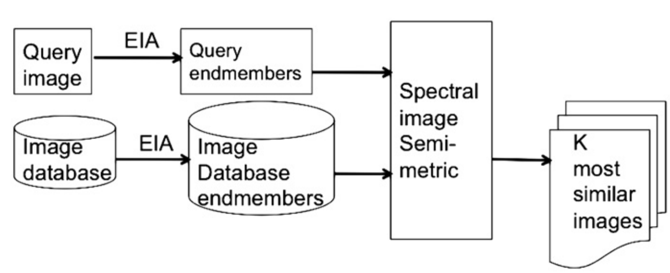

Fig. 1. Structure of a CBIR system based on the proposed hyperspectral image distance.