IMPROVED HYPER-TEMPORAL FEATURE EXTRACTION METHODS FOR LAND COVER CHANGE DETECTION IN SATELLITE TIME SERIES

By

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SUMMARY

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The growth in global population inevitably increases the consumption of natural resources. The need to provide basic services to these growing communities leads to an increase in anthropogenic changes to the natural environment. The resulting transformation of vegetation cover (e.g. deforestation, agricultural expansion, urbanisation) has significant impacts on hydrology, biodiversity, ecosystems and climate. Human settlement expansion is the most common driver of land cover change in South Africa, and is currently mapped on an irregular, ad hoc basis using visual interpretation of aerial photographs or satellite images. This thesis proposes several methods of detecting newly formed human settlements using hyper-temporal, multi-spectral, medium spatial resolution MODIS land surface reflectance satellite imagery. The hyper-temporal images are used to extract time series, which are analysed in an automated fashion using machine learning methods. A post-classification change detection framework was developed to analyse the time series using several feature extraction methods and classifiers. Two novel hyper-temporal feature extraction methods are proposed to characterise the seasonal pattern in the time series. The first feature extraction method extracts Seasonal Fourier features that exploits the difference in temporal spectra inherent to land cover classes. The second feature extraction method extracts state-space vectors derived using an extended Kalman filter. The extended Kalman filter is optimised using a novel criterion which exploits the information inherent in the spatio-temporal domain. The post-classification change detection framework was evaluated on different classifiers; both supervised and unsupervised methods were explored. A change detection accuracy of above 85% with false alarm rate below 10% was attained. The best performing methods were then applied at a provincial scale in the Gauteng and Limpopo provinces to produce regional change maps, indicating settlement expansion.

OPSOMMING

VERBETERDE HOË TYD-RESOLUSIE KENMERKONTTREKKINGSMETODES VIR DIE DETEKSIE VAN VERANDERING IN LANDBEDEKKING MET BEHULP VAN 'N SATELLIETTYDREEKS.

deur

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Graad:	Philosophiae Doctor (Elektronies)
Sleutelwoorde:	klassifikasie, groepering, veranderingopsporing, uitgebreide Kalman-filter, Fourier-transform, satelliet, tydsreekse

Die groei in die globale bevolking veroorsaak verhoogde verbruik van natuurlike hulpbronne. Die behoefte om basiese dienste te lewer aan hierdie groeiende gemeenskappe lei tot 'n toename in antropogeniese veranderinge aan die natuurlike omgewing. Die gevolglike transformasie van plantbedekking (bv. ontbossing, landbou-uitbreiding, verstedeliking) het 'n beduidende impak op hidrologie, ekosisteme en die klimaat. Nedersettingsuitbreiding is die mees algemene oorsaak van landbedekkingsverandering in Suid-Afrika en informasie oor waar en wanneer nuwe nedersettings, voorkom word tans op 'n onreëlmatige basis bekom deur die visuele interpretasie van lugfotos of satellietbeelde. Hierdie tesis stel verskeie metodes voor vir die opsporing van nuutgestigte nedersettings met behulp van hiper-temporale, multi-spektrale, medium ruimtelike resolusie MODIS-grondoppervlakte reflektansie satellietbeelde. Die hiper-temporale beelde word gebruik om tydsreekse te onttrek, wat dan outomaties ontleed word met behulp van masjienleer metodes. 'n *Post*-klassifikasie veranderingopsporingsraamwerk is ontwikkel om tydsreekse te analiseer deur gebruik te maak van verskeie kenmerkonttrekkingsmetodes en klassifiseerders. Twee nuwe hiper-temporale kenmerkonttrekkingsmetodes word voorgestel om die seisoenale patroon in die reeks te karakteriseer. Die eerste kenmerkonttrekkingsmetode onttrek Seisoen Fourier-eienskappe uit die tydsreeks, wat die temporale spektrum eienskappe van verskillende landbedekkingsklasse beklemtoon. Die tweede kenmerkonttrekkingsmetode onttrek toestand-ruimte vektore uit die tydsreeks, wat verkry word met behulp van ’n uitgebreide Kalman-filter. Die uitgebreide Kalman-filter is geoptimeer deur gebruik te maak van ’n nuwe maatstaf wat gebaseer is op die inligting in die ruimtelike-temporale domein. Die *post*-klassifikasie veranderingopsporingsraamwerk is geëvalueer met verskillende klassifiseerders; beide toesig en sonder-toesig metodes is ondersoek. ’n Veranderingopsporingsakkuraatheid bo 85% met ’n valsalarmkoers onder 10% is behaal. Die beste metodes is toegepas op ’n provinsiale skaal in die Gauteng- en Limpopo-provinsies om plaaslike veranderings kaarte te produseer.

