THE DEVELOPMENT OF THE METHOD FOR UPDATING LAND SURFACE DATA BY USING MULTI-TEMPORALLY ARCHIVED SATELLITE IMAGES

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ABSTRACT:

This study focuses on the problem of "time" affecting spatial data. The most substantial temporal problem for comprehensive use of spatial data is “time inconsistency”. Reducing “time inconsistency” within individual data, among multiple data, and between data and the real world can be achieved by frequent updating. The utilization of remote sensing is an effective method for updating various land surface data (e.g. land use, vegetation, soil and geology). The periodicity of usable data acquisition is quite stable for Synthetic Aperture Radar (SAR) data, because of its weather independence. The aim of this study was to develop a method for frequent updating of spatial data by taking advantage of the stable periodicity of multitemporal SAR images. Firstly, periodical and multitemporal SAR images were integrated by time series analysis. Following this process, temporal changes were restructured as a change process model and Speckle noise was reduced. The change process model described the trend of land surface changes. Secondly, newly acquired SAR image was assimilated into the database to strengthen the stability of the change process model. At this time, changes in land surface data were detected by comparing the change in the newly acquired image with the change process model. The effectiveness of this method was evaluated through comparison with actual spatial data. It is hoped that change detection in near real-time will be achieved using these procedures.

1. INTRODUCTION

Improvements in Geographic Information System (GIS) technology have expanded the potential of this powerful tool for solving complicated issues such as environmental problems, city planning, and disaster management. Issues are understood through the analysis of spatial data in GIS. These spatial data are an abstraction of features existing in the real world. In this sense, the accuracy of spatial data may directly affect the reliability of the analysis and understanding of the issues. Conventionally, existing spatial data, especially land surface data (e.g. land use, vegetation, soil and geology) have the following problems.

(i) Long-term survey may introduce problems of “time inconsistency” into individual spatial data sets. Features within these data cannot be assumed to exist simultaneously.
(ii) Different types of spatial data each have specific dates of acquisition (time stamps), periodicity, and frequency of updating according to the way they are measured. There will be “time inconsistency” among multiple spatial data. This suggests that some errors are inevitable in the results from integrated analysis using these data.
(iii) When the data updating is time consuming (from measurement to distribution), it may cause “time inconsistency” between the spatial data and the real world. In this case, current issues or problems are not able to be considered by suitable data.

Most conventional studies on data integration using GIS have not referred to the effect caused by “time inconsistency” in spatial data. The problem is only dealt with by using data with the closest time stamp. “Time inconsistency” within spatial data can directly affect the results that are calculated from these data. It can be quite dangerous to use spatial data without being aware of such problems. The problem may be worse nowadays, when considering the improvement of GIS: rapid spread of application fields, trends of data integration, and its impact on societies. It would be meaningful to consider the effect of “time inconsistency” within spatial data as an important problem, and to evaluate the effect on spatial analysis. The following two approaches can be taken to alleviate this problem. The first approach is to decrease “time inconsistency” within spatial data, and the second approach is to take this inconsistency into account in using the spatial data. It would be ideal to merge the above two approaches into one process. “Time inconsistency” within spatial data would be decreased by the former approach, and the remaining inconsistency would be extracted and its effect on the result quantified by the latter approach. This paper mainly focuses on the former approach, which is implemented as a post-processing step to decrease the “time inconsistency” of spatial data.

The utilization of satellite remote sensing can be considered as a most suitable tool for frequent spatial data updating. Earth observation satellites have advantages in periodicity and continuity of spatial data acquisition when compared to other monitoring techniques. Optical sensors acquire rich information in various spectral bands and provide clear images. However, optical sensors have a limitation in periodicity for useable data acquisition. In contrast, Synthetic Aperture Radar (SAR) sensors are almost independent of weather conditions, and data acquisition is performed in quite a stable manner. This study developed a method to: 1) detect changes in features (land surface objects), and 2) update land surface data frequently by analysing multitemporal SAR images. The applicability and efficiency for updating of various spatial data was evaluated.

