Int J Appl Earth Obs Geoinformation 67 (2018) 20–29

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

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

A modified temporal criterion to meta-optimize the extended Kalman filter for land cover classification of remotely sensed time series

B.P. Salmon[a,*], W. Kleynhans[b], J.C. Olivier[a], F. van den Bergh[b], K.J. Wessels[b]

[a] School of Engineering and ICT, University of Tasmania, Australia
[b] Remote Sensing Research Unit, Meraka Institute, CSIR, Pretoria, South Africa

ARTICLE INFO

Keywords:
Kalman filtering
Remote sensing
Satellites
Time series

ABSTRACT

Humans are transforming land cover at an ever-increasing rate. Accurate geographical maps on land cover, especially rural and urban settlements are essential to planning sustainable development. Time series extracted from MODerate resolution Imaging Spectroradiometer (MODIS) land surface reflectance products have been used to differentiate land cover classes by analyzing the seasonal patterns in reflectance values. The proper fitting of a parametric model to these time series usually requires several adjustments to the regression method. To reduce the workload, a global setting of parameters is done to the regression method for a geographical area. In this work we have modified a meta-optimization approach to setting a regression method to extract the parameters on a per time series basis. The standard deviation of the model parameters and magnitude of residuals are used as scoring function. We successfully fitted a triply modulated model to the seasonal patterns of our study area using a non-linear extended Kalman filter (EKF). The approach uses temporal information which significantly reduces the processing time and storage requirements to process each time series. It also derives reliability metrics for each time series individually. The features extracted using the proposed method are classified with a support vector machine and the performance of the method is compared to the original approach on our ground truth data.

1. Introduction

Human activities are transforming land cover at an ever-increasing rate and alters fundamental processes, including biogeochemical cycles, hydrological cycles, land-atmosphere interactions and biodiversity (Foley et al., 2005; Pielke et al., 2011). Land cover transformation is driven by the demand for resources by a rapidly growing human population, especially in developing countries (Montgomery, 2008).

Africa has the highest reported birth-rate of any continent, with about 60% of the population living in rural areas and nearly 4% population growth rates in urban areas which is nearly twice the global average (Eva et al., 2006). By 2030 more than 50% of Africa's population will have migrated to urban settlements (Montgomery, 2008) and this will contribute significantly to environmental impacts. Integrated land use and urban planning requires up-to-date spatial information on land cover, especially rural and urban settlement.

Our study area is located within the Limpopo province, South Africa. The province has a land area of approximately 125754 km^2 and houses more than 5.8 million people in the year 2016. There are various types of settlements ranging from highly dense suburban areas with dense vegetation to sparse rural areas with little existing vegetation. Two example images of the two land cover classes namely natural vegetation and human settlement are shown in Fig. 1. In Fig. 1(a) we can observe suburban settlements with medium vegetation distributed throughout the area, while in Fig. 1(b) a highly dense rural settlement with sparse vegetation. It is visible from these two images that the reflectance of land cover varies during the year due to seasonal variation in the vegetation (Lunetta et al., 2004).

Machine learning methods analyze geographical areas' spectral reflectance values and/or their spatial context to classify land cover. This approach to land cover mapping has been widely applied while only recently the high temporal resolution of coarse spatial resolution satellite sensors has been explored (Justice et al., 1998; Van den Bergh et al., 2012). Hyper-temporal imagery provides a time series which captures the seasonal land surface dynamics that can be used to differentiate various land cover types (Lunetta et al., 2004).

Lhermitte et al. (2008) used the magnitudes of mean and annual components from Fourier transform coefficient of the MODIS acquired NDVI time series to classify land cover. This was extended to a sliding window extracting short time Fourier transform on all seven MODIS

* Corresponding author.
E-mail address: brian.salmon@gmail.com (B.P. Salmon).

https://doi.org/10.1016/j.jag.2017.12.007
Received 3 October 2017; Received in revised form 18 December 2017; Accepted 18 December 2017
0303-2434/

