USE OF TEMPORAL KNOWLEDGE IN DETECTING UNPLANNED DEVELOPMENTS IN URBAN AREAS

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ABTRACT

Knowledge based classification incorporates knowledge derived from ancillary data and spectral information. A method that employs object, structural and spectral information from two remotely sensed data at different epochs to generate two classes namely developed and reserved (non-developed) for each epoch within an expert classification environment has been described. This information is then combined with a plan of future land use as temporal knowledge to predict areas designated for development. Further, the temporal knowledge was perturbed to replicate a scenario in a developing country where mushrooming of unplanned structures is prevalent. The outputs of these predicted land uses are then compared with the actual situation as shown by the epoch 2 image to detect unusual phenomena. These phenomena imply that, all that is planned is not necessarily implemented and this is in part due to problems associated with budgetary allocation and unpredictability of some factors resulting from the complexity and inconsistency of the real world. This information is a useful backdrop for strategic and reaction planning in the event where unusual phenomena have occured e.g. informal and illegal structures in developing countries.

1 INTRODUCTION

An urban environment can be characterised by two main classes, namely built up areas (developed) which comprise of industrial, residential, commercial, parking areas, etc and non-built up areas (reserved) e.g. gardens, sports field, green areas, urban agriculture, etc. The transition of reserved areas to developed or developed to redeveloped can be attributed to various factors namely, initial status i.e. current use; existing demand for land; infrastructure availability; physical constraints and the implications in overcoming them; zoning controls and limitations; and existing use of neighboring sites. Several models exist for predicting land use changes on a long term basis. For instance, changes between categories have been modelled using logistic or logit model. Two types of this model exist namely the binomial (two change possibilities) and multinomial (more than two change possibilities), [Landis and Zhang, 1997]. The land transformation model makes use of relative land transition probabilities generated by calculating drivers of land use change and cells under consideration [Pijanowski, et al., 1997]. The Cellular Automata paradigm whose unit of analysis is a cell, models change on the basis of two assumptions the initial status and the spatial context [Clarke,1997]. Markov models employ empirical data to characterise existing change both spatially and temporally. Results obtained from all such models could be checked using the Join-Count statistics which takes into account the joins between adjacent polygons or by means of other spatial attributes e.g. mean patch size, edge density, etc in Landscape Metrics [Wood, et al. 1997]. Further, use of entropy to estimate urban growth in very dynamic areas has also been investigated [Yeh and Li, 2001]. All these models attempt to predict long term land use changes. The underlying disadvantage with these models is that they require many observations to be statistically stable and moreover they are hampered by the inability to comprehensively model all the contributing factors to change. These factors have been summarized by Sui [1997] as unpredictability (inconsistent phenomena and complex systems), instability where small changes can result in dramatic effects, uncomputability (inability to express some phenomena using rules), irreducibility which involves breaking down of some phenomena into smaller units which does not necessarily lead to a better understanding, and co-evolution (the interaction of the different system components results in new properties not evident in any of the subsystems taken individually).

Town planning departments attempt to design plans (building and land use) depicting the type and extent of the permitted use of land and the corresponding constraints, whereby any change is expected to conform to these plans. However, it is not uncommon to unveil that these plans particularly in developing countries are not adhered to due to problems associated with budgetary allocation which implies that the necessary infrastructure is not implemented. Consequently, mushrooming of unplanned structures on available vacant areas are prevalent, e.g. with an estimate of 60% and 70% of the Nairobi and Dar-esalaam population respectively living in informal developments. This is in part due to high poverty levels with a negative growth rate of GDP per capita, for instance a decrease of 49$ from 1986 to 1995 was reported for the whole of Africa (UNECA, 1998). The general practice has been to carry out reaction planning once an unusual phenomena has been detected in

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order to eventually incorporate them in the plans as required by law. United Nations for Human Settlements (Habitat) is also actively collaborating with the urban planning departments in developing countries with the sole aim of improving the living conditions of those in the informal settlements. Therefore, the location of such phenomena, their extent and trend would be a useful input in devising an informed strategy. However, the current manual techniques have proved to be ineffecient particularly in situations whereby rapid dynamics of greater magnitudes are involved. Moreover, lack of capacity building has led to the slow adoption of new and cost effective techniques in problem solving.