2. MATERIALS AND METHOD

2.1 Study Site and Image Data

JERS-1 SAR images were used in this study. The JERS-1 satellite was operational between 1992 and 1998 and it had a repeat cycle of 44days. JERS-1 has already finished its mission, and the launch of a successor satellite (ALOS) is planned in 2004. This study is setting its sights on the practical use of ALOS/PALSAR data, and the method will be applied to ALOS/PALSAR after development based on JERS-1/SAR. The JERS-1/SAR sensor is quite suitable for the purpose of this study, because of the sensor's stable periodicity of data acquisition. The periodicity of data from these sensors is about 1.5 months, which is satisfactory when compared to the frequency of updating spatial data (1-5 years) in general. Kanagawa prefecture, Japan, was selected for the study site. The reason for this was that Kanagawa prefecture has appropriate characteristics as follows: a) There are various geographical characteristics (e.g. urban areas, agricultural areas, mountainous areas and water areas), and b) The area is located on the urban fringe of Tokyo. Figure 1 shows a comparison of data acquisition ratio between JERS-1/SAR and JERS-1/VNIR. It is clear that optical sensor image has a limitation for periodical monitoring.

2.2 Method

There are two types of features on the land surface. One is a changing features and the other is an unchanging features. The changing features can be further divided into stationary changes and nonstationary changes. The change in the agricultural area is an example for stationary change. The agricultural area changes its land surface in a certain cycle according to the stage of farming, such as seeding, growing, and harvesting. These changes are stationary as the land use does not change, and they should not be a trigger of updating for land use data. On the other hand, nonstationary change occurs randomly and suddenly most of the time. Nonstationary change can be explained by taking urban development and natural disasters as an example. Most of nonstationary changes require data updating, while stationary changes often do not. The rule for updating spatial data depends on the characteristic of each thematic data. The rule is decided mainly by the stationarity of the land surface change. Therefore, these two types of changes have to be considered as completely different changes. The method focused on the role of a support tool for making decisions as to whether or not the spatial data should be updated. Generally, changes of the feature are extracted by subtraction of two data sets having different time stamps. However, these methods based on pairs of data cannot tell whether the changes are stationary or nonstationary. Stationarity of change can be observed correctly only when data is archived in for a long enough time, periodically, and frequently enough. This

