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Predicting the subscribers of fixed-line and cellular phone in Japan by a novel prediction model

Guo-Dong Li [a,*], Shiro Masuda [a], Masatake Nagai [b]

[a] Department of System Design, Tokyo Metropolitan University, 6-6 Asahigaoka, Tokyo City 191-0065, Japan
[b] Graduate Institute of Educational Measurement and Statistics, National Taichung University of Education, Taichung 40306, Taiwan

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ABSTRACT

In this paper, a novel grey prediction model is proposed to enhance the performance of prediction for the amount of fixed-line and cellular phone subscribers in Japan. The cubic spline function is first integrated into grey prediction model to enhance its prediction capability. Then the particle swarm optimization (PSO) algorithm is applied, so that the prediction performance can be improved further. The prediction results using proposed models are very satisfactory.

1. Introduction

The prediction for the development trend of telecommunications industry has been researched by many researchers in order to plan marketing schedule for their products in the long term. The conventional prediction models are either linear, such as the autoregressive integrated moving average (ARIMA) model, or nonlinear, such as the nonlinear regression model. However, the prediction performance relies on a law for the distribution of original series as well as a large amount of observed data [1].

For these kinds of prediction problems, it is difficult to obtain the accuracy prediction model because of the influence from various kinds of social and economic uncertain factors and so on [1]. In order to resolve prediction problems for an uncertain system, Professor Deng [2] proposed the grey model based on grey system theory. From the 1980s, the grey prediction model GM(1, 1) has been playing an important role to make accurate prediction in various prediction fields such as engineering, natural science, economy, society, education, medicine and so on [3–5]. In this paper, we proposed an improved GM(1, 1) model to develop the prediction models of two main telecommunication items in Japan. They are the amount of fixed-line phone subscribers and cellular phone subscribers, respectively. The fixed-line phone subscribers are down year-on-year, and there was about 34 million at the end of 2010. The main basic telephone service in Japan is provided by NTT (Nippon Telephone and Telegraph Corporation), which used to be a public monopoly. However, KDDI, SoftBank Telecom, and other companies have a wide range of money-saving services. Meanwhile, the cellular phone subscribers make a rise year-on-year over 110 million at the end of 2009. According to statistics announced from the Ministry of Internal Affairs and Communications, this is 85% of Japan's total population [6]. There are five cellular service operators in Japan. They are NTTDoCoMo, KDDI, SoftBank, EMOBILE and Willcom. In Japan, cellular phones have evolved from just voice-only devices to personal digital assistants with digital cameras, GPS, clocks, alarms, calendars, mailers, and Internet browsers [7]. Therefore the growing trends of fixed-line and cellular phone subscribers can reflect the telecommunications technology development. The accurate prediction can provide useful information for the development program of Japanese telecommunications industry.

* Corresponding author. Tel./fax: +81 42 5858631.
E-mail address: guodong_li2006@yahoo.co.jp (G.-D. Li).

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The following procedures are used to improve the prediction accuracy of GM(1, 1). We first integrate cubic spline function into GM(1, 1) to enhance its prediction capability. We call the improved model as 3spGM(1, 1). Then, the particle swarm optimization algorithm is applied to the 3spGM(1, 1) so that the prediction accuracy can be improved further. Two real cases of the amount of fixed-line and cellular phone subscribers in Japan are used to validate the effectiveness of proposed models. The experimental results show that the proposed novel model has good performance.

This paper is organized as follows: Section 2 describes GM(1, 1) model which stands for first-order grey model with single variable. Section 3 discusses the improved 3spGM(1, 1) based on cubic spline function. In this model, the derivative and background values are calculated by cubic spline function. In Section. 4, the P-3spGM(1, 1) model based on PSO algorithm is discussed. The application analysis is presented in Section. 5. Finally, conclusions are drawn in Section. 6.

2. Grey prediction model

In recent years, the methodologies of grey prediction based on grey system theory have been successfully used in many fields. In terms of information availability degree, grey prediction walks out the shadow of large-sample statistics. The grey prediction model bases on the method of accumulated generating operation (AGO) rather than finding the statistics features to preprocess the original data so that the after processed data will become regular. Based on the processed data, we can use the differential equation to approximate such a regularity and hopefully to predict the next output from the system [8].

