Lecture Notes in Electrical Engineering 919

Sio-Iong Ao
Len Gelman *Editors*

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Proceedings of World Congress on Engineering 2021

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Preface

A large international conference on Advances in Engineering Technologies and Physical Science was held in London, UK, July 7–9, 2021, under the World Congress on Engineering 2021 (WCE 2021). The WCE 2021 is organized by the International Association of Engineers (IAENG); the Congress details are available at: http://www.iaeng.org/WCE2021. IAENG is a non-profit international association for engineers and computer scientists, which was founded originally in 1968. The World Congress on Engineering serves as good platforms for the engineering community to meet with each other and to exchange ideas. The conferences have also struck a balance between theoretical and application development. The conference committees have been formed with over three hundred committee members who are mainly research center heads, faculty deans, department heads, professors, and research scientists from over 30 countries. The congress is truly global international event with a high level of participation from many countries. The response to the Congress has been excellent. There have been more than four hundred manuscript submissions for the WCE 2021. All submitted papers have gone through the peer-review process, and the overall acceptance rate is 50.73%.

This volume contains eleven revised and extended research articles written by prominent researchers participating in the conference. Topics covered include mechanical engineering, engineering mathematics, computer science, electrical engineering, and industrial applications. The book offers the state of the art of tremendous advances in engineering technologies and physical science and applications and also serves as an excellent reference work for researchers and graduate students working on engineering technologies and physical science and applications.

Hong Kong — Prof. Sio-Iong Ao
Huddersfield, UK — Prof. Len Gelman

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Piecewise Monotonic Fitting for Covid-19 Data Analysis of the United Kingdom During 31-01-2020 to 19-11-2021

Evangelos E. Vassiliou, Ioannis N. Perdikas, Demetrius E. Davos, and Ioannis C. Demetriou

Abstract The least squares piecewise monotonic data approximation method is applied to daily Covid-19 new cases and deaths data of the UK for the period 31-01-2020 to 19-11-2021. The data demonstrate wide variation in parts and noticeable peaks over time. We are interested in estimating turning points of the data in that the fit is useful to analyzing the progress of the pandemic. An enormous number of combinations of turning points need be considered in order to find an optimal combination, but the method provides quite efficiently a global solution. Our results show the efficacy of the piecewise monotonicity method in locating optimal turning points that are significant to the Covid-19 analyses. We consider the facts that influence the choice of the number of peaks. Our analysis provided us with insights regarding the driving forces behind the turning points that the method detected, which further may be helpful to management, as part of the information on which decisions will be made.

Keywords Approximation · Combinatorial problem · Covid-19 pandemic data · Divided difference of first order · Least squares fit · Peak · Piecewise monotonic · Turning point · United Kingdom

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1 Introduction

There has been an explosion of scientific publications on the Covid-19 pandemic (see, e.g., [7]). The application and analysis of the piecewise monotonic method to peak estimation of Covid-19 data, which we address here, are conducted for the first time. Daily Covid-19 new cases and deaths data of the UK for the period 31-01-2020 to 19-11-2021 demonstrate wide variation in time, as well as some noticeable peaks of different magnitude along the time range. We are interested in estimating peaks and trends of these data that can assist in the decision making policy. Since the underlying laws are unknown, the estimation problem is made rather difficult. We assume, though, that if the underlying function is piecewise monotonic, then the number of its turning points is substantially lower than the number of turning points of the data.

Therefore, we apply the method of Demetriou and Powell [6] that makes least changes to the data by imposing a limit on the number of sign changes in the sequence of the first differences. Specifically, if $k-1$ is the limit, then the approximated values consist of at most k monotonic sections. Thus, if some value of k can be derived from the form of the underlying function, or if the user is willing to try several values of k, then no other knowledge of this function is required. In this paper, we define "least changes" to the data by minimizing the sum of squares of changes subject to the smoothness condition. Further, two consecutive monotonic sections meet at a turning point. The positions of the turning points are also integer variables of the optimization calculation whose optimal values have to be found automatically. However, about $\mathcal{O}(n^{k-1})$ combinations of positions can occur, which makes it impossible to test each and every one separately. Demetriou and Powell [6] have studied this problem, and, furthermore, Demetriou [1, 2, 4] has developed algorithms and software that obtain a global solution in only $\mathcal{O}(n^2 + kn\log_2 n)$ computer operations. When $k = 1$ (monotonic case) or $k = 2$ (unimodal case), this work is reduced to $\mathcal{O}(n)$. This excellent efficiency is due to a decomposition property of the solution. Indeed, the method partitions the data into at most k disjoint sets of adjacent values and solves a $k = 1$ problem for each set.

Besides reduction of complexity when finding the optimal turning points, piecewise monotonic approximation method has some more advantages compared to other approximation techniques. First, it avoids the assumption that $f(x)$ has a parametric form. Second, the approximation process is a projection because, if it is applied to the approximated values, then no changes are made thereto. Third, the method of [6] is so fast in practice that it allows running for a sequence of integers k if a suitable value is not known in advance. Fourth, due to the nature of the constraints on the approximation components, any irregular errors in the data do not cause ripples to the piecewise monotonic fit. Moreover, any peak in the data does not introduce perturbations away from the peak.

The piecewise monotonic approximation method is outlined in Sect. 2. In Sect. 3, the method is applied to both Covid-19 new cases and deaths data of the UK, some technical aspects of the fit are provided, the estimation of peaks is illustrated, the results of the calculation are explained, and the effectiveness of the method is demonstrated. In Sect. 4, the results of Sect. 3 are used in further analyzing the progress of the Covid-19 pandemic in the UK, in conjunction with various important dates and events pertaining to the timeline of the pandemic. In Sect. 5, some conclusions are presented and the possibility of expanding this research is discussed.

