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Texture-based classification of sub-Antarctic vegetation communities on Heard Island

Humphrey Murray [a], Arko Lucieer [b,*], Raymond Williams [c,*]

[a] Datalive Software, 6 George St, Launceston, Tasmania 7250, Australia
[b] School of Geography and Environmental Studies, University of Tasmania, Private Bag 76, Hobart, Tasmania 7001, Australia
[c] School of Computing and Information Systems, University of Tasmania, Private Bag 100, Hobart, Tasmania 7001, Australia

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ABSTRACT

This study was the first to use high-resolution IKONOS imagery to classify vegetation communities on sub-Antarctic Heard Island. We focused on the use of texture measures, in addition to standard multispectral information, to improve the classification of sub-Antarctic vegetation communities. Heard Island's pristine and rapidly changing environment makes it a relevant and exciting location to study the regional effects of climate change. This study uses IKONOS imagery to provide automated, up-to-date, and non-invasive means to map vegetation as an important indicator for environmental change. Three classification techniques were compared: multispectral classification, texture based classification, and a combination of both. Texture features were calculated using the Grey Level Co-occurrence Matrix (GLCM). We investigated the effect of the texture window size on classification accuracy. The combined approach produced a higher accuracy than using multispectral bands alone. It was also found that the selection of GLCM texture features is critical. The highest accuracy (85%) was produced using all original spectral bands and three uncorrelated texture features. Incorporating texture improved classification accuracy by 6%.

1. Introduction

1.1. Heard Island

Heard Island is a pristine sub-Antarctic island south of the Antarctic Polar Frontal Zone in the Indian Ocean. This Australian territory is a 2800 m high volcanic and glaciated island, and because of its remoteness, human visits to the island are very infrequent. Heard Island is unique in terms of its location, climatic conditions, vegetation communities, geology, volcanic activity, and glacial cover (Bergstrom and Chown, 1999; Bergstrom and Selkirk, 2000; Bergstrom et al., 2002; Scott and Bergstrom, 2006). Up-to-date and accurate spatial information is of crucial importance for sustainable management of the island. Because of the island's remoteness, satellite imagery provides advanced and cost-effective means to map its land cover and to quantify environmental changes. This information is important for sustainable management of this pristine island, to study the regional effects of climate change, and to assess the effects of human impacts. The glaciers on Heard Island have been receding since 1947 when glacial extent was first estimated from aerial photographs (Thost and Truffer, 2008). This recession was most likely caused by a temperature rise of $+0.9\,deg$ C between 1947 and 2004. Glacial retreat has exposed new land that has become available for colonisation of plant species.

During previous expeditions to Heard Island in 1986/1987, 1987/1988, 2000/2001 and 2003/2004 terrestrial plant ecology has been studied and vegetation maps have been produced. These maps were produced manually, based on visual interpretation of aerial photographs and satellite imagery, combined with GPS-based field samples (Bergstrom and Selkirk, 2000; Bergstrom et al., 2002; Scott, 1989; Australian Antarctic Division, 2009). Because of the inaccessibility of Heard Island, field surveys are often expensive and labour intensive, and expeditions can potentially be intrusive. Satellite images have been successfully used in vegetation mapping, monitoring, and ecological applications in the past (Aplin, 2005; Coppin et al., 2004; Jensen, 2000; Xie et al., 2008). Very high spatial resolution imagery (VHR) such as IKONOS (1-4 m spatial resolution, 4 multispectral bands) provides a valuable new source of information for remotely sensed vegetation mapping. Given that the island is rarely visited, satellite image classification could be a suitable technique to produce vegetation maps regularly and accurately. Satellite sensors are also able to capture imagery of large parts of the island or even the entire island, so that complete vegetation maps can be produced. If we can produce accurate vegetation maps from VHR satellite imagery,

* Corresponding author.
E-mail address: Arko.Lucieer@utas.edu.au (A. Lucieer).

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we can potentially map and quantify changes in vegetation cover, which for a pristine area like Heard Island provides an important indication of the regional effects of climate change. This study is the first to use satellite imagery for semi-automated vegetation classification on Heard Island.

1.2. Texture-based classification

The multispectral bands of satellite imagery are often transformed into thematic classes using an appropriate classification technique (Lu and Weng, 2007; Tso and Mather, 2001). Most of these techniques, however, only look at the spectral values of individual pixels and do not take into consideration the *spatial context* of pixels. With recent VHR imagery, real world objects or regions that were previously represented by only one or two pixels now consist of many pixels. Therefore, techniques that take into account the spatial properties of an image region need to be developed and applied. One approach for including the spatial relationship of pixels is modelling texture. Texture can be defined as the various measures of smoothness, coarseness, and regularity of an image region (Gonzalez and Woods, 1992). Previous studies have shown that combining both multispectral and texture data together can lead to improved classification accuracy (Ruiz et al., 2004; Zhu and Yang, 1998). The popular grey-level co-occurrence matrix (GLCM) texture model (Haralick et al., 1973; Haralick, 1979) has been widely used in remote sensing studies (Clausi, 2002; Franklin et al., 2001; Ouma et al., 2008). Recently, texture-based classification algorithms have been successfully applied to VHR satellite imagery (Aguera et al., 2008; Ouma et al., 2008; Puissant et al., 2005). Tsai et al. (2005) and Tsai and Chou (2006) applied the GLCM to VHR Quickbird imagery to detect invasive plant species. In this study, we apply GLCM texture-based classification to VHR IKONOS imagery of Heard Island.

