Slovak University of Technology in Bratislava
Faculty of Civil Engineering

Dissertation thesis

Advanced methods of time series modelling and their application in geodesy

Ing. Tomáš Bacigál

Bratislava March 2007

I acknowledge my immense gratitude to Prof. RNDr. Magda Komorníková, CSc. for her support and many helpful comments during the whole study.

Words of thanks should also be addressed to Prof. RNDr. Radko Mesiar, DrSc. and other colleagues from the Faculty of Civil Engineering for their contribution to my professional growth.

My special thank belongs to my parents, family and friends for having patience with me during the work on this thesis.

Contents

Introduction

Many technical disciplines involved in civil engineering such as geology, geodesy, hydrology, statics of structures and others deal with geometric and physical quantities to figure out processes that influence our environment (both original and man-made). Supported by advancements and automation on the field of measuring instruments, monitoring becomes robust and effective, yet demanding more appropriate methods of processing. The most obvious geometric concern in geodesy is to determine a position of particular points in time-space. For the purpose, variety of techniques has been developed to precisely measure all the related mediating parameters, yet there is a special one popularity of which has rocketed up in recent times.

The thesis focuses on modelling time-series arisen from observations by Global positioning system (GPS), which is satellite based navigational system developed and provided by the American Department of Defence and now widely used in civil sector. Observations had been performed daily in years 2001-2002 on GPS permanent stations, which take part in EUREF Permanent Network representing a regional densification of global IGS (International GPS Service) net in Europe which is used, among other purposes, for regular monitoring of recent kinematics of the Earth's crust (see [28]). The standard outcome, being in the form of three coordinates (`X,Y,Z`) in geocentric coordinate system, was transformed into local topocentric horizontal system (`n,e,v` - north, east, vertical component) - with the origin set into the mean position of the two year period - to be further processed.

Time series processing is the branch of statistics with relatively strong fan club, especially in the economic and financial applications, for which the majority of existing models and techniques has been developed so far. The most popular framework for modelling social-economic processes is autoregressive model and its various versions, which has long been applied to describe stationary phenomena. The idea of explaining the process by its past values has also been very useful for prediction. We use this approach as the groundwork in this thesis for introducing further extensions and developments, even as a contrast to completely different approach. That is the case we want to

find relations between simultaneous values of particular variables in order to understand the interactions in the system of interest (society or nature). Obviously, one would get a lot more information by relating the values of variables at the same time point rather than relating it to its own past. The perfect example of modelling purely the relationships is the concept of copulas. However, parallel discussion of relations and individual dynamics makes great sense many times in practice. Therefore the thesis focuses on multivariate modelling which has much more capacities to describe real world than univariate approach.

Application of models developed for clearly a different area and verification of its usefulness is one of the main purposes of our work. Another one is to bring modern methods, which are still evolving, closer to common practitioners in geodesy and other technical disciplines.

The thesis is organised as follows. After stating our main goals, we continue with an overview of methods widely used for time series analysis assuming linearity. The concepts described there are to be the shoulders to stand on in the next two chapters, specifically when non-linearity or common features are expected. The fourth theoretical chapter introduces approach, that is new to time series modelling and disposes of completely different battery of tools, entirely focusing on intervariate relations. The description of existing methods in these four chapters is here and there supplemented by our own theoretical achievements and these are summarized in the Conclusion among practical results. In the fifth chapter the application to GPS observations is given to illustrate the theory and a brief description of accompanying algorithms is provided, which themselves find their place in appendix.

Objectives

The dissertation thesis is aimed at

- time series modelling techniques that help to understand and predict individual and/or common properties of processes that constitute an observable system;
- models for non-linear structures;
- models that allow to utilize common components in time series to streamline the analysis and make it more accurate;
- models locating the random variables in probability space and describing their individual and "collective" properties separately;
- describing recent achievements on the mathematical models in a way, that is clear and formally implementable for researchers in applied sciences;
- theoretical improvement of model capabilities;
- providing general-purpose and user-friendly algorithm based on Mathematica programming language (model specification procedure, test for non-linearity, conditional estimation of regime-switching model, forecasting, common feature transformation, modelling dependence structure).