

小波分析在 GPS 变形监测数据处理中的应用

夏秋, 周金国

(国家测绘局 重庆测绘院, 重庆 400014)



摘要: 阐述了小波变换在变形监测数据处理中的应用方法, 将变形监测的数据序列视为不同频率成分组成的数字信号, 用 MATLAB 编程实现小波分析对监测数据的粗差识别、消噪、发展趋势的提取, 实例表明, 小波分析可以较好地适用于大坝变形监测的数据处理。

关键词: 变形监测; GPS 小波分析; 信号处理

中图分类号: P258

文献标志码: B

文章编号: 1672-4623 (2011) 06-0040-02

随着国民经济的发展, 国家建设的大型建构筑物越来越多, 其形变安全越来越受到重视, 变形监测也越来越重要。全球卫星定位系统 (GPS) 技术已发展了几十年, 已较为成熟, GPS 也已成功应用于建构筑物的变形监测, GPS 变形监测数据量庞大, 受干扰因素也非常多, 成功的从这些带有干扰噪声的数据中提取出所监测建构筑物的形变信息, 对建构筑物的安全使用至关重要。

本文阐述了小波分析基本原理, 利用小波分析理论对 GPS 变形监测数据从粗差识别、降噪处理、趋势提取三个方面进行实验分析, 得到了一些有意义的结论。

1 连续小波与小波变换

小波是函数空间 $L^2(R)$ 中满足下述条件的一个函数或者信号 $\psi(t)$

$$C_\psi = \int_{R^*} \frac{|\Psi(\omega)|^2}{|\omega|} d\omega < \infty$$

式中, $R^* = R - \{0\}$ 表示非零实数全体, $|\Psi(\omega)|$ 是对 $\Psi(\omega)$ 取模, 有时, $\psi(t)$ 又称为小波母函数或小波基函数, 上述条件称为“容许条件”, 对于任意的实数对 (a, τ) , 其中参数 a 必须为非零实数, 称如下形式的函数

$$\Psi_{(a,b)}(x) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{t-\tau}{a}\right) \quad a, \tau \in R, a > 0$$

为由小波母函数 $\psi(t)$ 生成的依赖于参数 (a, τ) 的连续小波函数, 简称小波, 其中 a 为伸缩因子, τ 为平移因子。

将任意 $L^2(R)$ 空间中的函数 $f(t)$ 在小波基下展开, 称这种展开为函数 $f(t)$ 的连续小波变换, 其表达式为

$$WT_f(a,b) = \langle f(x), \Psi_{a,b}(t) \rangle = \frac{1}{\sqrt{|a|}} \int_R f(t) \psi^*\left(\frac{t-\tau}{a}\right) dt$$

$\psi^*(t)$ 为 $\psi(t)$ 的共轭, $\langle f(x), \Psi_{a,b}(t) \rangle$ 为求两函数内积。

2 小波分析在 GPS 变形监测数据处理中应用

漫湾大坝共有 19 个坝段, 每个坝段长约 22 m。在第 7、12、15 坝段建造观测墩, 其与大坝牢固相连。滑坡位于大坝右侧, 选取 3 个变形特征点 09、10、31。在上述 6 个监测点各安装一个 GPS 天线, 在生活区办公室和宾馆的楼顶上分别安置一台 GPS 接收机, 作为 GAMS 2 个基准站。

在 GPS 变形监测系统正常运行之后, 抽取了监测期间两段数据, 作为本次观测实验数据。基线变形量构成一个大地四边形如图 1 所示。

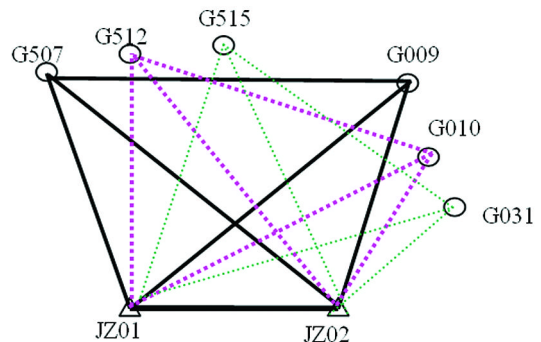


图 1 同步变形基线组成的大地四边形

2.1 监测数据的粗差识别

监测数据的粗差识别包括粗差定位和粗差诊断两部分, 首先对监测数据利用小波变换进行突变点定位, 找出粗差可能发生的位置, 然后再对找出的突变点进行判断, 看是否是粗差。