In addition, the issues of scale and complexity in texture definitions have been raised in previous remote sensing studies. The size of the texture window should ideally match the spatial scale of the object or class under consideration, but this is not always a trivial exercise. The window should be large enough to capture the relevant patterns, but if the window becomes too large edge effects could dominate the results (Puissant et al., 2005). Several studies have looked at the influence of the window size on classification accuracy (Aplin, 2006; Chen et al., 2004; Franklin et al., 1996). The GLCM texture model generates a range of correlated texture features that can be used in a classification (Haralick et al., 1973; Hall-Beyer, 2007). In this study, we systematically examine the effect of the GLCM window size and texture feature selection on classification accuracy.

In addition to spatial scale, thematic scale or complexity is another issue in classifying natural ecosystems (Aplin, 2006). In the last decade or so, a range of studies have explored the use of hierarchy theory in image classification (Akçay and Aksoy, 2008; Blaschke and Strobl, 2001; Benz et al., 2004; Burnett and Blaschke, 2003; Franklin et al., 2001; Ju et al., 2005; Wu, 1999). A classification hierarchy arranges thematic classes into a hierarchical tree with the most generic classes at the top and the more detailed classes further down, inheriting characteristics from their parent classes. In this study we apply a hierarchical classification approach toward classifying Heard Island's vegetation communities.

1.3. Aim and objectives

In summary, the main aim of this study is to investigate whether incorporating texture improves vegetation classification based on VHR IKONOS imagery of Heard Island. The objectives of the study are (a) to determine an appropriate window size for texture analysis; (b) to determine which texture features should be used for classification; (c) to perform a classification using texture alone; (d) to combine multispectral and texture features in a classification; and (e) to compare this approach to standard multispectral classification.

1.4. Paper Structure

Section 2 of this paper describes the study area and the imagery being used for this research. Section 3 presents the texture-based methods that were used in the study and explains the GLCM which was a fundamental component in all of the techniques described. Section 4 discusses the feature reduction and classification techniques used, as well as the techniques for validation. Section 5 presents and discusses the results obtained while Section 6 presents the conclusions that can be drawn from the methods and results.

2. Study area, imagery and field data

2.1. Study Area

Heard Island is a sub-Antarctic island located in the Indian Ocean at approximately 53.11°*S*; 73.54°*E*. Fig. 1 shows how the island is located with respect to Australia and Antarctica. The Territory of Heard Island and McDonald Islands (HIMI) was inscribed on the World Heritage List in 1997 for its outstanding universal natural values. In addition to being recognised internationally for their conservation values, the Heard Island and McDonald Islands and Marine Reserve are significant at the Australian national level for their contribution to the National Representative System of Marine Protected Areas (NRSMPA), their heritage values and their important wetlands (Bergstrom and Selkirk, 2000; Bergstrom et al., 2002; Australian Antarctic Division, 2009; Kiernan and McConnell, 1999; Scott, 1989).

Fig. 2 shows the topography of Heard Island. The island contains a large volcano, Big Ben, which is covered in ice, snow, and glaciers. However, the low lying coastal regions (approximately 20% of the island) are covered by many different vegetation communities. It is the only large sub-Antarctic island free of introduced predators and, because of its remote location, human visits are rare. Any observed changes to the island are likely to have resulted from causes that are not directly related to local human intervention. Therefore by observing changes in the vegetation on Heard Island, a valuable insight into the regional effects of climate change can be obtained.

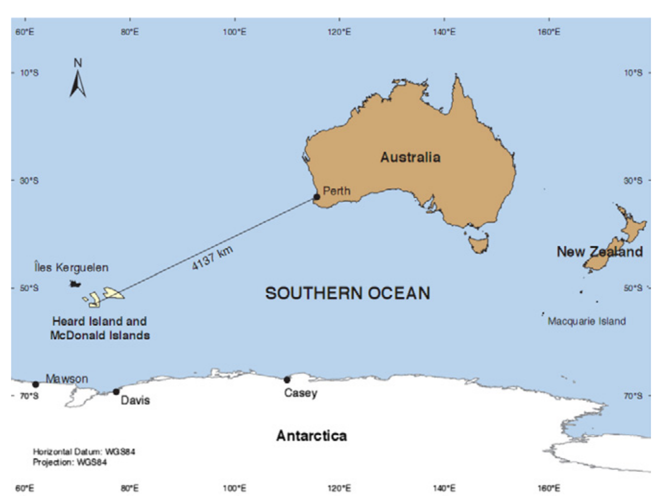

Fig. 1. Location of Heard Island (source: Australian Antarctic Data Centre, 2009).