

# 灰色模型与智能算法组合模型在变形预测中的应用



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**摘要:** 变形监测工程是一个复杂的综合系统, 各种参数具有很大的不确定性。目前变形的预测分析多采用单一的预测方法, 而各种方法都有各自的优缺点和应用范围, 有时单一的预测方法对判定工程性质带来了困难。引入了组合预测的思想, 在灰色 GM(1, 1) 模型的基础上, 构建了灰色+GA+BP 神经网络组合模型, 探索了时间序列的数据处理和预报问题, 通过实例计算分析, 证明该组合模型满足工程需要, 具有一定的使用价值。

**关键词:** 沉降监测; 组合模型; 灰色预测模型; 遗传算法; BP 网络

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建构筑物在施工和运营的过程中, 由于各种因素的影响, 一般会发生一定程度的沉降。这种沉降量在一定限差范围内被视为正常现象, 但如果超过限度, 就会影响建构筑物的安全和稳定。因此, 对于重要建(构)筑物进行定期监测, 并根据实测数据对沉降趋势作出准确的预报, 及时、有效地将沉降信息和变形情况反映给项目决策者和施工人员以提高作业效率和精度, 从而为整个工程提供技术支持和决策依据, 是一种快速、准确表达沉降观测成果的有效方法。目前, 预测建构筑物的沉降方法有很多, 如回归分析法、时间序列方法、灰色模型法、人工神经网络法、遗传算法等, 其中的每一种方法都有大量的研究成果和应用实例。由于影响建构筑物沉降量的因素有很多而且机理比较复杂, 到现在为止还没有一种系统而全面的预测方法能对其进行准确的预报。对于同一种情况, 上述的几种预测方法得出的结果可能会相差较大, 这就给实际应用中的模型选择带来了困难, 预测精度有时也会难以令人满意。针对这些情况, 引入了组合预测的思想, 将灰色模型(GM(1, 1))法、人工神经网络法(BP 网络法)、遗传算法(GA)的预测模型组合, 建立建筑物沉降的组合预测模型(GM-GA-BP 预测模型), 并通过实例加以验证。

## 1 灰色模型法<sup>[1]</sup>

运用灰色系统理论, 通过建立灰色模型所进行的预测, 即为灰色预测。在灰色系统理论中常用的模型是微分方程所描述的动态方程。最简单的是基于灰色系统理论模型 GM(1, 1) 以及 GM(1, 1) 模型的预测分析。

GM(1, 1) 模型可以弱化原始序列  $X^{(0)}$  的随机性和波动性, 为灰色模型提供更加有效的信息, 所揭示

的原始序列呈指数变化规律。设原始数据序列为:  $X^{(0)} = [x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)]$ , 为了弱化原始序列的随机性和波动性, 为灰色模型提供更加有效的信息, 在建立灰色预测模型前, 对原始数据进行预处理, 通常采用对序列  $X^{(0)}$  进行一次累加生成的处理方式, 即 1-AGO (Accumulating Generation Operator)。

为确保所建灰色模型有较高的预测精度和可信程度, 需要进行残差检验、关联度检验及后验差检验。

## 2 BP 神经网络

BP 算法又称反向传播算法 (Back Propagation), 是神经网络中最常用、最有效、最活跃的一种算法, 是为了解决多层前向神经网络的权系数优化而提出来的。反向传播算法分正向传播和反向传播, 其工作过程简述如下<sup>[8]</sup>: 正向传播, 输入的样本从输入层经过隐含单元一层一层进行处理, 通过所有的隐含层之后, 传向输出层; 输出层把现行输出和期望输出进行比较, 如果误差值在设定误差范围内, 则进入反向传播过程。反向传播, 把误差信号按原来正向传播的通路反向传回, 并对每个隐含层的各个神经元的权值和阈值进行修改, 使误差信号趋向最小。

## 3 遗传算法 (GA)

GA 建立在 Darwin 进化论和 Mendel 遗传学说之上, 是一种用于全局优化搜索的迭代算法, 它将生物进化过程抽象地描述为复制、交叉、变异 3 个算子。遗传算法一般由 4 部分组成: 编码方案、控制参数、适应度函数、遗传算子。在编码过程中, 将问题的一个解向量编码成一个字符串 (染色体), 解向量中的各因子 (基因) 可以是二进制码、实数或字符, 多个染色体构

