Automatic Annotation of Planetary Surfaces with Geomorphic Labels

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***Abstract*—We present a methodology for automatic geomorphic mapping of planetary surfaces that incorporates machine learning techniques. Our application transforms remotely sensed topographic data gathered by orbiting satellites into semantically meaningful maps of landforms; such maps are valuable research tools for planetary science. As topographic data becomes increasingly available, the ability to derive geomorphic maps efficiently is becoming essential. In our proposed framework, the mapping is achieved by means of scene segmentation followed by supervised classification of segments. The two mapping steps use different sets of features derived from digital elevation models (DEMs) of planetary surfaces; selection of appropriate features is discussed. Using a particular set of terrain attributes relevant to annotating cratered terrain on Mars, we investigate the design choices for both segmentation and classification components. The segmentation assessment includes K-means based agglomerative segmentation and watershed-based segmentation. The classification assessment includes three supervised learning algorithms: Naive Bayes, Bagging with decision trees, and Support Vector Machines (SVM); segments are classified into the following landforms: crater floors, crater walls (concave and convex), ridges (concave and convex) and inter-crater plains. The method is applied to six test sites on Mars. The analysis of the results shows that a combination of K-means based agglomerative segmentation and either SVM with a quadratic kernel or Bagging with C4.5 yields best maps. The presented framework can be applied without modification to generate geomorphic maps of sites on Earth.**

***Index Terms*—Digital topography, object recognition, segmentation, classification, Mars.**

I. Introduction

Remote sensing instruments onboard spacecrafts are providing increasingly large volumes of data on various aspects of Earth as well as surfaces of other planets. This data-rich environment challenges the scientific community to process, analyze, and ultimately turn into knowledge a significant portion of all collected data. In the context of planetary science, most data needs to be presented in the context of geomorphic maps [48] – basic staples of any planetary geology research. A geomorphic map is a categorical (thematic) map of topographical expressions (landforms). Traditionally, such maps are drawn by analysts through visual interpretations of images [42], [48].

In this paper we present a methodology for automating the process of geomorphic mapping. We are motivated by the slowness and expense of the traditional mapping process. If left to manual mapping, the percentage of planetary surface mapped to the level of detail permitted by an increased resolution of newly arriving data will continue to drop precipitously. Automating the mapping process can prevent this decline. We use topographic data as an input for machine mapping, because landforms can be better characterized by topographic features than by image features. Our method relies on segmentation-based classification of a landscape scene into constituent landforms. Such an approach yields results that, in their appearance and content, mimic manually derived maps.

A. Background

The overwhelming majority of previous work on automatic annotation of remotely sensed data was devoted to classification of multi-spectral images into different types of land covers. A standard approach to classification of raster data (images or digital elevation models or DEMs) is to use pixels as objects for classification [22], [23]. However, a pixel is not an ideal surface unit from the point of view of classification. Real life objects are characterized by a similarity of color and texture rather than a similarity of color alone. This observation led to the technique of segmentation-based classification wherein an image is first subdivided into meaningful objects that are subsequently classified [27], [45]. As a general rule, the segmentation-based approach produces better maps from images than the pixel-based approach [20]. The segmentation-based approach is even more attractive when working with topographic instead of imagery data. Pixels are just too small to constitute reasonable landscape elements; larger patches of surface better reflect local topographic expressions. This is important for supervised classification, where a domain expert must label each unit in a training set. Furthermore, geometric and statistical properties of landscape elements, such as shape, neighborhood properties, and statistics corresponding to terrain attributes calculated over an ensemble of member pixels, provide additional information that can be incorporated into classification.

The topic of auto-mapping landforms from topography has received little attention in the past, but with the introduction of segmentation-based classification methods, there is now a renewed interest in such mapping [13], [15]. However, published approaches rely on hand-made rules for classification and fail to take advantage of machine learning techniques.

B. Related Work

In the past, auto-mapping of planetary surfaces was restricted to identifying particular targets of interest, namely

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