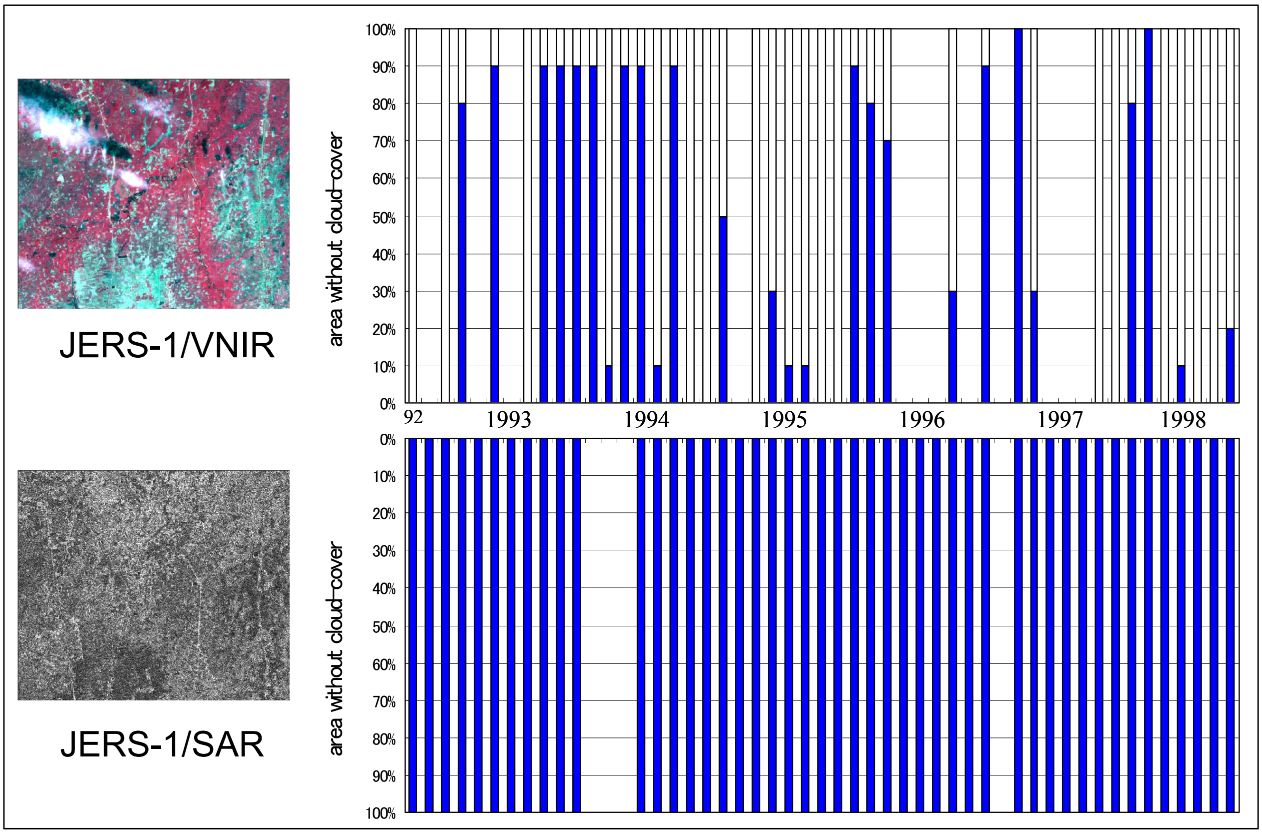

Figure 1. Comparison of data acquisition ratio between JERS-1/VNIR and JERS-1/SAR

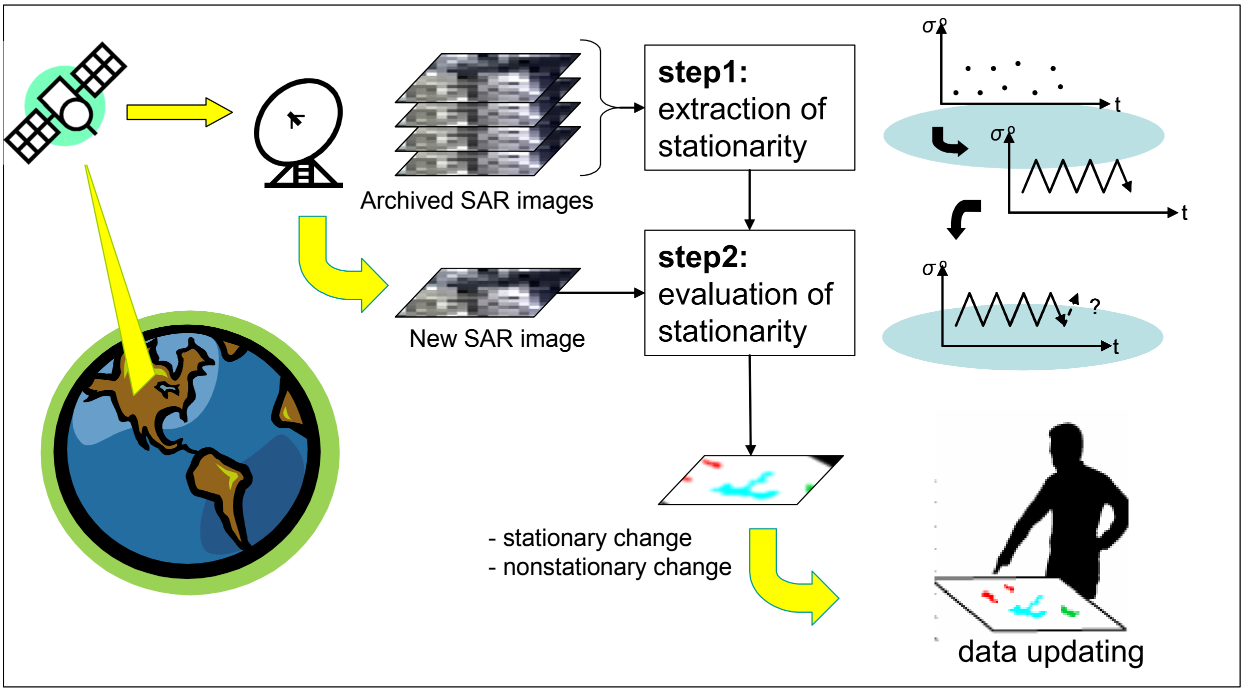

Figure 2. Flow of the method in this study

requirement can not be satisfied by optical sensors which can not regularly provide useable images of the land surface. In this sense, SAR imagery, which has an assured periodicity, is the most suitable data to satisfy the requirement.

The method developed in this study enabled the discrimination of "change" to be detected in the Nth (N > 1) observation, and separated into stationary change or nonstationary change by comparing the change with the former archived data (1 : N-1). The method consisted of two steps.

