

GIS-SUPPORTED PRECISE SPATIO-TEMPORAL MODELLING FROM AIRBORNE SAR IMAGERY

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ABSTRACT:

Precise spatio-temporal model can make it easy to obtain precise temporal and spatial information just like the true world, and it is of much importance to the planning and designing of Civil Engineering, the directing of disaster prevention and the plotting of military action. And airborne SAR (Synthetic Aperture Radar) has an advantage of full-time available and high resolution. So, in this paper the method and the potential of utilizing airborne SAR imagery to retrieve the precise temporal and spatial information will be researched. First, this paper researches the primary factors to reconstruct the precise spatio-temporal model from high resolution airborne SAR imagery, from which the information and texture structure of those factors can be exacted, including Digital Elevation Model (DEM), buildings and vegetation. Then, integrating Temporal GIS (TGIS) into the spatial model, this paper describes the mathematic model of retrieving temporal and spatial landscape in the nature, and discussed in detail the relationships between the factors which constructing the mathematic model. At the same time it puts forward to a kind of method to reconstruct the precise 4.5 dimension model with temporal and spatial factors by Virtual Reality (VR) technique. Within this paper, the corresponding accuracy criterion and the potential of forecasting the future model with the relative multi-temporal airborne SAR imagery are discussed.

1. INTRODUCTION

The modelling and monitoring of our environment and society is based on how things change, and these phenomena are highly dynamic in space and time. Precise spatio-temporal model is of much importance to the planning and designing of Civil Engineering, the directing of disaster prevention and the plotting of military action, because it can make it easy to obtain temporal and spatial information just like the true world.

There have been many works to research the space and time modelling (Wang, 2000; Appleton, 2003; El-Geresy, 2002; Becker, 1996; Liou, 1999). Yet, time as a dimension, is only marginally supported by current GIS technology. On the GIS-supported spatio-temporal modelling, there has been a conclusion is that the mismatch between static, two-dimensional GIS and causative, site-specific surface process modelling is so great that GIS-based spatial modelling may be premature, at least for some domains.

As an active sensor system, Airborne Synthetic Aperture Radar has several advantages comparing to optical sensors. Firstly, it has advantages of terrain surveying and high resolution, which can provide us with precise terrain and ground objects survey potentiality. Moreover, airborne SAR system not only can operate independent of time of day and weather conditions, but can provide us with remote sensing data at the time frequency of day, even hour, which make us can acquire enough temporal remote sensing data. At the same time, with the rapid development of high-resolution remote sensing sensor, the dynamic monitoring remote sensing database in China, has become more mature than ever before.

In this paper, we aim to discuss the method of reconstructing the precise space and time information model using the high-resolution airborne SAR images, and integrated the TGIS conception with spatial model derived from multi-temporal SAR images, to describe the conception of spatio-temporal model cell, the space and time representation, and the model cell basic relations and accuracy analysis issues.

2. PRICISE SPATIO-TEMPRAL MODEL RECONSTRUCTION FACTORS

For a precise spatio-temporal model, the spatial representation of the real natural landscapes is a predominant role to visualize the 2D remote sensing and GIS data. As it is required, the precise spatio-temporal model reconstructed from 2D data should be a precise simulation digitally of the complex of reality, and have high enough realism degree. Some research has pointed that the most important factor, which positively contributing to the degree of realism, is the terrain with the draped high-resolution aerial orthoimages, and the second important one is the building (Appleton, 2003).

It can be argued, that the spatial model of a true landscape has two important factors: terrain and buildings. However, there are three aspects embodied in the precise spatio-temporal model, that is, space, time, and attributes. On the other hand, for many practical planning and designing, the basis elements, which are required to represent in 3D spatial digital format, are comprised of terrain, buildings and vegetation. Hence, we can choose the precise spatio-temporal model reconstruction factors as follows:

- Terrain: the digital terrain data including Digital Elevation Model derived from high-resolution remote sensing data covered with orthoimages;
- Buildings: including the spatial location and attributes such as the height of the building and so on;
- Vegetation: including the elevated vegetation just as a tree or forest, and the ground land use information;
- Time stamp: the time state and its changes corresponding to the spatial model;
- Objects attributes: the ground objects states description;

And the above factors will be discussed in reconstructing spatio-temporal model from airborne SAR images.

3. TGIS-SURPPORTED SPATIAL MODEL CELL

3.1 Spatio-temporal model cell conception

A Temporal Geographic Information System (TGIS) is more truthful in the simulation of real world phenomena because it includes more real world dimensions of space, time, and attribute than a static GIS. At the present, in China, land use changes is very rapid and wide, thus the renewing Land Use Dynamic Monitoring Database (LUDMD) using remote sensing imagery is a frequent process. And so, the LUDMD may be researched as a TGIS.

