International Journal of Applied Earth Observation and Geoinformation 15 (2012) 79–91

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Super-resolution mapping of lakes from imagery with a coarse spatial and fine temporal resolution

Anuar M. Muad*, Giles M. Foody

School of Geography, University of Nottingham, Nottingham, NG7 2RD, UK

ARTICLE INFO

Article history:
Received 1 October 2010
Accepted 17 June 2011

Keywords:
Resolution enhancement
Mixed pixel
Halftoning
2D multiple notch filter
Object based morphology

ABSTRACT

The potential of super-resolution mapping (SRM) techniques for the representation of lakes was evaluated using both an established and a newly proposed method. Both super-resolution mapping techniques were typically able to provide representations that were visually and quantitatively more realistic than standard hard classifications. The new technique was able to represent more small lakes than the established technique. The results also demonstrate the value of using a time series of images as input to the super-resolution analysis, enabling researchers to usefully exploit the typically fine temporal resolution of coarse spatial resolution sensors for land cover mapping.

1. Introduction

The mosaic of land cover types that occur on the Earth's surface is a key variable in a range of environmental systems. For example, the landscape mosaic impacts on a large and diverse array of issues that include the aesthetic appeal of a region, its biodiversity and its climate. Land cover and land cover change are, for example, critical variables affecting ecological systems. Information on land cover is, therefore, required in a range of studies, with some, especially those associated with landscape ecology, requiring information on the nature of landscape patches (e.g. their size, shape, etc.). Remote sensing has considerable potential as a source of information on land cover at a range of spatial and temporal scales. The recent growth of interest in object-based analysis in remote sensing (e.g. Blaschke, 2010) should also help the extraction of useful ecological information from imagery. Although remote sensing is widely used as a source of land cover information for ecological studies (Newton et al., 2009) there are many factors that limit the accuracy of derived land cover information (Foody, 2002). These include the classification algorithm and pre-processing methods used as well as the temporal and spatial resolution of the data. The latter is the key focus of attention in this article, with the accuracy with which objects may be characterised known to be a function of the spatial resolution of the imagery and minimum mapping unit used (Saura, 2002).

The land cover mosaic of a region typically comprises a set of patches of relatively homogenous cover that can be considered as objects within a remotely sensed image. To characterise objects accurately it is important that the image spatial resolution or pixel size is smaller than the typical size of the objects (Woodcock and Strahler, 1987). This may require use of imagery with a fine spatial resolution.

Spatial resolution can be treated as a variable in sensor selection for a project and needs to be determined in relation to the project's specific goals and sensing systems properties (Warner et al., 2009). Imagery with a fine spatial resolution have been acquired from space for many years, notably through military systems such as the US Keyhole (KH) or CORONA series of satellites from the late 1950s to early 1970s (McDonald, 1995; Toutin, 2009). A large number of fine and very fine spatial resolution systems have also been developed in recent years. There are ~36 satellite systems in orbit or schedule for launch that are able to provide imagery with a spatial resolution of <3 m (Toutin, 2009). These systems have revolutionised aspects of remote sensing with, for example, the new fine spatial resolution sensing systems now allow mapping at scales ~1:5000 from ~0.6 m resolution QuickBird imagery (Topan et al., 2009). The main drawback to the use of these systems is the cost of the imagery (Toutin, 2009). For example, Toutin (2009) suggests that even relatively basic image products from fine spatial resolution sensors costs ~US\$20 km^{-2} and more highly processed products may be several times more expensive still. Imagery from slightly coarser spatial resolution systems such as SPOT HRG (spatial resolution ~4 to 10 m) costs only ~US\$3–5 km^{-2}. Moreover, the extent of the imagery from SPOT HRG is much larger than from IKONOS; some 36 IKONOS images would be required to cover the

* Corresponding author. Tel.: +44 115 84 67052; fax: +44 115 95 15249.
E-mail addresses: lgxamm@nottingham.ac.uk, anuar_mikdad@yahoo.com (A.M. Muad).

0303-2434/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jag.2011.06.002

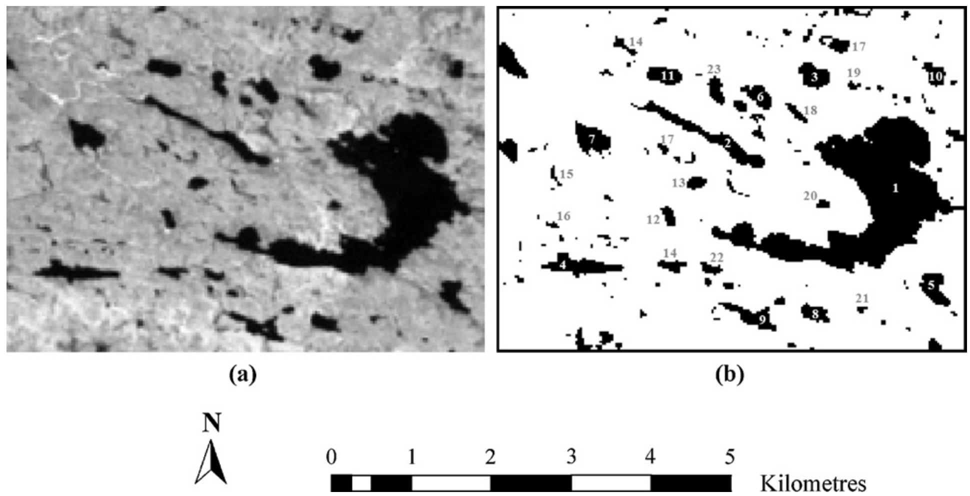

Fig. 1. The Landsat ETM+ data of the test site. (a) Near-infrared waveband image and (b) binary land cover map derived from hard classification.