In the first step, stationarity of change was extracted by time series analysis performed on the multitemporal SAR images and a change process model was built into each pixel. A disadvantage of using SAR data is its speckle noise, which makes image interpretation difficult. Most of the speckle noise reduction filters have a common defect of degrading spatial resolution. Principal Component Analysis (PCA) was adapted to multitemporal SAR images to reduce the speckle noise by maximizing the advantage of temporal information as a test. PCA resulted in much clear image compared to the single image (refer to Figure 3). In addition, there are several multitemporal speckle filters (e.g. Bruniquel and Lopès, 1997; Coltuc *et al*., 2000; Ciuc *et al*., 2001). But still PCA and most of their filters do not use the information of periodical change of feature. On the other hand, time series analysis has focused on the periodicity, and enabled the extraction of both authentic change (i.e. base fluctuation) and the noise (i.e. deviated fluctuation). A key distinguishing feature for developing this method is in its extraction of trend variations; cyclic and seasonal variations; and irregular variations. Intended change patterns were extracted by wrapping the noise and deviation inside irregular variation. Time series analysis was applied using a method which calculated base fluctuations by adapting the Maximum Entropy Method (MEM) as a spectral analysis method, and Nonlinear Least Mean Square (NLMS) algorithms as a temporal analysis method (Saito *et al*., 1994). This method

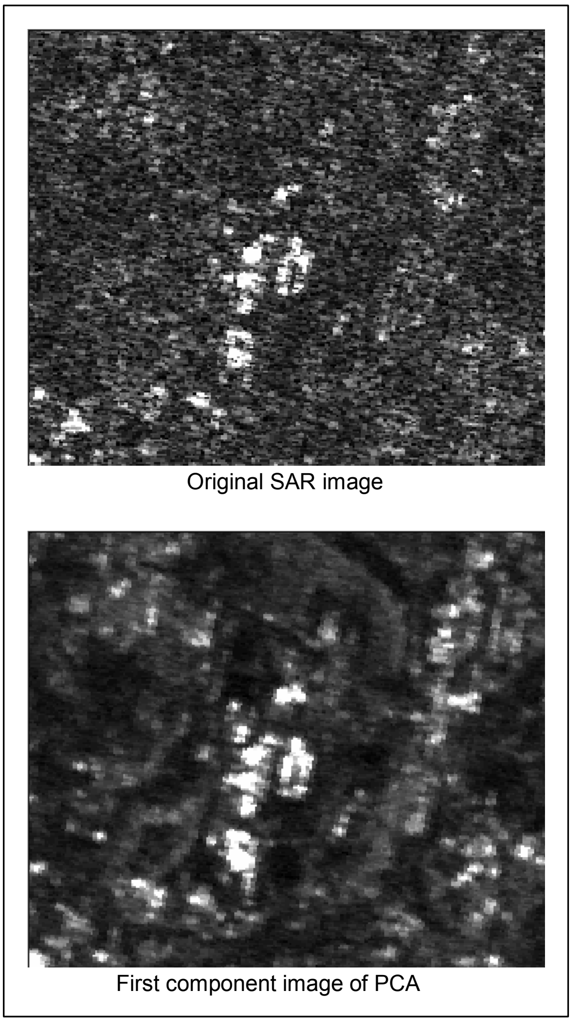

Figure 3. Effect of time series analysis

is focused on dealing with the finite time series, while conventional theories of time series analysis deal with the infinite time series.

In the second step, the detected changes in the N^{th} observation were discriminated into stationary change and nonstationary change by comparing them with the change process model calculated in the first step. Actual observed values of newly (N^{th}) acquired data were evaluated by comparison with the predicted value and its deviation (extent of the allowable error). Recalculation after adding the newly acquired data into the archive was performed when the change was discriminated as stationary change. This recalculation improved precision of the "base fluctuation" model. When the change was discriminated as nonstationary change, stationarity was recalculated by setting the newly acquired data as the default value. The method was able to discriminate the changes into stationary change ((i) in the Figure 4) and nonstationary change ((ii) and (iii) in the Figure 4), while conventional methods interpret them as the same type of change.