现以采集的数据中坝点 G512x 方向的变形量为例, 其中共有 70 个测值, 分别对 $t=20$ 时加粗差, 使 $x_{20}=9.0$ mm, 加粗差后的测值过程线如图 2 所示。

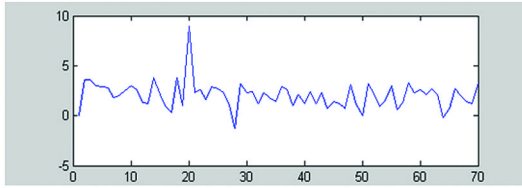


图2 加粗差后的测值图

现对加粗差的信号采用 db1 小波进行 5 层分解,其第一层高频系数如图 3 所示。由图可知,第一层高频系数在 $t=20$ 处有一可传播的模极大值,显然是信号的奇异点,即对应测值序列的粗差点。

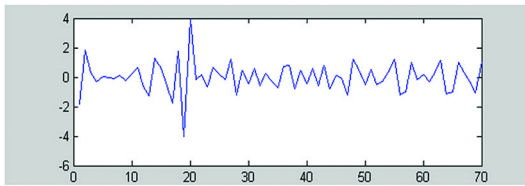


图3 观测值小波分解图(第一层)

需要注意的是,利用小波分析进行粗差诊断的方法只能定位出粗差点的位置,即定性分析,不能够定量的分析所定位出的粗差值是否是真实的粗差值。还需通过大坝安全监控的数学模型对粗差值进行进一步判断。

2.2 监测数据的降噪处理

在用小波进行降噪的过程中,方法很多,有强制降噪、软阈值降噪等方法。

现以采集数据中坝点 G512 x 方向的变化量为例,将变化量看作信号,图 4 中 s 为原始信号图,选用 db3 小波,将原始信号分解 3 层,分别采用上面所述的三种消噪方法进行处理,并比较各种方法的特点。

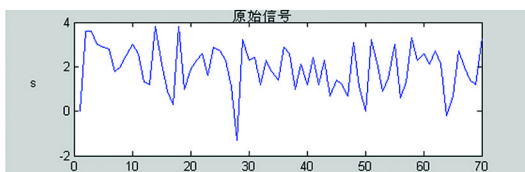


图4 原始信号

降噪信号如图 5 所示。

从图中结果可以看出,强制降噪会使降噪后的信号较为光滑,但有可能会损失一些有用信息。软阈值降噪和给定阈值降噪这两种方法对信号信息过滤较为适中,应用也较为广泛。

2.3 变形趋势提取

图 4 中 s 为该坝 G512 点 x 方向的变化量,利用离散小波变换对该点进行变形特征的提取。由文献 7 可知,坝区温度和上游水位均呈显年周期变化,其相应频率为 $2\pi/365=0.017$ 。因此,只要对掉大于 0.017 的高频部分进行过滤,剩下的即为 x 方向的变形趋势。

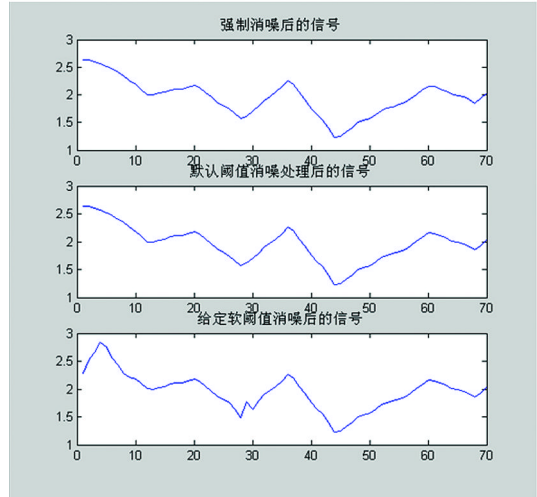


图5 降噪信号

对变化量信号 s 进行 FFT 分析,其最高频率为 4.35,由于 $4.35/2^8=0.017$,因此可用 db6 小波将信号分解到第 8 层,即 $s=d1+d2+d3+d4+d5+d6+d7+d8+a8$,结果如图 6 所示。

