URBAN EXPANSION MONITORING USING MODIS NDVI TIME SERIES

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ABSTRACT: Urban expansion is an important factor to indicate population, economic growthand, indirectly,civilization. Characterization of urban expansion is a benefit for urban planning and management. The main objective of this work is to extract urban area from coarse resolution remotely sensed data,on a yearly basis,in order to monitor urban expansion. Yearly MODIS NDVI time series is used as NDVI profile to classify urban area year by year. Savitzky-Golay filter is applied to reduce noise and smooth the signal. Mean and standard deviation of NDVI profile are applied as the features instead of using directly NDVI profile to reduce unnecessary features. Supervised Bayesian classification is applied to classify urban area. 3D-Majority filter and the rule of class translation are utilized to improve resultant accuracy. The experimentsare focused on the urban areas of UdonThani and NongKhai, located in the Northeast region of Thailand, also Vientiane, located near the border with Thailand,for 2001-2012. The results show that our proposed method extracts urban area to monitor urban expansion effectively.

Key word: Urban Expansion, Urban Area, MODIS NDVI, Savitzky-Golay Filter, Bayesian Classification

INTRODUCTION

An urban area, usually known asa city or town, is defined by a characteristichigh population density compared withsurrounding areas. Urban areasare an important topic since a significant number ofhumanityrests in this area and conduct productive activities in business, trade, communication, tourism and technologyin this area. Urban expansion is an important factor to indicateincreasing population density and economic growth, including prosperity. Metropolisesor capitalshave high urban expansion as they are the center of business activity,which cause them to grow rapidly and have various problems as an effect, e.g. pollution, traffic congestion and crimes etc. On the other hand, cities that grow slowly perhaps encouragethe oppositeproblems,a lack of:well-being, high education and prosperity.Thus characterization of urban expansion is agreatbenefit for analysis in urban planning and management.

Remote sensing is widely used for monitoring large scale areas. Urban area monitoringmakes use ofthis technology.Research was done to estimate urban area on a global scale (Schneider et al., 2003; Schneider et al., 2005; Potere and Schneider, 2007; Schneider and Woodcock, 2008; Schneider et al., 2009, Schneider et al., 2010). They exploitedModerate Resolution Imaging

Spectroradiometer(MODIS)and supervised classification to extract urban area data. Other urban area maps,on global scale, are suggested asGLC2000 (Bartholome and Belward, 2005) and GlobCover (Arino et al., 2007). Urban area in GLC2000 was classified by applyingSysteme Pour l'Observation de la Terre(SPOT) and urban area in GlobCover was esimated by using Medium Resolution Imaging Spectrometer (MERIS). Radar datawhich takes advantage of avoiding cloudswas also used to find the extent of urban spread (Henderson and Xia, 1997). Much research, with an emphasis on urban area monitoring,was conducted bySeto(et al., 2002), Xiao (et al., 2006) and Zhang (et. al, 2011). They focused on monitoringthe rate of urban expansion and changes in the urban form. For example; Zhang used nighttime light data or Defense Meteorological Satellite Programme-Operational Line Scanner (DMSP-OLS) to monitor urban area.

This work presentsa methodology to monitorurban area on a yearly basis. We usedatafrom NDVI (Normalized Difference Vegetation Index) MODIS Time series and supervisedBayesian classification method to estimate urban area. After that improvement process with 3D-Majority filter and the rule of class translation helps to smooth results ofurban area.

MATERIAL AND METHODOLOGY

MODIS NDVI Time series known as MOD13Q1 data, provided every 16 days at 250 meter spatial-resolution, are used to extract urban area year by year. MODIS NDVI Time series takes advantage of spectral and temporal domain. Roughly, in spectral domain, NDVI can separate vegetable area that provides high value of NDVI from non-vegetable areaincluding urban area that gives low value of NDVI. In temporal domain, plantation area has high varying value of NDVI while other areas including urban area do not.

Yearly MODIS NDVI time series is used as NDVI profile to classify urban area year by year. Savitzky-Golay filter is applied to reduce noises and smooth the signal. Mean and standard deviation of NDVI profile are applied as the features instead of directly using NDVI profile to reduce unnecessary features. Supervised Bayesian classification is applied to classify urban area. 3D-Majority filter and the rule of class translation are utilized to improve resultant accuracy.