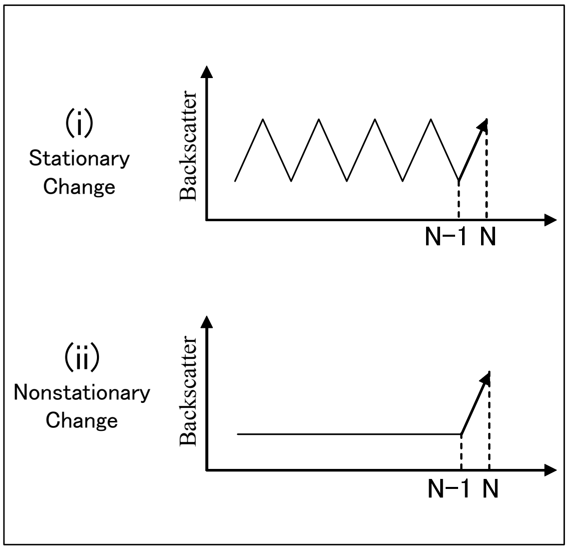

Figure 4. Evaluation of stationarity

3. RESULTS

Figure 5 shows the temporal behavior of the backscatter and stationary change process models in the sample area. Figure 6 shows the area where nonstationary change was detected through 1992-1998, as extracted by the method developed in this study. The precision of the detection was evaluated by comparing the existing spatial data and to the result. In this study, existing land use data and vegetation data were used as examples of spatial data which need updating. Figure 7 shows 100m meshed land use data (1991, 1997) and 1:50,000 scale vegetation data (1994, 1997). These are prepared nation-wide and are maintained by the national institute. The frequency of updating them is quite low (i. e. several years). Changes were observed in these data, and samples of the changes are also illustrated in Figure 7. Evaluation was especially focused on the following areas:

- Areas where change was detected by both existing data and the method developed in this study
- Areas where change was detected only by existing data,
- Areas where change was detected only by the method developed in this study

3.1 Areas where change was detected by both existing data and the method developed in this study

Area A is an area which changed from bare land to buildings. Both subtraction of existing data and the developed model were able to detect the nonstationary change. But it is difficult to tell "when" this change occurred from the subtraction of existing data. On the other hand, the result of the developed method suggests that the change had occurred after 14 May 1997. Compared to the base fluctuation, deviating elements were stable until 14 May 1997, and the profile indicates a different stationary pattern after then. This result suggests that the nonstationary change occurred between 14/May/1997 and 27/Jun/1997. Several more places which were indicating obvious nonstationary changes, such as the construction of new bridge and deforested areas were found in the study site.

3.2 Areas where change was detected only by existing data

Area B is a place which changed from bare land to a university campus. However, this change was not detected by the method developed in this study, while subtraction of existing data did. The reason was that opening of the campus (it was opened in 1990) was not reflected in either the land use data of 1991 or the vegetation data of 1994. It is clear that "time inconsistency" (problem (i) in the Introduction), is embedded in these data.

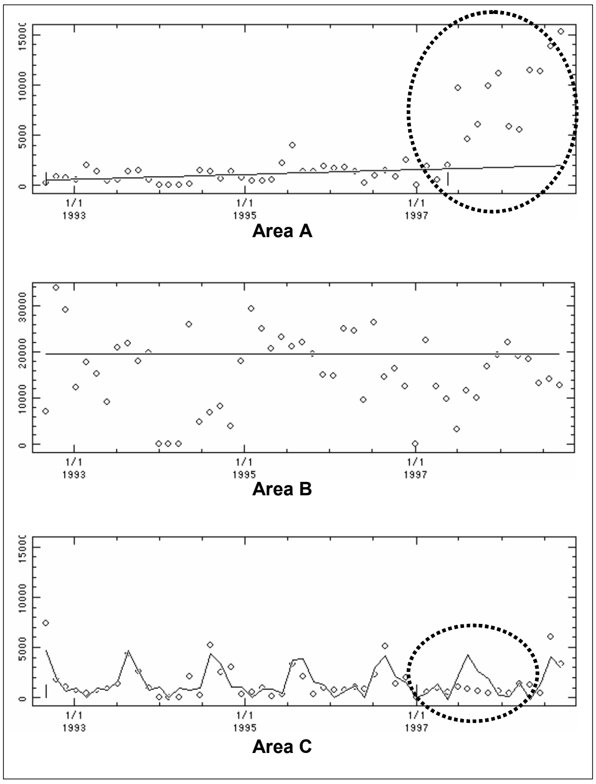

Figure 5. Temporal behaviour of backscatter (point) and stationary process (line)