same area as a single SPOT HRG image (Toutin, 2009). There have also been many major developments in medium-coarse spatial resolution systems (Goward et al., 2009; Justice and Tucker, 2009) and, critically, these can provide inexpensive imagery of relatively large areas. Projects may often be constrained to use such relatively coarse spatial resolution imagery for pragmatic reasons.

Often the spatial resolution of a remote sensor is too coarse for the intended application and inappropriate for optimal mapping. Land cover data derived in such circumstances should be used with care. The errors and uncertainties in land cover derived from remote sensing may sometimes go unrecognised and can greatly impact on the characterisation of landscapes (Shao and Wu, 2008). One major problem arising from the use of coarse spatial resolution imagery is mixed pixels (Fisher, 1997). A mixed pixel contains more than one land cover class and cannot be appropriately represented by the standard 'hard' allocation process used in conventional image classification algorithms (one pixel – one class). Unfortunately mixed pixels may be common and the proportion of mixed pixels tends to increase with an increase in pixel size, with mixed pixels typically vastly dominating imagery acquired at a coarse spatial resolution. A popular adaptation of the standard approach to land cover mapping that allows for mixed pixels is the use of a fuzzy or soft classification (Foody, 1996). The latter allows a pixel to have multiple and partial class membership and outputs typically a set of fraction images, each showing the proportion of the pixel's area that is covered by a specific land cover class. Although attractive in reducing the mixed pixel problems a concern is that the soft classification does not show the spatial distribution of the sub-pixel class fractions limiting its value as a source of information on landscape objects.

An alternative way to address the mixed pixel problem is to adopt some form of spatial resolution enhancement technique to increase the spatial resolution of imagery (i.e. to reduce the effective pixel size). For example, methods based on image sharpening, especially if the sensor operates at more than one spatial resolution (Mather, 2004) or super-resolution analyses (Lu and Inamura, 2003; Ling et al., 2010). The aim of the latter is to effectively decrease the pixel size, allowing interpretation of sub-pixel scale features. Approaches adopted are typically based on either super-resolution restitution or super-resolution mapping (Ling et al., 2010) and their use can add value to relatively inexpensive image data sets.

A variety of super-resolution mapping techniques have been used in remote sensing and related research (Tatem et al., 2001; Verhoeye and De Wulf, 2002; Mertens et al., 2003, 2004; Foody et al., 2005; Farsiu et al., 2006). Typically these techniques have been applied with a single coarse spatial resolution image as their input. Although the technique may be used to derive a map at a finer spatial scale than the input imagery, there are many concerns with their use. One is that small isolated patches of a land cover class are often not represented or only inaccurately. Additionally the use of a single input image may limit the accuracy of land cover representation and the use of multiple coarse resolution images may offer an ability to enhanced accuracy. Given that coarse spatial resolution systems often have a relatively fine temporal resolution it may be possible to derive multiple images of the same site over a short period of time as input to a super-resolution analysis. The images in the time series may differ in subtle ways, with the location of pixels varying slightly due to, for example, minor orbital translations of remote sensing satellites. The slight differences between images can be exploited by combining a time-series coarse spatial resolution images into an integrated image which may contain more information than a single coarse spatial resolution image (Packalen et al., 2006). Exploiting the fine temporal resolution that is characteristic of many coarse resolution remote sensing systems may, therefore, facilitate super-resolution analyses.

The aim of this paper is to present a new super-resolution mapping technique that should capture more information on small isolated lakes that were referred as objects and to evaluate the potential of using a time series of images for super-resolution mapping. The method will be evaluated against established super-resolution mapping and hard classification techniques.

2. Test site and data

A ∼25 km^2 area located in Quebec province, Canada, was selected for this study (Fig. 1). It is situated between latitudes 55°08′35″N and 55°06′05″N and between longitudes 77°41′53″W and 77°36′27″W. This region contains a variety of lakes of differing size and shape that provide a challenge for mapping from remote sensing. Not only do the lakes provide a challenge for object characterisation there is a desire for more information on such features in high latitude regions as they appear to be disappearing (Smith et al., 2005). Lakes are typically spectrally highly separable in the near-infrared wavelengths in which commonly used remote sensing systems operate in allowing the study to use data acquired in a single waveband to acquire information on important lakes. The approaches discussed should, however, be generalisable to other types of objects and data sets.