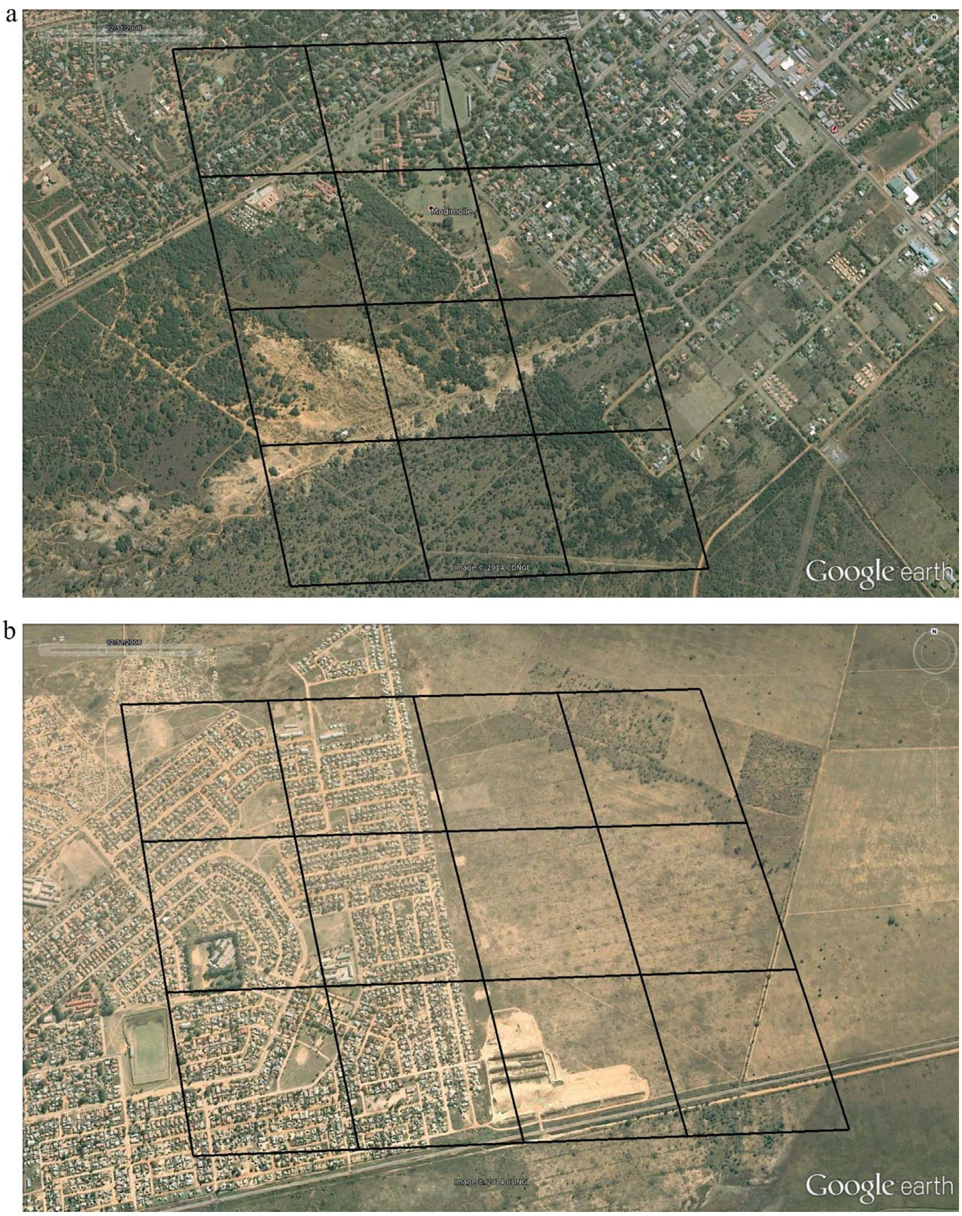

Fig. 1. Two examples of Quickbird imagery to show the various different settlement types and vegetation diversity in the study area. Both areas were imaged on the 31 December 2008 and are overlaid with an MODIS 500 m sinusoidal coordinate grid.

bands which was classified using an artificial neural network (Salmon et al., 2011a). This feature extraction method was proven viable as it produces meaningful results in classification (Salmon et al., 2011b). A windowless approach was proposed by Kleynhans et al. (2010), where a EKF was used to fit a triply modulated cosine model which jointly estimates the mean and annual components of a NDVI time series. The EKF regress a set of model parameters for each time index in the NDVI time series which is used to classify the time series.

The prediction capability of these model variables is dependent on the setting of two covariance matrices within the EKF. A meta-optimization method was proposed by Salmon et al. (2014a) which derives these matrices in an unsupervised manner using spatial information. The setting of these two covariance matrices improved the classification accuracy but was computationally very expensive and consumed a reasonable amount of computational resources. Although computing resource are becoming more cost-effective, this method does not scale with the increase in geographical area. Not only does it consume a lot more computational resources, it assumes a single parametric model can be used to represent the entire geographical area. It also assume similar annual growth cycles and average rainfall across the area which is not true for larger geographical areas.

In this paper we modify this criterion proposed in Salmon et al. (2014a) to utilize temporal information instead of spatial information which reduced the computational load significantly. This modification makes the approach completely parallelizable which allows the processing of large time series data sets in a fraction of the time. Additionally, it removes all the assumptions made in Salmon et al. (2014a) at the cost of not being able to compensate for large inter-annual climate variability such as drought which was experienced in our study area in the year 2002. This modified approach was briefly introduced in Salmon et al. (2014b) and will be more comprehensive investigated in this work. In addition, the method will also be evaluated on all the MODIS land bands and the combinations recommended in Salmon et al. (2011a). The land cover classification accuracy of the method is compared to the results produced in Salmon et al. (2014a) and a standard non-linear least squares.

The paper is organized as follows. Section 2 discusses the study area and data set. In Section 3 we present the method, and Section 4 present the experimental results. Section 5 presents the conclusions.