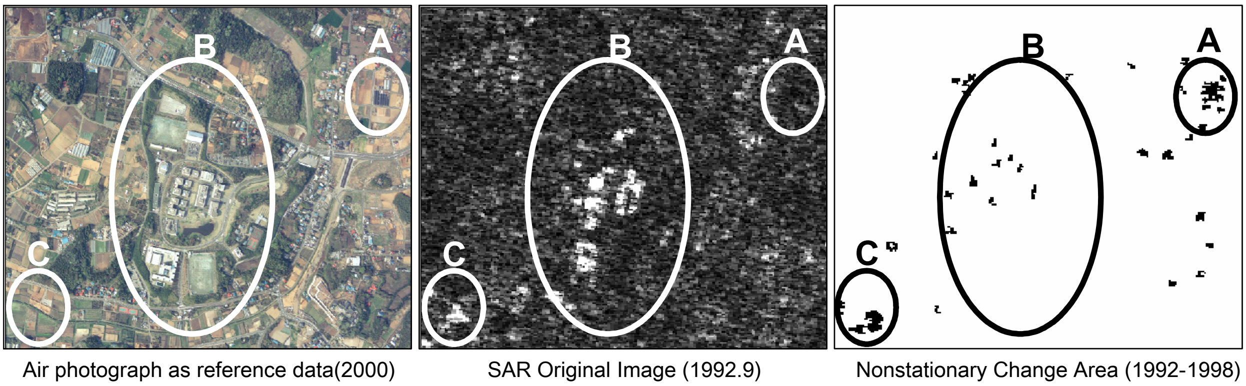

Figure 6. Extraction of nonstationary change area by developed method

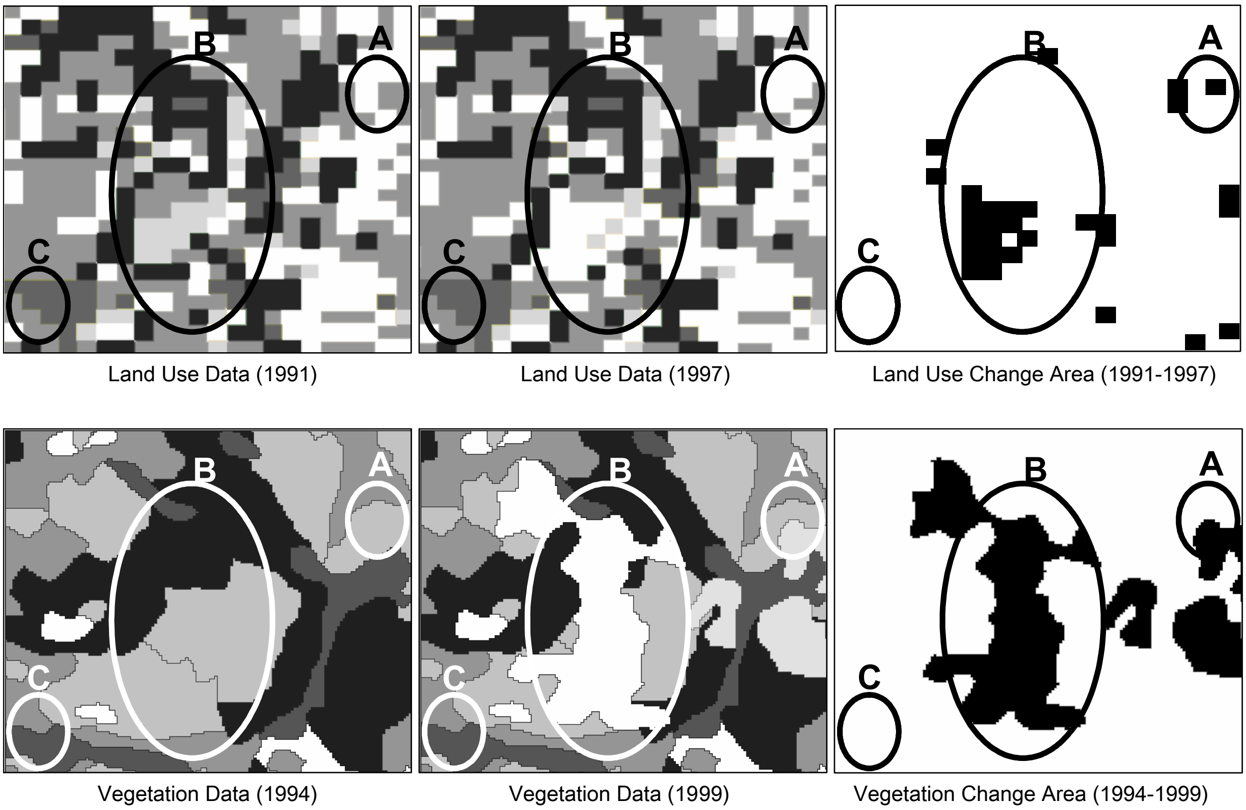

Figure 7. Land use data and vegetation data

In this case, analysis or research on campus conditions (e.g. land use surrounding the campus, environmental assessment, etc.) cannot be performed accurately until updating of the data (i.e. land use data of 1997 and vegetation data of 1999) has occurred. This means that real-time evaluation is impracticable. This problem is referred to in problem (iii) in the Introduction. The method developed in this study can solve these problems to some extent, and improve the data accuracy over time, as noted in 3.1 above.

3.3 Areas where change was detected only by the method developed in this study

Area C is a group of paddy fields. The method developed in this study evaluated the change occurring after 1997 as a nonstationary change. However, the change in Area C went back into stationary change again after 1998. It is highly likely that Area C was a fallow paddy field. This does not mean that the detection was a failure, for it is still a nonstationary change in the land surface; although it is not a change of land use or change of vegetation. Although, there may be applicable uses in many policy making areas for utilizing such detection of nonstationary change among the land use.

4. CONCLUSIONS AND FUTURE WORKS

This study developed a method for extracting feature change using time series analysis on multitemporal JERS-1/SAR images. The method consisted of two steps. In the first step, the stationarity of land surface change was extracted as a change process model, and in the second step, the stationarity of the newly acquired data was evaluated by comparing it with the change process model. Also the practicality of the method was examined from the view point of the "time inconsistency" problem. The results showed satisfactory values for change detection. The method is expected to provide an effective solution to "time inconsistency" problem.

In addition, insufficient results were observed in the developed method, which mostly stemmed from the limitation of using a single type of data. The goal of this study was to develop a method for automated change detection in near real-time which was capable of practical use. Improvement in the accuracy of the change detection in multiple aspects (e.g. spatial, temporal, thematic) will be conducted in the future through assimilating additional techniques such as construction of a detailed base data, use of optical sensor imagery, and development of spatial analysis algorithms.