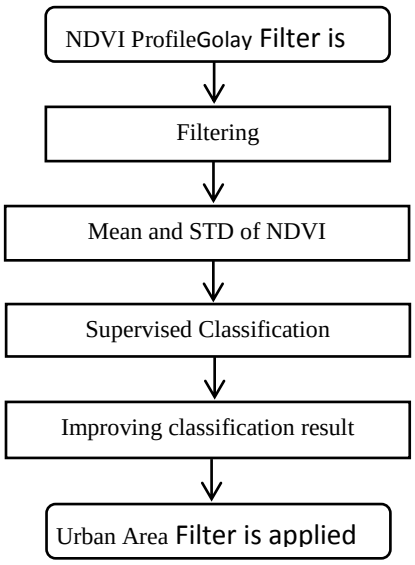


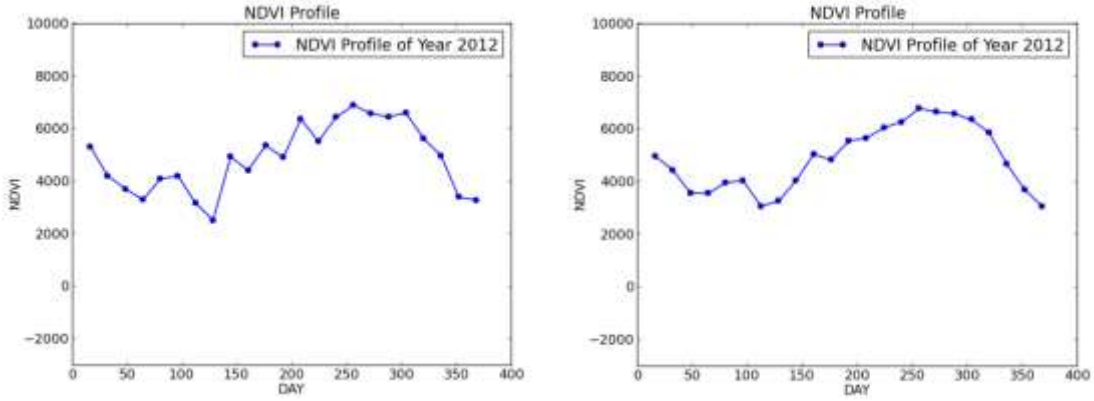
Figure 1. Flow chart of urban classification

a) NDVI Profile

To classifyurban area on anannual basis, NDVI time-series is separated into single year NDVI time-series known as NDVI profile. Fig. 2 shows NDVI profile in year 2012.

b) Filtering

The main problems of NDVI time-series are caused by clouds and the atmosphere - theyare responsible forthe noise inthe signal. Savitzgy-Golay filter is used to reduce noiseor to smooth the signal. From our experiment, the parameters of the filterwere assigned by testing in our experiments which providedthe signal with lessnoise.



(a) (b)

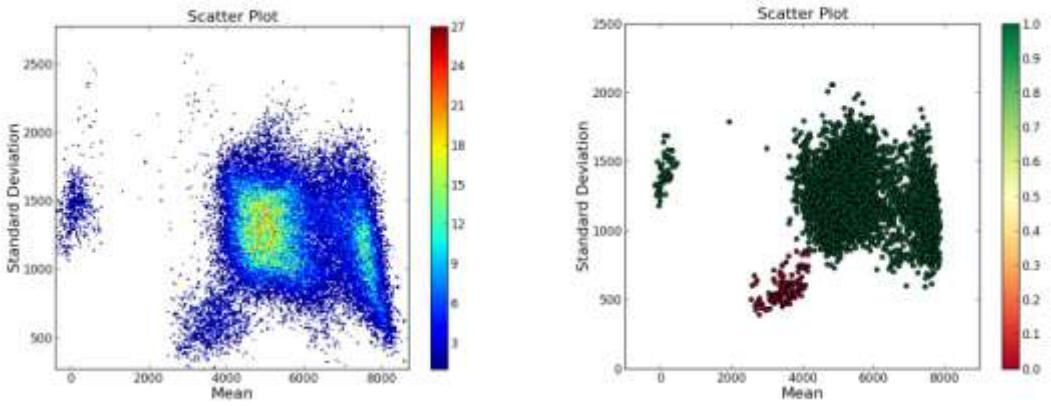
Figure 2. (a) NDVI Profile in 2012 (b) Filtered NDVI Profile in 2012

c) Mean and STD of NDVI

The feature extraction step is applied to reduce unnecessary features and transform a space into another spacein order todistinctly separate each class.In this work, mean and standard deviation of NDVI profile are applied as the features instead of directly using NDVI profile. From figure 3 (a), they can be divided into four groups; the first group is a forest area that has the highest value of mean of NDVI and a middle value of standard deviation of NDVI, second group is a plantation area that has high valuesof both mean and standard deviation of NDVI, the third group is a forest area that has low valuesofboth mean and standard deviation of NDVI, the fourth group is a water area that has the lowest value of mean of NDVI and a high value of standard deviation of NDVI.