In this paper a technique which employs classification scheme based on multispectral satellite imagery and GIS data to depict areas that are designated for development and reserved is described. Specifically, a scenario that depicts a situation in developing countries has been simulated. This information can then be used as a backdrop for an image taken within a temporal resolution of between 1-5years [Jensen and Cowen, 1999] to detect any unusual phenomena from where reaction and strategic planning can be executed if needed. The success of such knowledge based techniques depend on the appropriateness of the knowledge acquired and its effective representation.

2 BACKGROUND

Statistical approaches have proved to be inadequate in dealing with high resolution satellite images and particularly in the urban applications due to the heterogeneous nature and variable object sizes which cause spectral signatures to overlap e.g. [Karanja and Lohmann, 2000]. As far as change detection is concerned, several techniques exist. At pixel level, change can be detected through image differencing, ratioing, and principal component analysis. These techniques are hampered by the inability to comprehensively address variations in atmospheric and ground conditions, differences in illumination effects and sensor calibration at the two epochs in question. At feature or information level, post classification change detection techniques attempt to overcome the problems encountered at pixel level, nevertheless the results depend on the accuracy of the individual classification [Meinel, et. al., 1997, Macleod and Congalton, 1998, Zenk, 2000, etc]. Specifically, comparison of algorithms namely multi-layer perceptrons(MLP), learning vector quantization(LVQ), decision tree classifiers(DTC), and the maximum-likelihood classifier(MLC) in determining the nature of change in an urban environment have been done recently by [Chan, et. al, 2001]. However, the current trend is the use of systems which incorporate high level cognitive approaches to improve image analysis and understanding. Different architectures exist namely rules, frames, semantic networks, first-order logic and hybrids [Bondo, 1990]. Various studies employing any or a hybrid of these systems and addressing different areas of application have been reported, e.g. [Argialas and Harlow, 1990], [Mehldau and Schowengerdt, 1990], [Bolstad and Lillesand, 1992], [Koch, et. al., 1997], [Kunz, et. al., 1997]. Applications of temporal knowledge in the interpretation of satellite imageries has been done e.g.[Middelkoop and Janssen, 1991], [Growe, 2000], etc.

Such systems in principle incorporate knowledge about the objects of concern within the image data and are represented within the knowledge base. In addition, map or GIS data (e.g. with limited accuracy and currentness) is in most cases available giving an indication of the location of specific objects and serves as an initial symbolic scene description, thus forming a hypothesis about the objects suspected within the image to be interpreted. This hypothesis is tested against current image data and returns features, based on interpretation rules and a reliability measure. Within the interpretation, these features and their relationships are grouped and the hypothesis having the highest confidence value is selected. Whereas common satellite image analysis techniques are restricted to pixel based classification the new approaches, one of them being presented in this paper, uses a model-driven top-down approach together with a data-driven bottom-up process of image analysis.

3 METHODOLOGY

General Concept

Remotely sensed data lend itself to a useful source for deriving land use information particularly in situations where it is partially or non existent e.g. in developing countries. The amount of detail extracted depends among other factors on the spatial resolution of the data which is a function of the sensor resolution and the algorithms employed. In this study, object, spectral and structural information have been employed in the interpretation of the remotely sensed images taken at two different epochs showing two aggregated classes namely developed and reserved areas. A manually interpreted land use map from aerial photographs formed the backdrop for the verification of the automatic interpreted image at epoch 1 (check 1), whereas the epoch 2 ouput is checked against the plan of future land use map (check 2) figure 2. The land use information at epoch 1 is then combined with the planning information (infrastructure, socio-economic, demographic, etc) to depict areas designated for development and reserved. This is then compared with the interpreted image at epoch 2, to establish whether the designed plan was implemented, whereby in an ideal situation this is the expectation The operational methodology is shown in figure 1.