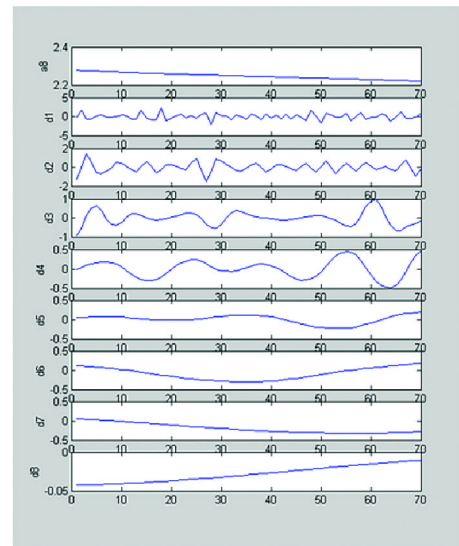


图6 信号 db6 小波分解

由图 6 可见,随着分解尺度(层数)的递增,信号的发展趋势逐步明显,分辨率也随之降低,在分解到第 8 层时,其高频(频率范围为 0.017 - 4.35)信息被滤去,剩下的即为信号的发展趋势(频率范围为 0 - 0.017),即 x 方向的形变趋势。

3 结论

通过实例表明,小波分析可有效提高大坝变形监测数据质量,特别是对监测数据中的粗差识别和噪声处理有良好作用。对于大坝后期变形特征分析提取,也具有较好的适用性,提取的变形趋势可用于判断大坝的稳定性。

(下转第 44 页)

日广泛被使用。

ArcGIS for AutoCAD 提供使用者在 AutoCAD 环境中快速且便利地取用 ArcGIS Server 所发布的企业级 GIS 资料。这个工具让设计师把 GIS 的分析结果包含在 AutoCAD 设计, 以及建立、操作与定义 CAD 数据是如何组织与属性化来作为 GIS 的, 如图 6 所示。

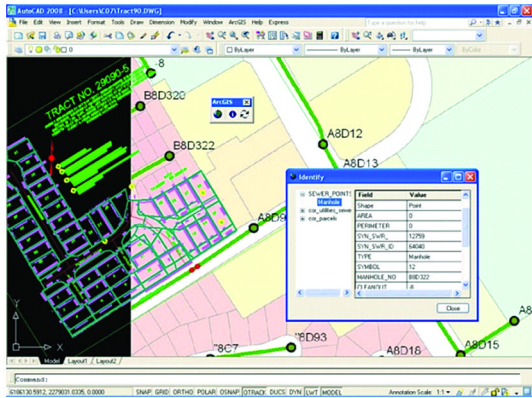


图 6 地理设计工具——ArcGIS for AutoCAD

3.3 ArcSketch

ArcSketch 是一款能够让用户在 GIS 地图和影像上草拟初步设计的地理草稿工具, 提供许多绘图功能, 如图 7 所示。利用 ArcSketch, 可以草拟出一套替代性的土地利用计划, 迅速建立救灾计划的空间组成部分, 勾画高速公路的位置, 或编排选址主计划。

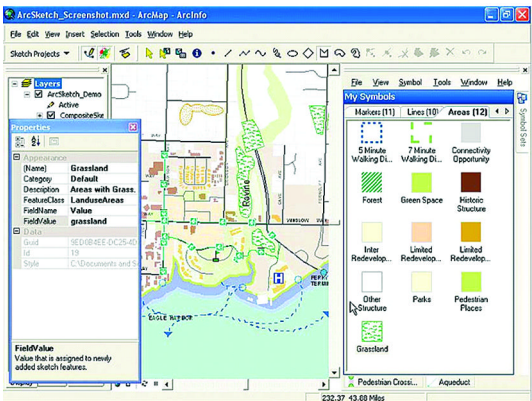


图 7 地理设计工具——ArcSketch

(上接第 41 页)

参考文献

- [1] Albert Boggess, Francis J. Narcowich. 小波与傅里叶分析基础 [M]. 北京: 电子工业出版社, 2004
- [2] 飞思科技产品研发中心. MATLAB 6.5 辅助小波分析与应用 [M]. 北京: 电子工业出版社, 2003
- [3] 冉启文. 小波变换和分数傅里叶变换理论及应用 [M]. 哈尔滨: 哈尔滨工业大学出版社, 2001
- [4] 徐洪钟, 吴中如, 李雪红, 等. 基于小波分析的大坝变形监测数据的趋势分量提取[J]. 武汉大学学报: 工学版, 2003, 36(6): 5-8
- [5] 聂学军, 侯玉成, 卢兆辉. 小波分析在大坝安全监测数据处理中的应用研究[J]. 红水河, 2004(2): 106-109

