GeoS4S Module Digital Terrain Analysis

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Abstract
Digital Terrain Analysis (DTA) is considered a digital information processing technology for terrain derivatives calculation, terrain features extraction and related geo-analysis by using digital elevation models (DEMs). DTA is to construct mathematical abstractions of the terrain surface to delineate or stratify landscapes and to examine or define the relationships between the terrain surface and various biophysical processes/patterns. This teaching module employs case studies and interactive exercises to introduce the philosophy, values, methods and tools used in DTA. The high-level goal of DTA module is to prepare the student for mapping and understanding the topography and geomorphology of the earth. The current paper summarizes the learning objectives, lesson contents, learning activities and evaluation schemes for this module.

1. Introduction

Terrain has been regarded as one of the most important natural geographical factors. The express and further analyses of terrain have been the core research contents among geographical studies, which are also the research focus among the disciplines of geomatics, cartography and geomorphology. With the development of geographical information science, the research of terrain has undergoing a revolution from qualitative surface description to quantitative terrain modeling and analysis. The understanding of geo-processes of the earth should be one of the core contents in the graduate education of geographical information science discipline. This module will help GIS practitioners map, recognize and understand earth surface morphology by using GIS theories, methods and tools.

1.1 Module Description

DTA, also termed as Geomorphometry, is the science of digital terrain modelling and quantitative land surface analysis. DEM is the digital representation of the continuous variation of surface morphology over space. The techniques of DTA by using DEM have been used to map the earth surface morphology, characterize the topographical environment, derive the terrain attributes, and analysis the surface process. Thus, the DEM and DEM-based DTA are playing a key role in various disciplines such as cartography, civil engineering, mining engineering, geology, geomorphology.

This module introduces the following major contents: understanding DEM and DTA, generation and editing of DEM; extraction of terrain derivatives and terrain features by using DEMs; applications of DTA in different research. The objective of this course is to help student understand the concepts and principles of DEM, and be familiar with DEM generation process by using GIS software, knowing the methods of DEM based geo-analysis. In the total 15 lessons, 9 lessons focus on the basic theories and methods of DTM and DTA, and the remaining 6 lessons are the advanced DTA applications. 8 interactive exercises and 2 assignments are offered to have a deep understanding of lessons of DTA. These practices are carefully designed to help students get a thorough and comprehensive understanding of DEMs as well as their applications in geo-analysis.

1.2 Learning Outcomes

- *Explain the differences between traditional terrain analysis and digital terrain analysis. Learn the concept of DEM, DTM and DTA.*
- *DEM modelling: Know the type of DEM, and the relationship and conversion of different types of DEMs; Grasp the methodology of DEM data collection and DEM construction, especially some new methods, i.e. InSAR, Lidar method; Edit DEM for specific terrain, like terrace land.*

- *Extraction of terrain attributes and features: Apply GIS software to derive terrain derivatives and terrain features, including slope, aspect, curvature, peaks, saddles, gully heads, ridges, streams, positive and negative terrains, viewsheds, and illuminated Contours.*
- *Advanced applications of DTA: Achieve a comprehensive understanding of DEM based geo-modelling and geo-analysis, such as simulation of light and heat condition, landform evolution modelling, engineering; learn the limitation & uncertainty of DEMs and DEM derivatives, such as the scale effect of slope derivation from DEM, uncertainty of terrain analysis.*
- *Regional landform analysis: Investigate DEM based regional landform analysis method, including terrain texture analysis, hypsometric integral analysis, slope spectrum analysis, terrain profile analysis, etc.*

2. Module Structure

2.1 Module Overview

This module consists of 15 lessons with slides and accompanying notes, plus required and optional reading assignments, practice exercises, and individual assignments. The overall student effort is estimated at 150 to 170 hours, and the module is intended to provide credit equivalent to 6 ECTS. The module materials are designed to be used flexibly, in either a traditional classroom setting or for on-line self-study. The module is organized into three sub-modules as described in section 4.

2.2 Summary of Lesson Content

This section briefly presents the content and goals of each lesson.

- *Lesson 1: Introduction* - This lesson introduces the history of terrain expression and conventional terrain analysis, discusses the differences of terms among DEM, TIN, DSM and DTM, and explains the concept of DTA and the major contents of DTA. In addition, the users and uses / applications of DEMs have been also briefly summarized in this lesson.
- *Lesson 2: Data Acquisition* - This lesson describes how original data sources of DEM could be acquired, introduces the popular used DEMs of global scale dataset and the high resolution LiDAR DEM of microscale dataset, and discusses how can we evaluate the quality of above DEM data.
- *Lesson 3: Terrain Modelling* - This lesson explains the data structures of raster DEMs and TIN DEMs, compares the advantages and disadvantages of raster DEMs and TIN DEMs, discusses the generation of raster DEMs by using spatial interpolation algorithm. It also highlights the process of the conversion of different DEMs.
- *Lesson 4: DEM Visualization* - This lesson discusses the principle of DEM visualization, introduces the DEM based 2-D terrain enhanced visualization and DEM based 3-D terrain visualization by using approaches of hill shading and height-based colouring. It also highlights some special DEM visualization methods like illuminated contours.
- *Lesson 5: Descriptive Terrain Parameters* - This lesson discusses the principle and method of descriptive terrain parameters which can be determined by a local window calculation operator in DTA. In addition, algorithms of terrain parameters of slope, aspect, surface curvature and roughness, and several surface complexity attributes have been highlighted in this lesson.
- *Lesson 6: Hydrological Analysis* - This lesson discusses the principle and method of hydrological analysis which is combined application of both window analysis and tracking analysis (sometimes known as global analysis against local analysis). The processes of drainage networks delineation, watershed detection, and flow length extraction have been also explained in this lesson.
- *Lesson 7: Extraction of Terrain Features* - This lesson explains the principle and method of extraction of terrain features, and gives examples of how to extract the terrain point features (like peaks, saddles, and runoff nodes), terrain line features (like gully and ridge), and terrain polygon features (like positive and negative terrains).
- *Lesson 8: Visibility analysis* - This lesson presents the principle of the visibility analysis and its research method. In addition, the applications of visibility analysis (like best point of viewshed, frequency of viewshed, and urban skyline) have been discussed in this lesson.
- *Lesson 9: Uncertainty in DTA* - This lesson explains the fundamental concepts of uncertainty in DTA, and gives examples of uncertainties of slope and aspect calculation with different DEM cell size and window analysis size. In addition, the uncertainty of stream networks delineation has also been discussed in this lesson.