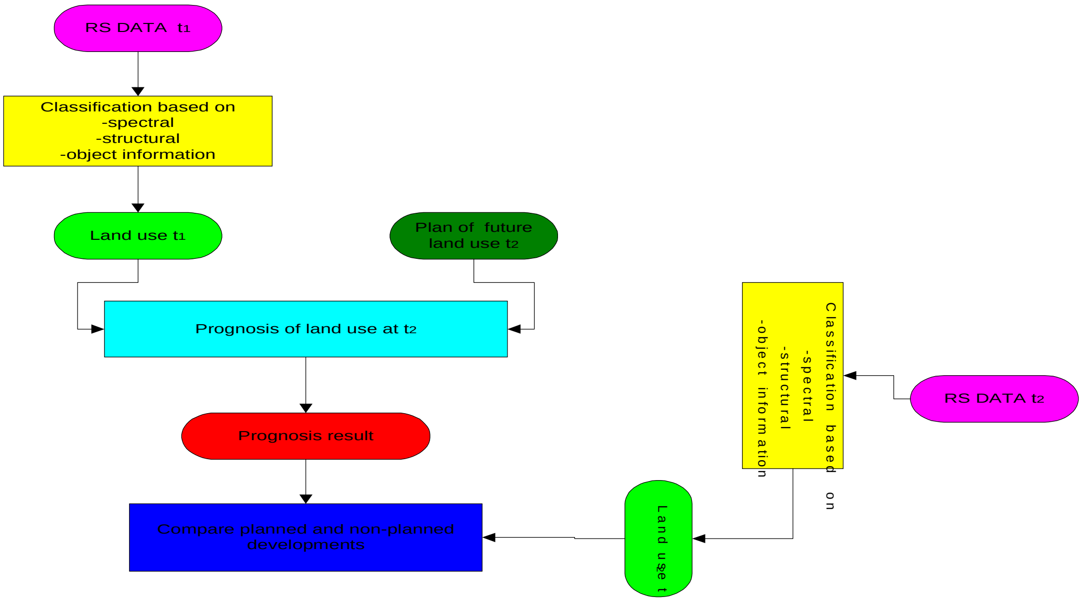

Fig. 1: Overview of the operational mode

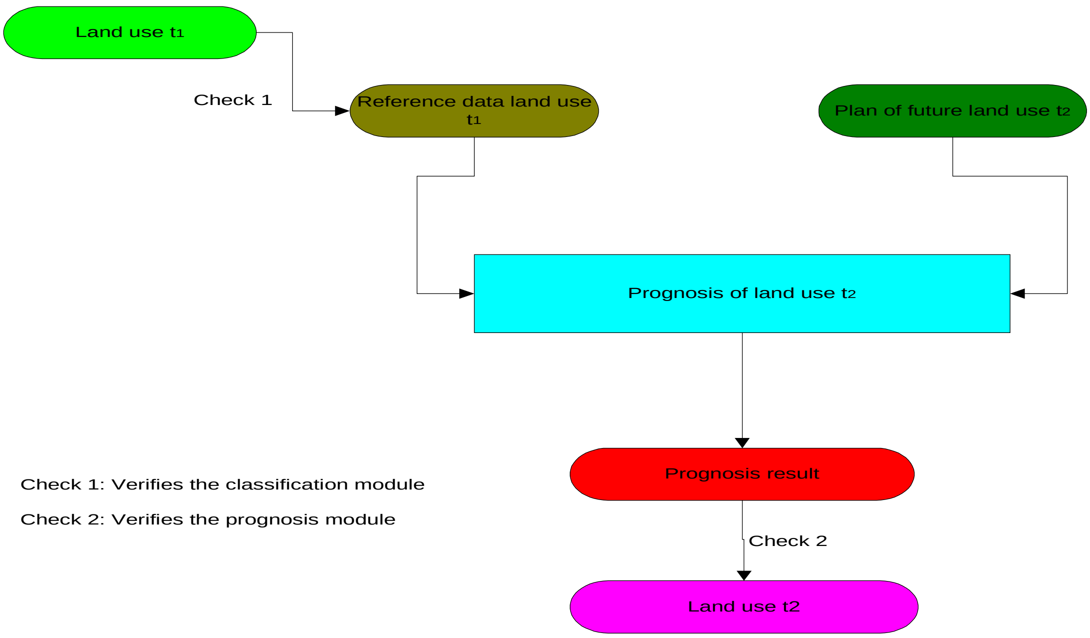

Fig. 2: Checking mode

Data and Study area

Use of aerial photographs and ground survey methods have proved to be expensive and counterproductive, hence unaffordable to most municipal budgets in developing countries. Furthermore, this is hampered by security restrictions. Consequently the underlying criteria in choosing a technique and tools should be cost-effectiveness, adaptivity to the conditions of the developing countries in terms of timeliness and information content. For urban applications, maps used for planning purposes by local governments are usually in the range of 1:10,000 to 1:50,000 which implies that satellite imagery are good candidates particularly where security restrictions, costs

and time prohibit the use of aerial photography. However, use of the very high resolution satellite imagery e.g. Ikonos, are still out of reach for most municipal applications due to cost constraints and therefore sources from Spot, IRS and Landsat TM images will continue to be explored. The coarse spatial resolution is of course a limitation in the urban application particularly in the assessment of e.g. housing units and estimation of population, etc. Techniques and tools have been developed to deal with low spatial resolution data e.g. through data fusion [Pohl and Genderen, 1998] and use of sub-pixel classifier algorithms [Petrou, 1999]. Nevertheless, in this study, the basis has been the application of enhanced Landsat TM (10 and 15m) within the Erdas Expert Classifier environment [ERDAS IMAGINE 8.4, 1999] to generate land use information that is verified against manually interpreted land use data and subsequently used to detect unplanned developments.
Problems associated with obtaining data from developing countries have necessitated use of simulated data from the Expo region in Hannover in developing and testing the methodology. The available sources included:

Raster based:

1. Colour aerial photographs 1995 and 1998 (1m resolution)
2. Landsat TM 1995 (30m resolution)