All the experiments were handled routinely by the Fortran program of Demetriou [2], which implements a variant of the method outlined in Sect. 2. We provided just the data sequences and the value of k; the optimal turning points and the smoothed values were automatically delivered by the method.

Piecewise monotonic data approximation may be applied to a variety of situations in which peak estimations are required, but sufficient information is lacking to state a parametric form for the underlying function. Such situations are quite common, so applications of piecewise monotonic approximation can occur in several fields. Examples arise from time series [8], from spectroscopy [3, 5] and from curve fitting to physical data, to mention few. More applications appear in the reference list of [4].

2 Piecewise Monotonic Approximation

Let $\{(x_i, \phi_i) : \; i = 1, 2, \ldots, n\}$ be pairs of real numbers, where the abscissae $\{x_i : i = 1, 2, \ldots, n\}$ are in the strictly ascending order $x_1 < x_2 < \cdots < x_n$, and where ϕ_i is the measurement of some unknown underlying function, or a process, $f(x)$ at x_i. Due to errors of measurement, it is possible that the number of sign changes in the sequence $\{\phi_{i+1} - \phi_i : \; i = 1, 2, \ldots, n-1\}$ is much greater than the number in the sequence $\{f(x_{i+1}) - f(x_i) : \; i = 1, 2, \ldots, n-1\}$. The piecewise monotonic approximation method makes the least change to the data so that the new values $\{y_i : \; i = 1, 2, \ldots, n\}$ have at most $k-1$ sign changes in the sequence $\{y_{i+1} - y_i : i = 1, 2, \ldots, n-1\}$, where k is any positive integer. In this paper we define the "least" change to the data that gives the smoothing condition by choosing the L_2 norm in $\mathbb{R}^n$. Therefore, the piecewise monotonic method calculates numbers $\{y_i : i = 1, 2, \ldots, n\}$ that minimize the expression

$$\Phi(y_1, y_2, \ldots, y_n) = \sum_{i=1}^{n} (y_i - \phi_i)^2, \tag{1}$$

subject to the constraints

$$\left. \begin{array}{l} y_{t_{j-1}} \le y_{t_{j-1}+1} \le \cdots \le y_{t_j}, \;\; j \text{ is odd} \\ y_{t_{j-1}} \ge y_{t_{j-1}+1} \ge \cdots \ge y_{t_j}, \;\; j \text{ is even} \end{array} \right\}, \tag{2}$$

where $\{t_j \colon j = 1, 2, \ldots, k-1\}$ are integers that satisfy the conditions

$$1 = t_0 \le t_1 \le \cdots \le t_k = n. \tag{3}$$

The integers $\{t_j\colon j = 1, 2, \ldots, k-1\}$ are also variables of the optimization calculation. This is a formidable combinatorial optimization problem that requires $\mathcal{O}(n^{k-1})$ combinations of integers in order to find an optimal combination. However, Demetriou and Powell [6] have developed a highly efficient method that generates the solution in quadratic complexity with respect to n. The efficiency of the calculation of Demetriou and Powell takes advantage of two main properties of the best fit, but here we give no further details.

The first property is that the turning points of an optimal fit satisfy the interpolation conditions

$$y_{t_j} = \phi_{t_j}, \quad j = 1, 2, \ldots, k-1. \tag{4}$$

The second property is that an optimal piecewise monotonic approximation can be generated by solving a separate monotonic approximation problem on each range $[t_{j-1}, t_j]$. Thus, the components y_i, $i = t_{j-1}, \ldots, t_j$ have the values that minimize the sum of squares of residuals

$$\sum_{i=t_{j-1}}^{t_j} (y_i - \phi_i)^2 \tag{5}$$

subject only to the constraints $y_i \le y_{i+1},\ i = t_{j-1}, \ldots, t_j - 1,$ if j is odd, or subject to the constraints $y_i \ge y_{i+1},\ i = t_{j-1}, \ldots, t_j - 1,$ if j is even. We denote the least value of (5) by $\alpha(t_{j-1}, t_j)$ and $\beta(t_{j-1}, t_j)$ for the increasing and decreasing cases, respectively. These values can be calculated in only $\mathcal{O}(t_j - t_{j-1})$ computer operations. Therefore, if the optimal sequence $\{t_j\colon j = 1, 2, \ldots, k-1\}$ is available, then the sum of squares of residuals of the calculated fit has the value

$$\sum_{i=1}^{n} (y_i - \phi_i)^2 = \alpha(t_0, t_1) + \beta(t_1, t_2) + \alpha(t_3, t_4) + \cdots + \alpha(t_{k-1}, t_k)[\text{ or } \beta(t_{k-1}, t_k)]. \tag{6}$$

We define

$$\gamma(\ell, t) = \sum_{i=1}^{t} (u_i - \phi_i)^2 \tag{7}$$

to be the value of the partial sum by an optimal fit $\{u_i : i = 1, 2, \ldots, t\}$ in $\mathbb{R}^t$ with ℓ monotonic sections. Then, we deduce the first ℓ terms of sum (6) by the following recursive procedure. The calculation begins from $\gamma(1, t) = \alpha(1, t)$, for $t = 1, 2, \ldots, n$, and, as $\ell = 2, 3, \ldots, k$, proceeds by applying the formulae

$$\gamma(\ell, t) = \begin{cases} \min\limits_{1 \le s \le t} \left[\gamma(\ell-1, s) + \alpha(s, t)\right], & \ell \text{ odd} \\ \min\limits_{1 \le s \le t} \left[\gamma(\ell-1, s) + \beta(s, t)\right], & \ell \text{ even}, \end{cases} \tag{8}$$