d) Supervised Classification

Supervised Bayesian classification is applied to classify urban area. A Bayes classifier is a simple probabilistic classifier based on applying Bayes' theory. In training session, data are divided into two groups, urban area and non-urban area, for estimating the parameters of the classifier. The images with two features from each yearare computed and turned into resultant binary images; “0” for urban area and “1” for non-urban area.



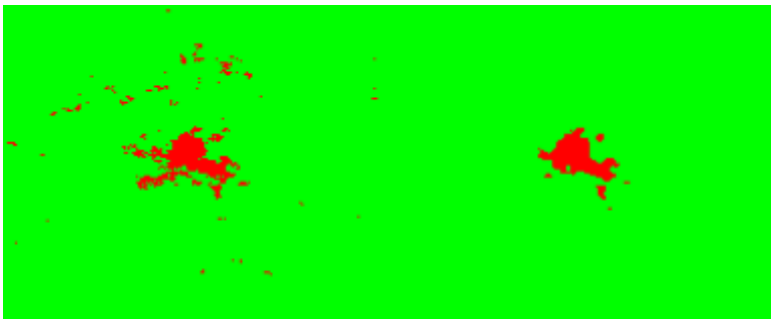
(a) (b)

Figure 3. (a) Scatter plot of Mean and STD of NDVI (b) Scatter plot of two classes; urban area (red) and non-urban area (green)

e) Improving Classification result

Unfortunately the resultsstill havesome noise;the 3D-Majority filter is employed to reduce the noise or to smooth the results. The 3D-Majority filter assigns a value or class by considering those that occur most frequently among neighboring pixels in 3 directions: x-axis, y-axis and z-axis.

In addition, accordingly we took care to consider probabilities of translation between urban and non-urban areas andwe found that the probabilities of translationfrom non-urban area to urban area is almost zero ($P_{urban\ area->non\text{-}urban\ area}$=0.0352) highly unlikely that an urban area will not change to a non-urban area.Therefore the rule of class translationwas defined as when a pixel for the current year is classified as urban area, next year the pixel will also be an urban area.



(a) (b)

Figure 4. (a) Result of Urban area(b) Result of Urban area with the improvement, located at UdonThani, Thailand in 2011