3. Landsat 7 TM 2000 (multispectral, 30m and panchromatic, 15m)

Vector based

1. Building plans which show among other information the extent and permitted type of use.

Experiment

This involved pre-processing, knowledge base development and subsequent image interpretation and prediction of designated areas for development and reserved and assessment of the results.

Pre-Processing

2. The absence of high resolution multispectral image for urban studies, necessitated the fusion of a panchromatic channel having a higher spatial resolution with the multiband image to increase the readability of urban structures. In this regard, a 10m panchromatic channel was obtained from the 1995 colour aerial photograph. Specifically, it was initially resampled to 10m and the resulting image subjected to an Intensity Hue Saturation Transformation, from where the Intensity channel was fused with the Landsat TM 1995 using the principal component algorithm. This algorithm yielded superior results compared to the Multiplicative and Brovey transform algorithms implemented in Erdas Imagine since it makes use of all the six multispectral bands as opposed to the other two. The study area was then zoned using the vector layer of the building plans. (Figure 3)
3. Also the Landsat 7, 2000 (pan and multispectral) datasets were fused to generate a 15m multispectral image showing the status of development in a span of 5 years. Resampling of the Landast 7 panchromatic channel to 10m and using it as a reference to generate a 10m multispectral image did not yield superior results in comparison to the 15m multispectral image. The 15m multispectral image was sufficient for the task. The study area was also limited to that covered by the building plans. (Figure 4)
4. A GIS vector layer showing the various land uses was generated from the 1995 colour aerial photograph through visual interpretation and digitizing. (Figure 5)
5. The different building plans covering the area of study were used in combination with the 1998 colour aerial photograph to extract a vector layer showing the extent and type of the permitted urban land uses i.e. zoned planned land uses (Figure 6)

