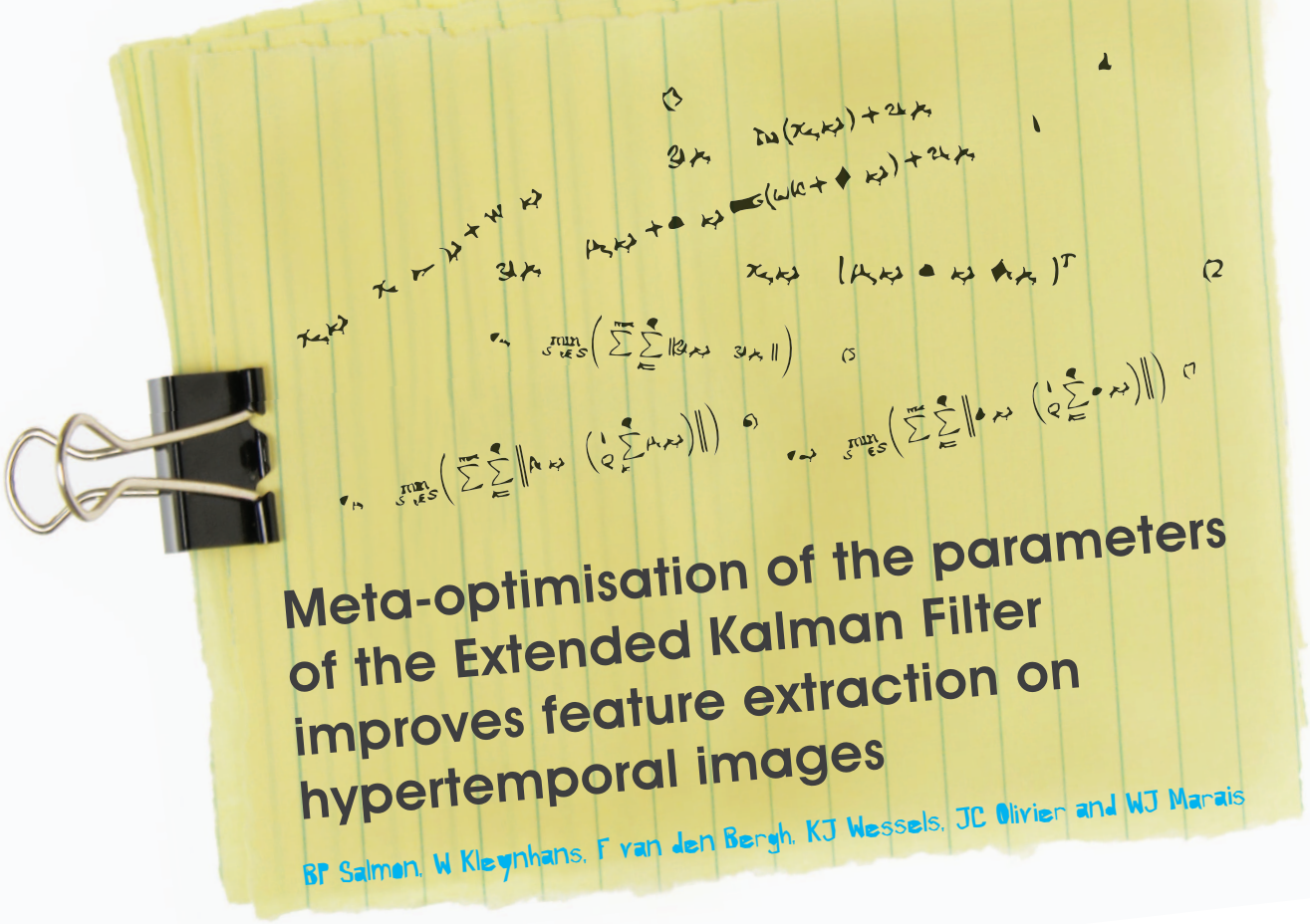


Meta-optimisation of the parameters of the Extended Kalman Filter improves feature extraction on hypertemporal images

BP Salmon, W Kleynhans, F van den Bergh, KJ Wessels, JC Olivier and WJ Marais

The reliable surveying of land cover and transformation has always been a key area of interest to the remote sensing community. The increase in the human population is one of the major contributors to settlement expansion, with several studies showing that anthropogenic activities have transformed more than a third of the earth's surface. Gauteng is of interest, as it is the fastest-growing province in the country, housing more than 10.5 million people. Reliable knowledge of land cover is a critical tool in the effective allocation and management of the environmental resources.

