Chapter XVI
Parallel Segmentation of Multi-Channel Images Using Multi-Dimensional Mathematical Morphology

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ABSTRACT

Multi-channel images are characteristic of certain applications, such as medical imaging or remotely sensed data analysis. Mathematical morphology-based segmentation of multi-channel imagery has not been fully accomplished yet, mainly due to the lack of vector-based strategies to extend classic morphological operations to multidimensional imagery. For instance, the most important morphological approach for image segmentation is the watershed transformation, a hybrid of seeded region growing and edge detection. In this chapter, we describe a vector-preserving framework to extend morphological operations to multi-channel images, and further propose a fully automatic multi-channel watershed segmentation algorithm that naturally combines spatial and spectral/temporal information. Due to the large data volumes often associated with multi-channel imaging, this chapter also develops a parallel implementation strategy to speed up performance. The proposed parallel algorithm is evaluated using magnetic resonance images and remotely sensed hyperspectral scenes collected by the NASA Jet Propulsion Laboratory Airborne Visible Infra-Red Imaging Spectrometer (AVIRIS).

INTRODUCTION

The segmentation of an image can be defined as its partition into different regions, each having certain properties (Zhang, 1996). In mathematical terms, a segmentation of an image *f* is a partition of its definition domain D_f into *m* disjoint, non-empty sets $s_1, s_2, \ldots, s_m$ called segments, so that $\bigcup_{i=1}^{m} S_i = D_f$ and $S_i \cap S_j = \emptyset,\ \forall i \neq j$. Segmentation of intensity images in the spatial domain usually involves four main approaches (Haralick & Shapiro, 1985). Thresholding techniques assume that all pixels whose value lies within a certain range belong to the same class. Boundary-based methods assume that the pixel values change rapidly at the boundary between two regions. Region-based segmentation algorithms postulate that neighboring pixels within the same region have similar intensity values, of which the split-and-merge technique is probably the most well known. Hybrid methods combine one or more of the above-mentioned criteria. This class includes variable-order surface fitting and active contour methods.

One of the most successful hybrid segmentation approaches is the morphological watershed transformation (Beucher, 1994), which consists of a combination of seeded region growing (Adams & Bischof, 1994; Mehnert & Jackway, 1997) and edge detection. It relies on a marker-controlled approach (Fan et al., 2001) that considers the image data as imaginary topographic relief; the brighter the intensity, the higher the corresponding elevation. Let us assume that a drop of water falls on such a topographic surface. The drop will flow down along the steepest slope path until it reaches a minimum. The set of points of the surface whose steepest slope path reachs a given minimum constitutes the *catchment basin* associated with that minimum, while the watersheds are the zones dividing adjacent catchment basins. Another way of visualizing the watershed concept is by analogy to immersion (Vincent & Soille, 1991). Starting from every minimum, the surface is progressively flooded until water coming from two different minima meet. At this point, a watershed line is erected. The watershed transformation can successfully partition the image into meaningful regions, provided that minima corresponding to relevant image objects, along with object boundaries, are available (Shafarenko et al., 1997). Despite its encouraging results in many applications, morphological techniques have not been fully exploited in applications that involve multi-channel imagery, where a vector of values rather than a single value is associated with each pixel location.

Many types of multi-channel images exist depending on the type of information collected for each pixel. For instance, color images are multi-channel images with three channels, one for each primary color in the RGB space. Images optically acquired in more than one spectral or wavelength interval are called multispectral. These images are characteristic in satellite imaging and aerial reconnaissance applications. The number of spectral channels can be extremely high, as in the case of hyperspectral images produced by imaging spectrometers (Chang, 2003). Finally, all image types above can be extended to the class of multitemporal images or image sequences, which consist of series of images defined over the same definition domain, but collected at more than a single time. Examples include magnetic resonance (MR) images in medical applications and video sequences.

Segmentation of multi-channel imagery has usually been accomplished in the spectral/temporal domain of the data only. Techniques include well known data clustering algorithms such as ISODATA (Richards & Jia, 1999). Other techniques, such as Soille's watershed-based multi-channel segmentation (Soille, 1996), are based on an initial spectral clustering followed by a post-classification using spatial information. This approach separates spatial information from spectral information, and thus the two types of information are not treated simultaneously.