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成种群。利用适应度函数来求解种群中各个体的适应程度，按优胜劣汰的原则，通过控制参数和遗传算子进行遗传进化，产生新的子代。经过若干代遗传进化后，获得最适宜的个体，即问题的最优解。

#### 4 预测模型 GM-GA-BP 构成及算法步骤

- 1) 输入原始数据资料；
- 2) 应用灰色模型 GM (1, 1) 进行预测，得到预测序列；
- 3) 将预测值作为输入量，原始数据作为期望值；
- 4) 构造 BP 网络；

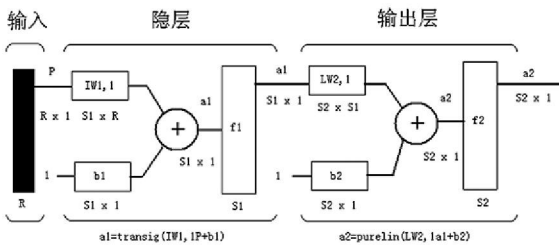


图 1 单隐层 BP 网络 (LW 表示层权重矩阵，用 IW 表示输入权重矩阵)

5) 根据 BP 网络的设计目标，一般的预测问题都可以通过单隐层的 BP 网络实现。根据 Kolmogorov 定理，和单隐层的设计经验公式<sup>[1]</sup>，以及考虑本例的实际情况，解决该问题的网络中间层（隐层）神经元个数，设计一个隐含层神经元数目可变的 BP 网络，通过误差对比，确定最佳的隐含层神经元个数，并检验隐含层神经元个数对网络性能的影响，隐层神经元为 7 的时候网络误差最小，所以模型的隐层神经元选择 7

(见图 1)；

6) 用 GA 优化网络的权；将网络的权值和阈值作为参变量，进行实数编码，本文编码方法为：GA 染色体编码长度遗传算法编码长度  $S=R*S1+S1*S2+S1+S2$ ，R 为输入节点数，S1 为隐含层神经元数，S2 为输出数。前  $R*S1$  对应表示输入节点与隐层权值， $S1*S2$  对应表示隐层与输出层权值，S1 对应表示隐层阈值，S2 对应表示输出层阈值，见图 1。在编码的解空间中，随机生成初始种群，种群中每一个位串表示一个神经网络的一种权值分布，本文设置种群数为 44 个，代数数为 300。对群体中每个个体进行适应度评价，本文算法的适应值为输出与样本误差平方和的倒数<sup>[6]</sup>。根据个体适应度值的大小，对群体中个体进行选择、交叉和变异遗传操作，生成新一代种群，本文选择操作采用排序选择方法 (normGeomSelect)，交叉操作采用算术交叉 (Arithmetic Crossover)，变异操作采用非均匀变异 (non-uniform mutation)。重复步骤 6 和 7，直到算法收敛到设定的精度或达到最大遗传代数。将 GA 算法的结果分解为 BP 网络所对应的权值、阈值的初始值，对神经网络进行初始化<sup>[6]</sup>；

- 7) 采用 L-M 优化算法对神经网络进行训练；
- 8) 将训练好的网络权值和阈值保存起来之后，把较好性能的网络用作最终网络，此时无须再进行训练，直接加载网络权值和阈值即可。

### 5 实例分析

#### 5.1 数据资料

表 1 ZG88 点水平位移变形监测值<sup>mm</sup>

观测时间	2005-12	2006-01-12	2006-02-20	2006-03-18	2006-04-18	2006-05-18	2006-06-16	2006-07-16	2006-08-17	2006-09-19	2006-10-17	2006-11-11
监测值	448.50	468.60	471.50	487.10	498.90	525.30	551.30	577.10	594.30	623.00	624.30	639.00

#### 5.2 分别用 3 种方法对监测值进行预测

1) 灰色 GM (1, 1) 预测模型。在 MATLAB6.5 平台下<sup>[5]</sup>，输入表 1 中的监测值即  $T=[448.5 \ 468.6 \ 471.5 \ 487.1 \ 498.9 \ 525.3 \ 551.3 \ 577.1 \ 594.3 \ 623.0 \ 624.3 \ 639.0]$ ，然后调用所编制的 M 文件，即可得出该预测模型的预测值 P，2006-12-16 的监测值 (650.60) 作为预测模型预测值的外部检验，结果见表 2。