The object-oriented spatio-temporal model based on space and time cube pointed by Worboys, 1992, has considered the changes of space, with the absence of attributes changes. This paper expands the thought and puts forward the object-oriented spatio-temporal cell based on real terrain surface segments. The real terrain surface will be segmented into many facets in conception, conformed with the ground altitude and the attributes with time stamp of objects including the space location distribution, height, state and so on, to form a spatio-temporal model cell. The whole spatio-temporal model comprised of many spatio-temporal cells, which can be reconstructed from high-resolution remote sensing data such as airborne SAR images and essential GIS data.

3.2 Space and time representation

The three elements of spatio-temporal model cell include the space distribution, time information and object attributes. And the spatial and temporal changes of the cell are described as a 4.5 dimension variable, that is, space with 3 dimensions, time with 1 dimension, and the attributes 0.5 dimension. Each object in the cell can be represented with the formula as follows:

$$O = F(I, X, Y, Z, T, A) \quad (1)$$

Where

I = identity code, corresponding to the spatio-temporal model cell

X, Y, Z= three axis of spatial location coordinates system, which represents the object spatial distribution, size, shape, and topology relations with the others

T= time information

A= attributes information of objects.

In the 4.5D representation, X, Y, Z and T coordinates axis are perpendicular with each other, and show the characteristic continuous changes of the spatial location and time state for a object. But, the attributes are not rigorously dimension and has not obviously continuous development, so can be processed as 0.5D.

For the objects reconstructed from remote sensing images, the unit of X-axis is meter, so as Y and Z. Resolution is the amount of detail used to represent an image. Temporal resolution is dependent on sampling frequency or the temporal scale at which a phenomenon operates. We define the unit of T axis is the day, because the airborne SAR system can provide us with enough time resolution in day. And, there is the formula as follows:

$$T \in [T_i, T_{i+1}] \quad i=1,2,3\dots \quad (2)$$

Where

i=order of the time interval.

The values of T are between the two threshold values, TB, the beginning time for the object come into being, and TE, the end time for it dieing out. Likely, the attributes values are between AB and AE, which represent respectively the beginning and ending attribute of the object, with a discrete value.

3.3 Model cell basic relations and accuracy analysis

Each cell in the spatio-temporal model is defined by a succession of periods indicating different landscape states, which are time stamped by the day that it represents. Although it is difficult to describe directly the relations between those cells, we can study the projection of the objects in the cell on the axes to open out it.

The projection of a object on X, Y, Z-axes show the spatial location, and the changes, including the engendering, dieing, extending, deflating, and moving of spatial attributes over time, will form a continuous process which is the spatial connection relationship between two adjacent model cells when reconstructed from two temporal high-resolution airborne SAR images.

On the other hand, the projection of an object on T-axis has the form of time interval. An example is a remote sensing image time and the time when the same image is recorded could be defined by a linear relationship. And each time interval can be expressed with (T_i, T_{i+1}) in two nearby model cells.

In addition, the relations between attributes of model cells are more complicated, which will include the changes including land use types in the regions, ownerships of the buildings and so on.

As a simulation process, from static to dynamic state, the spatio-temporal model reconstruction brings the problem of the accuracy standard. And three types of potential errors have been identified: temporal, spatial and attributes classification assignment. Moreover, remote sensing images are often used to assess change. For example, In order to detect change between

two images, A and B, subtract A from B to produce a sparse matrix AB of the delta values. While a straightforward method, careful attention to level of error is very important. Thus, we can decide the spatio-temporal model accuracy criterion:

- Spatial accuracy: depending on the spatial geometric errors, which include the plane errors (X, Y) and elevation error Z, with the unit of the meter.
- Temporal accuracy: depending on the projection error on the time axis, which can be substituted for time matching ratio, with the unit of percent (%).
- Attribute accuracy: depending on the agreement percent with the practical attributes, with the unit of percent (%).

4. SPATIO-TEMPORAL MODELLING METHOD FROM AIRBORNE SAR IMAGES

4.1 Required materials

To reconstruct the precise spatio-temporal model from airborne SAR imagery, the required materials is must be considered from space and time aspects.

On the one hand, it is necessary that the multi-temporal airborne SAR images are available, with the time resolution of the day. The airborne SAR images of the same research region should be acquired with the time interval of one day.

And the other hand, we need the stereo images of the same region and time to reconstruct the 3D spatial model. And, GIS basic graphics can provide us with the ground objects attributes and land use information.

