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Spline interpolation techniques applied to the study of geophysical data

Maria C. Mariani [a,*], Kanadpriya Basu [b]

[a] *Department of Mathematical Sciences, University of Texas at El Paso, Bell Hall 124, El Paso, TX 79968-0514, USA*

[b] *Department of Mathematical Sciences, University of Texas at El Paso, Bell Hall 220, El Paso, TX 79968-0514, USA*

HIGHLIGHTS

- Improve the analysis and understanding of parameters associated to critical events.
- Use different interpolation techniques and spline methodologies, more powerful and efficient.
- Perform spatial analysis for geophysical data.

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ABSTRACT

This work is devoted to the study of geophysical data by using different spline interpolation techniques. A spatial analysis of the California earthquakes geological data was performed, some of the methods proved to be more efficient than others depending on the number of data points considered. Overall, this class of interpolation surface proved to be a very powerful tool for analyzing geophysical data.

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1. Introduction

In this paper, we applied different interpolation techniques to geophysical data. We performed a spatial analysis of the California earthquakes geological data in different locations, by varying the latitude and longitude. We estimated the magnitude of the earthquake at any given time. The time (in our case the year) is fixed and based on data collected from different regions, we used interpolation models including some spline interpolation techniques to estimate the surface of best fit. In order to calculate the accuracy of the interpolation methods that were used on our geophysical data set, we computed the *Sum of Squared Error* (*SSE*) and *Coefficient of Determination* (R-square), that indicate how well data points fit a statistical model.

"Critical value phenomena" was analyzed in Refs. [1–3]. These papers discuss three modeling techniques for estimating major-events (in this case a major earthquake). Ising models have been used in Refs. [4,3], phase transition in Ref. [5], fitting the data with exponential sequence in Ref. [6], and using the so-called scale invariance property in Ref. [2]. In these works, by looking at the preceding data collected before a major earthquake, models estimate the parameters leading to these major crash. This modeling approach is similar to Ref. [3], where they have described the behavior of the financial market

* Corresponding author.
E-mail addresses: mcmariani@utep.edu (M.C. Mariani), kbasu@utep.edu (K. Basu).

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before the crash. Similarly in their second work where authors have generalized the scale invariant technique, and used a method that is developed on the generalization of truncated Lévy models where they estimate the first critical event that may surface.

In a previous work [7], we applied nonparametric regression methods to the same geophysical data considered here. We used two versions of the nonparametric method: (1) Loess and (2) Lowess. We performed a spatial analysis by using these methods on the same data set in order to predict the intensity of the earthquake in locations that were not used to estimate the regression surface. We fitted a prediction surface and estimated the earthquake magnitude in a location that was not used to generate the surface. In most cases Lowess performed better than its quadratic counterpart. The results were promising and efficient and the approach proved to be robust for estimating future earthquake intensities. In this work, we deal with the same data set but our motivation factor was different. We applied different complex interpolation techniques on the same geophysical data set and fitted a best prediction surface and *SSE* (Sum of Squared Error) due to different interpolation techniques.

The motivation for applying interpolation methods in order to estimate future earthquakes magnitude at a fixed location (i.e. latitude and longitude are being fixed) is unique and different from previous approaches analyzing similar spatial data. Instead of estimating the major earthquake date (i.e. deal with the time series data), we implemented a spatial analysis where we have fixed the time (in this case, the year), and we have collected the earthquake data from different locations of a particular geographical region. Based on these data trends, we applied different spline interpolation methods to fit a surface by using different interpolation techniques. The methods are efficient for dealing with these data sets. The computed parameters of best fit indicated an excellent fit of the estimating surface for most of the interpolation methods that were used.

We conclude that these interpolation techniques are very useful for analyzing spatial data in order to predict the future magnitude of an earthquake when given the location. Some interpolation techniques turned out to be more efficient than others depending on the situation and number of data points used. Overall, the methods are very simple to understand and apply. The results in terms of the surface of best fit given any data set are very accurate and promising.

Lots of applications of evaluation of spline interpolants in their ability to fit time series of geophysical data can be found in the late nineties and early twentieth centuries. Some of the papers are listed below, although there was not much done to see how different interpolation techniques work for spatial data. Here we applied different spline interpolation methods to earthquake data. Some of the methods worked better than others but overall we feel these techniques can be used as a powerful tool to perform spatial analysis. The results due to some of these methods are very interesting and effective. That uniqueness of using these tools for spatial analysis makes it a novel approach.

This write up is organized in the following manner: In Section 2 we explain the source of our geophysical data and our motivation to deal with it. Section 3 deals with detailed mathematical descriptions of the different interpolation techniques that have been used in this paper. Section 4 presents the results of using the techniques mentioned in Section 3 for a numerical experimentation with the data set. Section 5 ends this paper with a conclusion that discusses the suitability of our techniques applied to the data set.

2. The geophysical data

In this work we have used the geophysical data sourced at the US Geological Survey (USGS) from 1st January 1973 to 9th November 2010 [8]. The data contains information about the date, longitude, latitude, and magnitude of each recorded earthquake in the region. The location of the major earthquake chosen defines the area studied. This area cannot be too small (lack of data) or too big (noise from unrelated events). The data is obtained by using a *square* centered at the coordinates of the major event. The sides of the square were usually chosen as $\pm 0.1^\circ$–0.2° in latitude and $\pm 0.2^\circ$–0.4° in longitude. A segment 0.1° of latitude at the equator is ≈ 11.11 km ≈ 6.9 miles in length.

The earthquake magnitude is the recorded data used in the analysis. The policy of the USGS regarding recorded magnitude is the following [8]:

(i) Magnitude is a dimensionless number between 1 and 12.
(ii) The reported magnitude should be moment magnitude, if available.
(iii) The least complicated, and probably most accurate terminology is to just use the term "*magnitude*".

In the numerical study we use data collected from different locations at a given time to estimate the magnitude of the earthquake at a given location, where the real magnitude is known. The magnitude is recorded in the data that was used, and where available moment magnitude is used. For more information we refer the reader to the specific USGS documentation available at: http://earthquake.usgs.gov/aboutus/docs/020204mag_policy.php.

3. Spline interpolation methods

In numerical analysis, interpolation is a process for estimating values that lie within the range of a known discrete set of data points. In engineering and science, one often has a number of data points, obtained by sampling or experimentation, which represent the values of a function for a limited number of values of the independent variable. It is often required to