Satellite-based sensors are widely recognised by international and local agencies as a cost-effective method of acquiring periodic, systematic information of the earth's land surface. Land cover is defined as the physical composition of material on the surface of the earth, while land use is a description of how the land is used for socioeconomic purposes. Monitoring land cover is of great importance as this guides regulatory bodies on how to best utilise a country's resources without putting the environment at risk.

Two types of land-cover changes are usually investigated: land-cover modification and land-cover transformation. Land-cover modification is caused by internal changes within a particular land-cover class. These changes affect the current state of the land-cover class, but do not change the land-cover class, such as seasonal variation of natural vegetation. Land-cover transformation of a particular geographical area involves change from one land-cover class to another. Hypertemporal acquisition strategies of satellite-based sensors allow the construction of time series, which enables one to distinguish between these two types of land-cover changes for improved land-cover classification.

In a study conducted by researchers at the University of Pretoria and the Remote Sensing Research Unit of the Meraka Institute at the CSIR, time series were extracted from the first two spectral bands (red and near infrared wave lengths) of the MODerate-resolution Imaging Spectroradiometer (MODIS) land-surface reflectance product and were modelled as a pair of triply modulated cosine functions. A meta-optimisation approach was proposed for setting the parameters of the non-linear Extended Kalman Filter (EKF) to rapidly and efficiently estimate the internal state-space variables for the pair of triply modulated cosine functions.

This meta-optimisation approach uses an unsupervised algorithm to search for improved parameters over an appropriately defined manifold, using spatial and temporal information. Performance of the new method was compared to other applicable methods.

The state-space variables estimated by the EKF were then used as feature inputs to cluster the time series into different land-cover classes. Clustering is an unsupervised method used for grouping unlabelled objects into a set of categories. The algorithm used in this work was the K-means algorithm, which is usually used as a benchmark for

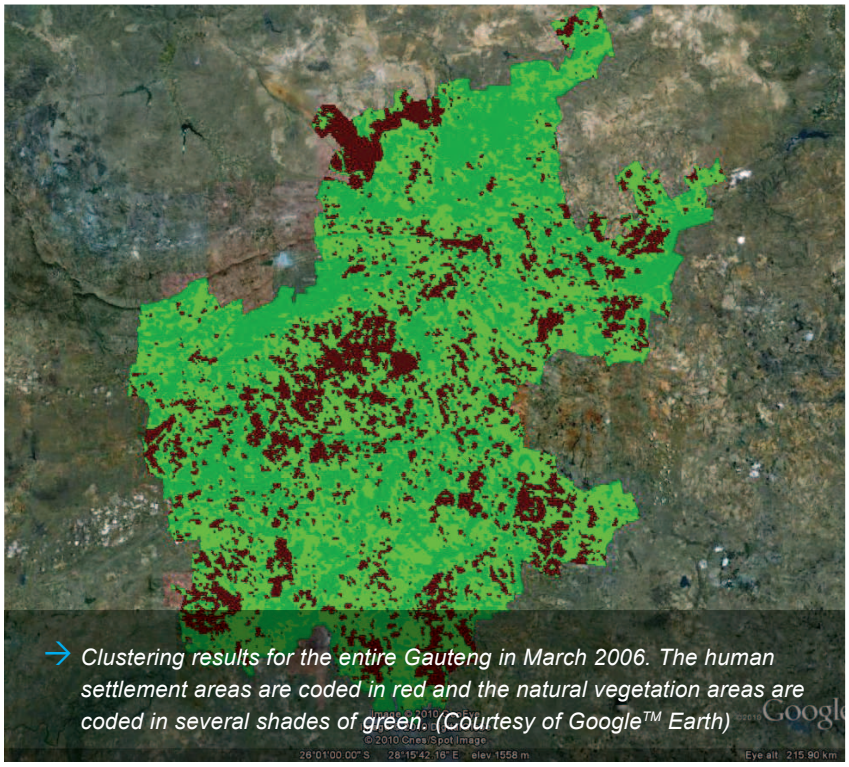
other algorithms. The proposed method was evaluated on a 285 km^2 study area in Gauteng, comprising mostly areas of natural vegetation and human settlements. The time series in the validated study area was verified using visual interpretation of SPOT images to map areas of no change in land-cover type during the study period for the temporal component of the analysis. The classification accuracies obtained by using the meta-optimisation method improved by more than 7% when compared to other methods.