2.1. Grey GM(1, 1) prediction model

For the original series $x^{(0)}(t)$, $t = 0, 1, \cdots, n$, a new series $x^{(1)}(t)$, $t = 0, 1, \cdots, n$, can be generated by the AGO as

$$x^{(1)}(t) = \sum_{i=0}^{t} x^{(0)}(i). \tag{1}$$

From $x^{(1)}(t)$, we can form the grey prediction model GM(1, 1) which is expressed by one variable, and first order differential equation as

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \tag{2}$$

where the coefficients a and b are called the grey development and grey input coefficients, respectively.

The grey derivative for the first order grey differential equation with AGO is conventionally represented as

$$\frac{dx^{(1)}(t)}{dt} = \lim_{\Delta t \to 0} \frac{x^{(1)}(t+\Delta t) - x^{(1)}(t)}{\Delta t}. \tag{3}$$

Let $\Delta t \to 1$ and obtain

$$\frac{dx^{(1)}(t)}{dt} \cong x^{(1)}(t+1) - x^{(1)}(t) = x^{(0)}(t+1). \tag{4}$$

Then the discrete form of GM(1, 1) differential equation model is expressed as

$$x^{(0)}(i) + az^{(1)}(i) = b \tag{5}$$

where $z^{(1)} = \{z^{(1)}(1), z^{(1)}(2), \cdots, z^{(1)}(n)\}$ is called background value of $\frac{dx^{(1)}}{dt}$ and calculated by

$$z^{(1)}(i) = \frac{1}{2}\left(x^{(1)}(i-1) + x^{(1)}(i)\right). \tag{6}$$

By least-square method, the coefficients a and b can be obtained as follows

$$\hat{\mathbf{a}} = \begin{bmatrix} a \\ b \end{bmatrix} = \left(\mathbf{A}^{\top}\mathbf{A}\right)^{-1}\mathbf{A}^{\top}\mathbf{X_n} \tag{7}$$

$$\mathbf{A} = \begin{bmatrix} -z^{(1)}(1) & 1 \\ -z^{(1)}(2) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \tag{8}$$

$$\mathbf{X_n} = \begin{bmatrix} x^{(0)}(1) \\ x^{(0)}(2) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}. \tag{9}$$

Then, the modeling value of Eq. (2) is obtained as

$$\hat{x}^{(1)}(i) = \left(x^{(0)}(0) - \frac{b}{a}\right)e^{-ai} + \frac{b}{a}. \tag{10}$$

The prediction series for original time series can be obtained as

$$\hat{x}^{(0)}(i) = \hat{x}^{(1)}(i) - \hat{x}^{(1)}(i-1) \tag{11}$$

where the data series, $\left\{\hat{x}^{(0)}(0), \hat{x}^{(0)}(1), \cdots, \hat{x}^{(0)}(n)\right\}$ are called fitting series, while series $\left\{\hat{x}^{(0)}(n+1), \hat{x}^{(0)}(n+2), \cdots, \hat{x}^{(0)}(n+k)\right\}$ are called prediction series. Usually, the number of data set used in GM(1, 1) is rather small because only two coefficients are required to be identified in Eq. (7). In other words, GM(1, 1) is often used as a short-term prediction scheme [9]. The GM(1, 1) model realizes the prediction based only on a set of the most recent data in a time series. Predictions of this kind are to establish a curve for the most recent data, and then make predictions based on the established curve.

2.2. Error analysis of grey model

It is commonly believed that differential equations are only suitable for continuous differential function. The advantage of grey prediction model with differential equation may be established on the basis of the AGO transformation series for original discrete data. Hence, grey model makes it possible to solve the prediction problems of uncertainty systems. However, this model has the irrational problems concerning calculation of derivative and background value. The irrational problems are explained as follows:

● The derivative for the first order differential equation with AGO continuous series is calculated in Eq. (3). For