This thesis is dedicated to:

God Almighty, for all the countless opportunities that He has given me;
My loving family and friends, thank you for all your love, support, and sacrifice throughout my life.

We all grow up with the weight of history on us. Our ancestors dwell in the attics of our brains as they do in the spiraling chains of knowledge hidden in every cell of our bodies. - Shirley Abbott

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LIST OF ABBREVIATIONS

Autocorrelation Function	ACF
Aikaike Information Criterion	AIC
Atmospheric Infrared Sounder	AIRS
Autocovariance Least Squares	ALS
Ante Meridiem	AM
Advanced Microwave Scanning Radiometer	AMSR
Advanced Microwave Sounding Unit	AMSU-A
Artificial Neural Network	ANN
Advanced Spaceborne Thermal Emission and Reflection radiometer	ASTER
Algorithm Theoretical Basis Document	ATBD
Advanced Very High Resolution Radiometer	AVHRR
Break For Additive Seasonal and Trend	BFAST
Broyden-Fletcher-Goldfarb-Shanno	BFGS
Best Matching Unit	BMU
Bidirectional Reflectance Distribution Function	BRDF
Bias-Variance Equilibrium Point	BVEP
Bias-Variance Score	BVS
Bias-Variance Search Algorithm	BVSA
Clouds and the Earth's Radiant Energy System	CERES
Change Vector Analysis	CVA
Chandra X-ray Center	CXC
Coastal Zone Color Scanner	CZCS
Discrete Fourier Transform	DFT
Extended Kalman Filter	EKF

Expectation Maximization	EM
Earth Observation System	EOS
Earth Resource Technology Satellite	ERTS
Enhanced Thematic Mapper Plus	ETM+
Enhanced Vegetation Index	EVI
Foreign Argicultural Services	FAS
Fast Fourier Transform	FFT
Farm Service Agency	FSA
Gigabit	Gb
Gross Domestic Product	GDP
Group on Earth Observations	GEO
Global Earth Observation System of Systems	GEOSS
Geographical Information System	GIS
Global Positioning System	GPS
Hierarchical Data Format	HDF
High Resolution Infrared Spectrometer	HIRS
Humidity Sounder for Brazil	HSB
Inverse Discrete Fourier Transform	IDFT
Inverse Fast Fourier Transform	IFFT
Instantaneous Field of View	IFOV
Least Squares	LS
Line Spread Function	LSF
Linear Spectral Mixture Analysis	LSMA
Land Use Land Change	LULC
Multi-angle Imaging SpectroRadiometer	MISR
Multilayer Perceptron	MLP
MODerate-resolution Imaging Spectroradiometer	MODIS

Measurements of Pollution in the Troposphere	MOPITT
Multi-Spectral Scanner	MSS
National Aeronautics and Space Administration	NASA
National Argicultural Statistics Services	NASS
Normalized Difference Vegetation Index	NDVI
Near InfraRed	NIR
National Land Cover	NLC
Ordinary Least Squares	OLS
Principal Component Analysis	PCA
Post Meridiem	PM
Point Spread Function	PSF
Radial Basis Function	RBF
Red Green Blue	RGB
Resilient backpropagation	RPROP
Smithsonian Astrophysical Obervatory	SAO
Seasonal Fourier Features	SFF
Signal-to-Noise Ratio	SNR
Self Organizing Map	SOM
Satellite Pour l'Observation de la Terre	SPOT
Signal-to-Quantization Noise Ratio	SQNR
Sum of Squares Error	SSE
Support Vector Machine	SVM
Thematic Mapper	TM
United Nations	UN
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