4 结 语

地理设计已经成为 GIS 发展的前沿。地理设计让 GIS 不再只是作为一款辅助工具存在, 而是贯穿项目的整个生命周期, 成为设计过程的组成部分, 有利于缩短设计调整的时间。可以预料, 在不久的将来, GIS 将对空间信息相关领域的设计过程产生重大深远的变革, GIS 将成为设计决策的辅助者和决策结果的表现者。

参考文献

- [1] 全国城市规划执业制度管理委员会. 城市规划原理 [M]. 北京: 中国计划出版社, 2008
- [2] 威廉·米勒. 地理设计定义初探. 中国园林 [J/OL]. <http://www.cnki.net/kcms/detail/detail.aspx?QueryID=0&CurRec=2&DbCode=CJFQ&dbname=CJFDLAST2010&filename=ZGYL201004019>, 2010-4
- [3] 麦克尔·弗莱克斯曼. 地理设计基础. 中国园林 [J/OL]. <http://www.cnki.net/kcms/detail/detail.aspx?QueryID=0&CurRec=1&DbCode=CJFQ&dbname=CJFDLAST2010&filename=ZGYL201004020>, 2010-4
- [4] 马劲武. GeoDesign 导读. 中国园林 [J/OL]. <http://www.cnki.net/kcms/detail/detail.aspx?QueryID=0&CurRec=5&DbCode=CJFQ&dbname=CJFDLAST2010&filename=ZGYL201004016>, 2010-4
- [5] 杰克·丹哲芒. 地理信息系统: 设计未来. 中国园林 [J/OL]. <http://www.cnki.net/kcms/detail/detail.aspx?QueryID=0&CurRec=4&DbCode=CJFQ&dbname=CJFDLAST2010&filename=ZGYL201004018>, 2010-4
- [6] 唐艳红. 地理设计: 新思维与新手法. 中国园林 [J/OL]. <http://www.cnki.net/kcms/detail/detail.aspx?QueryID=0&CurRec=3&DbCode=CJFQ&dbname=CJFDLAST2010&filename=ZGYL201004021>, 2010-4
- [7] 蒋波涛. 地理设计漫谈 [EB/OL]. <http://www.zgchb.com.cn/newspaper/show.php>, 2011-4-19

第一作者简介: 李莉, 工程师, 主要研究方向为地理信息、城市规划。

- [6] 黄声享, 刘经南, 柳响林. 小波分析在高层建筑动态监测中的应用[J]. 测绘学报, 2003, 32(2): 153-157
- [7] 陈继光, 李光东, 刘中波. 大坝变形数据处理中的离散小波分析方法[J]. 水电能源科学, 2003(2): 11-13
- [8] 龙兴明, 周静. 连续小波变换的一维信号检测[J]. 重庆邮电学院学报, 2004(4): 77-80
- [9] 张小飞, 徐大专, 齐泽峰. 基于小波变换奇异信号检测的研究[J]. 系统工程与电子技术, 2003(5): 47-48
- [10] 田胜利, 周拥军, 葛修润, 等. 基于小波分解的建筑物变形监测数据处理[J]. 岩石力学与工程学报, 2004(5): 2639-2642

第一作者简介: 夏秋, 工程师, 主要从事工程测量、变形监测工作与研究。

Key words basis of geographic information , aerial exploration , process modification ,Continuous Operational Reference System

(Page:27)

Construction of FJCORS and Its Application in Control Survey

by WANG Yanchun

Abstract Continuous Operational Reference System (CORS), which can provide real time positioning service, is one of hot spots about contemporary GPS development. Fujian Continuous Operational Reference System is illustrated in detail from the system composition and the technical indexes. A new control survey method based on FJCORS and Local Geoid is provided.

Key words FJCORS; Control survey; Local Geoid (Page:29)

Optimal Scale Selection of Rasterizing Vector Data in Guizhou Karst Mountainous Area

by ZHOU Xu

Abstract After a series of quantitative experiments, this paper proposed that complexities of study area, requirements of accuracy, and computing efficiency were the most important factors which affect the optimal scale of rasterizing vector data; it also concluded that the 25 m-30 m raster unit is the optimal scale for Geo-spatial analysis in Guizhou karst mountainous area.