2) GM-BP 组合预测模型。在 MATLAB6.5 平台下，编写相应程序计算，具体步骤如下：为了方便与 GM (1, 1) 模型预测相比较，取 2005 年 12 月-2006 年 11 月 11 日 12 个月的 12 个数据序列的预测值 P 作为 BP 网络的输入样本，12 个数据序列实际监测值 T 作为 BP 网

络的输出样本，对样本进行归一化处理，对神经网络的初始权值、阈值及网络结构进行设定，网络隐含层的神经元传递函数采用“S”形正切函数“tansig”，输出层采用线性函数“purelin”。隐含层神经元 7 个，输出层神经元 1 个，神经网络见图 1；训练函数：traingdm，设置网络训练函数的参数：网络最大训练次数 epochs=100 000，网络性能目标 goal=1e-4，学习速率 lr=0.08，对网络进行训练，得到每个结点的权值和阈值。图 2 为 BP 网络训练误差曲线；取 2006 年 1 月 12 日-2006 年 12 月 16 日的 GM (1, 1) 12 个预测值作为网络输入，仿真后得到相应的输出，预测完毕后再进行反归一化，即为 2006 年 1 月 12 日-2006 年 12 月 16 日的最终预测值，结果见表 2。

3) GM-GA-BP 组合预测模型。在 MATLAB6.5 平台下,编写相应程序结合 MATLAB 的遗传算法优化工具箱 (GAOT) 计算,具体步骤见上述 5)。训练、预测结果见图 3,GM-GA-BP 网络训练误差曲线见表 2。

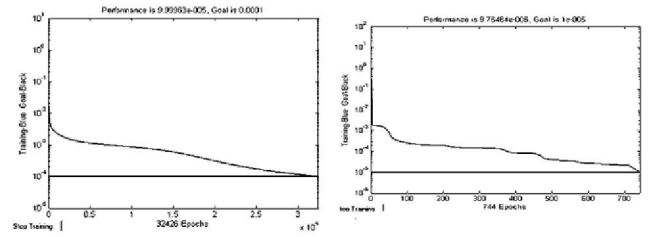


图 2 BP 网络误差曲线 图 3 GM-GA-BP 网络训练误差曲线

表 2 水平位移变形监测值与模型预测值/mm

时间	监测值	GM(1,1)预测值	预测值残差	GM-BP 预测值	工作残差	GM-GA-BP 预测值	工作残差
2005-12	448.5000						
2006-01-12	460.0700	460.0700	8.5300	467.2500	-1.3500	468.5200	-0.0800
2006-02-20	476.3800	476.3800	-4.8800	472.8400	1.3400	471.4800	-0.0200
2006-03-18	493.2600	493.2600	-6.1600	486.7200	-0.3800	487.0500	-0.0500
2006-04-18	510.7400	510.7400	-11.8400	499.1100	0.2100	499.2000	0.3000
2006-05-18	528.8400	528.8400	-3.5400	525.2400	-0.0600	524.6400	-0.6600
2006-06-16	547.5800	547.5800	3.7200	551.3300	0.0300	551.9300	0.6300
2006-07-16	566.9900	566.9900	10.1100	576.9600	-0.1400	576.8200	-0.2800
2006-08-17	587.0800	587.0800	7.2200	594.5700	0.2700	594.3400	0.0400
2006-09-19	607.8900	607.8900	15.1100	621.3300	-1.6700	623.0000	0
2006-10-17	629.4300	629.4300	-5.1300	626.2800	1.9800	624.3100	0.0100
2006-11-11	651.7400	651.7400	-12.7400	638.5400	-0.4600	639.0100	0.0100
2006-12-16	674.8300	674.8300	-24.2300	650.9200	0.3200	652.8900	2.2900

## 6 结 语

1) 从表 2 预测值残差大小得出,单一的灰色 GM(1,1) 预测模型在变形预测效果上有时较差。

2) 从表 2 学习残差、工作残差来看,无论是 GM-BP 组合预测模型,还是 GM-GA-BP 组合预测模型,虽然输入样本的值有所改变,最终预测值与网络仿真对相同点的预测值是一致,说明本次网络训练是稳定的,预测值也是稳定的。

