Linear System Methods for Geographic sciences

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1. Introduction

This introductory seminar is still developing after some trial discussions in 2017. The following set of seminars is planned as a second step to define the necessary if not sufficient topics it should cover. Its primary aim is to introduce graduate students in Earth- or Geosciences to some of the tools that are included in the linear systems theory for digital image processing (DIP). The outcome should be to identify what aspects of Linear Systems are especially useful to geographic sciences and provide enough understanding for graduates to decide and use them as tools in the future.

Linear system theory has its base in electrical and electronic engineering where the Laplace and Fourier domains and solutions of integral and differential equations as well as sampling systems have been everyday tools for solving problems. However, its concepts are very wide spread and have found applications to other areas such as:

- Digital image processing (DIP, image transformation and enhancement)
- Data filtering (smoothing, noise removal, differentiating, scale change)
- Geomorphometry (slopes, curvatures, streamlines and catchments of landforms)
- Geostatistics (semi-variograms and multi-scale analysis)
- DEM development (interpolation and data pre-processing)
- And others…

When the base data are in the form of images (multi-band data cubes that can be stored, displayed and analysed in raster format) they can particularly benefit from the tools that come with DIP. The nature of linear systems and the transformations that are used in this area (eg Laplace, Fourier, Hadamard, Wavelet etc) have convenient processing techniques which, along with image display tools and the growing store of remotely and non-remotely sensed data in image form, makes it a basic research tool in Geography and Geomorphology.

If there is a common theme in the course it is to show the relationships between detail in images and frequency structure in the Fourier domain and how these relationships allow you to analyse data and design techniques to solve problems. The Fourier domain is not as natural in earth sciences as it is in electronics. However, it is the basic tool for analysing and designing methods of filtering that seems to provide solutions for such studies. These applications are most obvious in studies of sampling, scale and resolution and multi-resolution processing and are increasingly involved in analysing image data in Earth Sciences.

2. Course Outline

Basic content and structure follows that of Castleman (2008) with additional background information from recent CSIRO Books (mainly from two volumes, 2B and 2C that are currently “In Press”). Examples have been constructed using IDL software. The locations of sections in Castleman are indicated in the collected materials so that students can read the sections before the class and find answers to detailed questions. Castleman has been used as it is (still) a very nice selection of methods and tools for the purposes and has matching books in English and Chinese.

The course starts with a discussion of image distortions and rectification and ends with an introduction to grayscale image segmentation. In between it is focussed on Linear Systems. Geometry is needed to ensure images are Euclidean and not distorted. Image segmentation is only a brief introduction and at this stage but leads in to morphological filters and methods that extend linear systems into more general data areas. Both can be expanded in the future.

Brief outline

1) Geometric Correction of Images.

Basics of image geocoding (putting location to a pixel) and geo-correction (resampling the image to a new projection). Using models or control points. Examples from different scanners. Registering images in mosaics and time series by control and tie points. (uses CSIRO Book 2B for illustration)

2) Introduction to Linear Systems and Fourier transform

Summary of Castleman Chapter 9 using Wang overheads. Chapter 9 introduces basics of filters and covariance, harmonic response etc. Then some material from Chapter 10 of Castleman including 10.3 & 10.4. Will introduce ideas of 1D and 2D FT plus continuous and discrete. Matrix form of DFT NOT specifically included. Finish with a FFT example based discussion of the relationship between detail in images and frequency (2D DFT) in Fourier domain.

3) Filtering and Filter Design.

First a discussion of common filters such as smoothing and differentiation and using filters in image processing (material from Book 2B). Discussion of common slope and curvature filters in DEM and Fourier domains and their DFTs. Then summary of material found in Chapter 11 of Castleman. Focus is on the process from basic to application. For example, we can focus on a low pass filter (eg Gaussian) application, how to design it, and its application in terrain or other image data. Only simple Weiner and Match filter cases covered with example from Lidar processing.

4) Sampling.

Parts of Chapter 12 of Castleman. Aliasing will be one focus as many people often ignore it and it will be similar to the corresponding lecture last year. Uses circular images again but also looks at FFT. Will introduce scaling related problems such as resolution, cellsize, MTF etc in time/image and frequency domains. Summary of Discrete Fourier DFT/FFT transforms. But **NOT** advanced FFT methods or linear matrix formulation of Hadamard transforms etc.

5) Multi-resolution & Wavelet Transforms.

5.1 First study is multi-resolution in spatial domain using filter banks. Will go through a previously studied filter bank document. By now its methods have been covered. Finish with demonstration of multi-resolution filterbank images (as last year). Demonstrate using FT to compare different ways to compute components.
5.2 Discuss Tiling for multi-resolution. Zoom and Pan, data coding and transmission.
5.3 Then follow with Chapter 14 of Castleman (will likely break over into new session). Emphasis on examples and relationship with the previous filter work.

6) Image Segmentation.

Selection from Chapter 18 of Castleman. Introduction to the use of filters for boundary detection and extraction using morphometric filters. More an introduction to an important area related to Linear systems but with more basic geometry that can be expanded to include Morphological methods and filtering later.

3. Reference

Castleman, Kenneth R. (1996). *Digital Image Processing*. Pearson Education Inc., Prentice Hall. (Reprinted by Pearson Education Asia Ltd).