Constructing the detailed base data

Although the method developed in this study was designed to detect change, it is still difficult to determine thematic aspects of the change. This limitation mainly stems from the fact that the method is relying on a single type of data (i.e. SAR image). Therefore, integration of other spatial data will be conducted to improve the interpretation of the change and determine thematic aspects. The base data will be constructed to archive the thematic information of the intended area to identify the thematic aspects "before" the change. The base data will include land cover data, land use data and topographic data. The spatial resolution will be 1-10m. Higher resolution than SAR data will be required for the base data. High resolution optical images (e. g. IKONOS, aerial photograph) and laser profiler data will be used to satisfy this requirement. The construction of the base data may enable the estimation of stationary changes itself. The method of integrating this estimation into the time series analysis of multitemporal SAR images will also be considered as a future work.

Use of the optical sensor image (not periodical)

Additionally, the utilization of optical sensor images will be conducted to enable the identification of thematic aspects "after" the change. It is true that the periodicity of optical sensor images is poor because of the effect of cloud cover. Even so, optical images contain very rich information and they will be useful for understanding thematic information about the land surface. There are several studies of integrating multitemporal SAR images and optical sensor images (e.g. Michelson *et al*., 2000; Le *et al*., 2000; Lombardo *et al*., 2003).

Integrating the result of spatial analysis into time series analysis

Most of the conventional time series analysis is done by pixel based analysis, which does not consider the relations among surrounding pixels. The pixel values of SAR images are mostly reflecting the shape of the terrain (and some of roughness and material). The classification result may improve if each pixel is understood through the segmented features. The information of the relation among pixels and its corresponding segment may be used as a parameter to improve the precision of the time series analysis on multitemporal SAR images. The segmentation technique used for the high-resolution satellite image (Baatz and Schape, 1999) is also planned to be used.

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