3) 从表 2 预测值的残差大小来看,无论是 GM-BP 组合预测模型,还是 GM-GA-BP 组合预测模型,预测值精度较高,预测效果好。

4) 利用训练样本通过遗传算法 GA 对 BP 神经网络结构进行初始化,对建立 BP 神经网络结构起到了很好的全局寻优作用。不论是学习残差、工作残差,GM-GA-BP 组合预测模型的精度都优于 GM-BP 组合预测模型。

5) 实例分析来看,本模型既可用于均匀时间序列,也可应用于非均匀时间序列。

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NETRS receiver, multipath and noise levels of L2C code was significantly higher than C/A code, contrary to expectations.

Key words GPS modernization ,L2C code ,SNR ,multipath effect (Page:75)

#### Landscape Pattern Analysis Based on High-resolution Remote Sensing Image by CHEN Zhiyun

Abstract On the basis of landscape ecology theory, using high resolution remote sensing data as sources, using RS and GIS techniques, the planning area of Meizhou City was divided into 9 land use types, including cultivated land, forest, grassland, urban land and highway land, lake, river, bare land and beaches. The basic structure of the landscape, the fragmentation and diversity of landscape-level and the spatial pattern characteristics of different landscape patches were studied and analyzed. At last, some recommendations were proposed to rational planning land development and utilization of the study area.

Key words high-resolution remote sensing image ,landscape pattern ,landscape indexes ,planning area of Meizhou City (Page:78)

#### Application of GPS Close-range Photogrammetry Crossing Location Technique in Surveying and Mapping on Island and Reef by LUO Liang

Abstract Surveying and mapping engineering on island and reef is one of five important items during 11th five-year planning in State Bureau of Surveying and Mapping. GPS close-range photogrammetry crossing location module is part of the quickly positioning information collection system. This technology can be completed on island and reef of the special terrain mapping mission. Particularly it can provide a new method to map difficulties coastline.

Key words island and reef, close-range photogrammetry crossing location, resection, forward intersection (Page:81)

#### Design and Realization of Query System of Geographic Information Based on ArcIMS by YANG Guofei

Abstract WebGIS, based on the Internet and the Web, is the main trend of the development of GIS currently. And one of the most popular platform for realizing it is ArcIMS. We summarized the characteristics and the system structure of the ArcIMS, then described the idea of designing and developing the query system of geographic information by using ArcIMS. At last we made geographic information released online and queried in multiple forms, managed and shared in network by users.

Key words Query of geographic information, ArcIMS, WebGIS (Page:84)

#### Design and Implementation of Campus Information Service Platform Based on Object by MAO Yanqing

Abstract Open and flexible campus services platform is the key to promoting campus information technology, the difficulty is the describing ,organizing and sharing of information and data. This article investigated the object-oriented spatial data model on the basis of proposing object-oriented method and process of information organization on campus , as well as the ways of designing the services platform. Focus on object-based information organization on campus and campus information management platform framework. To achieve a set of "people", "capital equipment", "geospatial information" resource management platform for the integration of campus information services, information service system for the construction of the campus and campus information sharing to provide new methods and ideas.

Key words GIS, object-oriented, campus information, service platform (Page:87)

#### Design of Provincial Land Resource Electronic Government Information System Based on ArcGIS by PENG Jianbin

Abstract This article researched on the design of the provincial land resource E-Government system, proposed the overall goals and framework of the system, particularly described the function modules of the system based on the soft platform of ArcGIS, finally discussed the key techniques and system features related with the system, formed a unified technical framework, operating environment and normative standards, achieved the integration management of land resource information.

Key Words land and resource ,E-government ,ArcGIS (Page:90)

#### Study of Land Quality Assessment Based on GIS by ZHOU Dan

Abstract The authors established the system of land quality assessment and evaluated the land quality of Shuangqiao in Dongxing district of Neijiang city based on the Analytical Hierarchy Process and graphic overlay methods, made the evaluation results map of the region, the region was divided into five types, the excellent or better quality land area was 699.45 km<sup>2</sup>, in possession of 72.87% of the whole region; the moderate quality land area was 184.43km<sup>2</sup>, which was in possession of 19.2% ; the land of lower or poor quality area was 76.4km<sup>2</sup>, in possession of 7.96%,according to the location and the modes of fanning of the region , the whole land quality of Shuangqiao in Dongxing district of Neijiang city was in good condition.