The method was then applied to the entire province. A silhouette graph is a graph-based approach used to determine the number of clusters that should be used by the clustering algorithm without any human supervision. The optimal number of clusters in Gauteng for the K-means algorithm was calculated to be five clusters using the silhouette graph. The formed clusters were evaluated by a human operator and grouped into either human settlement or natural vegetation areas.

Roughly 23% of the province's total area of 19 676 km^2 was classified as settlements by the clustering algorithm.

In conclusion, it was demonstrated that improved features can be obtained by using the information within a spatio-temporal window. The proposed unsupervised feature extraction method was not dependent on acquiring a labelled training data set. It was shown that with proper selection of the initial state parameters, observation noise matrix and process covariance matrix, the cluster separation of EKF-derived features could be improved.

The algorithm described in this article can be optimised by adjusting the temporal length of the spatio-temporal window to ensure that it takes cognisance of short-term inter-annual climate variability and adapts to longer-term trends in climate. The features extracted using the EKF can also be applied in combination with a variety of other machine-learning algorithms.



Clustering results for the entire Gauteng in March 2006. The human settlement areas are coded in red and the natural vegetation areas are coded in several shades of green. (Courtesy of Google™ Earth)

References

1. Beran, RJ. 1977. Minimum Hellinger distance estimates for parametric models. In: *Annals of Statistics*, 5(3), (pp 445–463).
2. Daily, G & Ehrlich, P. 1992. Population, sustainability, and earth's carrying capacity. In: *Bioscience*, 42(10), (pp 761–771).
3. Kaufman, L & Rousseeuw, PJ. 1990. (9th ed.). *Finding groups in data: An introduction to cluster analysis*. New Jersey: Wiley-Interscience.
4. Kleynhans, W, Olivier, JC, Wessels, KJ, Van den Bergh, F, Salmon, BP & Steenkamp, KC. 2010. Improving land cover class separation using an Extended Kalman Filter on MODIS NDVI time series data. In: *IEEE Geoscience and Remote Sensing Letters*, 7(2), (pp 381–385).
5. Ristic, B, Arulampalam, S and Gordon, N. 2004 (1st ed.). *Beyond the Kalman Filter: Particle filters for tracking applications*. London: Artech House.
6. Schaaf, CB, Gao, F, Strahler, AH, Lucht, W, Li, X, Tsang, T, Strugnell, NC, Zhang, X, Jin, Y, Muller, JP, Lewis, P, Barnsley, M, Hobson, P, Disney, M, Roberts, G, Dunderdale, M, Doll, C, D'Entremont, RP, Hu, B, Liang, S, Privette, JL & Royet, D. 2002. First operational BRDF, albedo nadir reflectance product from MODIS. In: *Remote Sensing of Environment*, 83(1/2), (pp 135–148).
7. Vitousek, PM, Mooney, HA, Lubchenco, J & Melillo, JM. 1997. Human domination of earth's ecosystems. In: *Science*, 277, (pp 494–499).

Brian Salmon *and* ***Waldo Kleynhans*** *are associated with both the Remote Sensing Research Unit of the Meraka Institute at the Council for Scientific and Industrial Research (CSIR) and the Department of Electrical, Electronic and Computer Engineering at the University of Pretoria.*

Frans van den Bergh *and* ***Konrad Wessels*** *are associated with the Remote Sensing Research Unit of the Meraka Institute at the CSIR.*

Corné Olivier *is associated with the Department of Electrical, Electronic and Computer Engineering at the University of Pretoria.*

Willem Marais *is associated with the Space Science and Engineering Center of the University of Wisconsin-Madison, Wisconsin, USA.*