Fig. 3: Landsat TM 95-10m resolution

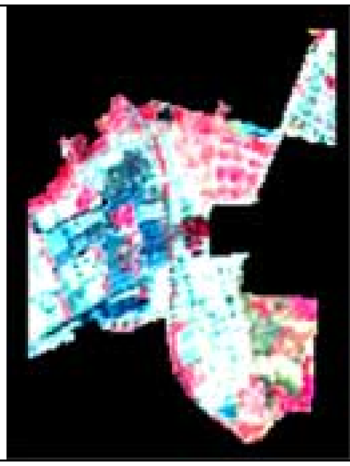

Fig. 4: Landsat7 TM 2000-15m resolution

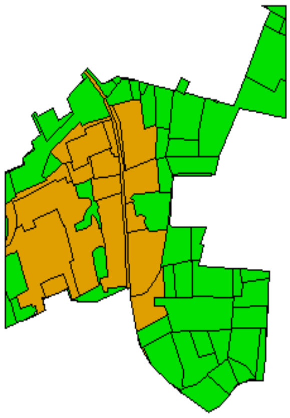

Fig. 5: 1995 Land use map

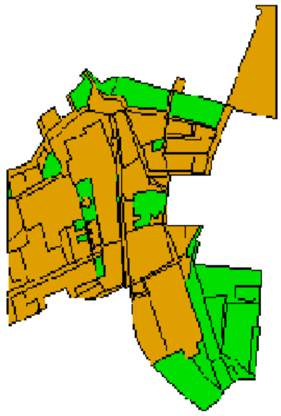

Fig. 6: Zoned Planned land uses

Developed Reserved

4. KNOWLEDGE BASE

The **definition** adopted for the two required output classes in this study are:

-Developed area
This is an already built up area e.g. residential, commercial, industrial, parking

- Reserved area
This is a non-built up area e.g. agricultural area, sports field, green areas, gardens, etc

Variables
The guiding principle in the generation and selection of the variables was based on the ability to discriminate between built and non-built up areas.
In this regard, the variables can be categorised into two i.e.:
The raster-based which include:

1. An NDVI layer which facilitates in the discrimination of vegetated and non-vegetated areas was generated. Contigous pixels were further aggregated into one thematic class. Figure 7 shows the image with the areas having predominantly high NDVI values clumped together and represented by the green colour.
2. An unsupervised classification layer was generated with 50 classes and with context introduced through use of a majority filter. Figure 8 shows the classified image where the various colours represent clusters, some of which are clear distinction of built and non-built up whereas others are a mixture of developed and reserved areas.

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3. Texture based on variance operators which describes the roughness and smoothness of objects, whereby in this particular area built up areas are characterised by heterogeneous pixel pattern and open landscape by homogeneous pattern, thus facilitating in the discrimination to a certain extent between the two classes. The resultant image is depicted in Figure 9 with the various colours representing the homonegeous segments.
4. The delineation between built and non-built up areas is very useful in this study. Hence a high pass filter was used to compute the edge magnitude. Figure 10 shows the outcome, with the two classes developed (orange) and reserved (green), whereas black is unclassified.

Fig. 7: Modified NDVI layer, 1995

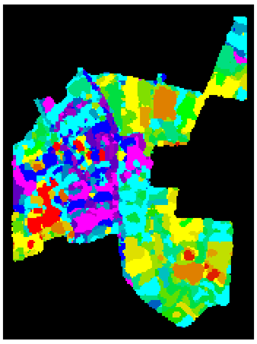

Fig. 8: Modified unsupervised layer , 1995

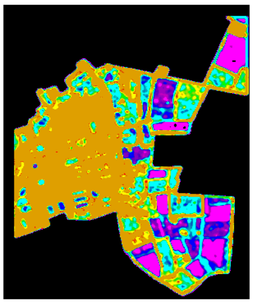

Fig. 9:Modified texture layer, 1995

Fig. 10: High pass filtered layer, 1995

The vector-based variables consisted of digitized layers showing the initial and planned land uses aggregated into two classes namely developed and reserved. These are shown in figures 5 and 6 respectively.