Key words GIS ,land quality assessment ,Neijiang (Page:93)

#### Delay Model and Accuracy Analysis of EGNOS Tropospheric

by LIU Jingye

Abstract Tropospheric delay in GPS positioning is a major source of error in the handling of the main methods of tropospheric delay correction through model difference method, etc, weakening or elimination of tropospheric delay error. When the distance is short baseline, baseline ends meteorological conditions are basically the same ,difference method can be very good correction troposphere delay error, when the baseline, due to the long distance between the meteorological data at baseline large , difference method can't eliminate the troposphere error well, but model can be a very good method to eliminate the troposphere error. In this paper, EGNOS model was introduced in detail, and through MATLAB programming. IGS tracking station data used to calculate statistical analysis, results showed that the EGNOS tropospheric correction model in elevation on the Saastamoinen model and the Hopfield model range, between the x, y direction precision.

Key words GPS , tropospheric model ,EGNOS , accuracy analysis (Page:96)

#### Measuring Method of Unified Annual Output Value Standard of Land Expropriation Based on GIS Technology by FU Weijia

Abstract Reasonable measuring method of unified annual output value standard of land expropriation is the basis and guarantee to improve the land expropriation compensation mechanism and protect farmers' rights of land. In this paper, revision and related measurements had been optimized with selecting the representative revision factors and building GIS spatial clustering model. At the same time, it used data organization method which integrated maps, data and database based on GIS. Finally, it achieved the measuring method of unified annual output value standard of land expropriation. Measuring results not only to present the spatial distribution of land expropriation compensation and the difference rule, but also to provide a new way to measure.

Key words Unified Annual Output Value Standard of Land Expropriation , GIS , Gongcheng County ,revision ,spatial clustering ,compensation standard (Page:99)

#### Building and Application of Remote Sensing Image Interpretation Signs of Eco-environmental in Four Rivers Valley of Tibet by GUAN Lei

Abstract In fully grasp the characters of natural geography and with the region of the TM images and related data contrast, we builded remote sensing image interpretation signs of Eco-environmental by using the classification system in Four Rivers Valley of Tibet. This work provided basis for Eco-environment or land resource remote sensing survey in south-east Tibet.

Key words remote sensing, interpretation signs , Four Rivers Valley , Tibet (Page:103)

#### Rendering Method Over 3D Vector Data in EV-Globe

by WANG Haitao

Abstract The paper, which based on the 3D plat roof of EV-Globe, analysed advantages and disadvantages of 3D vector-data, raster-data and mixed modals, realized symbolization and LOD display of vector data in 3D GIS. The method satisfied the rendering request of vector data in 3D GIS.

Key words 3D vector data modal, 3D vector data modal, modal based on feature, symbolization, LOD (Page:106)

#### Gray Model and Intelligent Algorithm Combined Model in Deformation Prediction by ZHANG Yutang

Abstract Because of various parameters have great uncertainty, deformation monitor project is a complicated integrated system . At present deformation prediction and analysis using a single forecasting methods ,but each method has their own application scope. Sometimes a single forecasting method made it difficult to determine the nature of projects .This paper introduced the idea of combination forecasting based on the gray GM (1,1) model ,Construction of the gray + GA + BP neural networks combination models ,explored the time series of data processing and prediction problems. Calculation and analysis by example proved that the combined model met the engineering needs and had a certain value .

Key words deformation monitor, combination model, gray prediction model, genetic algorithm , BP network (Page:109)

#### Control Surveying of the Combined Highway and Railway Yangtze Bridge of Tongling by ZHOU Ruixiang

Abstract This article brought forward and expatiated a method using GPS, electronic level and techniques of river-crossing leveling to fulfill the precision measurement task. The results not only verified the accuracy of this method, as well as provided references for other similar projects.

Key words bridge engineering ,construction control network ,GPS ,river-crossing leveling (Page:112)