EXPERIMENT AND RESULT

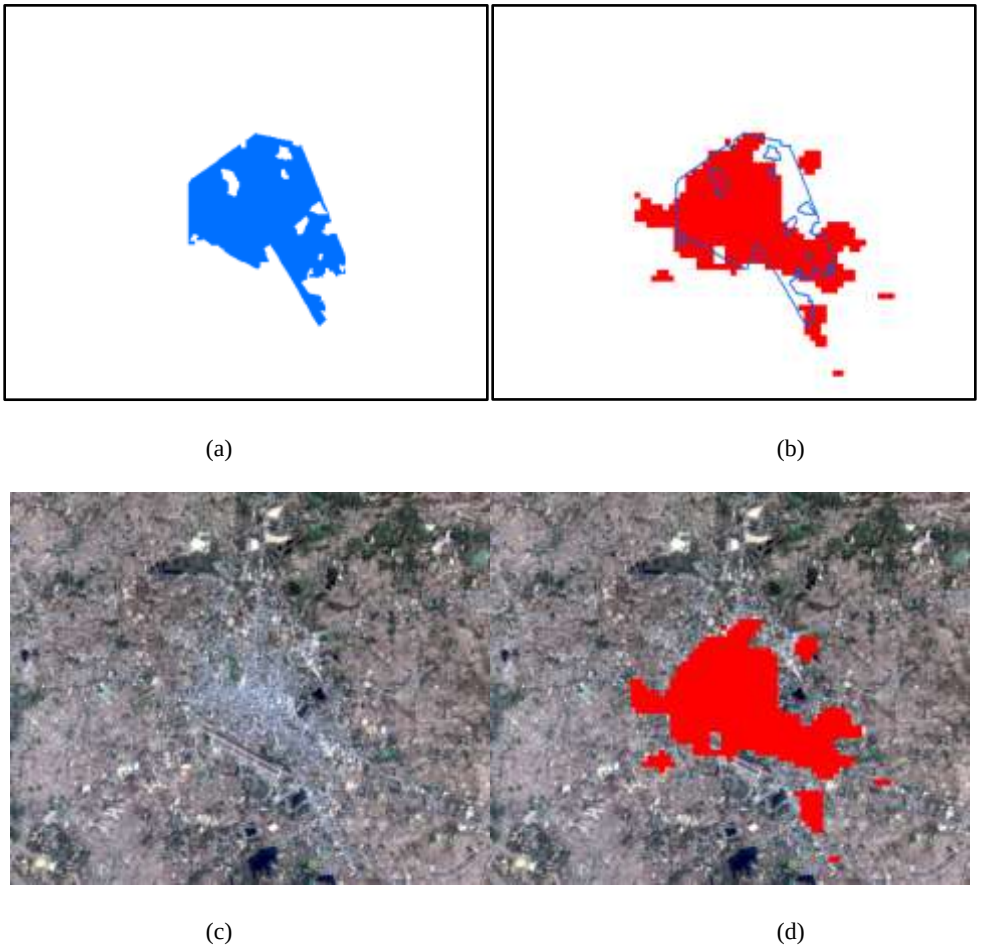
The experiments areconcentrated on the urban area of UdonThani, NongKhaiand Vientiane. UdonThani is a majorcenter of business in the upper North-East region of Thailandand the gateway to Laos.NongKhaiis the northernmost of the north-eastern provincesof Thailand and is located in the valley

of the Mekong River, which forms the border with Laos.Vientianeis the capital and largest city of Laos, located near the border with Thailand. It is the administrative capital and also has experienced fast economic growthin this past decade.

The resultof UdonThani in 2011was validated by comparison withLand Development Department (LDD)map derived from LANDSAT-5. The accuracy is about 87.32%, with 78.61% of true positive and 89.59 % of true negative (Table 2).The result was also compared in visualization with THEOSimage acquired on January 20, 2013. Figure 5 (d) shows that the urban areas in resultant images havea similarity to urban areas in the THEOS image.

Table 2.Comparison between and LLD's result and estimated result in UdonThani, Thailand

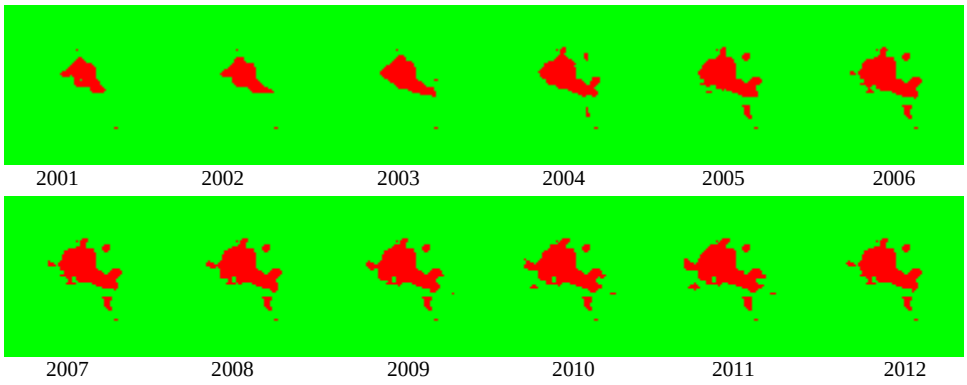
	Urban area of Estimation	Non-urban area of Estimation
Urban area of LDD	16727	4551
Non-urban area of LDD	8509	73254



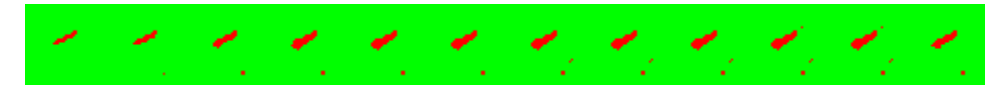
(a) (b)

(c) (d)