5. RULES AND CONDITION DEFINITION

Erdas Imagine Expert classifier has 3 main components namely, hypotheses, rules and conditions. The hypotheses represent the output and the intermediate classes and the rules define the hypotheses based on the input data sets through different combinations of the conditions.
The following table 1 summarizes the hypotheses, rules and conditions applied in the classification of the images in this study which were arrived at, through experimentation with various combinations and data sets. Recoding of some values for ease of manipulation was also largely employed.

The logical relationships of the decision hierachy are effected through ORing and ANDing criteria. The following two simple examples show in principle how these two criteria can be implemented using the IF…THEN conditions where relationships are represented in terms of condition-action pairs i.e.

IF (condition)
THEN (action)

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HYPOTHESES	RULES BASED ON CONDITIONS	
Developed	Texture	heterogeneous
	Spectral Class	built up
	Edge energy	high
	NDVI value	low
Reserved	Texture	homogeneous
	Spectral Class	non-built up
	Edge energy	low
	NDVI value	high

Table 1. Hypotheses, rules and conditions used in the knowledge base.

Rule 1: **CONJUNCTION (ANDing)**

IF NDVI value is *low <CONFIDENCE VALUE>*
AND Edge energy is *high<CONFIDENCE VALUE>*
THEN Hypothesis class is Developed.

Rule 2: **DISJUNCTION (Oring)**

IF Spectral Class is *non-built up<CONFIDENCE VALUE>*
OR Texture is *homogeneous<CONFIDENCE VALUE>*
OR Edge energy is *low <CONFIDENCE VALUE>*
THEN Hypothesis class is Reserved

The highest confidence values of the rules are used to determine the hypotheses. They may be assigned or computed from the conditions
The accuracy of the classified images was tested using ground truth data sets which were manually interpreted from aerial images.

6 RESULTS

Figures 11 and 16 show the interpreted images showing the designated areas for development and reserved at epochs 1 and 2 respectively. Figures 12 and 14 show the two scenarios i.e. ideal and simulated of the permitted land uses in form of future land use plan I and II respectively, whereas figures 13 and 15 are the subsequent prognosis results obtained thereof. The prognosis results show basically three classes namely areas that are developed and reserved in both epochs and a third class depicting those areas that have been converted from reserved to developed.
In general it is evident from these images that some changes have taken place in this region. Developments within an urban area can be characterised into two namely those that are legal (formal) and the illegal (informal) ones. Therefore, on this basis two scenarios have been depicted, specifically scenario 1, which shows that the expected outcome is in conformity with the original plans (figure 12), i.e. an ideal situation. On the other hand scenario 2, is a simulated situation which shows an area which is not supposed to be developed, nevertheless it has been developed as can be perceived from figure 16 showing the status as of year 2000.
The evaluation of the classification results done for the 1995 TM scene with the manually classified image from the aerial photographs yielded an overall accuracy of 82.0% , whereas that of the 2000 TM scene with the future land use map as the reference yielded 86.0%.

7 DISCUSSION

A thorough knowledge of the data and the expected outputs is very vital in extracting appropriate variables and defining the rules and conditions. However, a number of experiments with different combinations were conducted before an optimum set of rules and conditions that yielded the required outputs were arrived at. The challenge is therefore what data sets and how to combine them so as to come up with the best explanation of a particular land use class. Moreover, classification based on rules, has the disadvantage in the sense that the output classification is noisy which necessitates filtering so as to reduce the effects of salt and pepper, with smaller regions being compromised at the expense of bigger ones.