Key words rasterizing vector data , optimal scale selection ,Guizhou karst mountainous area (Page:31)

Design and Realization of City Flood Prevention Command System Based on Flex and ArcGIS Server

by ZHANG Hongwei

Abstract Aiming at and associating with the currently work conditions and problems of the flood control and disaster alleviation in Hua'an, We designed and exploited the WebGIS City Flood Prevention Command System, introduced the functions achieved in the system and the key technology used in the system development process and so on, which is based on related technologies such as ArcGIS Server, RIA/Flex and .NET, as well as analyzed and studied the whole design structure, database management and design and so on. Through the research and application of this system, the researchers can effectively enhance the work efficiency of flood control of city management and scheduling, and which has significant guide meanings to flood prevention and disaster alleviation, thereby minimizing the loss caused by flood damage to the city.

Key words city flood prevention and disaster reducing ; ArcGIS Server ; .NET ; RIA/Flex ; WebGIS (Page:34)

Feasibility Analysis of Anhui Meteorological GPS Data for Deformation Research

by ZHENG Haigang

Abstract To demonstrate Anhui meteorological GPS data for crustal deformation research of feasibility. This paper discusses the quality of Anhui meteorological GPS data with TEQC, gives out the quality report according to IGS data quality status, and selects the available data for GPS solution. On this basis, we process solutes available data with GAMIT/GLBOK(Release 10.34).The results showed that the change trend of sites horizontal components time series is consistent with the research results by associate researcher WANG Mei. Therefore, we consider that Anhui meteorological GPS data applied to crustal deformation research is feasible.

Key words GPS ;TEQC ;GAMIT/GLBOK ,feasibility analysis (Page:37)

GPS Deformation Data Processing Method Based on Wavelet Transform

by XIA Qiu

Abstract Described GPS deformation data processing method based on wavelet transform. the data of deformation monitoring sequence as

consisting of different frequency components of the digital signal is processed, with wavelet analysis of MATLAB programming, to achieve the gross errors of monitoring data, eliminate noise, trends extraction, examples show that the wavelet analysis theory applied to data processing of the dam deformation monitoring is practical and operational.

Key words wavelet transform; GPS; deformation monitoring; data processing (Page:40)

Ideology, Method and Tools of GeoDesign

by LI Li

Abstract GeoDesign is the most popular topic in GIS industry. It is not means that GeoDesign is designing nature and conquest nature as human beings' subject ideas, but that reasonable and scientific planning and deciding based on comprehensive analysis, and that promote harmonious develop between human beings and nature. GeoDesign Ideology is different in different age. In information age, GeoDesign is more and more tend to be people-oriented and pay attention to the relationship between people and environment. GeoDesign Method requires every link in design be based on geographic analysis. GeoDesign tools are not as perfect as possible in recent years. At the present stage, there are tools such as ArcCAD, ArcGIS for AutoCAD, ArcSketch. We believe that GeoDesign will bring GIS far-reaching change.

Key words GeoDesign, GeoAnalysis, GeoDesign Ideology, GeoDesign Method, GeoDesign Tools (Page:42)

Development of Monitoring and Control system of Excremental Residue Collecting and Transporting Based on WS/GPS

by ZHONG Bo

Abstract The study aimed at establishing a monitoring and control system than can efficiently monitor and control the vehicles for excremental residue collecting and transporting. We also created a module for each vehicle that consisted of a weight sensing system. This module sends integrated real-time positions and loadings data for excremental residue collecting and transporting during the daily operating period for each vehicle via the global positioning system(GPS) and the general packet radio service(GPRS). We also created a control center that integrated geographic information system(GIS), enabling the monitoring of possible improper usage conducted by the vehicles. Consequently, the system closely interconnects the delivery information between the vehicles, control center, and supervisor of local government.

Key words monitoring and control system ,Weighing System ,Global Positioning System ,General Packet Radio Service ,Geographic Information System (Page:45)

High Performance Parallel Remote Sensing Image Processing Based on CUDA

by XU Xuegui

Abstract As the development of space remote sensing technology in recent years witnessed a geometric growth in the data size of remote sensing images. Consequently, the process of remote sensing images is faced with such challenges as large data size, high intensity, high computational complexity and large computational quantity, and so on. Based on the analysis of the parallel architecture of the latest GPU and the flexible programmability of CUDA (Computer Unified Device Architecture), this paper presents an efficient method for processing remote sensing images on the basis of CUDA. This paper takes FFT, edge detection and template matching, three common methods in remote sensing image processing, as examples, and details the efficient parallel processing procedures of them. The experiments on different images with different data size proved that GPU is 10 to 40 times faster than CPU, which is a dramatic progress in remote sensing image processing.

Key words GPU; CUDA; remote sensing image; parallel processing (Page:47)