4.2 Data processing

For reconstructing the spatio-temporal model cell, the object-oriented spatial reconstruction model cell with special time tamp must be considered. At the present, there has been many methods to extract the Digital Elevation Model (Herland,1997; Yang, 2001; Peng, 2000) and 3D reconstruction spatial model from SAR images (Tsay, 1994).

Firstly, the stereo airborne SAR images can be processed to extract DEM of the model cell, and acquire the high-resolution digital orthoimages.

Then, utilizing the imagery segment and height estimation, the elevated ground objects such as buildings and trees or forest can be 3D visualized from airborne SAR imagery. Herein, some statistic algorithm such as Gibbs-Markov random fields can the adopted for imagery segment. And, about the height estimation, there will be three types of ground objects as follows:

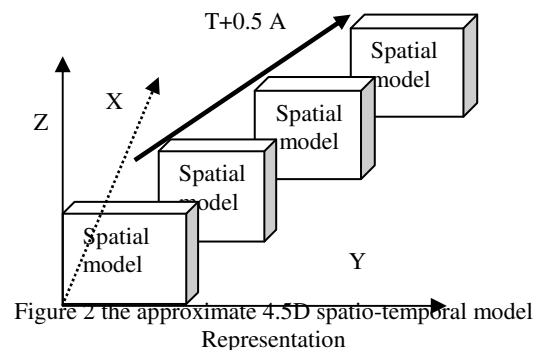
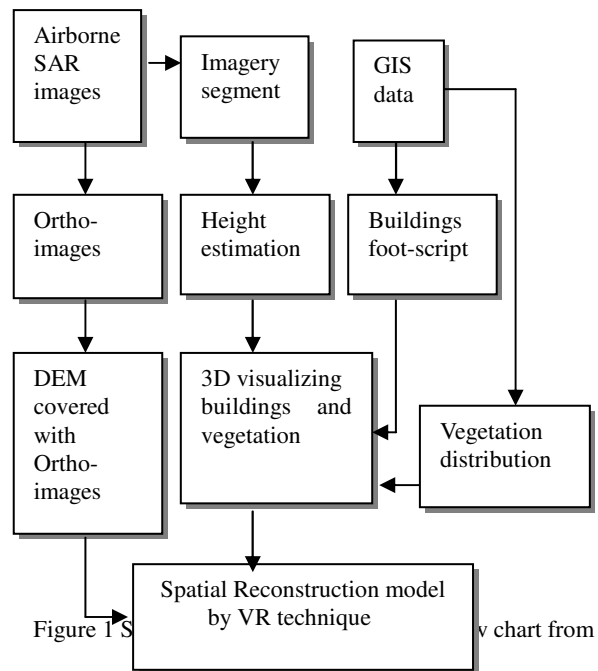
- Elevated objects without crown, like buildings, woods etc;
- Elevated objects with crown, like trees;
- The ground without elevated objects.

The height estimation methods of the first two cases have been described in some research (Kirscht, 1998), which must be computed from the geometric relations between the flight height,

antenna location, objects location on the ground, the corresponding SAR image coordinates, and the shape length of the objects. In the last case, the height of ground without elevated objects can be decide by the DEM in the spatial model cell. Just like the above, after the two important factors, DEM covered with orthoimages and buildings, have been extracted from airborne SAR images, the vegetation distribution and attributes information can be obtained from GIS basis graphics database, even other factors such as traffic roads, buildings foot-script and so on. Afterwards, the spatial reconstruction cell can be available, and the flow chart is as follows (see as figure 1).

4.3 Model reconstruction

By 3D visualizing the buildings and vegetation and adding the DEM covered with airborne SAR orthoimages, the reconstructed spatial model with the time stamp of the special day can be visualized by Virtual Reality technique. With the multi-temporal stamp, it is difficult to visualize directly the 4.5D spatio-temporal model reconstruction cell, however, it can be approximately described as a dynamic process like the Figure 2.



5. CONCLUSIONS AND DISCUSSION

From the above description, the multi-temporal remote sensing and 3D reconstruction model of real terrain surface segment facets conform a 4.5D spatio-temporal model, which will be supported by GIS essential data, and has the basic reconstruction factors, relations, conceptions, and accuracy estimation criterion. For example, the LUDMD should be treated as a space and time modelling process. So, it is feasible for the method to reconstruct the spatio-temporal model from high-resolution airborne SAR imagery, with the advantages of high time and space resolution.

There still are some aspects worth to discuss, like the problem of the potential for the reconstruction spatio-temporal model prediction. For the future states or the one of some special time point, the objects changes of space location and attributes in the reconstruction spatio-temporal model maybe obtained by interpolation the projection values on the axes. But, the practical operator method should be discussed in detail. In addition, the saving and opening the objects and their space and time information with corresponding attributes are the problems to be researched more.

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