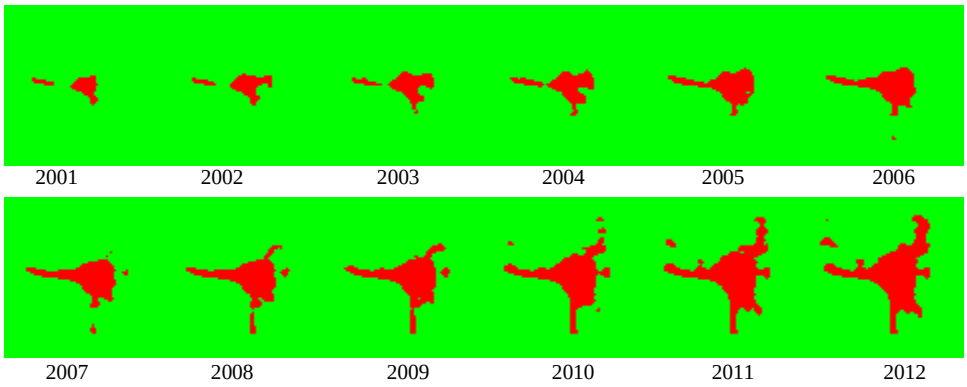
Figure 5.(a) LDD's Product in 2011 (b) Result using proposed method in 2011 (red) (c) THEOS Image on January 20, 2013 (d) Result using proposed method in 2012 (red), located at urban area of UdonThani, Thailand



(a) Urban Area of UdonThani, Thailand from 2001 to 2012



(b) Urban Area of NongKhai, Thailand from 2001 to 2012



(c) Urban Area of Vientiane, Loas from 2001 to 2012

Figure 6. Urban area of (a)UdonThani, (b) NongKhai and (c)Vientiane from 2001 to 2012

Table 1. Urban area of UdonThani, NongKhai and Vientiane from 2001 to 2012

Area (km^2)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
UdonThani	12.44	13.88	16.94	21.81	25.44	26.94	27.75	28.13	29.31	30.75	33.00	34.44
NongKhai	1.75	2.06	2.81	3.13	3.50	3.56	3.56	3.69	3.69	3.69	3.75	3.75
Veintian	8.25	11.69	15.31	18.13	22.06	25.13	27.56	31.75	35.75	43.19	51.81	57.06

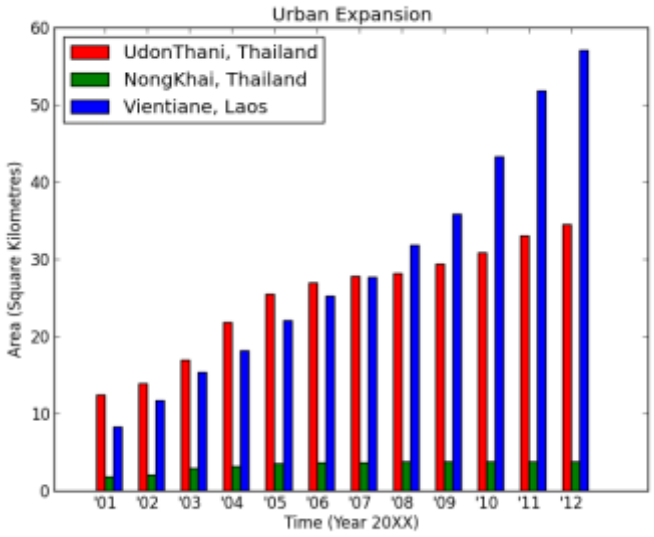


Figure 2. Bar graph of Urban Area of UdonThani, NongKhai and Vientiane from 2001 to 2012

From the experimental results, Vientianehasthe largest urban expansion form 8.25 km^2 in 2001 to 57.06 km^2 in 2012likely becauseVientiane is the capital of Laos and is the center of economic development in the area. Of the three, UdonThaniis inthe middle in terms of expansion, growing from 12.44 km^2 in 2001 to 34.44km^2 in 2012. The urban area of NongKhaihas slowly expanded from 1.75km^2 in 2001 to 3.75km^2 in 2012.

CONCLUSION

This work introduces urban expansion monitoring using MODIS NDVI Time-series.NDVI profile is used to extractyearly urban area. Savitzky-Golay filter reduces noise. Mean and standard deviation of NDVI profile are applied as the features instead of directly using NDVI profile. Supervised Bayesian classification is applied to classify urban areas. 3D-Majority filter and the rule of changing classes areexploited to enhance resultant accuracy. The experiments show that our proposed method extracts urban area to monitor urban expansion effectively. The main advantage of this research is used as information for supporting urban planning and management.

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