Scenario 1

Scenario 2

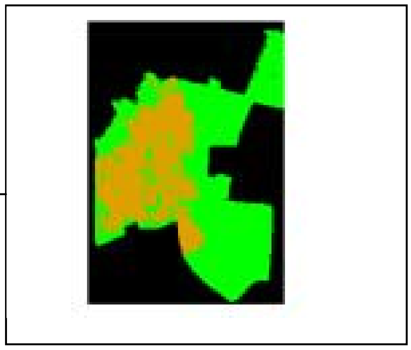

Fig. 11: 1995 Classified image

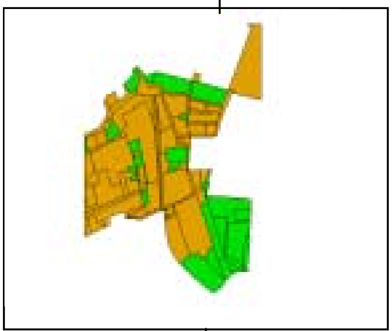

Fig. 12: Future land use map I

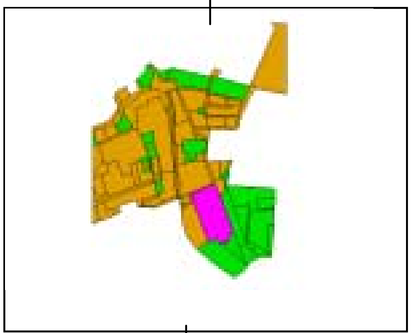

Fig. 14: Future land use map II

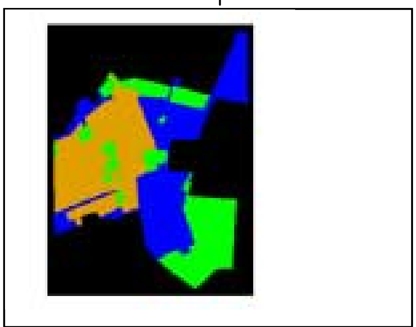

Fig. 13: Prognosis I

Developed

Reserved

Legal transition from
Reserved to Developed

Illegal transition from
Reserved to Developed

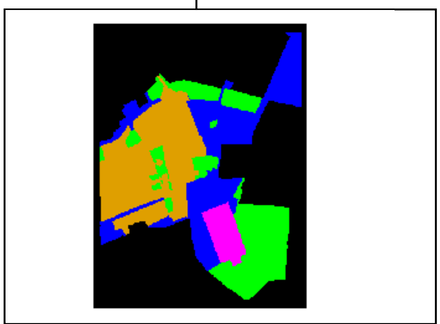

Fig. 15: Prognosis II

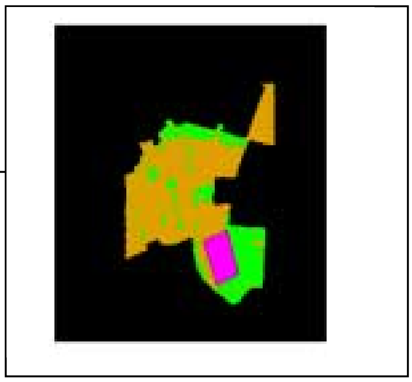

Fig. 16: 2000 Classified image

The concept developed here can be applied to situtations in developing countries where unplanned developments in terms of informal settlements are prevalent. However, the knowledge base would have to be tailored so as to reflect the real situation in a developing country since the urban structure differs from that of the developed countries. The idea is to have a sustainable technique which can be applied to rapidly highlight the seriousness of this phenomena and eventually facilitate planners take the necessary strategic and reaction planning measures.

8 CONCLUSIONS

GIS data from building or land use plans can be used as temporal information together with remotely sensed data to facilitate in the depiction of areas designated as developed and reserved. This information can be used as a backdrop, for another image taken at a later date to detect unusual phenomena or developments particularly in developing countries, where such plans are not adhered to, thus forming a basis for reaction or strategic planning. The results, show that, the success of knowledge based techniques in the interpretation of images depend on the adequacy and effective represented of the information thereof, which implies that a thorough analysis of the available input data including images, maps and other semantic information has to be done. Moreover, logical errors and use of conflicting rules should be checked as they can result in erroneous outputs, i.e. use of consistency checks within the knowledge base would ensure that such errors are prevented.

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