- o *Lesson 10: Agriculture Application* - This lesson gives three typical examples of agriculture applications by using DEM and DTA. These three examples contain simulation of light and heat condition with hill shading method, analysis of arable suitability and prediction of soil attributes with a certain terrain environment.
- o *Lesson 11: Urban-DEM & Applications* - This lesson explains what is urban DEM (U-DEM) and how can we construct U-DEM, describes the urban morphological analysis by using U-DEM, and gives several application cases of U-DEM (like macro 3D morphology of different cities and urban skyline analyst).
- o *Lesson 12: Disaster & Erosion Investigation* - This lesson considers flood forecasting, flood submergence analysis and landslide mapping as example to investigate the disaster by using DTA. In addition, USLE and erosion simulation have been also described as DTA application in this lesson.
- o *Lesson 13: Landform Classification* - This lesson presents the principle and method of landform classification in DTA, and gives the examples of landform classification at different scales as well as classification of typical landforms in China.
- o *Lesson 14: Engineering* - This lesson describes the engineering applications of DTA, and gives the corresponding cases of terrain terrace construction, excavated earthwork volume calculation, and mountainous area road planning and construction by using DTA.
- o *Lesson 15: DTA extension* - This final lesson discusses some extension of DTA application, like landform evolution modelling (LEM), planet craters and morphological analysis, and field model.

3. Hands-on Sessions

The module provides a number of interactive and hands-on activities to supplement the lecture content, deepen students' understanding, and develop their practical skills. Many of these activities are part of the module evaluation scheme.

- Terrain Modelling lesson contains three exercises and one assignment. These exercises are simple data acquisition, conversion of different DEM data formats, and data structures of DEMs and their conversions. The assignment is DEM Generation and visualization (Lesson 3).
- DEM Visualization lesson contains three exercises of DEM based 2-D terrain enhanced visualization, DEM based 3-D terrain visualization, and illuminated contour map (Lesson 4).
- Descriptive Terrain Parameters lesson contains three exercises of Slope & Aspect calculation, SOS & SOA calculation, and Other Surface Complexity Attribute calculation (Lesson 5).
- Hydrological Analysis lesson contains the exercises of depression filling, flow direction calculation, flow accumulation calculation, and stream network and watershed delineation (Lesson 6).
- Extraction of Terrain Features lesson contains two exercises of extraction of terrain point features and extraction of terrain line and polygon features (Lesson 7)
- Visibility Analysis lesson contains one exercise to enhance understanding of viewshed analysis (Lesson 8)
- Uncertainty in DTA lesson contains one assignment of how DEM resolution influences on slope extraction (Lesson 9)
- Urban-DEM & Applications lesson contains one exercise of constructing buildings with DEM (Lesson 11).
- Engineering lesson contains two exercises of terrain terrace construction and road construction (Lesson 14)

4. Teaching and Learning System

By using reflection and self-evaluation methods, the teaching and learning strategies are student-centered aiming to encourage students to form deep learning habits. The course will be divided into three sub-modules; each sub-module includes theoretic prelection and practice. Students will be required to use the theoretical and technical skill to deal with geo-problems.

Sub-module 1: (lessons 1-4) focuses on the specific problem of digital terrain modelling, which introduces definitions, concepts, philosophy and values for DEM and DTA. In addition, this sub-module should be the basis for the following lessons, which contains two excerises and one assigment.

Sub-module 2: (lessons 5-9) focuses on specific problems of terrain derivative and terrain feature calculation, as well as their unicertainties. Students will complete four hands-on excerises and one assignment.

Sub-module 3: (lessons 10-15) focuses on specific applications of DTA. Students will conduct several case studies. They will also complete two hands-on excerises, one focusing on urban DEM construction, the other using DEM data for engineering.

5. Evaluation System

Performance evaluation for this module involves two components: hands-on or interactive excerses (50%) and assignments (50%). For the interactive, discussion-based excerses, the instructor will provide feedback and suggestions, but grading will be based on apparent effort and thought. The purpose of all excerses is to give students practice with specific tools and techniques, and to engage them in both analysis and synthesis. The assignment will assess the degree to which students have internalized the concepts and techniques addressed by the module and can apply them to a specific case. These assignment is mainly used to test whether students can use GIS software to deal with problems of digital terrain analysis.

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